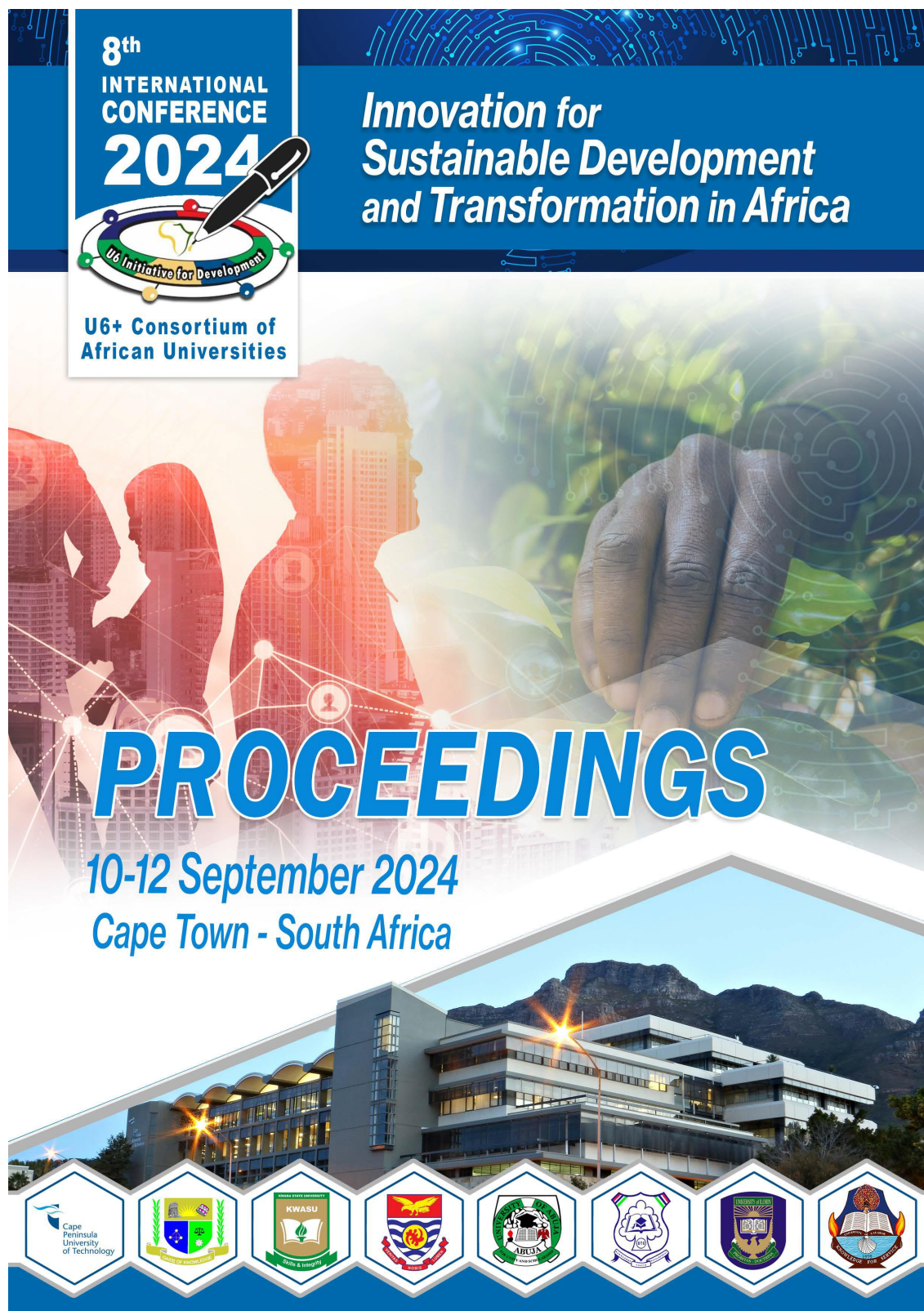


Conference Proceedings:
The 8th U6⁺ International Conference from 10-12 September 2024, Cape Peninsula University of
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Table of contents:

Article titles and authors	Theme	Page
1. Antiproliferative activity of <i>Helichrysum</i> species and compounds used against cancer: a review Idowu J Sagbo, Masixole Makhaba and Ahmed A. Hussein	Food security, health and wellness	5 - 34
2. Comparative analysis of genetic diversity in <i>Bilobata subsecivella</i> populations from Africa, India and Australia using mtDNA gene sequences Makhosi Buthelezi, Desmond Conlong and Godfrey Zharare		35 - 40
3. Palm oil consumption in Ondo State: a consumer preference ranking model approach Olatinwo L.K., Wahab M.J., and Nofiu N.B.		41 - 45
4. Historical perspectives on agricultural sustainability and food security in Yorubaland, Nigeria Aboyaji Oyeniyi Solomon		46 - 62
5. Apicultural economic and investment analysis in the Cape Winelands region of South Africa Mzwanele Lingani, Ella C Hough and Morris Fanadzo		63 - 70
6. Analysis of vitamin A, iron and iodine in commonly consumed foodstuffs in the Gambia Bilkisu A. Jallow and Anayo Chris Etonihu		71 - 79
7. The influence of different growing media on the mineral properties of blueberry fruits Mfeka N., Tanga M., Nel A.P., Mulidzi A.R., Lewu F.B.		80 - 88
8. Assessment of preservation techniques among vegetable marketers in Ibadan metropolis of Oyo state, Nigeria Abdulazeez Muhammad-Lawal and Basheerat Adeola Okunola		89 - 97
9. Genetic Gain on Agronomic and Malting Quality Traits among Selected Barley Cultivars in the Western Cape Province, South Africa Qiniso Kennwell Ndlovu and Morris Fanadzo		98 - 110
10. Role of mediation in addressing food security, health, and wellness in Nigeria: a comprehensive approach to sustainable solutions Barakat Adebisi Raji and Israel Adekunle Adeniyi		111–118
11. Chemical characterization of <i>Protea madiensis</i> extract and its antidiabetic activity Omotola M. Afuwape, Masande Yalo, Masixole Makhaba, Faleye F. Jide, Olugbenga K. Popoola, Robert C. Luckay and Ahmed Hussein		119 - 126
12. Direct Speech-To-Speech Multilingual Language Translation Model Using Long Short-Term Memory (LSTM): A Proposed Model Jumoke Falilat Ajao, Kazeem A. Gbolagade, Abdulazeez Olorundare Ajao, Ayisat W. Asaju-Gbolagade and Lukman Adewale Ajao		127 –135

13. <u>Preparing novice teachers for the reality of the classroom: a comparative study between South Africa and India</u> Anna Johanna Dippenaar and Meghna Mehndroo 14. <u>Adapting Moodle for effective English for Specific Purposes (ESP) instruction in under-resourced TVET Colleges</u> Rushaad White 15. <u>Posthumanism and actor-network theory: expanding perspectives in educational technology research</u> Ian M. Kennedy and Johannes C. Cronjé	Education, Equality, Culture and Indigenous Knowledge Systems	136 –142 143 –150 157
16. <u>A conceptual framework for enhancing sustainable construction practices among SMME's in South Africa</u> Virginia Shahida Ngonda and Hilary Kennedy Nji Bama	Designing for Sustainable Communities	151– 159
17. <u>The impact of digital communication technology on the development of the film industry in South Africa</u> Mncedisi Mbombo 18. <u>An overview of potential roles of artificial intelligence in enhancing formal education</u> Olatunji E. K., Ayepeku F. O., and Olabode O. J.	ICT, Media and Communication	160 –175 176– 183
19. <u>Raising climate change awareness in Nigerian lower basic schools by addressing challenges and promoting clean, sustainable environments</u> Muhinat Bolanle Bello 20. <u>Assessment of Heavy Metals in Groundwater and Associated Health Risks in Ilorin Metropolis, Nigeria</u> Hussein K. Okoro, Muyiwa M. Orosun, Adewale G. Adeniyi, Gbenle Ruth Temitope, Kingsley O. Iwuozor 21. <u>Community-based climate adaptation among smallholder farmers in Kwara State, Nigeria</u> Fasilat Olajumoke Rafiu and Lanre Tajudeen Ajibade 22. <u>Integrating bio-effectors in regenerative horticulture for sustainable nutrient supply in crop production amidst climate change</u> Awabo Manyaku, Cornelius Chiduzza and Hildegard Witbooi	Climate change and sustainable environment	184 –192 193 –217 218 –226 227– 239
23. <u>Mechanical Characterisation of a Banana Fibre / Recycled PET fibre Hybrid Composite for Furniture Boards Application</u> Nkosilathi Zinti Nkomo and Alfayo Alugongo	New Frontiers in Science, Engineering and Technology	240– 250
24. <u>Fact-checking hubs and Information Disorder in Nigeria: A Study of FactCheckHub, Dubawa, and AfricaCheck</u> Isiaka Zubair Aliagan and Habeeb Opeyemi Daranijo	Business, Leadership and Governance	251– 262
25. <u>Nitrogen Content and Proximate Composition of Burdock (<i>Arctium lappa</i> L.) In Response To Mineral Fertilizer Application</u> Mbappe Tanga, Francis. B. Lewu, Adebola. O. Oyedeji and Opeoluwa O. Oyedeji	Food security, health and wellness	263 - 271

ANTIPROLIFERATIVE ACTIVITY OF HELICHRYSUM SPECIES AND COMPOUNDS USED AGAINST CANCER: A REVIEW

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ABSTRACT

Although several anticancer agents or therapies have been used to manage cancer, these therapies are also associated with several health risks to the patient. These health risks, together with the high cost of therapies, have prompted the search for modern alternative therapeutic strategies for the treatment of cancer. Medicinal plants from the *Helichrysum* genus are used in different parts of the world for their antiproliferative properties. This review provides an update on the antiproliferative properties of *Helichrysum* species and their compounds in cancer management. A literature search relating to the antiproliferative activity of *Helichrysum* species was thoroughly conducted using several scientific databases. About thirty-nine (39) *Helichrysum* species have been successfully explored for antiproliferative activities, with thirty-four (34) antiproliferative compounds successfully identified. The *Helichrysum* genus is well known for its highly diverse chemical constituents, including terpenoids, phloroglucinols, and different skeletons of flavonoids. This review highlighted the diversity and therapeutic potential of *Helichrysum* species and their compounds in cancer management. Thus, further scientific studies on *Helichrysum* species and their compounds against cancer are recommended.

Keywords: Anticancer drugs, Bioactive compounds, *Helichrysum* species, Medicinal plants, Medicinal education

INTRODUCTION

Cancer is a dangerous, life-threatening disease triggered by uncontrolled cellular proliferation. It is a major health challenge that has produced an intolerable number of deaths globally. The cancer burden rose to 18.1 million new cases with 9.6 million deaths in 2018 (IARC, 2023). A recent report by the International Agency for Research on Cancer (IARC) revealed that new cancer cases per year are anticipated to reach 19.3 million and cancer-related deaths are projected to reach 16.4 million by 2040 (IARC, 2023). There are more than 200 types of cancer, and some cancers are more common than others, depending on racial or ethnic group, age, and gender (Alireza et al. 2005). Amongst the most used agents or therapies for cancer treatment are immunotherapy, medications, radiation, chemotherapy, and surgery (figure 1) (Regassa et al. 2022). However, despite their effectiveness, some of these therapies have serious side effects. Some of the side effects earlier reported include bone marrow suppression, nephrotoxicity, liver damage, skin disease, cardiotoxicity, neurotoxicity, and vaginal dryness (Sagbo and Otang-Mbeng, 2021; Warrington et al., 2019). These side effects, together with the high cost of therapies, have prompted the search for modern alternative therapeutic strategies for the treatment of cancer.

Due to some constraints with the use of current anticancer agents, the use of medicinal plants for the treatment of cancer has been on the rise lately. This is because of fewer probable side effects, lower costs, accessibility, and efficiency with protective mechanisms mediated by their different phytochemical constituents (Greenwell and Rahman, 2015; Iqbal et al., 2017; Moudi et al., 2013). Several phytochemicals (flavonoids, tannins, curcumin, resveratrol, and gallic acid) in plants have also been reported to play a significant role in regulating cellular and molecular events such as activation/inactivation of oncogenes and tumor-suppressor genes, apoptosis, deoxyribonucleic acid (DNA) repair, cell proliferation, metastasis, and angiogenesis. In general, phytochemicals and many medicinal plant species have been reported to have strong potential to curtail the spread of cancer in the body, and this continues to attract several researchers to further explore more medicinal plants and their phytochemicals against cancer (Samec et al. 2020).

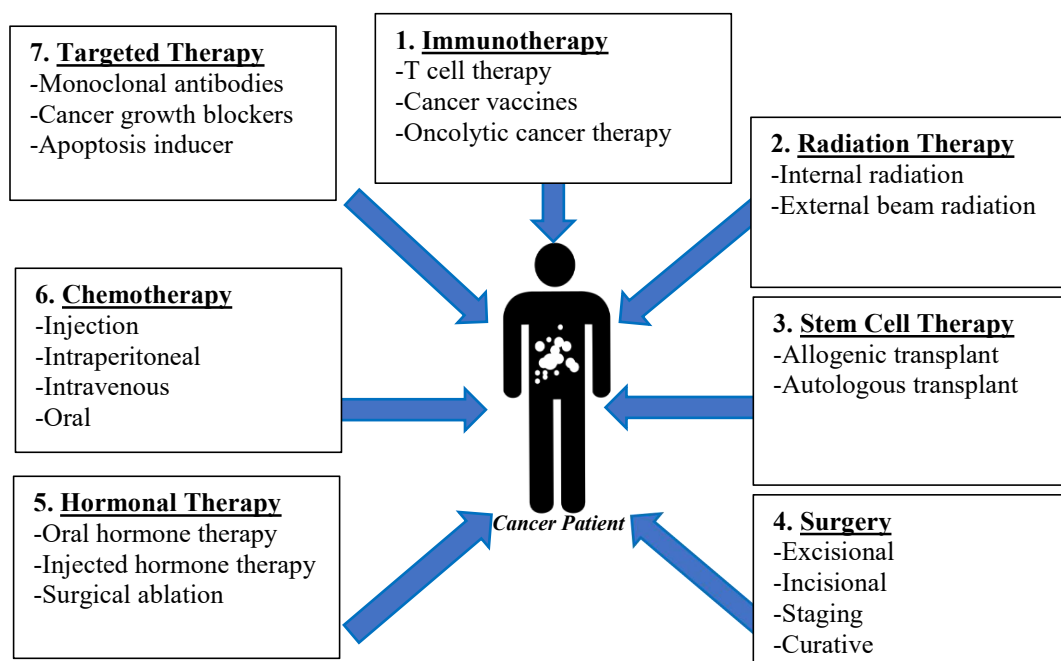


Figure 1. Various types of therapies used currently for cancer treatment.

Researchers have also discovered many plant species that have exhibited anticancer properties, with a lot of focus on those that have been used in herbal medicine in developing countries (Sagbo and Otang-Mbeng, 2021). For example, Sagbo and Otang-Mbeng (Hamedi et al. 2022; Sagbo and Otang-Mbeng, 2021) explored several anticancer plants used in the treatment of cancer in the Eastern Cape province of South Africa. In this study, the authors reported about 24 plant species used for the traditional management of cancer in the Eastern Cape Province. Another review study reported by Hamedi et al. (2022) also indicated the anticancer potential of several medicinal plants grown in Iran. In this study, the authors proposed several anticancer mechanisms of action (mitochondrial suppression, apoptosis, cytotoxicity, cell cycle arrest, and DNA damage) of the studied plants. A report by Usman et al. (2022) also revealed the phytochemical and anticancer potentials of the members of the Fabaceae family. In the study, the authors reported several anticancer species from the Fabaceae family together with their rich phytochemicals. Medicinal plants from the *Helichrysum* genus are used in different parts of the world for their cancer management. Despite various reports in the literature with sufficient information validating their effectiveness against cancer, a comprehensive and systematic review of the anticancer activities of these species is still lacking. This review provides an update on the antiproliferative properties of *Helichrysum* species and their compounds in cancer management.

MATERIALS AND METHODS

Numerous combinations of words or terms such as 'anti-proliferative activity', 'cytotoxicity' 'medicinal plants', '*Helichrysum* species', 'cancer cell lines' 'phytochemicals', and 'anticancer activity' were used to search in several scientific databases (Scopus, Web of Science, Science Direct, Google Scholar, Medline, PubMed, and Medline). In addition, several ethnobotanical books and dissertations were also retrieved from various databases of university libraries to obtain information about the antiproliferative activity of the *Helichrysum* species against various cancer cells. The review focused on the data collected from articles published up to November 2023. Regarding the selection criteria, only articles that were applicable to the research title and objectives were included in the review.

RESULTS

A total of thirty-nine (39) *Helichrysum* species have been successfully explored for antiproliferative activities (Table 1), with thirty-four (34) antiproliferative compounds successfully identified (Figure 3). Of these species, thirty-one (31) are indigenous to South Africa (Figure 2). A detailed discussion regarding their effectiveness on various cancer cells is provided.



A



B



D



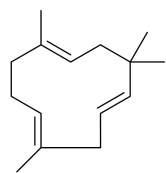
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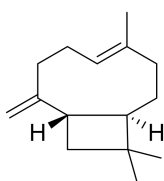
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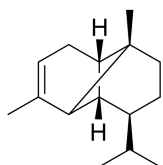
Figure 2. Images of some *Helichrysum* species (A= *H. adenocarpum*, B= *H. appendiculatum*, C = *H. aureonitens* D= *H. callicomum*, E= *H. cymosum*, F= *H. dasyanthum*, G= *H. excisum*, H= *H. felinum*, I= *H. foetidum*, J= *H. indicum*, K= *H. nudifolium*, L= *H. odoratissimum*, M= *H. oreophilum*, N= *H. pandurifolium*, O= *H. patulum*, P= *H. petiolare*, Q= *H. splendidum*) with reported antiproliferative activity (South African National Biodiversity Institute, 2023).



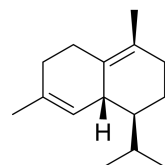
1. alpha-Humulene



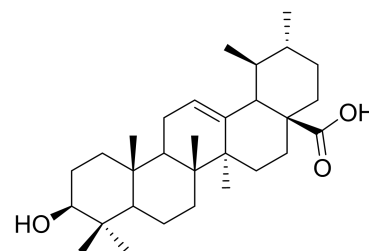
2. beta-Caryophyllene



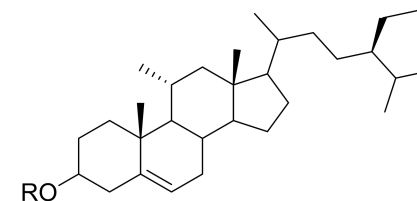
3. alpha-Copaene



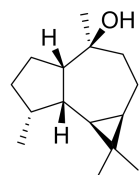
4. delta-Cadinene



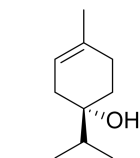
5. Oleanolic acid



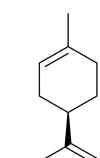
6. R = Glc., (**β-sitosterol-3-O-glucoside**)



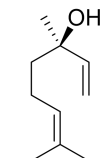
7. Viridiflorol



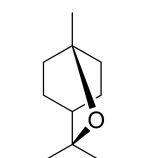
8. Terpene-4-ol



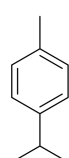
9. Limonene



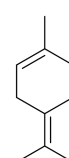
10. Linalool



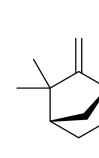
11. 1,8-Cineole



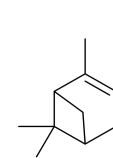
12. p-Cymene



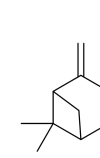
13. Terpinolene



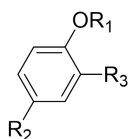
14. Camphene



15. alpha-Pinene

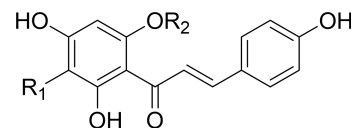


16. beta-Pinene



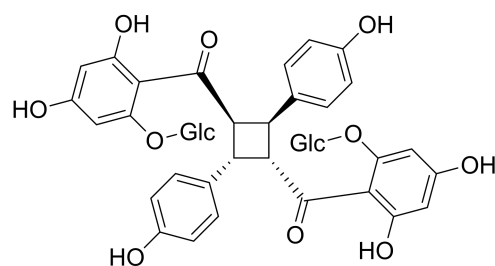
17. R₁ = R₃ = H, R₂ = Glc., (**Arbutin**)

18. R₁ = H, R₂ = Cl, R₃ = $\text{---C}\equiv\text{C}\equiv\text{C}\equiv\text{C}\equiv\text{C}\equiv\text{C}\text{---}$, (**4-Chloro-2-(hepta-1,3,5-triyn-1-yl)-phenol**)

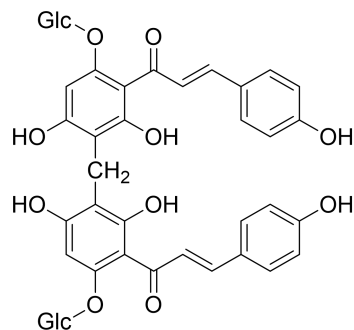


19. R₁ = H, R₂ = Glc., (**Isosalipurposide**)

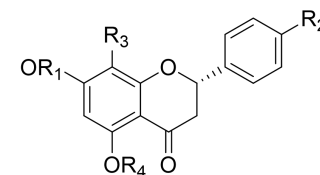
20. R₁ = dimethyl allyl, R₂ = H, (**Desmethylxanthohumol**)



21. Tomoroside A



22. Tomoroside B

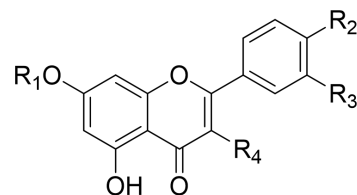


23. R₁ = CH₃, R₂ = R₃ = R₄ = H, (**Pinostrobin**)

24. R₁ = R₃ = R₄ = H, R₂ = OH, (**Naringenin**)

25. R₁ = H, R₂ = OH, R₃ = dimethyl allyl, R₄ = Me, (**Isoxanthohumol**)

26. R₁ = Glc., R₂ = OH, R₃ = R₄ = H, (**Naringenin 7-O-β-D-glucopyranoside**)



27. $R_1 = H, R_2 = R_3 = R_4 = OH$, (**Quercetin**)
 28. $R_1 = H, R_2 = OH, R_3 = R_4 = H$, (**Apigenin**)
 29. $R_1 = H, R_2 = R_3 = OH, R_4 = OMe$, (**3-O-Methylquercetin**)
 30. $R_1 = R_2 = R_3 = H, R_4 = OH$, (**Galangin**)
 31. $R_1 = R_3 = H, R_2 = R_4 = OH$, (**Kaempferol**)
 32. $R_1 = Glc., R_2 = OH, R_3 = R_4 = H$ (**Apigenin 7-O-beta-D-glucopyranoside**)
 33. $R_1 = Glc.-(1 \rightarrow 6)-glc., R_2 = OH, R_3 = R_4 = H$ (**Apigenin 7-O-gentiobioside**)

Figure 3. Chemical structures of the isolated compounds from *Helichrysum* species with known antiproliferative activity (Afoulous et al. 2011; Aljančić et al. 2014; Aydin, 2020; Bigović et al. 2011; Bohlmann et al. 1979; Diller et al. 2009; Gismondi et al. 2020; Jadalla et al. 2022; Matić et al. 2013b; Morikawa et al. 2009; Sinda et al. 2022; Staver et al. 2018; Yagura et al. 2008).

Table 1. Antiproliferative activities of *Helichrysum* species

S/N	<i>Helichrysum</i> species	Distribution	Assayed extract(s)	Active compound(s)	Targeted cancer	Type of susceptible cancer cell line	Mechanism of cytotoxicity	Reference
1	<i>H. acutatum</i>	South Africa, Swaziland, and Zimbabwe	Dichloromethane, ethyl acetate, methanol, and chloroform: methanol (1:1)	*	Colon, and breast	Caco-2, HepG2 cells	*	(Oyetunde-Joshua et al. 2022)
2	<i>H. adenocarpum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Lourens et al. 2011)
3	<i>H. appendiculatum</i>	South Africa, Lesotho, and Swaziland	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Lourens et al. 2011; Mnengwane, 2005)
4	<i>H. arenarium</i>	Europe, central Asia, and China	Aqueous	Naringenin-7-O- β -D-glucopyranoside, apigenin 7-O- β -D-glucopyranoside, apigenin 7-O-gentiobioside, and apigenin 7,4'-di-O- β -D-glucopyranoside	Leukemia, colon, and fibroblast	U937, Caco-2, and L929 cells	Apoptosis occurs via tumor necrosis factor-alpha apoptosis.	(Eshbakova and Aisa, 2009; Morikawa et al. 2009)
5	<i>H. aureonitens</i>	South Africa, Lesotho, and Swaziland	Chloroform: methanol (1:1), and ethanol	4-Chloro-2-(hepta-1,3,5-triyn-1-yl)-phenol, and galangin	Brain, prostate, and lung, liver, breast, colon, and gastric	SF-268, DU145, A549, HCC, HepG2, Hep3B, PLC/PRF/5, MCF-7, HCT-15, HT-29, and MGC 803 cells	Inhibition of calcium channels in hepatocellular carcinomas. Apoptosis in breast cancer occurs by mitochondrial pathway and PI3K/Akt inhibition and cell cycle arrest	(Ha et al. 2013; Lourens et al. 2011; Liang et al. 2021; Liu et al. 2018; Shelembe et al. 2022; Su et al. 2013; Wang et al. 2017; Ziaratnia et al. 2009)

6	<i>H. caespitium</i>	South Africa, Lesotho, Zimbabwe, and Swaziland	Dichloromethane and aqueous	*	Liver	H411E cells	*	(Mamabolo et al. 2018)
7	<i>H. callicomum</i>	South Africa, Botswana, Zimbabwe, and Lesotho	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Hyde et al. 2023; Lourens et al. 2011)
8	<i>H. cephaloideum</i>	South Africa, Malawi, Mozambique, Zimbabwe, Lesotho, and Swaziland	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Hyde et al. 2023; Lourens et al. 2011)
9	<i>H. cymosum</i>	South Africa	*	Pinostrobin, isoxanthohumol, and desmethoxythohumol	Breast, ovarian, prostate, skin, and lymphoma	MCF-7, MDA-MB-231, A-2780, DU145, PC-3, B16F10, and BJAB cells	Apoptosis is regulated by inhibition of transforming growth factor- β . In skin related cancer, inhibition occurs via autophagy	(Bohlmann et al. 1979; Delmulle et al. 2006; Diller et al. 2009; Le et al. 2000; Jadalla et al. 2022; Krajnović et al. 2022; Miranda et al. 1999; Serwe et al. 2012; Zenze, 2012)
10	<i>H. dasyanthum</i>	South Africa	Chloroform: methanol (1:1)		Brain, and breast	SF-268 and MCF-7 cells	*	(Gabayi M, 2014; Lourens et al. 2011)
11	<i>H. excisum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Lourens et al. 2011)
12	<i>H. felinum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2009; Lourens et al. 2011)
13	<i>H. foetidum</i>	South Africa, Tropical Africa, and Madagascar	Chloroform: methanol (1:1)	Kaempferol	Brain, and breast	SF-268, MDA-MB-453, MDA-MB-231 cells	Induction of tumor cell apoptosis	(Azevedo et al. 2015; Lourens et al. 2011; Nono et al. 2023; Swelankomo, 2005; Zhu and Xue, 2019)

14	<i>H. graveolens</i>	East Europe to Caucasus, Turkey, and Iran	Aqueous	*	Colon	C26 cells	*	(Kutluk et al. 2018; Taghavizadeh et al. 2020)
15	<i>H. gymnocephalum</i>	Madagascar	Essential oil	1,8-cineole, Terpinene-4- ol, β -pinene, and limonene	Breast, lung, leukemia, skin, colon, liver, and ovarian	MCF-7, A549, HL- 60, KB, SCC9, SCC2, OSC, HCT116, RKO, and SK-OV-3 cells	Induction of G0/G1 and/or G2/M cell cycle arrest, including cell apoptosis. In vivo through the reduction of miR- 122 and suppression of TGF- β 1, FSCN1, vimentin, MMP-9, and VEGF	(Abdallah et al. 2022; Afoulous et al. 2011; Anandakumar et al. 2021; Cao et al. 2023; Cao et al. 2022; Cai et al. 2021; Casalle and de Andrade, 2020; Chebet et al. 2021; Di Martileet al. 2021; Machado et al. 2022; Mandal and Parija, 2022; Nakayama et al. 2017; Rodenak- Kladniew et al. 2020; 33-45)
16	<i>H. indicum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2009; Lourens et al. 2011)
17	<i>H. italicum</i>	Mediterranean Region	Aqueous, diethyl ether, and essential oil	Kaempferol, 1,8-cineole, terpinene-4- ol, β -pinene, limonene, camphene, α - pinene, p - cymene, α - copaene, β - caryophyllene , α -humule, δ - cadinene	Leukemia, colon, breast, lung, leukemia, ovarian, liver, prostate, brain, pancreatic, and skin	U937, Caco-2, MCF-7, B16F10, MDA-MB-453, MDA- MB-231, A549, HL- 60, KB, SCC9, Huh7, SMMC-7721, HepG2, Hep3B, OVACR-3, SCC2, OSC, HCT116, HT29, RKO, SK-OV- 3, B16F10-Nex2, 22Rv1, BEL-7402, PANC-1, N2a cells	Induction of tumor cell apoptosis, and G0/G1 and/or G2/M cell cycle arrest. Upregulation of Chk1 and Chk2 levels, downregulation of CDC25 and CDK1 levels. In vivo through the reduction of miR-122 and suppression of TGF- β 1, FSCN1, vimentin, MMP-9, and VEGF	(Abdallah et al. 2022; Cai et al. 2021; Cao et al. 2023; Cao et al. 2022; Casalle, and de Andrade, 2020; Di Martile et al. 2021; Eshbakova and Aisa, 2009; Karasartov et al. 1992; Machado et al. 2022; Mandal and Parija, 2022; Nakayama et al. 2017; Rodenak- Kladniew et al. 2020; - 45,48- 64,121,122,124)

18	<i>H. maracandicum</i>	Central Asia	Ethanol	Isosalipurposide	Skin	SENCAR mouse skin transformed tumor cells	Suppressing the p38 mitogen-activated protein (MAP) kinase	(Yagura et al. 2008)
19	<i>H. melanacme</i>	South Africa	Chloroform: methanol (1:1)	3-O-methylquercetin, quercetin	Brain, skin	SF-268, and A375 cells	Induction of tumor cell apoptosis	(Doneda et al. 2021; Chien et al. 2009; Foden and Potter, 2005; Lall et al. 2006; Lourens et al. 2011)
20	<i>H. miconiifolium</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Lourens et al. 2011)
21	<i>H. nudifolium</i>	South Africa, Lesotho, and tropical Africa	Dichloromethane, dichloromethane: methanol (1:1), and chloroform: methanol (1:1)	*	Skeletal muscle, melanoma, and brain	L6, UACC62, and SF-268 cells	*	(Fouché et al. 2008; Lourens et al. 2011; Mokoka et al. 2011)
22	<i>H. odoratissimum</i>	Lesotho, Swaziland, South Africa, Mozambique, and Zimbabwe	Aqueous, ethanol, and methanol	Kaempferol, quercetin, β-sitosterol-3-O-glucoside, oleanolic acid	Kidney, cervical, breast, brain, and colon	HEK-293, HeLa, MDA-MB-453, MDA-MB-231, A172, Caco-2, and HCT15 cells	Induction of tumor cell apoptosis, and inhibition of macrophage M2 polarization	(Azevedo et al. 2015; Chien et al. 2009; Fujiwara et al. 2011; Kusaczuk et al. 2022; Li et al. 2002; Maiyoo et al. 2016; Sinda et al. 2022; Twilley et al. 2017; Zhu and Xue, 2019)
23	<i>H. oreophilum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Lourens et al. 2011)
24	<i>H. pallidum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Lourens et al. 2011)
25	<i>H. pandurifolium</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2009; Lourens et al. 2011)

26	<i>H. patulum</i>	South Africa	Chloroform: methanol (1:1)	Arbutin, β -sitosterol-3-O-glucoside, and viridiflorol	Brain, skin, breast, liver, colon, and lung	SF-268, Daoy, B16-F10, MCF-7, HepG2, Huh7, Caco-2, HCT-116, and A549 cells	Stimulation of apoptosis through the estrogen receptor- α signal pathway	(Akiel et al. 2022; Chang et al. 2017; El-Halawany et al. 2019; Hazman et al. 2021; Lourens et al. 2011; Li et al. 2002; May and Notten, 2019; Swartz, 2006; Vo et al. 2020)
27	<i>H. petiolare</i>	South Africa	Methanol, ethanol, chloroform: methanol (1:1), and essential oil	*	Brain, skeletal muscle, and skin	SF-268, HepG2 (C3A), L6, B16F10, and MeWo cells,	The methanolic extract was found to induce cell arrest in the S phase and M phase, respectively, on B16F10 and MeWo cells.	(Lourens et al. 2011; Sagbo and Otang-Mbeng, 2020)
28	<i>H. plicatum</i>	Eastern Mediterranean and Iran	Methanol and ethanol	Apigenin, naringenin, and kaempferol	Cervical, prostate, colon, ovarian, and leukemia	HeLa, PC3, MCF-7, HT-29, MG63, HCT-116, A549, A2780, and K562 cells	Cell apoptosis, autophagy, and immune response	(Azevedo et al. 2015; Bigović et al. 2017; Bigović et al. 2011; Motallebi et al. 2022; Rahmani et al. 2022; Shukla and Gupta, 2010; Yan et al. 2017; Zhao et al. 2019)
29	<i>H. psilolepis</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Lourens et al. 2011)
30	<i>H. retortum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2009; Lourens et al. 2011)
31	<i>H. rosum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2005; Lourens et al. 2011)
32	<i>H. rudemale</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Foden and Potter, 2009; Lourens et al. 2011)
33	<i>H. scitulum</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Kamundi and Raimondo, 2019; Lourens et al. 2011)
34	<i>H. simillimum</i>	South Africa	Chloroform: methanol (1:1)	Kaempferol	Brain, breast	SF-268, MDA-MB-453, MDA-MB-231,	Induction of tumor cell apoptosis, inhibiting migration, and invasion of	(Azevedo et al. 2015; Brusselmans et al.

						MCF-7 cells	breast cancer cells	2005; Elgorashi et al. 2008; Foden and Potter, 2009; Hazman et al. 2021; Lourens et al. 2011)
35	<i>H. splendidum</i>	South Africa, and tropical Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Lourens et al. 2011; van der Walt, 2005)
36	<i>H. stoechas</i>	West and Central Mediterranean	Methanol	Quercetin	Cervical, breast and brain	HeLa, MDA-MB-231, and A172 cells	Induction of apoptosis in cells associated with brain and breast cancer.	(Chien et al. 2009; Kusaczuk et al. 2022; Lavault and Richomme, 2004; Les et al. 2017)
37	<i>H. wilmsii</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Lourens et al. 2011; von Staden, 2016)
38	<i>H. zeyheri</i>	South Africa	Chloroform: methanol (1:1)	*	Brain	SF-268 cells	*	(Lourens et al. 2011; Foden and Potter, 2005)
39	<i>H. zivojinii</i>	Macedonia	Hexane, ethyl-acetate, butanol, methanol, and dichloromethane	Tomoroside A and B, apigenin, naringenin, apigenin 7-O- β -D-glucopyranoside,	Cervical, melanoma, leukemia, brain, breast, colon, ovarian, prostate, and lung	HeLa, Fem-x, K562, MDA-MB-361, MDA-MB-231, PBMC, NCI-H460, MCF-7, HT-29, MG63, HCT-116, A549, A2780, PC-3, and NCI-H460/R cells.	Cell apoptosis, autophagy, and immune response. Tomoroside A influenced the expression of genes implicated in MDR (topoisomerase II alpha (topo II α), hypoxia-inducible factor 1-alpha (hif-1 α), and multidrug resistance 1 (mdr1) genes). While tomoroside B only affected the expression of hif-1 α genes	(Aljančić et al. 2014; Matić et al. 2013a; Matić et al. 2013b; Motallebi et al. 2022; Morikawa et al. 2009; Rahmani et al. 2022; Shukla and Gupta, 2010; Yan et al. 2017; Zhao et al. 2019)

* = Not available

DISCUSSION

The genus *Helichrysum* Miller (family = Asteraceae, tribe = Inuleae, subtribe = Gnaphalieae), which consists of over 500 species worldwide (Hilliard and Leistner 1983), is diverse and most distributed in the family of Asteraceae. Species of this genus occur throughout the African continent, southwest Asia, India, Sri Lanka, Australia, and Southern Europe (Lourens et al. 2004). For centuries, they have been known to exhibit beneficial properties to treat various ailments such as cancer (Akinyede et al. 2021). Figures 2 and 3 show a list of some *Helichrysum* species and compounds with known antiproliferative activity to cancer cells, respectively, while Table 1 shows the reported antiproliferative activities.

Helichrysum acutatum DC. is a perennial woody herb native to South Africa, Swaziland, and Zimbabwe (Foden and Potter 2005). It is an aromatic plant that grows in grassland areas with flowering stems and basal leaves up to 17 x 55 cm in height (Hilliard and Leistner 1983; Oyetunde-Joshua et al. 2017). The antiproliferative activity of the root extracts (dichloromethane, ethyl acetate, and methanol) of the plant was reported against cancerous cells: liver hepatoblastoma (HepG2) and colorectal adenocarcinoma (Caco-2), with half-maximal inhibitory concentration (IC_{50}) values between the range of 126-4533 $\mu\text{g/mL}$ and 165-4719 $\mu\text{g/mL}$, respectively (Oyetunde-Joshua et al. 2017). In a study conducted by Lourens et al. (Lourens et al. 2011), the chloroform:methanol (1:1) extract of the plant displayed significant cytotoxic activity against human breast cancer (MCF) cells. No active phytochemicals have been identified, and no in vivo reports were conducted on the plant.

Helichrysum arenarium (L.) Moench, also called the dwarf or sandy everlasting, is native to Europe, Central Asia, and China (Dănilă-Guidea et al. 2022; Yang et al. 2009). This perennial herbaceous plant can grow to an average height of 20 cm but can reach 10 to 50 cm (Dănilă-Guidea et al. 2022). The leaves appear whitish-green due to the hair that covers them, and the stem of the plant is generally branched at the upper part and carries alternate leaves of about 2 to 5 cm in length (Eshbakova and Aisa, 2009; Pljevljaković et al. 2018). Kramberger and co-workers (2021) revealed that the aqueous extract of this plant was toxic with the highest concentration of 5% (volume per volume, v/v) against lymphoma (U937) cells. While the same extract displayed toxicity even at lower concentrations (1%, v/v) in both the human colorectal adenocarcinoma (Caco-2) and primary colon fibroblast (CCD112CoN) cell lines. No reports were found involving in vivo research on the plant species. The active metabolites responsible for the anticancer activity are yet to be identified.

Helichrysum caespititium (DC.) Harv. is a perennial creeping herb, whose habitat stretches across South Africa to Zimbabwe (Hyde et al. 2023). *H. caespititium* can grow up to 20 cm in height, the leaves are compacted along the stem (6-10 mm long), and the flowers are white-yellow (Maroyi, 2019a). In in vitro studies (Mamabolo et al. 2018), the whole plant dichloromethane (100%) extract of *H. caespititium* displayed a significant cancer activity in rat hepatoma carcinoma (H411E) cell lines. In this study, a lethal concentration 50 (LC_{50}) value of 82.86 $\mu\text{g/mL}$ was reported (compared to the standard control doxorubicin, LC_{50} = 10.80 $\mu\text{g/mL}$). The active constituents showing anti-cancer activity are yet to be reported. Also, in vivo studies are limited.

Helichrysum foetidum (L.) Moench is a vigorous aromatic herb with elliptic, sparsely hairy, white-woolly stems (0.3-1 m from the base) and leaves up to 120 x 150 mm (Swelankomo, 2005). The inflorescence consists of involucre bracts and flowerheads shaped like an umbrella. This species is native to South Africa (Swelankomo, 2005), Tropical Africa, Madagascar, and the Arabian Peninsula (POWO, 2023). The anticancer activity of the plant (leaf and stem chloroform: methanol (1:1) extract) was shown against MCF-7 breast adenocarcinoma cells at 0.1 mg/ml concentration (Lourens et al. 2011). The in vivo studies and the phytochemicals responsible for the antitumor effects are yet to be evaluated.

Helichrysum graveolens (Bieb.) Sweet is native to Eastern Europe, the Caucasus, Türkiye, and Iran (Reidel et al. 2017). This aromatic species is greyish-green with bright yellow flowers and linear, simple leaves. The aqueous extract of the plant exhibited no inhibitory activity to colon carcinoma (C26) cells at the tested concentrations (Kutluk et al. 2018; Taghavizadeh Yazdi et al. 2020). There are no in vivo studies from *H. graveolens* and bioactive phytochemicals responsible for its antitumor effects.

Helichrysum gymnocephalum (DC) Humbert is a perennial shrub that can grow up to 4 m in height and is found in rocky areas in the central region of Madagascar (Ambodivoanjo-Ambohijatovo, 2016; Taghavizadeh Yazdi et al. 2020). The stems are covered with greyish hairs, while leaves are alternate and attenuated towards the base in short petioles with small flowers grouped in compound inflorescences (Afoulous et al. 2011). The cytotoxic effect of the leaf essential oil of *H. gymnocephalum* was shown on human breast cancer cells MCF-7 by Afoulous et al. (2011). The study reported a strong activity of the oil with an IC_{50} value of 16 ± 2 mg/L. Analysis of the constituents of the oil using gas chromatography-mass spectrometry (GC-MS), showed 1,8-cineole (47.4%) as one of the major

compounds (Afoulous et al. 2011). The antiproliferative activity of this compound, whose mode of action is through the activation of various pathways, has been reported (Cai et al. 2021; Rodenak-Kladniew et al. 2020). In addition, this compound was also shown to exhibit its anticancer activity through a series of pathways, such as the reduction of micro-ribonucleic acid (miR)-122 as well as suppression of transforming growth factor-beta (TGF- β 1), fascin actin-bundling protein 1 (FSCN1), vimentin, matrix metalloproteinase-9 (MMP-9), and vascular endothelial growth factor (VEGF) (x3/36) protein. Furthermore, terpinen-4-ol (2.7%), β -pinene (1.1%), and limonene (0.5%), were reported as minor compounds in the study (Afoulous et al. 2011) and their anticancer effects against several cancer cell lines have also been reported (Anandakumar et al. 2021; Cao et al. 2022; Cao et al. 2023; Chebet et al. 2021; Di Martile et al. 2021; Casalle and de Andrade, 2020; Machado et al. 2022; Mandal and Parija, 2022; Nakayama et al. 2017).

Helichrysum italicum (Roth) G. Don is an aromatic perennial herb native to the Mediterranean region. It has a growth potential of up to 70 cm in height and occurs in dry, rocky, and sandy areas (Viegas et al. 2014). The leaves appear small and evergreen with a revolute margin, and the stems are erect, hairy, and between 20 and 50 cm long (Ninčević et al. 2019). The anticancer activity of the aqueous ex-tract of the aerial parts of *H. italicum* was shown by Kramberger et al. (2021) against lymphoma (U937), adenocarcinoma (Caco-2), and primary colon fibroblasts (CCD112CoN) cells. The study reported that the infusion was not toxic up to 5% v/v concentration in U937 cells. In CCD112CoN and Caco-2 cells, the toxicities were detectable at 2% v/v and 1% v/v concentrations, respectively. Staver et al. (2018) reported moderate inhibitory effects of the essential oil obtained from the fresh aerial parts of the plant on human cervix adenocarcinoma (HeLa) cells (IC₅₀ = 0.075 mg/mL) and human breast cancer (MCF-7) cells (IC₅₀ = 0.057 mg/mL) via apoptosis. In another study (Gismondi et al. 2020), a strong cytotoxic potential of the essential oil from the flower heads of *H. italicum* was shown against murine melanoma (B16F10) cells.

The phytoconstituent-ents of the oil that were identified through GC-MS included 1,8-cineole (Abdallah et al. 2022; Cai et al. 2021; Rodenak-Kladniew et al. 2020), terpinene-4-ol (Cao et al. 2023; Cao et al. 2022; Casalle and de Andrade, 2020; Di Martile et al. 2021; Nakayama et al. 2017), β -pinene (Machado et al. 2022), limonene (Anandakumar et al. 2021; Chebet et al. 2021; Mandal and Parija 2022), camphene (Girola et al. 2015), α -pinene (Allenspach and Steuer, 2021), linalool (Elbe et al. 2023; Zhao et al. 2020), terpinolene (Aydin et al. 2013; Kig et al. 2021), p-cymene (Jin et al. 2021), α -copaene (Turkez et al. 2014), β -caryophyllene (Dahham et al. 2015; Dahham et al. 2021; Chung et al. 2019; Irrera et al. 2020), α -humulene (Chen et al. 2019; de Lacerda Leite et al. 2021), δ -cadinene (Hui et al. 2015). *Helichrysum maracandicum* Popov ex Kirp is native to the mountain ridges of Central Asia (POWO, 2023). The leaves of this plant vary depending on the habitat, from broad to narrow (Sarabekov, et al. 2022). The ethanolic flower extract from *H. maracandicum* showed antiproliferative activity against SENCAR mouse skin transformed tumor cells (SST-T cell) with an IC₅₀ value of 62 μ g/mL, which was more effective than the positive control (quercetin, IC₅₀ = 331 μ g/mL) (Yagura et al. 2008). A pure compound, isosalipurposide (figure 3), obtained from the ethanol extract displayed an IC₅₀ values of 115 μ g/mL. In addition, the pure compound also demonstrated in vivo activity in two-stage mouse skin carcinogenesis tests by suppressing the p38 mitogen-activated protein (MAP) kinase (Yagura et al. 2008).

Helichrysum nudifolium (L.) Less. Var. *pilosellum* (L.f.) Beentje is a perennial herb that can reach up to 40 cm in height (Hyde et al. 2023). This fast-growing plant occurs in the grassland areas of South Africa to the subtropical east of Central Africa. The leaves appear dark green, rough, shiny, with hair beneath, and large up to 600 x 130 mm (Van Wyk and Gorelik, 2017). Extracts from *H. nudifolium* were investigated against several cancer cells. The root dichloromethane (100%) extract of *H. nudifolium* exhibited moderate cytotoxic activity against human breast cancer (MCF7) cells, and human metastatic melanoma (UACC62) cells (Fouché et al. 2008). The whole plant dichloromethane: methanol (1:1) extract of the plant displayed low inhibitory activity on rat myoblast (L6) cells (IC₅₀ = 47.7 μ g/mL) (Mokoka et al. 2011). The chloroform: methanol (1:1) extract of the same plant had inhibitory effects only on glioblastoma (SF-268) cells and breast adenocarcinoma (MCF-7) at the tested concentration (0.1 mg/mL) (Lourens et al. 2011). Presently, information about the active phytochemicals with anticancer activity and the in vivo studies from this plant are limited.

Helichrysum odoratissimum (L.) Sweet is an everlasting shrub that can grow up to 20–200 cm high and is native to South Africa and neighboring countries like, Lesotho, Swaziland, Mozambique, and Zimbabwe (De Canha et al. 2020). The leaves of *H. odoratissimum* are variable in shape (linear to oblanceolate) and are covered in grey to white velvet hairs on both leaf surfaces (Maroyi, 2019b). The cytotoxic study of the ethanolic (100%) leaf and stem extracts of *H. odoratissimum* against malignant melanoma (A 375), human epidermoid carcinoma (A 431), and cervical epithelial carcinoma (HeLa) cell

lines showed IC₅₀ values at 55.5, 37.1, 33.1, and 15.5 µg/mL, respectively (Twilley et al. 2017). In another study (Lourens et al. 2011), the leaf and stem chloroform: methanol (1:1) extract of the plant exhibited cytotoxic effects to glioblastoma (SF-268) cells (48%) and breast adenocarcinoma (MCF-7) cells (7.4%) at 0.1 mg/mL concentration. No bioactive compounds are responsible for its anticancer activity. The in vivo studies have also not yet been reported in the literature.

Helichrysum petiolare Hilliard & B.L.Burt is indigenous to South Africa (Foden and Potter, 2009). The leaves of this vigorous everlasting shrub (up to 60 cm tall) are round covered with silver-grey hair and stems are loosely branched and straggling (Oliver, 2004). The methanolic extract of the plant displays anticancer activity on mouse melanoma (B16F10) cells and human melanoma (MeWo) cells by inducing cell arrest in the S phase and M phase (Sagbo and Otang-Mbeng, 2020), respectively. A research study conducted by Lourens et al. (2011) revealed that the chloroform: methanol (1:1) extract of the plant had toxic effects on glioblastoma (SF-268) and breast adenocarcinoma (MCF-7) cells at 0.1 mg/mL. No reports were found in the literature involving in vivo studies and the active compounds responsible for the anticancer activity are yet to be reported.

The native range of *H. plicatum* DC is the eastern Mediterranean to Iran. The leaves and stems of this perennial shrub are glandular (Bigović et al. 2017). A study that assessed the antiproliferative activity of the ethanolic (100%) extract of the plant against human cervix adenocarcinoma cells (HeLa), prostate cancer (PC3) cells, and myelogenous leukemia (K562) cells reported IC₅₀ values of 42.1 ± 0.05, 39.2 ± 1.1, and 25.9 ± 1.5 µg/mL, respectively (Bigović et al. 2011). A high-performance liquid chromatography-photodiode array detector (HPLC-PDA) analysis of the constituents of the extracts from *H. plicatum* indicated the presence of apigenin, naringenin, and kaempferol (Bigović et al. 2011). These compounds have been shown to express antitumor effects against various cancer cells through the regulation of several pathways (Shukla and Gupta, 2010; Motallebi et al. 2022; Rahmani et al. 2022; Yan et al. 2017; Zhao et al. 2019). Apigenin, one of the compounds identified in *H. plicatum* has been reported against prostate cancer (PC-3) tumor xenografts in nude mice (Shukla and Gupta, 2009; Pandey et al. 2012). Therefore, it is imperative to state that the antiproliferative activity of this plant may be due to these phytochemicals. It should be noted that the in vivo studies involving the extract, or its constituents of this plant are limited.

Helichrysum stoechas (L.) Moench is a Mediterranean everlasting shrub (up to 0.5 m in height) with woolly, spoon-shaped, and revolute leaves (Ascensão et al. 2001; Rios et al. 1991). The inflorescences consist of involucre bracts and globular yellow flowers (Aydin et al. 2013). While no in vivo studies have been conducted on this plant, Les et al. (2017) showed moderate anticancer activity of the aerial part of methanolic extract against cervical cancer cells (HeLa). The bioactive phytochemicals responsible for the anticancer activity *H. stoechas* are yet to be identified.

Helichrysum zivojinii Černjavski & Soska is an endemic perennial plant growing in the former Yugoslav Republic of Macedonia (Aljančić et al. 2014). The phytochemistry of this aromatic species is poorly described in the literature. Concerning its antiproliferative activity, Matić et al. (2013a) reported a selective cytotoxicity effect of the n-hexane (100%) extract (aerial parts) on human breast adenocarcinoma (MDA-MB-231) cells with an IC₅₀ value of 22.4 ± 2.7. The hexane extract was more effective among the tested extracts (dichloromethane, ethyl-acetate, n-butanol, and methanol) and even stronger than cisplatin, the control drug (IC₅₀ = 28.4 ± 2.6). In another study (Matić et al. 2013b), the n-hexane extract (aerial parts) of the plant also displayed a stronger inhibitory effect on K562 cells (IC₅₀ = 11.78 ± 0.94 µg/mL) among the tested extracts. The isolated compounds, tomoroside A and B, obtained from the leaves of *H. zivojinii*, were shown to exhibit strong cytotoxic effects against human-sensitive non-small cell carcinoma cell line NCI-H460 (Aljančić et al. 2014). Tomoroside A (figure 4) exhibited strong toxicity (with an IC₅₀ value of 44.4 µM) as compared to the tomoroside B. HPLC-mass spectrometry analysis of the constituents of the extracts from *H. zivojinii* consisted of known compounds with reported antitumor activity (Matić et al. 2013b). Compounds such as apigenin (Shukla and Gupta, 2010; Yan et al. 2017; Rahmani et al. 2022), apigenin-7-O-β-D-glucopyranoside (Matić et al. 2013b, Morikawa et al. 2009), and naringenin (Motallebi et al. 2022; Zhao et al. 2019) identified from this plant have been reported to exhibit antiproliferation.

Apart from the antiproliferative activity, several other studies have been reported from the *Helichrysum* species that are reviewed in this study, for instance: antioxidant was shown in *H. acutatum* (Oyetunde-Joshua et al. 2022), *H. arenarium* (Czinner et al. 2000; Eshbakova and Aisa, 2009), *H. aureonitens* (Shelembe et al. 2022), *H. caespitium* (Mamabolo et al. 2017), *H. dasyanthum* (Lourens et al. 2004), *H. excisum* (Lourens et al. 2004), *H. felinum* (Lourens et al. 2004), *H. foetidum* (Tirillini et al. 2013), *H. graveolens* (Süntar et al. 2013), *H. italicum* (Rosa et al. 2007; Sala et al. 2002; Węglarz et al. 2022), *H. maracandicum* (Ahmedova and Asrarov, 2021), *H. melanacme* (Gouveia-Figueira et al. 2014), *H. odoratissimum* (Legoale et al. 2013; Matrose et al. 2021; Matrose et al. 2023), *H. pandurifolium* (Jadalla

et al. 2022), *H. pertiolare* (Adewinogo et al. 2022; Vujic et al. 2020), *H. plicatum* (Bigović et al. 2011; Haddouchi et al. 2014; Taşkın et al. 2020), and *H. stoechas* (Jäger et al. 1996; Kherbache et al. 2020; Les et al. 2017). The anti-inflammatory activity is well elaborated in *H. excisum* (Lourens et al. 2004), *H. felinum* (Lourens et al. 2004), *H. graveolens* (Süntar et al. 2013), *H. italicum* (Sala et al. 2002), *H. nudifolium* (Karaca et al. 2009; Lourens et al. 2008; Maroyi, 2019c), *H. odoratissimum* (De Canha et al. 2020; Legoale et al. 2013), *H. pertiolare* (Adewinogo et al. 2022), *H. plicatum* (Aslan et al. 2007; Haddouchi et al. 2014), and *H. stoechas* (Les et al. 2017). Whereas, antidiabetic activity has only been reported from a few species, including *H. graveolens* (Aslan et al. 2007), *H. odoratissimum* (Aladejana et al. 2020; Njagi et al. 2015), *H. pertiolare* (Akinyede et al. 2022; Aslan et al. 2007), *H. plicatum* (Acet et al. 2020; Sibandze, 2009), and *H. stoechas* (Jäger et al. 1996). In Table 2 below, a summary of some reported biological studies is given from the *Helichrysum* species that are reviewed in this study.

Table 2. Various biological activities from *Helichrysum* species.

S/N	<i>Helichrysum</i> species	Other known biological activities	Bioactive phytochemical(s)	References
1	<i>H. acutatum</i>	Antioxidant and antimicrobial activity	*	(Oyetunde-Joshua et al. 2022; Sibandze, 2009)
2	<i>H. adenocarpum</i>	*	*	*
3	<i>H. appendiculatum</i>	Antiviral	*	(Heyman, 2013)
4	<i>H. arenarium</i>	Antioxidant, antibacterial, and anti-atherosclerosis	Narirutin, naringin, luteolin, eriodictyol, galuteolin, astragalin, and kaempferol	(Babotă et al. 2018; Czinner et al. 2000; Eshbakova and Aisa 2009)
5	<i>H. aureonitens</i>	Antiviral, antibacterial, and antioxidant	Galangin	(Shelembe et al. 2022; 1 Meyer and Afolayan, 1995; Meyer et al. 1997)
6	<i>H. caespitium</i>	Antimicrobial, antifungal, anti-gonorrhea, and antioxidant	Caespitate	(Bassey et al 2021; Mamabolo et al. 2018; Mamabolo et al. 2017; Mathekga et al. 2000)
7	<i>H. callicomum</i>	Antibacterial, antimicrobial	*	(Lourens et al. 2011; Mathekga and Meyer, 1998)
8	<i>H. cephaloideum</i>	Antimicrobial	*	(Lourens et al. 2011)
9	<i>H. cymosum</i>	Antimicrobial, antimalarial, antidiabetic, and anti-tyrosinase	Helihumulone, allopatuletin, helichrysetin, and dihydrobaicalein	(Adewinogo et al. 2022; Jadalla et al. 2022; Van Vuuren et al. 2006)
10	<i>H. dasyanthum</i>	Antioxidant, antimicrobial	*	(Lourens et al. 2004)
11	<i>H. excisum</i>	Antioxidant, antimicrobial, and anti-inflammatory	*	(Lourens et al. 2004)
12	<i>H. felinum</i>	Antioxidant, antimicrobial, and anti-inflammatory	*	(Lourens et al. 2004)
13	<i>H. foetidum</i>	Antiparasitic, antimicrobial, antibacterial, antifungal, antioxidant, and protease inhibition	Apigenin-7-O-β-D-glucoside, 6'-methoxy2',4-dihydroxychalcone-4'-O-β-D-glucoside, kaur16-en-18-oic acid, foetidumin C, erythroxytol A, and kaempferol	(Babotă et al. 2018; Bassey et al. 2021; Mathekga et al. 2000; Malolo et al. 2015; Matić et al. 2013a, Nono et al. 2023; Steenkamp et al. 2004)
14	<i>H. graveolens</i>	Anti-diabetic, antibacterial, anti-	Apigenin	(Aslan et al. 2007; Aydin, 2019; Coşar and Cubukcu,

		tyrosinase, wound healing, anti-inflammatory, and antioxidant,		1990; Süntar et al. 2013)
15	<i>H. gymnocephalum</i>	Anti-plasmodial and antimalarial	Pinocembrin, 3-O-acetylpinobanksin, and 5,7-dihydroxyisoflavone	(Afoulous et al. 2011, Ranaivoarisoa et al. 2020)
16	<i>H. indicum</i>	Antimicrobial	*	(Lourens et al. 2011)
17	<i>H. italicum</i>	Antimicrobial, antiviral, anti-tyrosinase, genotoxicity, anti-inflammatory, antioxidant, antibacterial, and antifungal	Arzanol, 4,2',4',6'-tetrahydroxychalcone-2'-glucoside, kaempferol-3-glucoside, naringenin-glycoside, tiliroside, 12-acetoxytremetone, desmethylyangonine-4'-O-β-D-glucopyranoside, and 4-hydroxy3(isopentent-2-yl) acetophenone	(Angioni et al. 2003; Appendino et al. 2007; Bakkali et al. 2005; Cui et al. 2015; D'Abrosca et al. 2013; Facino et al. 1990; Jakupović et al. 2023; Nostro et al. 2001; Nostro et al 2003; Rigano et al. 2014; Rosa et al. 2007; Sala et al. 2002; Stupar et al. 2014; Tomás-Barberán et al. 1990; Węglarz et al. 2022; Zheljazkov et al. 2022;)
18	<i>H. maracandicum</i>	Antioxidant and hepatoprotective	*	(Ahmedova and Asrarov, 2021)
19	<i>H. melanacme</i>	Antiviral, antimicrobial, antimycobacterial, antioxidant	2,4',6'-trihydroxy-3'-prenylchalcone, and 4',6',5''trihydroxy-6''6''-dimethyldihydropyrano(2'',3''-2',3') chalcone	(Lall et al. 2006; Lourens et al. 2011; Gouveia-Figueira et al. 2014)
20	<i>H. miconiifolium</i>	Antimicrobial	*	(Lourens et al. 2011)
21	<i>H. nudifolium</i>	Anti-inflammatory, antibacterial, antifungal, antiplasmodial, and antiviral	*	(Clarkson et al. 2004; Heyman, 2009; Heyman et al. 2015; Jäger et al. 1996; Lourens et al. 2008; Maroyi, 2019c; Mathekga, 2004; Seaman, 2005)
22	<i>H. odoratissimum</i>	Antimicrobial, antibacterial, antifungal, antioxidant, anti-inflammatory, and anti-diabetic	3-O-Methylquercetin and 3',4',3,5-tetrahydroxy-7-methoxyflavone	(Aladejana et al. 2020; De Canha et al. 2020; Lawal et al. 2015; Legoale et al. 2013; Matrose et al. 2021; Matrose et al. 2023; Serabele et al. 2021; Van Puyvelde et al. 1989; Zantanta et al. 2022)
23	<i>H. oreophilum</i>	Antimicrobial	*	(Lourens et al. 2011)
24	<i>H. pallidum</i>	*	*	*
25	<i>H. pandurifolium</i>	Antidiabetic, antioxidant	3',4',5,7-tetrahydroxy-3-methoxyflavone	(Jadalla et al. 2022)
26	<i>H. patulum</i>	Antimicrobial, antifungal	*	(Kubínová et al. 2021; Scott et al. 2004)
27	<i>H. pertiolare</i>	Antioxidant, anti-diabetic, antimicrobial, antibacterial, genotoxicity, and anti-inflammatory	Dicaffeoylquinic acid	(Adewinogo et al. 2022; Akinyede et al. 2022; Aladejana et al. 2020; Kubínová et al. 2021; Lourens et al. 2004)

				Lourens et al. 2011; Sagbo and Mbeng, 2018)
28	<i>H. plicatum</i>	Antiarcardial, antimicrobial, antibacterial, antidiabetic, anti-inflammatory, antineurodegenerative, wound healing and genotoxicity	Nonacosanoic acid	(Acet et al. 2020; Aslan et al. 2007; Aydin, 2020; Bigović et al. 2017; Bigović et al. 2011; Demir et al. 2009; Erhan et al. 2010; Jovanović et al. 2020; Karaca et al. 2009; Miloglu et al. 2023; Taşkın et al. 2020; Vujic et al. 2020)
29	<i>H. psilolepis</i>	Antimicrobial	*	(Lourens et al. 2011)
30	<i>H. retortum</i>	Antimicrobial	*	(Lourens et al. 2011)
31	<i>H. rosum</i>	Antimicrobial, antibacterial	*	(Lourens et al. 2011,230)
32	<i>H. ruderae</i>	Antimicrobial	*	(Lourens et al. 2011)
33	<i>H. scitulum</i>	Antimicrobial	*	(Lourens et al. 2011)
34	<i>H. simillimum</i>	Antimicrobial, antimutagenic	Kaempferol	(Lourens et al. 2011,231)
35	<i>H. splendidum</i>	Antifungal	*	(Mashigo et al. 2015)
36	<i>H. stoechas</i>	Antimicrobial, antibacterial, anti-inflammatory, antioxidant, antidiabetic, antihypertensive, and antinociceptive	Italipyrone, lignoceric acid, lanost-5-en-3 β -ol-26-oic acid, and lanost-5-en-26-oic acid	(Albayrak et al. 2010; Kherbache et al. 2020; Les et al. 2017; Haddouchi et al. 2014; Hussain et al. 2022; Hwisa et al. 2011; Roussis et al. 2002; Shukla and Gupta, 2010; Sobhy and El-Feky, 2007; Valero et al. 2022)
37	<i>H. wilmsii</i>	Antimicrobial	*	(Lourens et al. 2011)
38	<i>H. zeyheri</i>	Antimicrobial	*	(Lourens et al. 2011)
39	<i>H. zivojinii</i>	*	*	*

* Not available.

CONCLUSION

Several plants from the *Helichrysum* genus have been revealed to play a vital role in traditional medicine against several diseases, including cancer, in many parts of the world. The presence of their bioactive compounds' accounts for their several pharmacological actions. The present review study has highlighted the *Helichrysum* species' diversity and therapeutic potential and their compounds for cancer management. However, limited scientific reports exist on some *Helichrysum* species with anticancer properties in the literature. Thus, there is a need to further explore all the species from *Helichrysum* genus, as they are shown to be potential sources of beneficial bioactive medicinal compounds that could be exploited in cancer drug discovery and development. Also, it is imperative to note that these species and their compounds are yet to be clinically studied. Thus, effort needs to be devoted to clinical studies on cancer.

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COMPARATIVE ANALYSIS OF GENETIC DIVERSITY IN *BILOBATA SUBSECIVELLA* POPULATIONS FROM AFRICA, INDIA AND AUSTRALIA USING MTDNA GENE SEQUENCES

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ABSTRACT

Bilobata subsecivella (Zeller) (Lepidoptera: Gelechiidae) is a major pest of *Arachis hypogaea* (L.) and *Glycine max.* Merr (L.) in Asia and Africa. Molecular work conducted in South Africa revealed that *B. subsecivella* populations in India, Africa and Australia are very closely related, despite earlier assumptions of their differences. Thus, we investigated the evolutionary relationships of *B. subsecivella* specimens collected from Australia, India, Mozambique and South Africa by comparing sequences of three gene regions of the mitochondrial DNA (COI, COII, cytb). Sequenced samples included 46 collected from four sites in South Africa, four from Mozambique, three from Australia and three from India. Evolutionary history was assessed using Maximum Parsimony (MP) and Neighbour Joining (NJ) analysis. In the phylogenetic trees for all three gene regions, a similar pattern was observed in the way that the sequences were assembled into different groups, i.e., some sequences from Australia grouped separately from the others, but some Australian gene sequences were associated closely with those from India and South Africa. Phylogenetic analysis results of the current study indicate that *B. subsecivella* populations in Africa, India and Australia are genetically connected and likely represent a single species, with the Australian population displaying the greatest genetic diversity, suggesting a longer evolutionary history.

Keywords: *Aproaerema modicella*, *Aproaerema simplexella*, Maximum Parsimony, Neighbour Joining, phylogenetics

INTRODUCTION

Groundnut/soya bean leaf miner (GSLM), *Bilobata subsecivella* (Zeller) (Lepidoptera: Gelechiidae) (Figure 1) is a significant pest of groundnut (*Arachis hypogaea* L.) and soya bean (*Glycine max.* Merr. L.) in Indo-Asia and Africa. When it was first recorded in Africa in 1998, it was widely believed to be an invasion of *Aproaerema modicella* (Deventer) (Lepidoptera: Gelechiidae) from the Indo-Asian continent (Kenis & Cugala 2006). However, subsequent analyses of mitochondrial DNA (mtDNA) COI sequences from GSLM specimens collected from South Africa matched 100% with the Australian soybean moth *Aproaerema simplexella* (Walker) (Buthelezi et al. 2012). Correct identification of insect pests is crucial for developing effective control strategies. For decades, insect identification relied solely on morphological and taxonomic studies. However, difficulties in morphological identification led to the adoption of molecular techniques for identifying and characterizing different taxa (Mandal et al. 2014). Phylogenetics can be useful in describing the relationships between insect species (Utsugi et al. 2011) as it can incorporate both molecular and morphological data to classify organisms. Mitochondrial DNA

(mtDNA) has been one of the most widely used molecular markers for phylogenetic studies in animals (Avice 2004). In the current study, mtDNA gene regions (COI, COII, cytb) were used to investigate the evolutionary history of GSLM populations collected from Africa, Australia, and India.



Figure 1. Pictogram of *B. subsecivella* adult moth (adapted from Buthelezi et al., 2012).

MATERIALS AND METHODS

Specimen Collection

In South Africa, specimens were collected from groundnut, soya bean, lucerne (*Medicago sativa*) and pigeon pea (*Cajanus cajan*) at Brits (25°59'1.35" S 27°76'8.75" E), Nelspruit (25°45'4.52" S 30°97'1.54" E), Manguzi (26°95'5.32" S 32°82'3.56" E) and Vaalharts (27°95'7.61" S 24°83'9.91" E). In Mozambique, they were collected from groundnuts at Pambara EP1 (21°94'33" S 35°10'06" E) and Pambara Produtor (21°99'84" S 35°15'13" E). In India, they were collected from groundnut at Hyderabad- ICRISAT (17°21'57" N 78°28'33" E). In Australia, moths were captured using pheromone traps installed in natural vegetation containing wild soya bean in Brisbane (27°32'08" S 152°51'35" E). All specimens were placed in 10-ml polycarbonate vials containing absolute ethanol, sealed with press-on plastic lids, and stored at minus 80°C in a cryogenic freezer until DNA sequencing.

DNA Analyses

DNA extraction and polymerase chain reaction (PCR) amplification, editing of DNA sequences, and sequence alignment were conducted following the procedures outlined by Buthelezi et al. (2012).

Primers were designed by Inqaba Biotech Industries, and are detailed as:

- mtDNA COI: Forward – GRTCHCCWCCTCCTCYHGGRTC; Reverse – GATTTTGATCAGGWATAC
- COII: Forward – GGCTACTTGATCAAATCTTA; Reverse – CCGGGTTAGCATCAACTTTT
- mtDNA cytb: Forward – GCGTCTACCTACACATTGG; Reverse – CGAGCTCCGATTCATGTTA

Sequence Analyses and Phylogenetic Reconstruction

Phylogenetic analyses used Maximum Parsimony (MP) and Neighbour Joining (NJ) methods with PAUP* 4.0b10 (Swofford 2003). The tree-bisection-reconnection (TBR) algorithm and bootstrap re-sampling (1000 iterations) were applied. The nucleotide substitution models were GTR+I for COI and cytb, and HKY+I for COII (Posada & Crandall 1998). Genetic distances were calculated using PAUP* 4.0b10 (Swofford 2003).

RESULTS

Mitochondrial DNA COI Gene

The phylogenetic tree (Figure 2) is based on 308 nucleotides of the mtDNA COI gene from various *Aproaerema* species and out-groups from National Center for Biotechnology Information (NCBI). Most *B. subsecivella* sequences from South Africa, India, Mozambique, and one from Australia grouped together, representing 75% of the total, with 84-96% bootstrap support. One sequence from Vaalharts and another from Mozambique form a separate group. Australian sequences cluster into three distinct groups: one with two sequences (GLM 1, KF388723, KF389952), another with two more sequences (GLM 2, GLM 3), and a third with KF388320 and KF392065. Genetic pairwise distances range from 0.97% to 3.60%, with GLM 1 identical to KF388723 and KF389952.

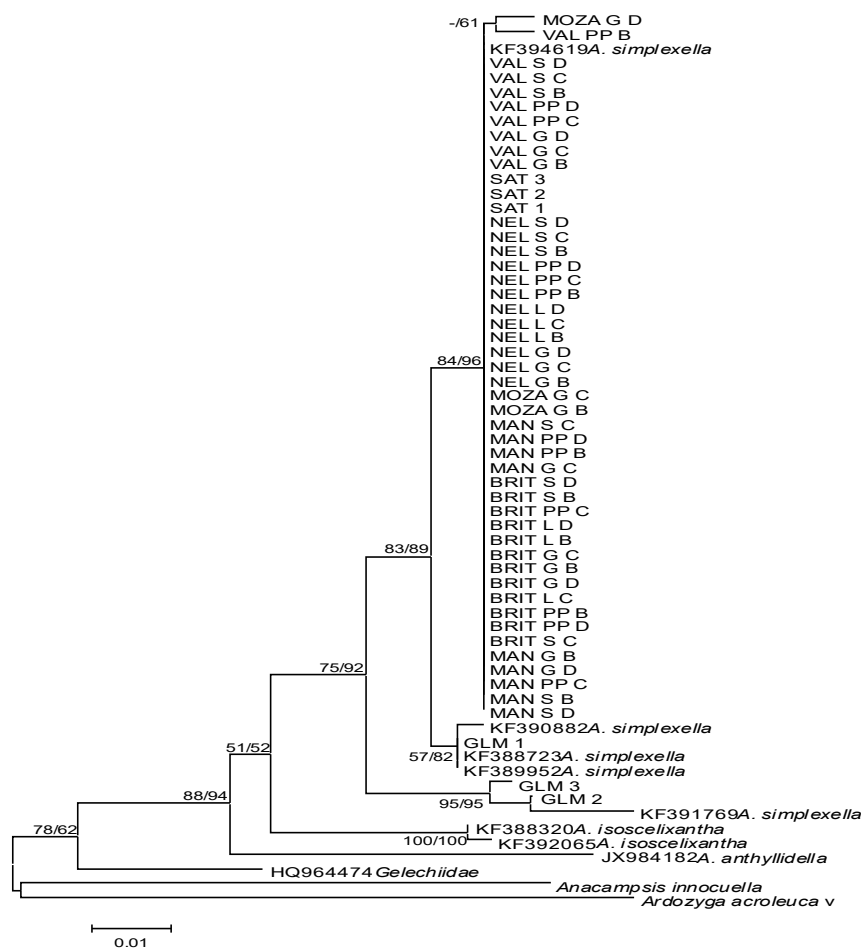


Figure 2. phylogenetic tree of *B. subsecivella* populations from Africa, India, Australia, and NCBI sequences based on the mtDNA COI gene. Taxon labels denote sampling locations, host plants (S: soybean, G: groundnut, L: lucerne, PP: pigeon pea), and replications (A-D for Africa, 1-3 for India and Australia). The tree also includes sequences from other *Aproaerema* species, one Gelechiidae, and two out-groups (*Anacampsis innocuella*, *Ardozyga acroleuca*) from the NCBI gene bank. *A. simplexella* represents the Australian *B. subsecivella* population.

Mitochondrial COII Gene

The phylogenetic tree (Figure 3) is based on 431 nucleotides from *B. subsecivella* and two out-groups from NCBI. The tree shows five groups: the first with six South African sequences, the second with three additional South African sequences (both with 60-65% bootstrap support), the third with 43 South African, two Mozambican, and two Indian sequences (78% of total, 93-94% bootstrap support), the fourth with one Indian sequence, and the fifth with one Australian sequence. Genetic distances range from 0.19% to 2.32%.



Figure 3. A phylogenetic tree showing the relationship between mtDNA COII gene. The tree is based on congruent neighbour joining and maximum parsimony analyses; node support is indicated as [nj bootstrap %/ mp bootstrap %].

Mitochondrial Cytb Gene

The phylogenetic tree (Figure 4) is based on 399 nucleotides and two out-groups from NCBI. It shows three groups: the first with 31 South African, three Indian, and two Mozambican sequences (87% of the total, 99-100% bootstrap support), the second with one Australian sequence, and the third with two more Australian sequences. Genetic distances range from 0.25% to 9.77%.

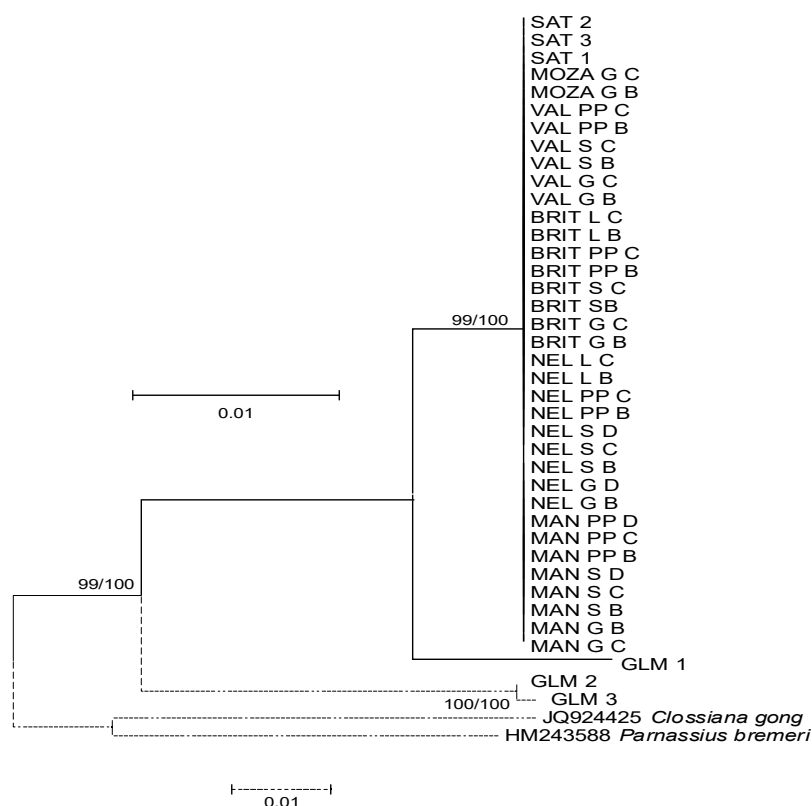


Figure 4. A phylogenetic tree showing the relationship based on mtDNA cytb gene. The tree is based on congruent neighbour joining and maximum parsimony analyses; node support is indicated as [nj bootstrap %/ mp bootstrap %].

DISCUSSION

In all phylogenetic trees, *B. subsecivella* sequences from Australia differed from those in South Africa, Mozambique, and India, which showed little genetic diversity, suggesting a common origin. However, Australian COI sequences were closely related to African and Indian populations. Literature suggests that genetic variation may be due to host specialization or geographic isolation (Alpers et al. 2004). Unfortunately, no host-plant associated genetic relationships were found in South African *B. subsecivella*, but geographic separation was evident. This aligns with the findings of Assefa (2006) on *Eldana saccharina* Walker (Lepidoptera: Pyralidae), where populations attacking different hosts within geographically similar areas lacked genetic differentiation, but those from different geographic areas were genetically distinct. Given the current data, it is challenging to determine whether the South African *B. subsecivella* population originated from India or Australia. Additionally, the Indian and Australian specimens that were sequenced in the current study were very few (only three from each country) and were only collected from a single site in each country. Nevertheless, the mtDNA COI analysis, which included sequences of *B. subsecivella* downloaded from the NCBI gene bank, indicated genetic diversity within *B. subsecivella* populations in Australia which included other populations matching closely with the South African and Indian populations. Therefore, at present, it could be suggested that Australia, rather than India, is the likely origin of the *B. subsecivella* that invaded Africa.

CONCLUSION

The current study revealed that populations of *B. subsecivella* in Australia, Africa and India are genetically very closely related, indicating that they constitute a single species, possibly originating in Australia. Based on these findings, further molecular and morphological analyses are proposed, which include collecting and sequencing more samples from key geographic areas, notably in Australia and India, to confirm these hypotheses.

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PALM OIL CONSUMPTION IN ONDO STATE: A CONSUMER PREFERENCE RANKING MODEL APPROACH

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ABSTRACT

Palm oil, a versatile vegetable oil, plays a crucial role in global food security and industrial applications. This study investigates consumer preferences and consumption patterns of palm oil in Ondo State, Nigeria, using a consumer preference ranking model. A systematic sampling was used to select 132 consumers from six major markets. Primary data collected through structured questionnaires were analyzed using descriptive statistics and a preference ranking index. Results reveal that taste (85.41%) is the primary factor influencing palm oil purchasing decisions, followed by packaging (50.00%) and colour (47.91%). Socio-economic analysis shows that most consumers are males (62.9%), married (48.5%), and educated (72.5% with secondary education or higher). Price variability and brand proliferation emerge as major constraints to palm oil consumption. These findings provide valuable understandings for policymakers, producers, and marketers in the palm oil industry, potentially contributing to enhanced food security and economic development in Nigeria. The study recommends strategies for improving palm oil quality, affordability, and market access to meet consumer preferences and address identified constraints.

Keywords: Consumer Preference, Food Security, and *Palm Oil*,

INTRODUCTION

Palm oil is a vegetable oil derived from the fruit of the palm tree, it is used for both food and non-food consumption. Total global production of palm oil is estimated at over 45 million tonnes, with Indonesia and Malaysia as the major world producers and exporters. The palm oil industry has experienced rapid growth in recent decades and has become a significant contributor to the world market for vegetable oils (World Growth, 2011). Marketing of agricultural products are as essential as the product itself (Food and Agriculture Organization, 2009). Though palm oil is produced in southern Nigeria, it needs to be evenly and efficiently distributed if it must serve the needs of the greater population of the country. The marketing channels of palm oil can be discussed in terms of accessibility and availability of the product to the final consumers. There have been shortfalls in palm oil supply over the years, which showed that consumption was more than production. Nigeria's palm oil supply shortfall was estimated to be 1.42metric tonnes, local consumption 2.4metric tonnes, local production as at 2018, was 980,000metric tonnes, this shows that the country have spent estimated 1.4billion USD on palm oil importation for the past five years from 2014-2019 (Global import data, 2019). The satisfaction of gains from palm consumption in Ondo state is not yet ascertained because, it is not well understood the benefits consumers get from the higher prices they pay for palm oil. The findings from this study will therefore fill these existing gaps in literatures.

Objectives to the study

The main objective of this study was to analyze Palm oil consumption in Ondo state, Nigeria, while the specific objectives of the study were to:

- i. describe the socio-economic characteristics of palm oil consumers,
- ii. examine the preferences of consumers in palm oil consumption,
- iii. Identify the constraints associated palm oil consumption in the study area.

MATERIALS AND METHODS

Study Area

The study area was carried out in Ondo State, Nigeria. Ondo State lies between latitude 5° 45' and 8° 15' North of the equator and longitude 4° 45' and 6° 60 East of the Greenwich meridian. The State is bounded in the North-West by Ekiti State, West-Central by Osun State, South-East by Ogun State, South-East by Delta State and in the South by Atlantic Ocean. The climate is tropical with two distinct seasons, the rainy season, (April-October) and dry season (November – March) with slight variations from year to year. Ondo State is one of the states created on 3rd February, 1976 with the capital in

Akure, it covers an area of 14,798.8 Sq Km. The people of the State are predominantly Yorubas. Ondo state enjoys luxuriant vegetation where various cash crops such as Cashew, Palm produce, Kola nut, Timber, Maize, Yam, Plantain, Cocoyam, Cassava, and Banana are grown. The traditional occupation of the people inhabiting the study area is agriculture. Two market were selected for this study. The palm oil consumers were selected using systematic sampling. Consumers were selected using systemic sampling technique based on their visit to palm oil marketers. The sampling was done based on their visit to the palm oil vendors within the study area. A total of 132 consumers were randomly selected for this study. The sampling of consumers was presented in Table 1.

Table 1: Summary table for sample size of palm oil consumers

Retail Outlets	Sample size
Sabo ore	83
Odigbo	49
Total	132

Source: Field Survey, 2021

Data for this study was obtained through primary sources. The primary data was obtained through personal interview with a well-structured questionnaire to gather information from all the consumers in the study area. The primary data collected includes socioeconomic characteristics of consumers, preference attributes for palm oil consumption, and constraints associated with palm oil consumers in the study area. Data for this study were analysed using descriptive statistics and consumer preference ranking model.

RESULTS

Socio-economic characteristics of consumers

The socio-economic characteristics of consumers were presented in Tables 2 and 3, respectively. The variables considered include age, gender, and marital status, highest level of education, household size, and occupation of consumers.

Table 2: Age and Household size of Palm oil Consumers

Variables	Frequency	Percentages (%)	Minimum	Maximum	Mean	Standard deviation
Age (Years)			18.00	52.00	30.00	8.53
18-24	44	33.3				
25-31	33	25.0				
32-38	30	22.7				
39-45	19	14.4				
46-52	6	4.5				
Household Size(Persons)			1.00	6.00	3.00	1.52
1-3	91	68.9				
4-6	41	31.1				

Source: Field Survey, 2021 n=132

Table 3: Sex, marital status, highest level of education, and occupation of Palm Oil Consumers

Socio-economic variables	Frequency	Percentages (%)
Sex		
Male	83	62.9
Female	49	37.1
Marital status		
Single	44	33.3
Married	64	48.5
Divorced	5	3.8
Widowed	19	14.3
Highest Level of Education		
Primary school	35	26.5
Secondary school	50	37.9
Tertiary	47	35.6
Occupation		
Civil servant	25	18.9

Traders	61	46.2
Student	27	20.5
Artisans	19	14.4

Source: Field Survey, 2021. n= 132

Consumer preference ranking index (PRI) for palm oil attributes influencing its consumption in the study area.

The result for the consumer preference ranking of palm oil was presented in Table 4. The results revealed that the majority (85.41%) of the consumers ranked the taste of palm oil first in their preference ranking; it was followed by packaging (50.00%) and colour of palm oil (47.91%) respectively. The results also shows that price (39.58%), aroma (22.91%) and availability of palm (29.16%) were among the preferences of consumers in the study area. The least ranked preference among consumers was ease of cooking (20.83%) and texture (4.16%), respectively.

Table 4: Consumer Preference Ranking Index for Palm Oil Attributes Influencing its Consumption in the Study Area

Palm oil attributes	Preference Index	Ranking	Ranking
Taste	0.8541		1 st
Packaging	0.5000		2 nd
Colour	0.4791		3 rd
Price	0.3958		4 th
Availability	0.2916		5 th
Aroma	0.2291		6 th
Ease of Cooking	0.20833		7 th
Texture	0.0416		8 th

Source: Field Survey, 2021.

Summation Xi or PRI=0.375, IEE = 0.625, AIEE= 0.078125

Constraints faced by consumers in the study area

The constraint faced by palm oil consumers was presented in table 5. The first and most important constraint was variability in prices of palm oil in the market (31.1%), this was due to the fluctuation in the price of the product, the consumers will prefer to demand for palm oil more when the price is favorable or low, while period when prices are high the demand for palm oil tends to be low, thus some of the consumers prefers to consumer close substitute to palm oil. The issue of branding (22.7%) was another major constraint, this is because there are a lot of brands of palm oil in the markets and this normally confuse the consumers on which palm oil to consume, thus branding affects the consumer choice in the study area.

Table 5: Constraints faced by consumers in the study area

Constraints	Frequency	Percentage (%)	Ranking
Variability in price	41	31.1	1 st
Branding	30	22.7	2 nd
Poor access to product market	25	18.9	3 rd
Poor taste	22	16.7	4 th
Low quantity	14	10.6	5 th

Source: Field Survey, 2021

n=132

DISCUSSION

The age of palm oil consumers was presented in Table 2. The result shows that most (33.3%) of the consumers were between the age ranges of 18-24years, (25.0%) were between the age ranges of 25-31years, while (4.5%) were between 46-52years. The distribution also reveals the mean age of 30years. This result showed that the consumers are still young and are in their active of consumption of palm oil in the study area. This finding disagrees with Akinsulu et al; (2019) who discovered that mean age of consumers in Ogun state was greater than 30years. Household size results shows that most (68.8%) of the palm oil consumers have household size between 1-3persons, while (31.2%) of them have household size between 4-6persons. The distribution also reveals a mean household size of 3 persons. This implies that the household size for consumers in the study area was small, which implies less consumption within the household. The sex of palm oil consumers was presented in table 3. The result showed that most (62.9%) of the palm oil consumers were males while (37.1%) were females. This result shows that males consumed palm oil more than females in study area. The marital status result

shows that majority (48.5%) of the palm oil consumers were married, (33.3%) were single, (14.3%) were widowed, and 4.5% were divorced. This result showed that most of the consumers of palm oil in the study area were married. The results of consumers based on the level of education showed that most (37.9%) of them have secondary education, (35.6%) have tertiary education, while (26.5%) have primary school education. This result showed that most consumers of palm oil have formal education. This finding is similar to that of Akerele *et al*; (2012) who discovered that most consumers in Oyo state were educated.

The occupation of palm oil consumers shows that most (46.2%) were into traders, (20.5%) were students, and (18.9%) were civil servants, while (14.4%) were artisans. This result showed that most of the consumers of palm oil were entrepreneurs in one business or the other. Thus this implies trading is a major occupation of individuals within the study area. This finding is similar that Akinsulu *et al*; (2019) who discovered that most of the consumers in Ogun state were traders. The result from the preference ranking in the study area revealed that the taste of palm oil is the most important attribute that influenced consumer choice when purchasing palm oil for consumption, the packaging and colour of the palm oil are other factors in order of preference that influenced consumer choice in the study area. This implies that good taste is a major attribute that influence consumer decision when purchasing palm oil for consumption in the study area. The findings from this study agrees with Akerele *et al*; (2020) who discovered that good taste is non-price attribute that influence consumer choice in Ogun state. The other constraints faced by consumers includes poor access to product market (18.9%), poor taste of palm oil (16.7%), and quantity of palm oil sold (10.6%) in the study area. The finding from this is contrary to Akinsulu *et al*; (2019) who discovered that the major constraints faced by consumers were low income and high level of poverty.

CONCLUSION AND RECOMMENDATIONS

The study concluded that most palm oil consumers were males, married and have formal education in the study area. The study also shows palm oil consumers in the study area ranked good taste as the most important factor that influenced their decision when purchasing palm oil for consumption. Variability in prices and branding were the major constraints faced by consumers. Palm oil marketers should minimize cost of palm oil to ensure consumers affordability. Consumers should identify brands with high quality of palm oil for better consumption. There is need for consumers to explore several marketing channels to curb palm oil market access issues.

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Data availability statement: Data used for this study were the relevant ones.

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HISTORICAL PERSPECTIVES ON AGRICULTURAL SUSTAINABILITY AND FOOD SECURITY IN YORUBALAND, NIGERIA

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ABSTRACT

The truism '*food for the stomach*' and the ancient proverb 'health is wealth' have become increasingly poignant in Nigeria, where the quest for food security and wellness is beset by formidable obstacles. This study explores the historical dynamics of agricultural sustainability and food security in Yorubaland, Nigeria. Findings reveal that historically, agriculture was the backbone of Nigeria's economy, generating over 70% of its income in the pre-colonial era. However, by the early 1970s, the oil boom had begun to replace agriculture as the mainstay of the economy (as oil exports by 1971 accounted for 74.4% of total exports, valued at approximately \$1,239.9 while agriculture contributed only 22% to the economy. The oil boom's success came at the expense of agriculture and rural economies, but proved short-lived. This paper emphasizes that the post-colonial administration in Nigeria failed to reform agricultural policies inherited from the colonial era, which prioritized the export of cash crops. Consequently, the agricultural sector experienced significant decline within the first decade of independence, exacerbated by the Nigerian civil war (1967-1970) and inconsistent policies. Despite numerous attempts to revitalize the sector, Nigerian agriculture remains in a state of decline, characterized by food insecurity and stagnation. The study concludes that agricultural sustainability in Yorubaland and Nigeria at large, demands a collective effort, transcending educational and occupational boundaries. A multi-stakeholder approach, involving government, private sector, civil society, and farmers, is crucial; with key strategies that must include: reforming agricultural policies, investing in agriculture, and promoting education and awareness. This study adopts a historical and analytical approach with a combination of primary and secondary sources of data collection.

Keywords: Historical perspectives, Agricultural sustainability, Food security, Yorubaland, Nigeria.

INTRODUCTION

The poor performance of many African economies has become a matter of great concern for scholars and analysts. Nigeria's economy is in a precarious state, threatened by a multitude of crises, including rapid population growth, dependence on foreign food, stagnation of local industries, and widespread food insecurity. The importance of the agricultural sector to the national economy cannot be over-emphasized. This is premised on the fact that it contributes substantially to the country's Gross Domestic Product (GDP), it serves as a source of foreign exchange, and a major source of labour for the nation's economy. The transformation of Yorubaland and Nigeria's economy; from an agricultural-based system in the pre-colonial era to an oil-dominated economy by the 1970s, highlights the unintended consequences of commercial growth. The success of Nigeria's oil industry came at the expense of agriculture and rural economy, which suffered a significant decline, underscoring the need for a balanced economic approach. As would be proven beyond doubt with major references drawn in Yorubaland, it is evident that despite the growth in manufacturing, mining and oil explorations, agriculture remains vital to Nigeria's economy, employing most of the workforce, providing food security, and generating foreign exchange.

Food is the fundamental physiological requirement for human sustenance, superseding other essential needs. According to Abraham Maslow's seminal hierarchy of needs theory, food occupies a paramount position, preceded only by basic physiological needs (Maslow, 1943:370-396). The rationale underlying this prioritization is the severe consequence of food deprivation, which manifests as hunger and malnutrition. These afflictions transcend geographical boundaries, socio-economic strata, ethnic divides, and religious affiliations, underscoring the universality of food insecurity. The far-reaching implications of

food deprivation necessitate a nuanced understanding of the complex interplay between food availability, access, and utilization.

Yorubaland, situated in south-western Nigeria, boasts a rich cultural heritage of farming and food production, having historically served as a hub of agricultural production. However, the discovery of oil in Nigeria in the late 1950s marked a pivotal turning point in the country's economic trajectory, precipitating a rapid shift away from agriculture and towards oil production. This transformation has had far-reaching consequences, including the decline of agriculture and the rural economy in Yorubaland. Despite the growth in manufacturing, mining, and oil exploration, agriculture remains a vital component of Nigeria's economy, providing employment for the majority of the workforce, ensuring food security, and generating foreign exchange. Nevertheless, the neglect of the agricultural sector has led to widespread food insecurity, forcing millions of Nigerians to rely on imported food to meet their basic needs.

The interplay between economic growth, agriculture, and food security is complex and multifaceted. This paper provides a historical analysis of the impact of Nigeria's oil industry on agriculture in Yorubaland, underscoring the need for a balanced economic approach that prioritizes food security and sustainable agricultural development. By examining the intricate relationships between economic growth, agriculture, and food security, this research aims to identify key lessons for sustainable agricultural development and food security in Nigeria.

Global Food Security Challenges and United Nations' Initiatives for Sustainable Agriculture and Food Security

In every culture and community, the security and sustainability of food systems are rooted in four fundamental pillars: availability, access, utilization, and stability (Guiné et al., 2021:1-10). *Food availability* is a critical component of food security, encompassing the supply side of food security. In South-West Nigeria, comprising states such as Ogun, Oyo, Osun, Ondo, Ekiti, and Kwara and Kogi in North-Central, food availability is determined by production (local food production capacity); stocks (food reserves held by traders, governments, and households); trade (market-driven food imports and exports); and food aid from governments and/or agencies. *Food access* is a vital aspect of food security, encompassing the ability of households to acquire nutritious food in a safe, timely, and affordable manner. This concept extends beyond purchasing power, incorporating physical access to markets, social acceptance, and protection issues. Households in Yorubaland employ various means to access food, including subsistence farming, hunting and gathering, market purchases, income and barter exchange, and gifts and transfers. These means enable households to overcome social barriers and acquire nutritious food.

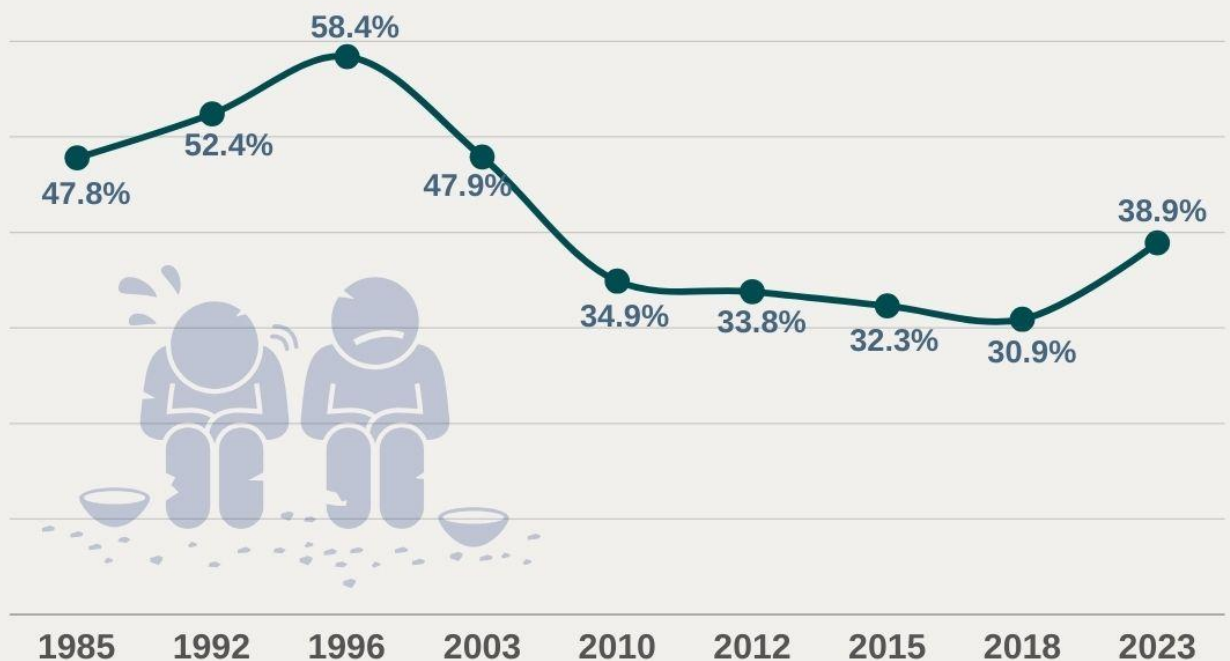
Food Utilization is the effective use of food by households to ensure optimal nutrition. Food utilization is influenced by two critical factors. Firstly, food handling and preparation methods, including storage, processing, cooking, water quality, cooking fuel, and hygiene practices, significantly impact food safety and nutritional value. Secondly, targeted feeding practices tailored to vulnerable populations, such as children, the elderly, and pregnant women, are essential for meeting their unique nutritional needs. These practices involve customized dietary approaches to address specific health concerns and nutritional requirements. *Food stability* refers to the consistency and reliability of food supplies, access, and utilization over time. It involves reducing the risks of adverse effects on the other dimensions of food security, ensuring that households do not lose access to food due to sudden shocks or cyclical events. Key indicators of food stability include: constant food availability and access; stable prices and government policies; uninterrupted physical access to markets and agricultural inputs; and resilient food systems and supply chains.

Food security remains a pressing global challenge, affecting over 820 million people worldwide who suffer from hunger, with an additional 2 billion people experiencing moderate to severe food insecurity, underscoring the need for sustainable and equitable food systems (FAO, 2020: 8-10). Although food security is a universal challenge, its severity and impact vary greatly between developed and developing countries, with the latter facing a disproportionately larger burden.

Poverty in Nigeria

Poverty rate: 87 million
Nigerians raise rate to 38.9%
in 2023

Poverty rate in Nigeria (1985 - 2023)



Source: World Bank

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Chart 1: Poverty rate: 87 million Nigerians raise rate to 38.9% in 2023. Source: IntelPoint. (2023). Poverty in Nigeria. IntelPoint. <https://intelpoint.co/insights/poverty-in-nigeria/>

As of December 2023, Nigeria struggled with widespread poverty affecting approximately 70 million individuals. Rural areas are disproportionately affected, with 89% of the impoverished population residing there, while 11% reside in urban areas. Extreme poverty in Nigeria is characterized by severe deprivation of fundamental human needs (IntelPoint, 2023).

Developed countries combat food insecurity with targeted solutions: direct food relief, food stamps, and subsidized production, ensuring that vulnerable populations have access to nutritious food. To address this global challenge, the United Nations has developed initiatives and frameworks that prioritize sustainable agricultural practices, environmental stewardship, and food security, with the ultimate goal of achieving wellness and prosperity for all people and the planet. Some of these United Nations (2020) countries, include the following:

- i. Sustainable Development Goals (SDGs): Specifically, SDG 2 (Zero Hunger) and 12 (Responsible Consumption and Production) focus on sustainable agriculture and food systems.
- ii. Food and Agriculture Organisation (FAO): The FAO promotes sustainable agriculture practices, supports small-scale farmers and addresses climate change, water scarcity and biodiversity loss.

- iii. Committee on World Food Security (CWF): The CWF develops guidelines and policy recommendations for sustainable agriculture and food security.
- iv. United Nations Environment Programme (UNEP): UNEP addresses the environmental aspects of sustainable agriculture, such as pollution, soil degradation, and climate change.
- v. International Fund for agricultural Development (IFAD): IFAD supports small-scale farmers and rural developments through sustainable agricultural practices.
- vi. World Food Programmes (WFP): WFP addresses food insecurity and promotes sustainable food systems.
- vii. Sustainable Agriculture Initiatives: Initiatives such as Archaeology, Permaculture, and Regenerative Agriculture have been promoted by the UN to enhance soil health, biodiversity, and ecosystem services.
- viii. Climate-Smart Agriculture: The UN supports climate resilient agriculture practices to address the impacts of climate change on food security.
- ix. Water for Food Security: The UN focuses on efficient water use and management in agriculture to ensure food security.
- x. Food Loss and Waste Reduction: The UN aims to reduce food loss and waste throughout the supply chain to ensure more efficient food systems.

For a healthy and food-secure Yorubaland, Nigeria, sustainable agriculture is the essential bedrock, supporting the region's prosperity, and nurturing the well-being of its people, now and in the future.

The Yoruba People's Cultural Beliefs and Values in Agriculture and Food Systems

The Yoruba, one of the largest and most sophisticated ethnic groups from West Africa, reside mainly in south-western Nigeria (particularly in the states of Oyo, Osun, Ondo, Ogun, Ekiti, Kogi, and Lagos); Kwara in the north-central region as well as in neighboring countries such as Benin and Togo, with ancestral ties to the god-hero Oduduwa. They can be found in various regions worldwide, particularly in areas with historical and contemporary diasporic connections such as Brazil, Cuba, the United States, the United Kingdom, and the Caribbean (Falola & Childs, 2004:10). The areas of these countries primarily inhabited by Yoruba are often collectively referred to as Yorubaland or territory. Yoruba have lived in advanced urban kingdoms for more than 1,500 years. Akintoye attested that *"the Yoruba are a culturally sophisticated and urbanized people, with a long history of city-state development and complex societal structures"* also correlates with John Peel's attestation that *"the Yoruba are a nation with a strong tradition of monarchy and leadership, exemplified by the Ooni of Ife and other Yoruba kings"* (Peel, 1989:45-50).-

Johnson (1921:10-15)'s description of the Yoruba as *"a nation of farmers, traders, and craftsmen with a strong tradition of monarchy and a complex religious system"* attests to the fact that the Yoruba communities traditionally thrived in agricultural compounds, where they cultivated the land and honoured their ancestors through a vibrant native religion. This is in line with Soyinka (1976:23-30) that *"the Yoruba are a people with a deep spiritual heritage, emphasizing the importance of Orisa (deities) and ancestral reverence."* Several Yoruba communities hold the New Yam festival with high esteem as a significant event in the town's cultural calendar. The annual New Yam Festival or *Odun Ijesu* (2024, July 13) took place at Olusun Palace Square, Isanlu-Isin, Kwara State in July, 2024 (witnessed by the author as one of the guest speakers). The Festival of Ile-Ife New Yam (August 8, 2024), was celebrated at the Palace of Ooni of Ife in Osun State in August, 2024. These festivals are a testament to the importance of yam in Yoruba culture and the community's appreciation for the harvest season. Lovejoy (2000:150) reveals that *"there are about 40 million Yoruba world-wide and Yoruba, their tonal language, spoken by millions across the country, is a cornerstone of their identity."*

The Yoruba people's reverence for agriculture is beautifully encapsulated in the classic song: *"Isẹ agbẹ ni'sẹ ilẹ wa, ẹni ko sisẹ a maa jale, iwe kikọ lai si ọkọ ati ada, ko i pee o, ko i pee o"* (farming is our fore-father's job, whosoever is indolent will definitely steal, sound education without farming tools is incomplete education. Yes! It's an incomplete education). Such other words or phrases to buttress include: *isẹ oko pe* or *agbẹlere* (farming is profitable) and *agbẹlọba* (farming is the principal vocation) that conform to God's injunction in both *The Holy Qur'an* (80:26-32) and *The Holy Bible* (Genesis2:15, Leviticus 25:18-22, Psalm 104:14, Proverbs. 12:11, Isaiah 30:23-24) on the need to engage in agriculture and the God-factor.

Sayings and proverbs in Yorubaland attest to the *ilera lora* (health is wealth) concept, as a healthy diet empowers individuals to unlock physical, mental, emotional, and spiritual well-being, leading to a transformative and fulfilling life. The Yoruba saying, “*Oun t’a ó jẹ l’àgbà oun ta ó se*” (what we want to eat is, on the hierarchical scale, superior to what we want to do) emphasizes the importance of fuelling the stomach before any significant physical/laborious activity such as bush clearing, cultivating, planting, weeding, harvesting, etc (Akosile, 2024). Even while the need for the appropriate and effectiveness of the tool to work with, is well established in the saying-“*Igbehin l’o ma ndun oloku ada si*” (the one who decides to farm with a blunt cutlass will surely face the consequences of such a choice); the fact that food provides the physical strength needed to accomplish a task is well stressed in the saying, “*ailapa ni ada o mu, omori se lagi*” (a lazy man will always complain about tools, even one can break plank with a pestle). Again, the widely held saying that “*ona ofun ni ona orun*” (the path to the stomach is the path to paradise/heaven) reveals that the Yoruba fascination with hunger is legendary. It remains factual that when hunger strikes, many things can go wrong.

Another colloquial says “*omọ ita l’ebi*” meaning - hunger is a thug. Hunger can even bring a king on his knees, leading to anger (a hungry person is an angry person) and causing a range of physical, emotional, and social effects. Like the famous biblical Esau in Genesis 25:29-34 who sold his birth right to his twin brother for food, a hungry person is prone to losing his sense of reasoning and rationality at the very moment. The people of Oyo during the reign of *Oba Awole Arogangan* (1789-1796) suffered from severe famine just like several Yoruba wars such as the Ijaiye War, Kiriji War, *Jalumi* War, Ogele War, and Dahomey War, etc were instances where people suffered from food hunger. In the real sense, the *Mugbamugba* War derived its name from *igba* (locust bean fruit) which was the only saving grace for ravenous soldiers during the Oyo army’s second attempt to regain Ilorin from the Fulani.

Similarly, the expression, *ebi kii wonu, ki qran mi o wo* (hunger does not enter the stomach and allow anything else in) attests to the fact that concentration, calmness and comfort are far away from a hungry soul. The nutritional and medicinal value of Yoruba hierarchical foods and delicacies is inherent in the saying, “*Iyan lounjẹ, Oka loogun* (pounded yam is food, while *Oka/amala* is merely medicine) and *ounjẹ lora awọ, ounje to dara a maa sara loore* (good food is complexion friendly, sumptuous meal nourishes the body) attests to the fact that access to nutritious food makes food a healthy diet (medicine) which is ‘a solution to many of health-care problems’ (The World Economic Forum, 2023).

The realization of agriculture for food security and wellness from ages past is well captured in the Yoruba proverb, “*Ti ebi ba ti kuro ninu isẹ, isẹ buse*” (when hunger is taken out of poverty, poverty ends). Nothing in life defies a solution - just as education is the antidote to ignorance - food is the remedy for hunger - unlocking the door to physical and mental well-being. Yoruba believes that one that works hard must eat well as hard work and good food go hand in hand. Hence the saying, *bi oo se, oo jẹ* (no work/sweat, no food/sweet). This is much in line with Socrates’ quote, “Eat to live, not live to eat” and Virgil’s wisdom that *food sustains the body and health is the ultimate wealth*; hence, the Yoruba, have always realized that they must prioritize sustainable agriculture to guarantee food security, wellness, and a prosperous future.

Yoruba’s history is therefore, deeply tied to their favorable environment, where a unique blend of geographical advantages, a peaceful atmosphere, strong social bonds, work ethics, and agricultural beliefs came together to create a thriving indigenous economy, built on optimal resource utilization and a strong foundation for food security and wellness. People created a strong economy through farming, trading, and art production. Their resourcefulness and innovative techniques significantly boosted both agrarian and non-agrarian activities, providing employment opportunities for most of rural dwellers. In addition to crafting essential tools such as hoes, cutlasses, and axes, they employed a range of advanced agricultural methods, including: terracing to optimize land use, shifting cultivation to maintain soil fertility, crop rotation to promote healthy soil and reduce pests, green manuring to enrich soil with organic matter, mixed farming to diversify crops and reduce risk, poultry farming to provide a source of protein, and regulated swamp farming to harness the potential of wetland areas (Ehinmidun, 2024).

All said and done attest to food, being an antidote to poverty and for healthy living in Yorubaland. Their saying, “*Oun ti eiye ba je ni eiye ngbe fo*” (what a bird eats, it flies with) implies that what one is or becomes is influenced by what one eats. The concept of food security has undergone significant evolution over the past five decades. The World Food Summit’s definition (1996, revised 2001) is widely accepted, emphasizing the multidimensional nature of food security: “Food security exists when all

people have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and preferences.”

The Golden Age of Agriculture in Yorubaland, Nigeria

A survey of Nigeria's food crises is indeed historical and analytical. Prior to foreign contact and oil discovery in Nigeria, Yorubaland was a peaceful hub for farming, hunting, fishing, manufacturing and trading. Agriculture was the main basis of the wealth of pre-colonial Yoruba, as every citizen was a farmer. Trade with Sudan was another source of wealth before the 18th century, when Yoruba exported kola nuts, locally woven cloth, livestock, etc to Sudan and imported commodities such as salt, potash, shea butter, wool, milk and horses. Taxes from the provinces and tributes from subject states provide a greater bulk of royal revenue. However, from the 19th century, there was a gradual change in the direction of the Yoruba economy from the north to the south where coastal trade with the Europeans developed. From then on, the sale of slave exports and the import of European fire arms formed an important aspect of the economic activity of the people. This marked the beginning of a transformative relationship between Europeans and Africans that began in the 15th century, forever altering Nigeria's history. Onwubiko (1985:94) attests thus to the following:

The most striking feature of the economic development of Yorubaland in the 19th century was the shift from the direction of its trade from north to south. Trade with the south was growing and consisted mainly of slave exports.

The conquest and occupation of Nupe and northern Yorubaland by Fulani at the beginning of the 19th century resulted in the dislocation of traditional trade with the north (Saharan trade). Therefore, increasing attention was paid to trade with the coast (Atlantic trade), and the Yoruba civil wars provided a steady supply of slaves sold in exchange for firearms and a few other European goods.

In spite of the civil wars, however, many economic activities continued in Yorubaland, and farming continued to some extent. It is worth noting that Alaafin Atiba the founder of the new Oyo encouraged the growth of yams and kola nuts; the missionaries in Abeokuta encouraged agriculture especially the growth of cotton and oil palms. Domestic slaves were then increasingly diverted to the farms to cultivate these crops and to prepare them for export. Palm oil exports thus became so important much that by 1856, 15,000 tons of palm oil was exported from Egbaland alone (Onwubiko, 1985:95). By the 19th century therefore, palm exports doubled in West Africa, as Nigeria took the lead. Notably, like the Niger Delta region, many Yoruba states in the south-western region have ever since become enterprises, partly because of the abundance of palm trees in its hinterland and also because the Niger River provides easy transportation for oil across the Atlantic.

The ports of Badagry and Lagos served as gateways for British trade in Yorubaland, initially in slaves and later in commodities such as palm produce, timber and rubber. Lagos, the chief port, had five routes connecting it to the interior, with the Egba, Remo, and Ijebu-Ode routes being the most significant. The struggle to control these routes was the primary cause of civil wars throughout the 19th century. The British occupation of Lagos in 1861 underscored the importance of peaceful trade relations in Yorubaland for the prosperity of Lagos and growth of British commerce. Consequently, British intervention in Yoruba politics was driven by economic interests, facilitated through treaties and military force, and characterized by the exchange of local goods (e.g., native cloths, palm oil, and kernels) for European commodities (e.g., salt, clothes, and firearms). The Lagos administration made use of C.M.S. missionaries to bring peace in 1886, after the longest civil war in Yorubaland- The *Kiriji* War that 'ended' with the peace treaty signed on September 23, 1886, at Igbajo and Imesi-Ile now in Osun State. Thereafter, the British imposed colonial rule (Falola, 1991:87).

The trend of an agrarian base economy in Nigeria continued well into the British colonial period when agriculture stood as the largest employer of labor within the colonial economy. As part of the colonial policies, the authority placed much emphasis on cash- crops production (cocoa, coffee, rubber) as against food crop production, in order to provide a regular and ready source of raw materials for European manufacturing industries. The British authority placed much emphasis on cash crop production to provide a regular and ready source of raw materials for European manufacturing industries (Corwin, 2003).

In Nigeria's independence in 1960, agriculture was the backbone of the economy, accounting for more than 70% of the country's revenue. The sector's prominence was driven by farmers' motivations to

produce both domestic consumption and exports. Regional specialization in cash crops, such as cocoa in the west, cotton and groundnuts in the north, and palm oil and cassava in the east and middle -belt, contributed significantly to the development of their respective regions. The impressive statistics on agricultural production at the time instilled optimism for Nigeria's future economic growth and development. For instance, by 1958, the acreage of cocoa plantations in the Western Region alone totalled 981,091 acres and in 1961, when the country's exports were valued at nearly £200 million, about 20% of it or £34.8 million was derived from cocoa. In the same year, groundnut production in the Northern Region topped over one million tons, while Palm Oil and palm kernel production in the Eastern Region exceeded 20 percent of total exports. The land, as it was, was the main locomotive of the agriculture-based economy (Igiebor, 1987:21). Nigeria's agricultural sector experienced remarkable growth in the 1950s and the 1960s, largely due to decentralized control vested by regional governments. The 1954 and 1963 constitutions designated agriculture as a regional responsibility, enabling regional governments to invest heavily in the sector and to retain a significant proportion of export revenues. This has led to flourishing regional economies, driven by cash crop exports, which in turn has facilitated social and economic development programs.

Over time, things began to diminish. By 1966, agriculture contributed only about 60% of the country's total exports, compared badly with its former contribution of 80%. Military intervention in 1966 focused on regional autonomy, and more so when the country was broken up into 12 states on May 27, 1967. As the military government was being essentially more of a unified command, the federal government mostly took over the residual powers and responsibilities of the states. Hence, there was a drastic reduction in the revenue accruing to the state. The 1979 Constitution formalized the major shift of power from the states to the federal government when it placed agriculture on the concurrent list, making it a joint responsibility of both the state and federal governments. A federal Ministry of Agriculture was established until 1973 (Aboyeji, 2020:187).

Agriculture in Yorubaland and Nigeria's Oil Wealth Economy

One auspicious development that had a profound effect on the government's attitude to agriculture occurred in 1958, when the Shell Oil Company began production and exported the first Nigerian crude oil of 5,134 barrels per day from Oloibiri, Rivers State (Igiebor, 1987:21). Traditional agriculture entered a period of decline as able-bodied youths migrated to urban cities leaving old men and women who have been incapacitated by old age - to cultivate food capable of feeding the whole country. Negative development since the discovery and production of oil relies on oil that eclipses agriculture as the engine of the Nigerian economy. For example, from less than 1 per cent in 1960, the contribution of oil to gross domestic product (GDP) rose to 14.6, 21.9 and 26-29% in 1970, 1975 and 1979 respectively. By 1992, it had reached a height of 46.8%. The contribution of oil to Nigeria's export earnings was much higher. From 58.1% in 1970; it rose to 95.6% in 1979. Throughout the 1980s and 1990s, it remained very high, accounting for ₦210 billion or 96.1% of total export earnings in 1996 (Ogbogbo, 2014:75).

Faced with the unsustainable burden of soaring food import costs, the Nigerian government has introduced various initiatives aimed at promoting self-sufficiency and self-reliance in food production. These schemes sought to mobilize national efforts towards achieving food security, boosting foreign exchange earnings through increased export production, and providing raw materials for domestic manufacturing. Various governments have attempted to implement policies to reform agriculture. Such include: i. *The Strategic Grains Reserves Programme* (SGRP) of the Gowon-led regime by the mid-1970s; ii. *The Operation Feed the Nation* (OFN) of the Obasanjo military regime; iii. *The Green Revolution programme* of the Shagari administration, ditto his river basin development authorities and agricultural development programs (ADP); iv. *The Strategic Grains Reserve Scheme* (Buhari -led military regime); v. *The National Directorate of Employment* (NDE) under Buhari led the military administration; vi. *Natural Agricultural Lands* (NALDA); *Agricultural and Rural Management* (ARMTI), *the Directorate of Food, Roads and Rural Infrastructure* (DFRRI); *Structural Adjustment Programme* (SAP); *National Centre for Agricultural and Mechanical* (NCAM)-all under the Babangida led military regime; *Agricultural Revitalization Scheme* (2002); *Root and Tuber Expansion Programmes* (2003)- Obasanjo's civilian led administration; *The Transformation Agenda* (Yar'Adua); *The Subsidy Re-investment and Empowerment Programme* (SURE-P) launched in 2012 by the Goodluck Jonathan led administration; *The Anchor Borrowers Scheme* of the Buhari-Civilian administration; *Food Security and Agricultural Mechanization Programme*, a state of emergency in the *agriculture sector* and ongoing intervention plan on food security by President Ahmed Bola Tinubu.

Nigeria's agricultural initiatives over the years to promote self-sufficiency in food production and reduce reliance on food imports have had mixed results. The successes of these schemes include the Strategic Grains Reserve Scheme's ability to stabilize food prices and ensure availability of grains. The Operation Feed the Nation Scheme, launched in 1976, achieved significant increases in food production, particularly in the first two years of its implementation. The program also strengthened agricultural extension services, providing farmers with training, inputs, and technical support. Similarly, the Green Revolution program, launched in 1980, led to significant increases in crop yields, particularly for crops such as wheat and rice. The program also introduced new agricultural technologies, such as tractors and threshers, which improved the efficiency of farming operations. The National Directorate of Employment's creation of jobs through agricultural projects, and the Natural Agricultural Lands' (NALDA) promotion of agricultural development in rural areas. Additionally, the Agricultural and Rural Management (ARMTI) and the Directorate of Food, Roads and Rural Infrastructure (DFRRI) have improved agricultural productivity and infrastructure, while the Structural Adjustment Programme (SAP) has helped to liberalize the agricultural sector. The Agricultural Revitalization Scheme and the Root and Tuber Expansion Programmes have also increased production and productivity in the agricultural sector. The Agricultural Transformation Agenda (ATA), launched in 2011, is a notable success story. It focused on increasing the production of key crops like rice, maize, and cassava, resulting in Nigeria becoming the world's largest producer of cassava and significantly reducing rice imports. Another successful initiative is the Anchor Borrowers' Programme (ABP), which provided farmers with access to finance, leading to increased production, particularly in the rice sector. The political will demonstrated by the Muhammadu Buhari-led administration in diversifying the economy received tremendous support, as many Nigerians went into farming. Despite these limitations, restricting land border imports, greatly encouraged Nigerian farmers, especially rice producers. This opened the gate for some Nigerian industries, especially cottages to return on-stream owing to certain policies put in place.

The launch of the Food Security and Agricultural Mechanization Programme by President Ahmed Bola Tinubu marks a significant milestone in Nigeria's efforts to enhance its agricultural sector and ensure food sufficiency. The programme aims to deploy cutting-edge agricultural machinery and technology to promote large-scale agro-value chain development, with key objectives including increasing food production, promoting agricultural mechanization, and supporting local industries (Tribune Online, January 29, 2025). The programme has shown promise in increasing food production, with notable successes such as Nasarawa State's harvest of 2000 hectares of rice farm as part of the food security programme. Additionally, the introduction of new agricultural technologies, such as tractors and implements, has improved farming efficiency. These initiatives demonstrate the government's commitment to transforming the agricultural sector and ensuring food security for its citizens.

Unfortunately, all concerted efforts made by different *administrations* over the years to improve the standard of living and revitalize agriculture have not justified these hopes. Raji, 2024:8) best describes efforts as "*motion without movement*". Nigeria, especially after the recent nose-diving of crude-oil in the global market, has realized the dangers of a mono-product economy. The global crude oil pricing crisis significantly contributed to the country's drift into a recession. The income that the country generates nose-dived substantially and there were no 'shock absorbers' to stem the tide, as the country's foreign reserves had been depleted. The resultant hardship that came with the recession made the mantra of economic diversification prominent and acceptable to different strata of Nigerians. Despite these good initiatives and notable successes, many initiatives have been plagued by inefficiencies, corruption, and lack of sustainability. The Strategic Grains Reserves Programme (SGRP), for example, failed to achieve its objectives due to inadequate funding and poor management. The OFN scheme was criticized for its lack of sustainability, as it relied heavily on government funding and subsidies. Additionally, the program had limited impact on rural poverty, as the benefits of the program were largely captured by large-scale farmers. The Green Revolution program, launched by the Shagari administration was criticized for its dependence on imported inputs, such as fertilizers and pesticides, which increased Nigeria's dependence on foreign exchange. The program's focus on intensive agriculture led to the neglect of the needs of small-scale farmers, environmental degradation, including soil erosion and water pollution. The National Directorate of Employment (NDE) struggled to create sustainable jobs. Similarly, the Agricultural Revitalization Scheme and the Root and Tuber Expansion Programmes had limited impact on agricultural productivity and food security. Overall, despite some progress, Nigeria's agricultural sector continues to face complex challenges, hindering sustainable food security. The numerous schemes launched by the government have been plagued by challenges and failures, underscoring the need for a more effective and sustainable approach.

Current Challenges to Agricultural Sustainability and Food Security in Yorubaland

A critical survey and analysis of the various policies and programs of governments clearly reveal myriad problems leading to food insecurity, most so formidable to increase this tendency unless serious preventive measures are taken.

An Underdeveloped Agricultural Sector: The main problem confronting food supply in Nigeria is the fact that an overwhelming proportion of food crop production is in the hands of peasant farmers operating within the framework of traditional agricultural systems. Agriculture faces challenges from rapid population growth, limited technical assistance, limited access to finance, poor rural infrastructure, dependence on rain-fed agriculture and poor soil fertility management, leading to unsustainable expansion into infertile lands and low productivity. Government incentives rarely reach farmers, who cannot tackle farm challenges alone, underscoring the need for adequate support (Ehinmidun, 2024).

Insecurity: The need to genuinely address prevailing national security challenges especially those posed by Boko Haram insurgency, herdsmen, kidnapping and armed banditry. Conflicts between herdsmen and farmers become rampant. Just a case of many is Wole Soyinka's ordeal captioned by Ajibade (2022) thus: *Nobel Laureate and Fulani cattle breeders (I)* and another headline reported by Agboola (2021) with the headline '*Herders hack 56-yr-old farmer to death in Oyo*'. Historically, farming and nomadism coexisted peacefully in Yorubaland, with minor skirmishes between the Yoruba and Fulani nomads. However, since the 1980s, disputes over water sources and farmland trespasses have escalated. The conflicts intensified over time, culminating in recent violent attacks by armed herdsmen and kidnappers on farming communities, resulting in significant human and material losses- as well as the displacement of indigenous farmers.

The issue of kidnapping and banditry in the south-western region of Nigeria continues to be a pressing concern, receiving ongoing attention and calling for action. Olufemi (2024) reports that "Ooni of Ile-Ife, Oba Adeyeye Ogunwusi on Friday, March 1 hosted the 2024 Yoruba Security Summit, where he met with other traditional rulers in the south-west region, and deliberated on practical solutions to kidnapping and banditry in the region."

Storage, Pest and Disease Management: A study by the International Institute of Tropical Agriculture (IITA) found that in southwestern Nigeria, which includes Yorubaland, post-harvest losses for crops such as maize, cassava, and yams ranged from 20% to 40% (IITA, 2019). At the *1st Post-harvest Connect Conference and Exhibition*, held in Abuja, the United States Agency for International Development (USAID) through the Mission Director- Melissa Jones, stated that about 50% of fresh agricultural produce in Nigeria is lost at the post-harvest stage. According to her, such losses are partly responsible for the rising food inflation in the country which reached 40.01% in March 2024 (Tones, 2024). Perishable crops, such as plantains and tomatoes, are highly susceptible to spoilage because of their short lifespan. Inefficient storage and marketing systems exacerbate this problem, leading to market gluts and price fluctuations. Similarly, yam, a staple crop in Yorubaland, experiences significant post-harvest losses due to pests, diseases, and poor storage systems, resulting in estimated annual losses of 30-50% of the 15 million tons produced.

Ill-thought-out and inconsistent government policies- The Nigerian government has implemented various agricultural programs and policies to address food security and wellness. However, these efforts have been marred by inconsistencies, absolute lack of direction, and lack of continuity. For instance, the Yakubu Gowon administration introduced the National Accelerated Food Programme (NAFP), which was later cancelled by the Obasanjo regime and replaced by Operation Feed the Nation (OFN) in 1976. The OFN was patterned after Ghana's operation. However, when Shagari came to power in 1979, he ditched the OFN and launched the Green Revolution, which was modelled after Asian agricultural projects. This pattern of discontinuity has been a recurring theme in Nigeria's agriculture sector. The frequent renaming, reorganization, and proliferation of agricultural ministries and programs have created confusion and disrupted the existing initiatives. For example, Gen Yakubu Gowon created the Federal Ministry of National Resources, which was later merged with the Ministry of Agriculture and National Resources by the Obasanjo regime, to be separated again by Pres. Shehu Shagari in 1979. These ministries were later merged again by Buhari's administration as the Head of State. President Bola Tinubu has since 2023 given a new title to the Federal Ministry of Agriculture and Rural Development (FMARD) as the Ministry of Agriculture and Food Security (MAFS).

Over-reliance on Mono-product Economy: Nigeria's over-reliance on crude oil has led to the decline of other sectors, including agriculture, mining, manufacturing and industrialization. These sectors

possess significant potential for employment generation, which could effectively address the country's unemployment challenges. Through these sectors, Nigeria's GDP could be close to that obtained in fairly-developed countries of the world if not surpass them (Henry, 2018: 262). Policies that promote monopolistic competition for large-scale industries hurt cottages and small industries.

Increasing Paucity of Cheap Labour: The oil boom of the 1960s to the 1970s triggered a massive rural-urban migration that depleted rural communities, as millions of able-bodied youths went to the cities (i.e. Lagos, Ibadan, Abeokuta, Akure, Ado-Ekiti, Osogbo) in search of white-collar jobs and education. As a result, agriculture was relegated to secondary status.

Economic and social challenges facing farmers: Difficulty in the farmers' ability to procure and raise loans to pay for farm inputs such as fertilizers, herbicides, tractor hire services and labor is undeniable. Access to fertilizer use is constrained by market liberalization and trade policies that increase fertilizer prices relative to commodity prices; limited access to markets and infrastructure; limited development of output, input and credit markets; poverty; and cash constraints that limit farmers' ability to purchase the needful. Programmes meant to aid farmers with credit and inputs are often plagued by diversion, which denies them the intended benefits. Globalization threatens food security and perpetuates poverty in developing countries through subsidized produce dumping, unfair competition, and exploitation by transnational companies, with inadequate labor protections (Ehinmidun, 2024).

Climate Change: Global agricultural and environmental challenges, such as climate change and soil degradation, have far-reaching implications for sustainability. Agricultural and environmental sustainability is an integral harmonious balance between food production and environmental stewardship that requires collaboration among farmers, policymakers, researchers, and communities through the adoption of the principles and practices that equilibrate the needs of agriculture with the preservation of the environment (Ononogbo et al., 2024). Food production is vulnerable to adverse weather conditions, which leads to an overall decline in farm input investment, including fertilizers, seeds, and technology adoption. Climate change affects the practice of agriculture in Yorubaland, Nigeria, via unpredictable rainfall patterns, increased temperature, drought, flooding, soil degradation, nutrient depletion, water scarcity, and loss of biodiversity. Over the last decade, the most significant evidence of climate change is increase in atmospheric temperature, short and intense rainfall which generates greater run-off water and limiting the amount available for use, prolonged dry season and incessant flooding. Climate variability significantly impacts agriculture, a primary livelihood source in Yorubaland. Over the past decade, south-western Nigerian states, particularly those with coastal and riverine areas (e.g., Lagos, Ogun, Ondo, Ekiti, Osun, and Oyo), as well as Kwara and parts of Kogi in the north-central, continue to experience recurrent flooding, exacerbated by their proximity to major rivers, dams, and the River Niger. Flooding in Nigeria's southwest states was part of the larger national issue in 2024, with floods affecting 31 states and resulting in over 300 deaths and 1.2 million people affected (United Nations Office for the Coordination of Humanitarian Affairs, 2024). Like previously along Asa Dam (2008, 2015), flooding in Kwara State, specifically in Patigi, has emerged as a persistent and pressing concern, yielding devastating consequences for local residents. The region's unique geographical characteristics, marked by its proximity to a large river and classification as a wetland, render it susceptible to flooding, a vulnerability exacerbated by climate change. Recent flood events have affected multiple local towns in Nigeria, particularly multiple local government areas within Kwara State, resulting in significant humanitarian impacts, including the displacement of over 233,268 individuals and 24,808 households (International Organization for Migration, 2024). Likewise, Ondo State experienced several cases of flooding, particularly in 2024. Prolonged heavy rainfall precipitated widespread flooding in Ondo City, necessitating the displacement of residents and adversely impacting multiple communities. According to official reports from the National Emergency Management Agency (NEMA), the flood event resulted in at least one confirmed fatality (FRCN Positive FM 102.5, October 6, 2024). The floods have not only caused agricultural disasters, environmental degradation but in some cases led to cases of acute diarrhoea diseases and cholera-related illnesses.

Poor Management of Research Findings: The development and dissemination of innovative agricultural technologies and best practices are hindered by inadequate research and extension services provided by academic and agricultural institutions. Research findings often remain underutilized when, collecting dust in libraries and file cabinets. Furthermore, the scarcity of extension service workers has exacerbated the gap between farmers' research and practical application. Additionally, farmers' adherence to traditional methods can render them unreceptive to new ideas, perpetuating stagnation in agricultural progress.

Strategies for improving Agricultural Sustainability and Food Security

Food insecurity in Yorubaland and Nigeria was directly correlated with poverty, ill-health and death. Like the adage, 'a hungry man is an angry man,' food insecurity does not just signal ill-health due to malnutrition, but can also cause political crisis just like the rice riot of 1980 that unseated President Tolbert of Liberia. It was also a food riot that provided an opportunity to topple the regime of President Nimeiry of Sudan in 1985. A well-fed population can be pacified to sustain social and political stability, but unfed and underfed populations cannot. The table below shows that achieving food security in Yorubaland and Nigeria is feasible, but it necessitates a multifaceted approach that encompasses the right policy measures, a correct mind set, steadfast commitments, collaborative efforts, strategic investments, innovative technologies, and a strong political will.

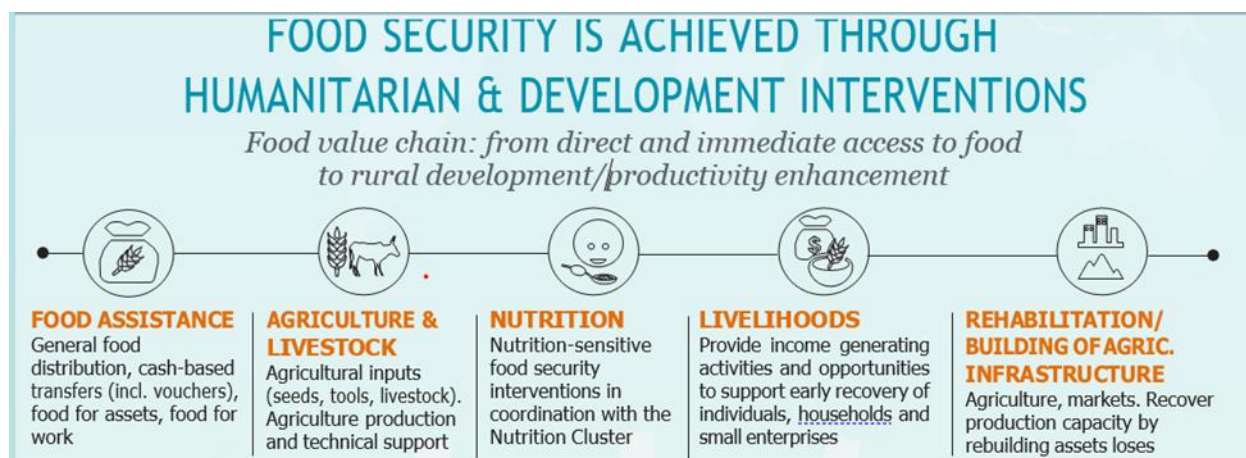


Figure 1: Food value chain toward achieving food security through humanitarian and development interventions. Source: <https://eu.docworkspace.com/d/slCHy58TfAaia9L4G?sa=601.1123>

Hence, food security via poverty alleviation schemes and wealth creations for the target population can be achieved through the following strategies:

Government Policy and Support: Government's roles towards the diversification of the economy (focusing on agriculture and industries); agricultural empowerment (implement policies that empower farmers, such as providing credit facilities, agricultural equipment, and training programs; and effective monitoring and evaluation cannot be over-emphasized. The Nigerian government must encourage diversification of its mono-cultural dependence on the oil sector as it is the only way to survive the current environment of global uncertainty with the volatility of oil price; a state cannot be rich when its revenue is from one source and "there are strong indications that countries that depend on mineral resources as the basis of foreign exchange and overall development are susceptible to the volatility of their market" (Aghalino, 2014:3). Isa (2019:60) attests thus: "Countries that are counted among the successful ones in the world attained their status largely through economic diversification. A state like China is effectively utilizing her agricultural mining and industrial sectors where hundreds of millions of citizens get employment, which in turn drive the economic development of China through the production of wealth".

Improved Budgetary Allocation, Monitoring and Evaluation Strategies: The Buhari-led government's allocation of ₦228.4 billion to the agricultural sector in 2023, accounting for only 1.05% of the total budget, raised concerns about the administration's commitment to achieving food security. The allocation was the lowest in seven years, despite the growing concern about food insecurity in Nigeria. As shown in Figure 2, experts argued that this meager allocation could by no means address pressing issues such as mechanization, irrigation, storage, and research, which continue to hinder farmers' productivity.

The Nigerian government's 2025 budget allocates ₦826.5 billion to agriculture, a 100% increase from the 2024 allocation of ₦362.94 billion. This significant boost aims to enhance food security, generate employment, and promote economic diversification (BusinessDay. 2024, October 25). However, concerns persist about the allocation's sufficiency in addressing the nation's food deficit, particularly given the country's growing population and poverty rates. It still remains a far cry from the Maputo

Declaration threshold of 10% (African Union, 2003). Nigeria's agricultural sector requires strategic investments and effective management to drive growth and development. Increasing budget allocation to at least 10% of the national budget, prioritizing critical areas, and ensuring transparency are crucial steps. Moreover, establishing clear indicators, conducting regular monitoring, and engaging stakeholders in M&E processes will ensure accountability and responsiveness. To further enhance agricultural development, agricultural insurance programs, capacity building for stakeholders, and private sector engagement are necessary. These initiatives will mitigate risks, enhance skills, and leverage resources, expertise, and technology to drive growth.

Agric Allocation in Proportion to National Budget

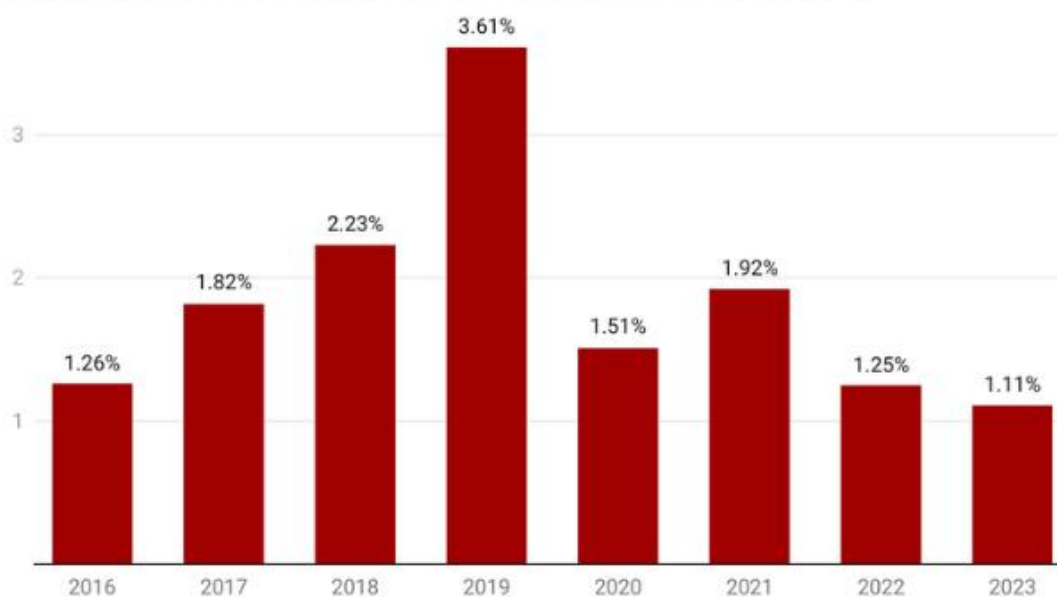


Chart: BusinessDay • Source: budget Office of the federation • Created with Datawrapper

Figure 2: Charts showing inconsistencies in Nigeria's Agricultural Sector Budgets

Source: BusinessDay. (2024, October 25).

Nutritional Interventions: Malnutrition is a pervasive issue among impoverished populations, resulting in elevated mortality and morbidity rates, diminished cognitive abilities, and reduced quality of life (WHO, 2018). To achieve food sufficiency, Nigeria must prioritize not only quantitative increases in food production but also qualitative improvements through dietary diversification. Government, private sectors and farmers can achieve this through the implementation of nutrition education programs, the promotion of nutrient-rich crops, and support for research on nutrition and health.

Market Accessibility: The projected gains of world trade liberalization tend to be minimal in sub-Saharan Africa. Perhaps it is time for Yoruba to produce for Nigerians and Africans in order to have more market control. Nigeria could champion the African market. Market accessibility can be enhanced by producing for local and African markets, through the development of local processing and packaging industries, trade agreements, and market support. Promoting market accessibility is crucial for the economic development of Yorubaland. To achieve this, various institutions play a vital role. Research and development institutions such as the International Institute of Tropical Agriculture (IITA), National Institute for Agricultural Extension and Research Liaison Services (NIERALS), and Federal Institute of Industrial Research, Oshodi (FIRO) conduct research and provide training and support to farmers. Agricultural training and capacity building institutions like the Agricultural and Rural Management Training Institute (ARMTI), National Agricultural Extension and Research Liaison Services (NAERLS), and Oyo State Agricultural Development Programme (OYSADEP) provide training and capacity building for agricultural professionals and farmers. Market development institutions such as the Nigerian Commodities Exchange (NCX), Agricultural Commodities Marketing and Development Company (ACMDC), and Southwest Agricultural Commodities Market (SWACOM) provide platforms for farmers to sell their produce and access markets. For example, the National Centre for Agricultural Mechanization (NCAM) Ilorin plays a pivotal role in enhancing market accessibility for farmers and agricultural entrepreneurs in Kwara State and beyond. By developing and disseminating improved agricultural

technologies, NCAM Ilorin contributes to increased agricultural productivity and efficiency. The centre's training programs and capacity-building initiatives enable farmers to produce high-quality products that meet market demands. To achieve sustainable agricultural development, NCAM Ilorin's interventions must be sustained and scaled up. This requires continued investment in agricultural research and development, capacity building, and market development. By enhancing market accessibility, NCAM Ilorin can contribute to food security, poverty reduction, and economic growth in Kwara State and beyond.

Rural off-farm Opportunities: Providing opportunities for landless rural poor and failed entrepreneurs can curb rural-urban migration and induce urban-rural migration. To motivate farmers towards efficient farming practices, initiatives such as cottage industries, credit provision, contract processing facilities, and market facilitation can be implemented. Collaboration among stakeholders is essential to enhance shelf life and facilitate marketing in distant markets.

Capacity Building (Education and Training): As an intervention to food security, education must practically provide avenues for farmers to be listened to, being the primary beneficiaries of food security related - policies, and also transfer knowledge of research findings on matters relating to: food preservation, alternative medicine to make health more affordable, more efficient agricultural extension, options for improving soil fertility, the best approach to manage different agricultural systems, and marketing strategies. Moreover, education is not a hindrance to engaging in agriculture, as the imperative of food security transcends socio-economic boundaries. Hunger is an indiscriminate and universal challenge that affects individuals regardless of their educational background. Hence, making agriculture a compulsory subject in the Nigerian educational curricula as well as providing regular training and retraining programs for farmers will not only promote awareness and skills but also improve their productivity.

Good Governance, Policy Reform and Consistency: Nigeria is often said to be 'rich' in natural and human resources but 'poor' in governance, its one-hundred and eighty million people are sometimes said to be either 'positively' committed to 'negative' things or 'negatively' committed to 'positive' things; its system of government has been described as a 'functioning anarchy,' where, though the 'best' is impossible, yet, the 'worst' is unlikely. In-built in all these paradoxical epithets and statements of incredibility is the reality that the country exhibits major contradictions of what is expected and what has so far been delivered (Abiodun, 2019:4-5). More often than not, sustainable food security measures are long-term strategies which need to be protected from the volatile political interests of leaders. It is also in everybody's interest to have only the best hands without political interference from governments and donors. All these strategies can only work in a peaceful, corruption-free environment and an inward-looking government. It is obvious that the various programmes and schemes since independence have failed woefully to supply food domestically, and yet, food importation is not the remedy.

Collaborations and Multi-stakeholder Approaches: This is essential in addressing the complex challenges facing the agricultural sector, particularly in reducing post-harvest losses. Collaborations facilitate the exchange of ideas, expertise, and best practices among stakeholders, governments, private sector companies, NGOs, civil society organizations, farmers' organizations, and research institutions. Jones (2024), speaking on the subject 'Currently, Nigeria post-harvest losses are almost 50% for fresh produce' called on "stakeholders to collaborate to ensure the effects of the unpleasant statistics are reduced for vulnerable populations who have been thrown into hardship." Collective responsibility is captured by The Mission Director, USAID, Melissa Jones (2024 thus, "it is critical that we all come together to focus on ensuring that the hard work of farmers is not lost in post-harvest and passes to the consumers who are in need." Public-private partnerships can foster private sector participation, promoting agricultural development and food security through investments that enhance productivity and efficiency.

Food Security in Yorubaland: A Comparative Analysis

A comparative analysis of food security in Yorubaland and other Nigerian regions reveals that more concerted efforts towards self-sufficiency in the southwest have been achieved due to a more conducive political and geographical atmosphere than elsewhere. Food security, as defined by Nwajiuba (2000), requires adequate food access for an active and healthy life. The components under consideration include availability, stability, access and utilization. The South-West Region has demonstrated notable progress in ensuring food availability, accessibility, utilization, and stability, thereby reducing poverty and unemployment. Food availability and accessibility in Yorubaland are ensured through food production, which serves various purposes ranging from human consumption for biological growth, animal feed, replanting, or processing, and export to other countries.

Noticeably, Yorubaland, mostly in the south-western region, has fewer grave political challenges that threaten food security and wellness than any geopolitical region. This contrasts with other regions, such as the North-West Region (Jigawa, Kaduna, Kano, Katsina, Kebbi, Sokoto, and Zamfara) being threatened with desertification, livestock rustling, banditry, and low literacy rates. The North-East Region (Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe) contend with insurgency (Boko Haram), displacement, poverty, and low literacy rates. The North-Central Region (Benue, Kogi, Kwara, Nasarawa, Niger, Plateau, and Abuja [FCT]) face challenges such as ethno-religious conflicts, kidnapping, banditry, and poverty. The South-South Region (Akwa Ibom, Bayelsa, Cross River, Delta, Edo, and Rivers) and the South-East Region (Abia, Anambra, Ebonyi, Enugu, Imo, and Rivers (sometimes considered part of South-South Region)) constantly battle with environmental degradation (oil spillage), vandalism, militancy, and piracy. All these socio-political cum political crises are inimical to the attainment of agricultural sustainability and food security. The South-West Region (Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo) face the challenges of urbanization, traffic congestion, and pressure on infrastructure. However, a worrying trend has emerged in the face of food security challenges. The South-West region is confronting significant constraints, including: limited cultivable land, increasing population pressure on available land, and social environment where educated adults and youth are abandoning farming pursuits. This trend portends a future where the region may rely heavily on internal food transfers from the North, rather than maintaining self-sufficiency.

Furthermore, the agricultural sector is the economic backbone of most Yoruba states, except for Lagos, which is Nigeria's premier industrial hub. Despite its limited food production, Lagos ensures food availability and accessibility through market mechanisms and food aid. This accomplishment represents a substantial stride towards self-sufficiency, a crucial factor in social satisfaction and reduced reliance on external food aid. The South-West states' favorable agricultural conditions, situated within the forest region, confer a comparative advantage in food security. The region's agricultural productivity yields numerous benefits, including diversified food options (array of food choices, reducing dependence on imported goods and enhancing food security); specialized crop production (renowned for cultivating crops such as cocoa, cassava, yam, maize, and oil palm, with Ondo and Osun states leading Nigeria's cocoa exports); and animal products and by-products (production of beef, mutton, goat meat, pork, bush meat, chicken, fish, and snails).

The Yoruba people's cultural heritage has cultivated a distinctive culinary tradition, characterized by a unique blend of flavors, spices, and ingredients. Yoruba cuisine is a product of the region's history, geography, and cultural influences, yielding a distinct gastronomic identity. Traditional dishes, such as *egusi* soup, jollof rice, and *akara*, exemplify the region's culinary expertise. Such specialities in delicacies prominently include *Akara* Ogbomoso, *Gari*, *Gari* Osi, *Dodo* Ikire and lots more. By providing access to nutritious food, the region mitigates the spread of diseases and social problems. The cultural significance of Yoruba cuisine underscores the importance of food security, highlighting its role in perpetuating cultural heritage, community cohesion, and societal well-being.

Also worthy of note is the uniqueness in the individual adjustments and family coping strategies in Yorubaland. Access to adequate food remains a pressing problem for most Nigerian households, despite perceived abundance. High inflation, food price instability, and low wages have rendered many Nigerians food insecure. The declining real household income and purchasing power exacerbate food inaccessibility. Unequal food distribution and poor access to nutrition have compromised food utilization and nutritional well-being. Vulnerable groups, including the poor, smallholder farmers, and children, are disproportionately affected. The Yoruba people's adaptive response to food insecurity involves coping strategies such as consuming less preferred foods and practicing portion control. Statistical analysis reveals that food insecurity indices decline with higher income and educational attainment, while increasing with household size and number of dependents. Interestingly, contemporary Yoruba couples have deviated from traditional norms, adopting family planning strategies and opting for smaller family sizes, averaging two or three children, in response to economic pressures and other factors. The traditional Yoruba blessing "*Waa bi meje pe*," which wishes newlywed couples a minimum of seven children, has given way to economic pragmatism. A newer coping strategy is reflected in the proverb "*Qmọ bẹẹrẹ, osi bẹẹrẹ*," which translates to "many children, many troubles." This aphorism acknowledges the challenges of raising a large family, implying that smaller family sizes may be more conducive to economic stability and well-being (Oyedepo, 2025).

Although there's still much work to be done, the region is home to various innovative agricultural projects, showcasing its potential for growth and development. South-West Nigeria's efforts to address food insecurity are gaining momentum through government interventions and agricultural initiatives. Targeted

policies, such as poverty reduction and nutrition education, are crucial in alleviating food insecurity. Despite challenges in food production, including declining indigenous farmers, increasing reliance on imported food, difficulties in transporting surplus produce to distant areas due to infrastructure and security issues; governments in the region are committed to achieving food self-sufficiency. The Nigerian government's commitment to agricultural development is evident in initiatives like the Special Agro-Industrial Processing Zones (SAPZ) program. By focusing on food production and processing, SAPZ seeks to address the country's agricultural challenges. In the South-West region, states like Ogun and Oyo are adopting a crop-specific approach, with Ogun concentrating on rice, cassava, poultry, and fisheries, and Oyo prioritizing cassava production, alongside soybeans and rice. The Federal Government's decision to appoint Osun State as the coordinator for the Food System Transformation Pathways in the South-West geopolitical zone is a strategic move. This initiative promotes regional cooperation, encourages innovation, and enhances food security. Commissioners of Agriculture from Lagos, Oyo, Ondo, Ogun, Osun, and Ekiti states in Southwest Nigeria, as well as their governors are indeed collaborating to boost rural agricultural development and achieve food sufficiency. To support farmers, governments are providing: quality inputs (high quality seeds, herbicides, and farming tools); mechanization support (subsidizing tractorization to enhance farm productivity); and security measures (deploying local vigilantes and the *Amotekun* corps to protect farmers and their crops). These initiatives demonstrate the region's commitment to achieving food self-sufficiency (Agronigeria, 2025).

The South-West states of Nigeria possess a significant comparative advantage in agriculture, which has driven substantial economic growth. By capitalizing on their agricultural strengths, these states have increased production capacity and reduced reliance on imports. Leveraging their agricultural advantages can further reduce dependence on imported goods, fostering self-reliance and economic stability. Sustainable agriculture in the region offers numerous benefits, including employment opportunities, rural development, and increased foreign exchange. However, food insecurity remains a challenge, with a significant portion of the population experiencing mild food insecurity. To achieve food security, Nigeria must ensure year-round food availability, adequate food quantity and quality, and access to food through both production and market purchase. Ultimately, household food security is crucial, determining access to nutritious food.

CONCLUSION

A critical examination of Nigeria's economic history revealed that agriculture has long been the linchpin of the forest region's economy. The country's rich endowments of arable land, human capital, and natural resources create fertile ground for economic development. Notably, the pre-independence agrarian economy of Nigeria's ethnic groups was characterized by a high degree of regional specialization and adaptability, underscoring the importance of contextualizing economic development within specific geographical and cultural contexts. Agricultural sustainability is crucial for food security and wellness, yet its implementation remains insufficient. The four dimensions of food security – availability, accessibility, utilization, and stability – are not being adequately met, emphasizing the need for improved strategies and collective action. While the rest of the world has made significant progress towards the sustainability of agriculture for food security and wellness, the continent of Africa, especially sub-Saharan Africa, continues to lag behind. This study examines how the agrarian base of the Nigerian economy dates back to the pre-colonial period. It was agriculture that largely provided sustenance to the economy of the ancient kingdoms and empires in pre-colonial Nigeria which made prominent Yoruba kingdoms and empires such as Ife, Oyo, Ibadan, and Abeokuta. The problem of food security has worsened since the 1970s when attention shifted from agriculture to oil wealth. Nigeria's shift from an agriculture-based economy to an oil-based economy has had far-reaching consequences. The decline of rural economies and food production has compromised the country's food security and sustainability. All efforts made ever since to reverse from a dwindling economy to a once-on-a time sustainable one seems like a mirage. The major challenge to food security in Yorubaland and Nigeria is the underdeveloped agricultural sector which is characterized by over-reliance on primary agriculture, low fertility soils, minimal use of external farm inputs, environmental degradation, significant food crop loss both at pre- and post-harvest, minimal value addition and product differentiation, and inadequate food storage and preservation that result in significant commodity price fluctuations. Summarily put, observable changes and worries in South-Western Nigeria include that: indigenous farmers are gradually disappearing; food production is declining rapidly; those once classified as migrant labourers are taking over farms and becoming landlords; wetlands (*akurẹ*) are being taken over and farmed for huge profits by migrants particularly from northern Nigeria, young people are becoming increasingly apathetic and demonstrating complete lack of interest in farming; we continue to depend increasingly on imported food items and food from other regions of Nigeria; and increasingly becoming more vulnerable

to food insecurity than other parts of Nigeria (International Institute of Tropical Agriculture [IITA], 2017). The study concludes that enhancing agricultural development requires a multifaceted approach, and critical strategies for sustainable development include: diversification, market accessibility, nutritional interventions, rural off-farm opportunities, capacity building, good governance, and stakeholder collaborations are essential for sustainable development. By implementing these strategies, stakeholders can collectively contribute to achieving sustainable food security in Yorubaland. That food opportunities abound in Yorubaland owing to the abundance of land for agricultural and industrial use suggests that every society is left to define its relationship with the available opportunities. A nation's inability to feed itself renders it vulnerable to the whims of other nations with robust economies, leaving it exposed to severe repercussions on its Gross Domestic Product (GDP) and the life expectancy of its citizens. Food security transcends national pride, constituting a vital component of a country's sovereignty, stability, and overall well-being. Food security is essential for a nation's well-being, as it improves living standards, reduces social problems, and enhances health outcomes. It also promotes a positive international image, supports good governance, and reduces youth unrest. Sustainable agricultural development is critical for ensuring a brighter future and creating an enabling environment for good governance, ultimately benefiting current and future generations. Therefore, as food is the only cure for hunger, achieving a solution to food security lies in increasing food availability, access and adequacy. Agricultural sustainability is a collective responsibility that requires the involvement of all stakeholders. A multi-stakeholder approach, involving government, private sector, civil society, and farmers, is crucial for driving meaningful change. By working together, Nigeria can revitalize its agricultural sector, promote food security, and ensure a sustainable future for its citizens.

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APICULTURAL ECONOMIC AND INVESTMENT ANALYSIS IN THE CAPE WINELANDS REGION OF SOUTH AFRICA

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ABSTRACT

The global decline in bee populations and the many challenges faced by beekeepers in South Africa, such as drought, the overuse of chemicals, unavailability of forage and cheap honey imports, have caused huge challenges for the industry. The study sought to determine viable options among the bee production systems. Primary data was collected from 51 beekeepers owning between 150 and 1,000 beehives in the Cape Winelands District. Gross margin analysis, net present value, internal rate of return and payback period were used for the economic and investment analysis. The results of the study revealed that apiculture provides a positive gross margin regardless of the production system. However, investment analysis had opposite results for the split production of honey and pollination. Therefore, the study concluded that the combination of honey production and pollination yields positive profits. Beekeepers are recommended to own more than 500 beehives and combine the two production systems.

Keywords: Beekeeping, Enterprise budgets, Gross margin, Honey production, Pollination services

INTRODUCTION

In South Africa, the demand for honey and pollination services has increased over the years due to dietary changes and increase in horticultural plantations, especially in the Western Cape province. The demand for honeybees was also supported by the 2019 beekeeper's database, which has shown a 68,8% increase from 105000 to 176215 colonies between 2016 and 2019 (Department of Agriculture, Forestry and Fisheries 2019). In addition, honey imports have increased by 4,000 tonnes over a period of 18 years, an increase of over 1000% (Quantec 2019). The increase in bee colonies, together with the demand for honey, may not result in positive benefits for apiarists, as Langenhoven (2018) indicated that the honey output per hive in South Africa is insignificant if equated to other countries in the Southern Hemisphere. In South Africa, the average yield per hive is estimated at 15 kg, while, for example, in Australia, it is between 50 and 70 kg. As outlined by Peter (2015), the reason for the lower yield could be associated with a myriad of reasons such as the unavailability of forage, the use of pesticides, theft, drought and vandalism.

Globally, over 70% of crops depend on pollinators for sustained yield and production (Food and Agriculture Organization 2018). Furthermore, in the past, there were no expenses incurred by crop farmers for pollination, but this changed as the population grew and food demand increased. The increase in food demand has therefore resulted in changes in farming practices, which introduced the use of chemicals that have resulted in the reduction of the bee population. Kanninen et al. (2013) noted a decline of 29% for 2008 and 2009 in the number of colonies, which might not have only affected honey production, but also crop production. The turnover for apiarists comes in three different forms such as honey sales, provision of pollination services, and the sale of other products, which is an important decision apiarists need to make before investing in beekeeping. Beekeepers, therefore, choose an option that suits their specific purposes. Many apiarists opt for one of the three or all three options.

Studies conducted in other countries revealed interesting findings in terms of production techniques and profitability. Lee et al. (2017) reported that in the United States, pollination accounts for 41.1% of the

gross income, with the rest being honey sales and other related products. Conversely, Devkota et al. (2016) reported that honey production accounted for 100% in the Chitwan district of Nepal. Many studies on beekeeping profitability in other countries have revealed that the enterprise is viable (Sumner and Boriss 2006; Peter 2015; Devkota et al. 2016; Dia et al. 2018; Šakić Bobić et al. 2018). Despite the enterprise being viable in other countries, there is a need for investigation on economic and investment analysis in South Africa as there is no documented evidence about investment analysis, especially on different production systems. The need for the study is important for the beekeeping industry as fuel prices have increased drastically over the years, coupled with prices for natural honey that does not increase proportionally. Lundall-Magnunon (2018) also noted the concern of cheap honey that is caused by cheap imports, put more pressure on local honey producers.

MATERIALS AND METHODS

Description of the study area

The Cape Winelands region, formerly referred to as the Boland region, forms part of the six regions formally known as district municipalities of the Western Cape province of South Africa. The Western Cape forms part of the 44 municipalities in South Africa. The Cape Winelands is situated in the south-west of the Western Cape province and borders two other provinces, the Eastern Cape and Northern Cape (Cape Winelands District Municipality 2019). The Western Cape province, where the Cape Winelands is located, covers an area of approximately 129,370 km², which roughly covers 10% of the whole land area in South Africa, whereas the Cape Winelands District Municipality covers an area of 21,478 km² (Municipalities of South Africa 2024).

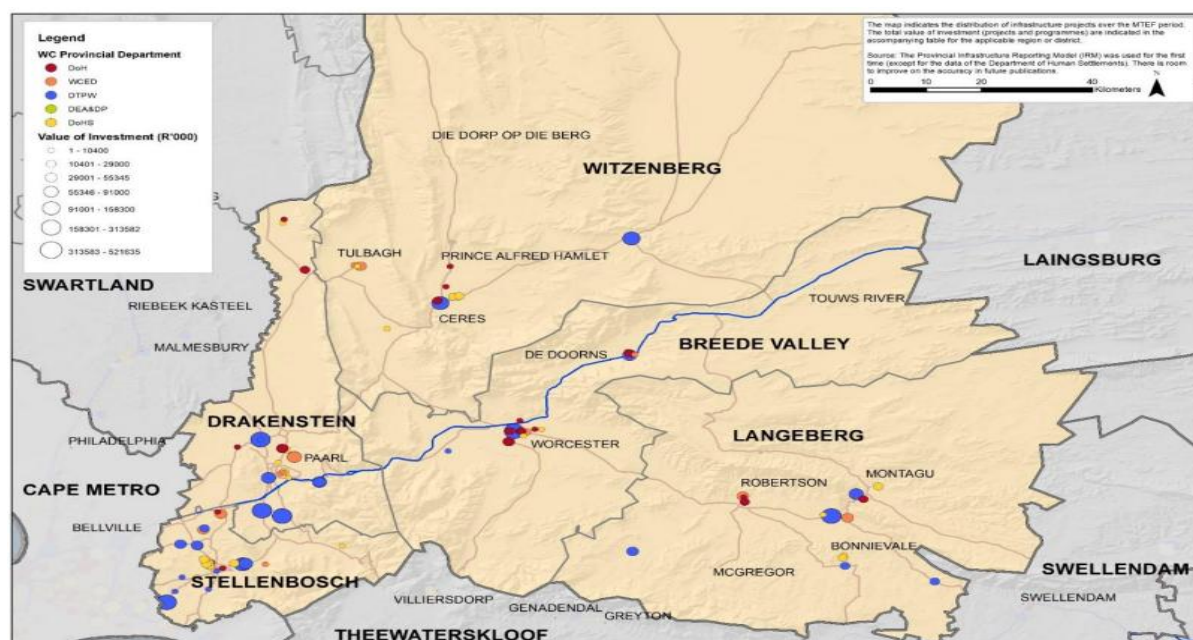


Figure 1: Map depicting the location of the Cape Winelands District Municipality Source: Municipalities of South Africa (2024)

This region is the second biggest economy in the province with a GDP of 43.7 billion in the 2016 financial year, and agriculture contributes 13% of the employment numbers (Cape Winelands District Municipality 2022). The population of the region in 2020 was estimated at 905 057 with 235 016 households and a Gini coefficient of 0,62 (Cape Winelands District Municipality 2022).

Sampling procedure

A structured questionnaire was compiled and used between February and May 2020 to gather information about the different beekeeping techniques in the Cape Winelands region. This information included economic and investment aspects of beekeeping. The non-probability sampling method was used in collecting data from beekeepers in the five local municipalities in the Cape Winelands region.

The study made use of the non-probability sampling method, which included 51 small-scale, commercial and professional beekeepers out of 67 beekeepers from the five local municipalities of the region. Hobbyist beekeepers were not included in the total numbers of beekeepers, as they are not keeping beehives for business purposes. Budget limitations and time constraints were one of the reasons why non-probability sampling methods was employed.

Data analysis

Beekeeping farms were categorised according to the number of beehives owned and the production system used. Beekeeping farms in the study managed between 150 to 1 000 beehives. Data was analysed and three categories of beekeeping systems were identified, being the production of honey, pollination services, and the combination of both honey production and pollination. Data analysis made use of the gross margin analysis, net present value (NPV), internal rate of return (IRR) and payback period. In accordance with Van Reenen and Marais (2010), long-term viability of an investment is determined using NPV, IRR and the time it takes to repay the invested capital. A cash flow and a capital expenditure budget were compiled from the primary information received from beekeepers and the following formulae were used:

$$NPV = \sum_{t=0}^n \frac{R_t}{(1+i)^t} - I \dots\dots\dots (1)$$

NPV is the difference of the present value of cash inflows and outflows in a determined period. *R_t* denotes the net cash flows over a determined period *t*, and *i* represents the discount rate, whereas *I* stands for the initial investment amount.

$$IRR = \sum_{t=0}^n \frac{R_t}{(1+i)^t} = 0 \dots\dots\dots (2)$$

IRR is used to calculate the profitability of the investment in an enterprise. It makes the NPV of all discounted net cash flows over a determined period to equal zero. From Equation 2, *R_t* denotes net cash flows over period *t*, while *i* represents the discount rate.

$$Payback\ Period = \frac{I}{R_t} \dots\dots\dots (3)$$

The time it takes the enterprise to pay back the capital invested into the project from its net cash flow is known as payback period. Therefore, based on Equation 3, *I* denotes an initial investment into the project, while *R_t* denotes net cash flow resulting from the project.

$$GM = (P_y * Q_{ys}) - \sum_{i=1}^n (P_{xi} * Q_{xi}) \dots\dots\dots (4)$$

Gross margin denoted by *GM* is the difference between sales and variable costs of an enterprise. *P_y* and *Q_{ys}* represent product market price and quantity of the output sold, respectively. *P_{xi}* and *Q_{xi}* denotes the cost of variable input and quantity of the input used.

RESULTS AND DISCUSSION

Demographic characteristics of beekeepers

The results revealed that males aged over 50 and married were the majority in the study area (Table 1). The results of the study were consistent with the results of the study by Mwakatobe et al. (2016) on women and youth participation in apiculture. In general, beekeeping is associated with men due to the nature of the enterprise. The results on marital status were also similar to the study conducted in Ethiopia about beekeeping (Abejew and Zeleke 2017); whereas Peter (2015) noted that more married persons showed stability in being involved in agriculture.

Table 1: Beekeeper’s gender, marital status and age

Categories	Frequency	Percentage (%)
Gender		
Male	46	90.20%
Female	5	9.80%
Total	51	100.00%
Marital status		
Married	42	82.35%
Single	7	13,73%
Other	2	3.92%
Total	51	100.00%
Age of beekeeper		

<25 years	1	1.96%
25–30 years	2	3.92%
31–39 years	8	15.69%
40–49 years	11	21.57%
50–59 years	19	37.25%
60–70+ years	10	19.61%
Total	51	100.00%

Source: Field data (2020)

Vaziritabar and Esmaeilzade (2016) conducted a profitability study on beekeeping and honey production in Iran, and the results were similar with the study findings of the Cape Winelands region. The study reported that 97% of the beekeepers interviewed were males with over 80% being 40 years of age and above. Furthermore, the majority were also married. Studies by Saner et al. (2004) and Vural and Karaman (2009) in Turkey, and Kalanzi et al. (2015) in Uganda had similar findings on gender, age and marital status.

Economic analysis

The gross margin analysis for the honey, pollination as well the combination of the production of honey production and pollination services is illustrated in Table 2. The results showed that apiarists with 150 beehives and focusing on honey production and pollination, had gross margins of R39 194 and R110 112, respectively, whereas the combination of two systems (honey and pollination) had a better gross margin of R300 033. Moreover, it is noted that the combined system had a share of 50,68% and 49,32% for honey and pollination services from the turnover. It is therefore evident that whichever production system used, beekeeping provides positive gross margin. The return on investment for the split production was 57,34% and 114,22% for honey and pollination, respectively, while the combination had a return on investment of 365,6%.

Table 2: Beekeeping enterprise budget on honey and pollination services

150 Beehive enterprise	Honey	Pollination	Honey & pollination
Gross income (R000')	R112,50	R192,00	R388,05
Direct variable cost (R000')	R68,35	R76,35	R82,06
Interest on working capital (R000')	R4,95	R5,53	R5,94
Gross margin above cost (R000')	R39,20	R110,12	R300,05
500 and 1 000 Beehive enterprises		Honey & Pollination	Honey & pollination
Gross income (R000')		R1 080,00	R2 470,00
Direct variable cost (R000')		R333,75	R858,33
Interest on working capital (R000')		R24,97	R62,23
Gross margin above cost (R000')		R722,05	R1 549,45

Likewise, the gross margin analysis for the production of honey and pollination services for beekeepers with 500 and 1 000 beehives were also positive. The gross margin for 500 beehives was R722 053 with a return on investment of 216%, whereas the gross margin for 1 000 beehives was R1 549 446 and the return on investment of 180%. The results of the gross margin analysis in all the production systems are similar to the findings of the study conducted by Čejvanović et al. (2011) in Bosnia and Herzegovina. The results of the study in these two areas were positive with a gross margin of R1 287,69 and R463,83 per hive, respectively. It can be noted that the honey yields in these two areas were very high compared

to the yields of the Cape Winelands districts. In addition, the results of the study by Peter (2015) in the Eastern Cape also had a positive gross margin.

Analysis of investment appraisal

The results of a cumulative cash flow and an investment analysis is illustrated in Figure 3. The study findings revealed that the capital investment of R488 270 for honey production and R482 250 for pollination services for beekeepers with 150 beehives resulted in a negative cumulative cash flow of R1 128 770 and R649 350, respectively. However, if honey production and pollination services for beekeepers with 150 beehives are combined, the results show a positive cash flow of R442 230. The three different beekeeping systems provided the same negative results as the cumulated cash flow figures. The net present value for honey production was R923 051, while that of pollination services was R595 680. Therefore, it is evident that beekeeping with only 150 beehives does not result in any benefit from the investment if honey production is separated from pollination services. The positive net present value of R143 367 is realised when honey production is combined with pollination services.

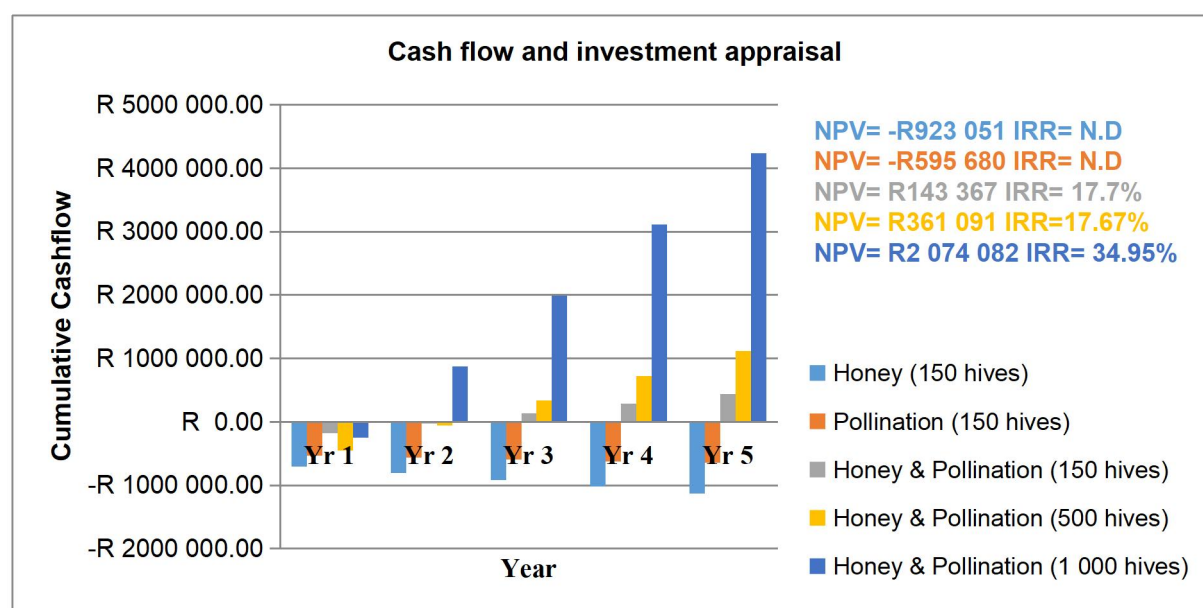


Figure 3. Investment appraisal and cash flow for different beekeeping systems

The study results further provided the internal rate of return for 150 beehives. The internal rate of return for the production of honey and pollination could not be calculated because the discount rate is not adequate for net present value to be nil. Therefore, it means that there would be no financial return in the investment, especially because the payback period was also undefined. The combination of honey and pollination services provided a positive internal rate of return of 17.7% and a payback period of just over three years, meaning that R17.70 is expected as a return per R100 invested in the enterprise.

Figure 1 further illustrates the investment appraisal of beekeeping with 500 and 1000 beehives. According to the results, a net cash flow of R1115480 and R4233 398 is realised in an investment of R1 233 450 and R2 489 590, respectively, for 500 and 1000 beehives, meaning that 500 and 1 000 beekeeping enterprises are viable. The IRR for the 500 and 1,000 beehive enterprises is 17.67% and 34.95%, while the repayment period is three and two years, respectively, proposing that more beehives are associated with a quick or short repayment term. The results of the study for the 500 and 1 000 beehives are similar to the study by Elpawati (2017) on financial feasibility. The NPV in the study was positive with an IRR of 45.7% and payback term of 2,7 years; however, the number of beehives owned were not included.

CONCLUSION AND RECOMMENDATIONS

Challenges faced by beekeepers, including the decline of bee populations, low prices of honey and the reduction in bee forage, necessitated an investigation into the financial viability of beekeeping enterprises. The findings revealed that the majority of beekeepers were males aged 50 and older, and married,

aligning with previous studies on women and youth participation in apiculture. This association of beekeeping with men was consistent with the nature of the enterprise, and the prevalence of married individuals in beekeeping was also noted in other studies. Furthermore, the economic analysis indicated positive gross margins and return on investment for beekeepers engaged in honey production, pollination services, and their combination. Notably, apiarists focusing on the combination of honey production and pollination services demonstrated the highest gross margin, highlighting the financial benefits of integrating these two systems. These findings were supported by similar results in previous studies, emphasising the consistency of positive economic outcomes across different regions.

Moreover, the investment appraisal revealed that beekeeping with 500 and 1 000 beehives was viable, with positive net present values, internal rates of return, and relatively short repayment periods, further corroborating the financial feasibility of scaling up beekeeping operations. Overall, the study's results underscored the profitability and financial feasibility of beekeeping, especially when integrating honey production and pollination services, and suggested promising opportunities for beekeepers to enhance their economic prospects. To improve profit margins, it is recommended that beekeepers combine honey and pollination at all times. It is recommended that bulk honey prices need to be regulated by the South African Bee Industry Organisation as is the case for the cost of pollination. Beekeepers are advised to stick to the set price per hive for pollination because crop farmers do not exploit new beekeepers. The market price of honey at the moment is very low due to cheap imports of substandard quality compared to local honey. In addition to cheap imports, the industry is not well regulated nationally. To understand these matters, beekeepers need to form part of local associations for technical information sharing and the challenges the industry are facing.

Informed Consent Statement: Informed consent was obtained from the subjects before data was collected.

Data Availability Statement: The full report is located at the library, Cape Peninsula University of Technology, together with all the datasets.

Ethical Clearance: The study was granted permission by the Faculty of Applied Sciences Research Ethics Committee and an ethical clearance certificate (216275237/07/2020) was received to gain access to the beekeepers in the Western Cape.

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ANALYSIS OF VITAMIN A, IRON AND IODINE IN COMMONLY CONSUMED FOODSTUFFS IN THE GAMBIA

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ABSTRACT

Food fortification can effectively address micronutrient deficiencies and significantly influence nutritional outcomes including the world-wide alleviation of vitamin A, iron, and iodine deficiencies. Vitamin A in edible oils, iron in wheat flours, and iodine in edible salts are useful vitamins and minerals for the human body. The study analyzed the levels of iron, vitamin A and iodine in wheat flour, edible oil, and salt, commonly consumed foodstuffs in The Gambia using advanced analytical iCheck tools. Sample collections from the different major markets in The Gambia were conducted according to sampling protocols standard. The edible oil samples (EO1, EO2, EO3, EO4 and EO5), wheat flour samples (WF1, WF2, WF3, WF4 and WF5) and edible salt samples (ES1, ES2, ES3, ES4 and ES5) were analyzed as purchased without further pre-treatment. Among the samples, for iron content in wheat flour, levels ranged from 24.8 mg/kg (WF5) to 110.6 mg/kg (WF2). Only samples WF2 and WF3 met The Gambia standard for iron fortification among the wheat flour samples. The vitamin A content in edible oil samples varied between < 9.99 IU/g (EO2 and EO4) to 23.9 IU/g (EO3). These values showed that only the EO3 sample met The Gambia recommended standard for vitamin A fortification. Salt analysis showed that only sample ES3 has dietary iodine content of 15 ppm, which was within the recommended Gambia standard for household salt. The findings could contribute to the solution of reducing the risk of anemia and micronutrient deficiency in The Gambia food chain.

Keywords: Food fortification, micronutrient deficiency

INTRODUCTION

Micronutrient deficiencies are a global challenge as it is estimated that at least two billion people are deficient in at least one of the essential micronutrients needed to prevent latent hunger, growth, development, and survival (Black, 2008). According to the World Health Organization (WHO), at least 1 in 5 people in the world suffers from a lack of nutrients, which leads to irreparable damage such as fatigue, hair loss, headache, dizziness, decreased mental function, fetal tube deficits, low birth weight, low intelligent quality (IQ), reduced work abilities, disease, and death in some cases (WHO, 1995 –2005; Silva *et al.*, 2018; Gupta, 2017; Ritchie and Roser, 2017; UNICEF/Bangladesh, 2019).

Among the most important micronutrients, vitamin A deficiency (VAD) is widespread and can increase the risk of morbidity and mortality (Ebata *et al.*, 2020). Vitamin A deficiency, a major public health concern, is not only prevalent amongst children living in rural areas and in children age 24 to 59 months but affects people of all genders and ages, as well as certain risk groups (Petry *et al.*, 2019). In Southeast Asia between 1995 and 2005, 45–55% of preschool children were severely vitamin A deficient. A total of 2.55 million pre-school children in Africa suffer from night blindness due to vitamin A deficiency (Etonihu *et al.*, 2010; Pignitter *et al.*, 2016), which absence not only cause specific diseases, but can also aggravate the infections and the risk for chronic diseases, greatly impacting morbidity, mortality, and

quality of life (Tulchinsky, 2010; Gaffey *et al.*, 2014; Wirth *et al.*, 2017) and is the leading cause of preventable blindness (Vijayaraghavan, 2018).

Despite widespread access to iron-rich foods, iron deficiency anaemia (IDA) is still prevalent in the 21st century (Daneshzad *et al.*, 2015). This may be due to the high intake of phytates-rich diet in some populations that limits the bioavailability of essential nutrients like iron. IDA is a major health issue which affects 1.62 billion individuals globally (Troesch *et al.*, 2013; Black, 2008) with symptoms such as paleness, weakness, irritability and indigestion. In the early stages of IDA, the body's iron content are depleted and the serum iron level decreases, then the total iron-binding capacity (TIBC) of the transferrin increases, and the serum ferritin, the size of the red blood cells (RBCs), and the hemoglobin content in each RBC decreases (Michelazzo, 2013).

Iodine is the basic substrate needed for the synthesis of the thyroid hormones T3 (triiodothyronine) and T4 (tetraiodothyronine or thyroxine), which are implicated in all vital functions of the organism. Multiple studies have shown that thyroid volume is inversely proportional to iodine intake (Abdurrahim *et al.*, 2023). In the absence of a diet supplying an adequate amount of iodine, the human body is subject to certain pathologies known as iodine-deficiency disorders (IDD). Iodine deficiency, which leads to the development of goiter and cretinism, maternal and fetal hypothyroidism, increased risk for the child and maternal mortality, pregnancy loss, and growth retardation, has become a major health problem and leads to the cause of avoidable intellectual impairment, although it can be prevented very easily and cheaply with iodine supplementation. Iodine deficiency occurs in people who avoid seafood, processed food and iodized salt (Pearce *et al.*, 2004; Haldimann *et al.*, 2005; Etonihu *et al.*, 2009; Etonihu *et al.*, 2013).

The national prevalence of iron deficiency in The Gambia among children and women was found to be 59.0% and 41.4%, respectively (Petry *et al.*, 2019). In The Gambia, the supply of adequate iodized salt is low and recent nationwide representative cross-sectional studies reported pregnant women in rural areas with iodine deficiency (Eriksen *et al.*, 2020). The median iodine concentration in the urine of pregnant women in The Gambia indicates iodine deficiency; especially in rural dwellers and in families with insufficient iodized table salt. In 1999, an evaluation of the iodine level of school children in The Gambia showed an average urinary iodine concentration of 42 µg/L, which classified these children as moderately iodine deficient. The results indicate that past and ongoing efforts did not eliminate iodine deficiency, as only a small fraction of the salt consumed in The Gambia is adequately iodized (Petry *et al.*, 2019).

Common salt and bottled vegetable oils used for cooking varieties of dishes and wheat for bread and confectionaries are staple foodstuffs in The Gambia. In this study, the levels of vitamin A in edible oils, iron in wheat flours and iodine in edible salts were investigated for their nutritional and public health information.

MATERIALS AND METHODS

Area of the Study

The study was carried out in The Gambia, a total of fifteen samples of edible oil, wheat flour, and salt were collected in selected towns, Banjul, Kanifing Municipality, and West Coast Region. In these areas are located most of the main local markets, supermarkets, and bakeries from where the samples were obtained. Not only the possibility of obtaining verifiable brand values for each of the samples is advantageous but it was commercially viable to carry out a study in these areas as the entire village market finished products are sourced from these markets. There was sufficient room in the region for the samples to be selected at any possible size and not much of the brands, particularly those from supermarkets, are available in the provinces. Samples were obtained from four local markets and one supermarket; the local markets are located at Brikama, Serrekunda, Bakau and Banjul. Brikama is second largest city in The Gambia while Banjul is the capital city of The Gambia and the fourth largest city located in the western part of the Country. Serrekunda is the largest city and the most populous residential area, which has the biggest market in the country; while Bakau is the third largest city in The Gambia (Gambia Bureau of Statistics, 2021).

Sample Collection and Identification

Samples were randomly collected at five different places that lasted from 4th April to 7th May, 2023, and in accordance with the Food Safety and Quality Authority (FSQA) of The Gambia sampling protocols standard. Samples were collected at Brikama, Serrekunda, Bakau, Banjul local markets and Kairaba shopping center. Flour samples were collected using a new zip lock plastic bag, while the salt and oil samples were collected in their original container sealed; one cup of each oil in a new bottle and one cup of salt in a container and labeled. All samples were coded as WF1, WF2, WF3, WF4, and WF5 for wheat flours; ES1, ES2, ES3, ES4, and ES5 for edible salts; and EO1, EO2, EO3, EO4, and EO5 for edible oils, respectively and transported to the laboratory of the FSQA. The wheat flour samples were collected after

visiting 3 different bread bakeries to ensure that they are the most commonly used wheat flour for bread making in The Gambia.

Sample Preparation and Treatment

No further treatment was carried out on the samples; they were tested as obtained from the market. All information on the sample labels was manually entered on the FSQA form before being registered for analysis. Samples were assigned laboratory numbers and labels before storage in the sample store cupboard for analysis. The reagent vials and measuring unit were stored at room temperature (20 – 30 °C) prior to analysis. Devices batteries were charged and samples were thoroughly mixed before analysis. All measurement devices were kept on a flat surface. iCheck Chroma 3 and iCheck Iron were turned on and each device standard was inserted into the measurement chamber for device control and validation and then set on measurement mode.

Determination of Vitamin A in Edible Oil

The determination of vitamin A was according to the method of the Food Safety and Quality Authority of The Gambia (FSQA, 2018 a). A standard was inserted into the measurement chamber for device control and then set on measurement mode, while the oil sample was poured into a petri dish and stirred thoroughly. At least 0.3 mL of oil was drawn using a new syringe included as part of the portable device test kit, and bubbles were removed. Holding the syringe pointed up, the volume was adjusted to exactly 0.1 mL and injected slowly through the red rubber septum into the reagent vial along the glass side. The vial glass was cleaned and inverted once, then placed immediately into the measuring chamber of the measuring unit. The device program algorithm converts the absorption units of the color reaction of the measurements into results of vitamin A in mg RE/kg and IU/g. The same procedure was done for all the oil samples each in 3 reagent vials and values are recorded as vials 1, 2, and 3 (FSQA iCheck Chroma 3 Manual, 2018).

$$\text{Average} = \frac{\text{Vial 1} + \text{Vial 2} + \text{Vial 3}}{3} \quad (1)$$

$$\text{Total Vitamin A in the sample (IU/g)} = \text{Average (mgRE/kg)} \times 3.33 \quad (2)$$

Determination of Iron in Wheat Flour

Exactly 18 mL of concentrated HCl (36% v/v) solution was prepared in a 1000 mL volumetric flask. The scale balance provided with the iCheck case was calibrated using the weight provided with the iCheck case. The wheat flour sample of 10 g was weighed on a paper dish and recorded. 100 mL of the diluted HCl was poured in a beaker and 10 g of flour was added, sample was mixed until homogenous. The mixed sample solution in the beaker was drawn using a 1 mL syringe in the test kit box taken up to 0.4 mL, holding the syringe pointed up to remove bubbles. Then the 0.4 mL of homogenized sample was injected into the new iCheck iron-activated reagent vial and shaken vigorously for 10 seconds. The vial was incubated for 1 h at 20 to 30 °C and shaken every 15 min. The vial was centrifuged using a hand centrifuge for 2 to 3 minutes. iCheck Iron standard was inserted in the measurement chamber for device control and set on sample mode. The vial was cleaned and quickly inserted into the iCheck measurement chamber for measurement; vial was turned from time to time as indicated on the display. The same procedure was repeated for each wheat flour sample in 3 reagent vials and mean values were recorded as vials 1, 2, and 3 (FSQA, 2018 b). The result was expressed in mg/L.

$$\text{Average} = \frac{\text{Vial 1} + \text{Vial 2} + \text{Vial 3}}{3} \quad (3)$$

$$\text{Dilution Factor (DF)} = \frac{\text{Total diluted sample volume}}{\text{Weight of Sample}} \quad (4)$$

$$\text{Amount of Iron in the sample (mg/kg)} = \text{Dilution Factor} \times \text{Average} \quad (5)$$

Determination of Iodine in Edible Salt

Samples were analyzed using the spot testing kits (MBI KITS International) provided at the Food Safety and Quality Authority of The Gambia according to the FSQA Procedure (2018 c). It was used to determine the level of iodine content in salt. The small cup in the kit was filled and levelled up with salt. Two drops of test solution from a white ampoule were added to the surface of the salt by piercing it with a pin. The iodine content in the salt was determined by comparing the color change on the salt with the color chart. The values 0 ppm, 7 ppm, 15 ppm, and above 30 ppm with the corresponding color chart in the test kit were used to compare with the salt color to determine the level of iodine in the sample salt. If no color appears (after 1 min), on a fresh salt sample was added 5 drops of the recheck solution in the red ampoule then followed by 2 drops of test solution on the same spot. Then, a comparison was done with the color chart indicators for salt iodine content.

RESULTS

The Levels of Iron in wheat flour

Results of quantitative analysis of iron in selected wheat flour samples in the Gambia using iCheck Iron are shown in Figure 1.

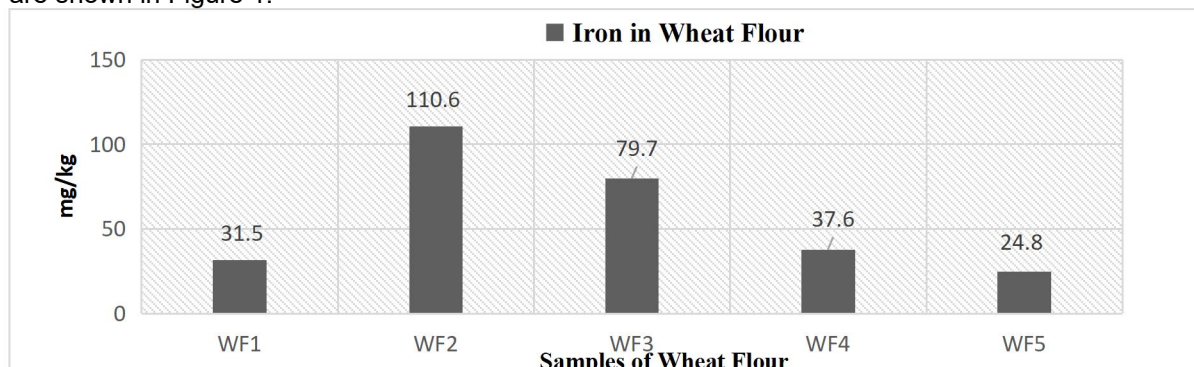


Figure 1: Levels of Iron in selected wheat flour in the Gambia

The Levels of Vitamin A in edible oil

Figure 2 shows the results of vitamin A levels in selected edible oils using iCheck Chroma 3.

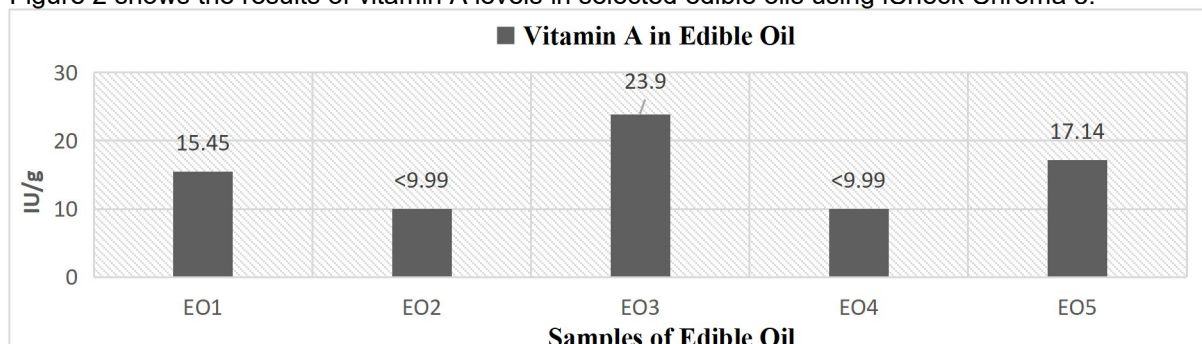


Figure 2: Levels of vitamin A in selected edible oils in The Gambia

Iodine Content in edible salts

The concentrations of nutritional iodine in the five different salt samples in The Gambia are shown in Figure 3.

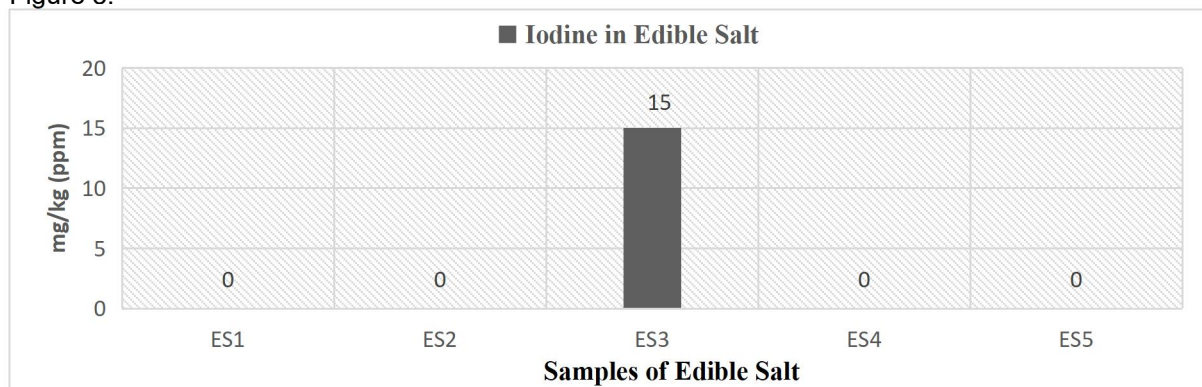


Figure 3: Concentrations of iodine in selected edible salts in The Gambia

DISCUSSION

The Levels of Iron in wheat flour

From the results (Figure 1), iron content ranged from 110.6 mg/kg (sample WF2) to 24.8 mg/kg (sample WF5). The fortification tolerance standard of iron in The Gambia is 55 – 65 mg/kg (for Fe fumarate), 36 – 44 mg/kg for sodium iron EDTA (NaFeEDTA) and 54 – 66 mg/kg (for Fe Sulphate) (TGSB, 2018a). Both samples WF2 and WF3 met the minimum standard for flour fortification in The Gambia. Iron contents in

the literature have been reported in the ranges of 2.51 – 9.86 mg/100g in wheat samples (Panghal *et al.*, 2019). The iron fortification levels in these flours are higher than as reported by Mohamadi *et al.* (2023) for the main breads made in Iran from wheat flour that ranged from 32.81 ± 3.98 ppm to 14.02 ± 4.99 ppm; and fell below the level (40 – 85 ppm) recommended by the Iranian Ministry of Health and Medicine as the final content of iron in iron-fortified flour; while the iron-fortified flour premix consists of 30 ppm ferrous sulphate and 1.5 ppm folic acid (Sadighi, 2008). The variations indicate the need for consistent fortification strategies to ensure a reliable source of this vital nutrient. Findings are consistent with previous studies that have reported fluctuations in iron content in wheat flour due to fortification strategies, the wheat variety, country of production, environmental factors, processing methods, and agricultural practice on the nutrient content in cereal foods (Gyori, 2017; Smith and Myers, 2018).

The Levels of Vitamin A in edible oil

The required vitamin A in fortified edible oil or fat according to The Gambia standard is minimum 20mg/kg and maximum 40 mg/kg (TGSB, 2018b). The analysis of vitamin A in edible oil also shows the diversity in nutrient content. Among the edible oils, sample EO3 had the highest vitamin A content (23.9 IU/g) and lowest in sample EO2 and sample EO4 (below 9.99 IU/g).

Vitamin A content of 25 samples of edible oil of five types (soybean oil, sunflower oil, rice bran oil, mustard oil, and palm oil, each from 5 different brands) collected from a local city market from Dhaka, Bangladesh using a high-performance liquid chromatograph showed a range of 1.67 to 2.85 (for soy bean oil), 1.34 to 7.23 (for rice bran), and 1.46 to 10.57 ppm (for palm oil). Bangladesh Standards and Testing Institution set the standard for fortified edible sunflower oil because the sunflower oils tested were imported from developed countries where vitamin A deficiency is not a significant problem; vitamin A was not found in any of the sunflower oils. Vitamin A was not found in any mustard oil tested because mustard oil was not included in the vitamin A fortification program due to some technological difficulties. Although all soybean oils, rice bran oils, and only 60% of the palm oil tested contained vitamin A, their levels were well below normal (15-30 ppm). According to the National Edible Oil Fortification Law 2013, vitamin A should be fortified to the desired level in all edible oil in Bangladesh in order to reduce vitamin A deficiency in the mass population of Bangladesh (Lisa *et al.*, 2018). A study by Jungjohann *et al.* (2017) on market evaluation of vitamin A oil/ghee fortification in Pakistan concluded that 2/3rd of the oil/ghee does not follow the fortification requirements in which one-third is not fortified.

The results of the study (Rafil *et al.*, 2021) that evaluated the various cooking oils available in the markets of Lahore in Pakistan for their vitamin A content, revealed that among the 14 cooking oil samples, although 70 % of the edible oil samples were fortified with vitamin A and D, only 28 % of them met the nationally prescribed standards. While 30% of samples were not fortified with vitamin A. In Pakistan, the PSQCA recommends the addition of Vitamin A in cooking oils in the range of 29700 – 36300 IU/ kg. But practically no fortification of this vitamin is in practice markedly because many factors may affect the amount of these vitamins in the oils. Improper processing, no certified labs, untrained employees all can lead to deterioration of vitamin A which are sensitive to oxidation. Moreover, many companies do not check the quality of the vitamins being added in the oils which causes them to break up hence not reaching the prescribed level of fortification.

From the report of Jungjohann *et al.* (2021), out of 66 packaged brands of edible oil analyzed for vitamin A content, 39% were not fortified, 42% were fortified above the minimum standard (≥ 15 ppm RE) with a mean of 23.2 ppm Retinol Equivalent above all brands and 18% were below the enriched minimum standard (<15 ppm Retinol Equivalent) with a mean of 8.1 ppm Retinol Equivalent. These variations in Vitamin A content may be due to many factors that involve the handling and packaging of the fortified edible oils. Fat-soluble vitamins are liable to oxidation so proper processing, handling, and packaging are very important to prevent the oxidation of these vitamins in oils (Marc-Pignitter *et al.*, 2016). Similar studies have emphasized the influence of processing on the retention and stability of vitamin A in edible oils (Katragadda *et al.*, 2010). Vitamin A in vegetable oils does not have good storage stability if not well stored away from high temperature and air (Laillou *et al.*, 2012). People who add vitamins to the oils usually have no idea about the prescribed limits of these vitamins. They may add vitamins but the quantity was not checked and validated by the higher authorities. Substandard products are also fortified but improper processing can lead to the deterioration of vitamin A. Certified labs and eligible employees also play an essential role in maintaining the quality and quantity of these vitamins in the oils. Some companies also don't add vitamins to minimize the cost for their benefits, while the type of packaging of oils can also result to the loss of the vitamins in the oils due to oxidation (Pignitter and Somoza, 2017). Begum *et al.* (2024), investigated different quality parameters of three types (soybean, sunflower, and palm) of extensively consumed fortified edible oils in Bangladesh. Analysis showed that the vitamin A fortification level of

most of the oil brands (73 %) did not comply with the Bangladesh Standard and Testing Institution (BSTI) standards (1.5–3.0 mg/100 g). vitamin A contents of soybean, sunflower, and palm oil brands ranged from 0.13 to 2.06, 0.92–1.34, and 0.99–1.31 mg/100 g, respectively. Inter-brand values of vitamin A were also significantly different ($p < 0.05$). They concluded that, although the vitamin A status of most of the fortified edible oil brands was poor, the key quality indicators (except iodine value) of most of the oils were within the Codex and BSTI standard limits and were acceptable for human consumption.

The Content of Iodine in edible salts

Iodine is a trace element necessary for human health. It plays an important role in mental and physiological development. Based on an ideal level of table salt consumption (≤ 5 g per day), WHO, UNICEF, and the International Council for the Control of Iodine Deficiency Disorders (ICCIDD) recommend that 20 to 40 mg of iodine per kilogram be added to table salt (WHO, 2007). The results (Figure 3) indicated that only sample ES3 has iodine (15 ppm), among all the samples within the detection limits of the MBI measuring kit used; the other salt samples (ES1, ES2, ES4, and ES5) had negligible iodine content (0 ppm). This MBI kit shows only 0 ppm, 7 ppm, 15 ppm, and above 30 ppm. The allowed levels of nutritional iodine in salt according to The Gambia standards are 40 – 55 ppm at the production point, 20 – 55 ppm at the market level, and 15 – 55 ppm at the household level (TGSB, 2018c). Only sample ES3 (at 15 ppm) has met the TGSB nutritional iodine requirement for household salt, but below the recommended daily intake of 40 ppm per day for most adults. Smaller children require less iodine, while pregnant and nursing mothers need more (Etonihu *et al.*, 2009; Akram *et al.*, 2020). While samples ES1, ES2, and ES3 were bought in sealed containers, sample ES5 was in an open container as sold in the market. Kitwa *et al.* (2012) reported that 52 of 375 samples of table salt (13.9%) did not contain iodine; these samples came primarily from markets and stores in semi-urban and rural zones in the DR Congo, as only 44.8% of salt samples had adequate iodine content. When compared with the salt samples from Keana and Awe in Nigeria which iodine contents ranged from 246.70 to 37.10 ppm (for Keana salt samples) and from 102.70 to 69.90 ppm (for Awe samples), these Gambia salt samples are low in dietary iodine (Etonihu *et al.*, 2009). Iodized salt is a functional internal quality control program that works in tandem with the iodization process, which seems to be generally less effective in coarse salt than in fine salt due to differences in particle size, impurities, or iodination methods (Jooste *et al.*, 2003). It is essential to know the iodine content of iodized salt both during manufacturing and at retail to minimize the consequences of iodine deficiency, which requires both qualitative and quantitative iodine analysis. An accurate estimation of the iodine losses that take place between the time of iodization and the time of consumption is needed to determine the adequate amount of iodization. Packaging and exposure to oxidation are limiting factors that can affect the iodine content. The packaging of table salt in small amounts (5 to 500 g) in polyethylene plastic boxes or in glass jars, which are more waterproof than the usual bags, prevents the loss of iodine content during transport and vending, as well as during household storage. It has been shown that glass conserves the iodization level of salt better than polyethylene plastic, which conserves iodine better than cellulose paper (Diosady *et al.*, 1998). Another possibility is that the markets and stores are fraudulently selling craft, non-iodized salt or industrial salt that has been diverted for human consumption.

CONCLUSION

The study assesses the content of essential nutrients including vitamin A in edible oils, iron in wheat flour and iodine in edible salt commonly consumed in The Gambia. Samples were collected from the major markets in The Gambia and in accordance with the Food Safety and Quality Authority (FSQA) of The Gambia sampling protocols standard. The results of the analysis for iron content in wheat flour revealed that only samples WF2 and WF3 met the regulatory Gambia standard for iron fortification. The evaluation of vitamin A content in cooking oils ranged from < 9.99 to 23.9 IU/g, and showed that only sample EO3 was within The Gambia standard for vitamin A fortification. From the edible salt analysis, nutritional iodine was present in only sample ES3 with iodine content of 15 ppm which is within the acceptable regulatory Gambia standard for iodine for household use. Fortification, regular quality control, and surveillance by the regulatory authority of iron in wheat flour, vitamin A in cooking oils, and dietary iodine in edible salt is quite necessary in The Gambia so as to ensure the recommended levels of these nutrients in foods.

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THE INFLUENCE OF DIFFERENT GROWING MEDIA ON THE MINERAL PROPERTIES OF BLUEBERRY FRUITS

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ABSTRACT

Blueberries are largely grown in media because of the plant's requirement for acidic soils, which is often not attainable in the soil. However, using different growing media influences the chemical composition of blueberries, which essentially influences the overall nutritional content of blueberries as they are mainly consumed fresh. The aim of the study was to evaluate the influence of different growing media combinations on the nutritional content of blueberries. Treatment was comprised of media combination coir, mushroom compost, zeolite, and peatmoss. Berries were hand-harvested during the 2023/2024 harvesting season, and 2.0g per treatment was analyzed for selected macro-micronutrients. Data was captured and examined using SPSS 29.0, and means separation was done using Fisher's LSD test. The media combination significantly influenced primary macronutrients. Treatment 3 obtained the highest P and K percentage; N was highest on T5. The combination of coir, zeolite, and peat moss had the highest Cu content and was significantly different from all treatments. The media significantly influenced micronutrients; notably, T5 had the highest Fe content, T7 had the highest Zn content. An increase in macronutrients was observed for treatments 3, 5, and 6; however, these findings need further investigation.

Keywords: blueberry, growing media, macro and micronutrients.

INTRODUCTION

Blueberry (*Vaccinium corymbosum*) belongs to the Rosaceae family, *Fragaria* genus, with the wild and

cultivated species of great agronomical reputation found globally, in different climatic areas, and from sea level to high altitude (Bhatt & Debnath, 2021). All the cultivated varieties are derived from *Fragaria X ananassa*, which originated in Europe in 1700 after hybridizing two natural hybrid species from America, *Fragaria chilosensis* and *Fragaria virginiana*. There are eleven species of *Fragaria* found in their native habitats in Europe and North and South America under a Mediterranean climate (Giordano *et al.*, 2020). *Vaccinium* species are known for their medicinal properties (Martău *et al.*, 2023). Blueberries are predominantly cultivated in the northern hemisphere's continents, such as North America, Asia, Europe, and some other countries of the southern hemisphere, such as Argentina, Uruguay, South Africa, New Zealand, Chile, and Australia (Routray & Orsat, 2011). In South Africa, the commonly planted varieties are Rabbiteye, Northern Highbush, and Southern Highbush (Louw, 2018).

Mineral elements that are naturally available in soils or supplemented are critical in the growth and development of plants in general, which essentially influence yield and quality (Kuang *et al.*, 2021). The chemical composition of blueberry fruit is vital as it contains the important macro and micro minerals critical for human consumption and diet (Dunford, 2022; Karlsons *et al.*, 2018). However, this is strongly influenced by substrate composition, variety, cultivation practices, and the climatic conditions under which the blueberry plants are cultivated (Mazzoni *et al.*, 2020; Ochmian & Kozos, 2014). The physical and chemical characteristics of the substrate used on blueberries are of great importance as they will determine the overall growth (Ortiz-Delvasto *et al.*, 2023). The use of different substrate composition ratios (50% coir + 25% peat moss + 25% zeolite) on potted blueberry

plants are effective as each substrate used contributes useful attributes (properties) for plant growth (Kingston *et al.*, 2020). The following minerals, such as K, Ca, P, Mg, Fe, Mn, Cu, Zn, Na, Al, Si, Co, & Cr, were identified as the main elements contributing to human nutrition (Dekazos, 1978). This is in agreement with the findings of the World Health Organization (WHO, 2003), which indicates that the consumption of fresh fruits and vegetables greater than 400g per capita per day contributes to human nutrition. Other important elements in human nutrition include vitamins, fibers, fatty acids, and folate (Seeram, 2008). According to (Ortiz-Delvasto *et al.*, 2023), the substrate types used when cultivating blueberries greatly influence the concentration and uptake of various minerals. Using plant-growing media such as peat moss and coir improves the uptake of nutrients such as nitrogen, phosphorus, magnesium, and sulfur.

This investigation will evaluate the effect of different growing media on fruit quality, which will contribute to improving blueberry production in South Africa. The objective of this study was to examine the influence of the four growing media combinations used as a substrate on the mineral content (12 elements) of fresh blueberry fruits.

MATERIALS AND METHODS

A pot experiment was conducted in a tunnel at the Cape Peninsula University of Technology, Agricultural Hub 2023/2024. The plants were cultivated under a cooling tunnel covered with a polythene roof with a 40% white shade net and a cooling fan that is automated to run as temperatures increase to 25°C inside the tunnel (Smrke *et al.*, 2021). Blueberry cultivar Legacy was used in the experiment; upon ripening, fresh berries were hand-harvested using the selective picking method (Dekazos, 1978). A combination of seven treatments (substrate), as outlined by (Mfeka *et al.*, 2023), was used in 45L on elevated stands. The experiment design was laid out in a randomized complete block design with five replicates. The growing media used in the study is per Table 1 below.

Table 1: Growing media composition

Treatments	Media composition
1	100% coir (control)
2	80% coir + 20% zeolite
3	60% coir + 40% mushroom compost
4	60% coir + 40% peat moss
5	40% coir + 20% zeolite + 40% mushroom compost
6	40% coir + 20% zeolite + 40% peat moss
7	40% coir + 30% mushroom compost + 30% peat moss

The growing media combinations were sent to Bem Lab (<https://www.bemlab.co.za/>) and analyzed before transplanting. Table 2 below provides details of the media combination analysis.

Table 2: Media combination analysis

Growing media	pH (KCl)	Stone Volume	%		mg/kg							
			C	Na	N	P	K	Cu	Zn	Mn	B	Fe
T1	3.8	0.93	19.74	2.13	53.7	5.4	159	0.33	3	4.4	0.32	43.1
T2	4.2	1.52	11.81	14.86	73	2.6	553	0.33	1	4.9	0.37	24.8
T3	6.4	1.93	20.78	6.44	6.4	154	225	1.6	23.4	22.7	0.69	83.8
T4	3.3	0.93	21.88	1.81	132	6	148	0.33	2.8	2.9	0.32	50.1
T5	6.6	0.93	11.59	9.66	11.2	118	484	1.2	19.4	19	0.38	62.6
T6	4.7	0.93	18.44	30.23	87.4	6.2	196	0.33	2.5	5.1	0.62	32.6
T7	6.1	0.93	22.38	4.35	30.1	109	765	1.8	5.8	60.7	0.89	19.3

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 40% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30 mushroom compost + 30% peat moss

For mineral analysis, fresh samples were harvested and kept frozen at - 20°C (Zhang *et al.*, 2014) up until analysis. Fruit mineral analysis was done at the Department of Agriculture, a commercial laboratory in the Western Cape Province, to determine total N (3g per sample) using the Kjeldahl's method, P, K, Ca, Mg, Na, Mn, Fe, B, Al, and Zn (2g per sample) using the standard plasma emission spectrometer. Irrigation scheduling and application were implemented per Mfeka *et al.*, (2023) methodology. The fertilization was applied as follows: 9 g N per pot (ammonium sulfate) will be applied in the first year (2022/2023), while 12 g N per pot (ammonium sulfate) will be applied in the second (2023/2024) (Wilber & Williamson, 2008), other minerals were applied uniformly. Cultivation practices such as manual weed control, pH, and EC monitoring were done regularly.

Manual data capture was done in the tunnel and thereafter captured on a Microsoft Excel cloud account for later statistical analysis. All data was subjected to IBM SPSS version 29.0. A comparison of means was carried out on the 12 elements, and a one-way analysis of variance (ANOVA) and Duncan's multiple comparisons were performed at a 95% confidence level. Correlation analysis was done to evaluate the correlation between the observed mineral elements.

RESULTS

Twelve mineral elements of the blueberry cultivar Legacy were investigated, and detailed results are presented below (Table 3). Fruit cultivated in media combination containing either peat moss or mushroom compost had the highest content of N. It was significantly different ($p<0.05$) from berries cultivated in media containing coir and zeolite. Treatment containing 60% coir and 40% mushroom compost had the highest P and K content. The highest Na concentration of 676.6 mg kg^{-1} was attained on berries cultivated on the growing media with 40% coir, 20% zeolite, and 40% peat moss. There was no significant effect on minerals Ca and Mg across the different media used in the study.

Table 3. Influence of growing media of the macro minerals of blueberry fruits

Growing media	%					mg/kg
	N	P	K	Ca	Mg	Na
T1	0.55±0.41 ^b	0.07±0.002 ^c	0.47±0.002 ^{abc}	0.14±0.090 ^a	0.38±0.002 ^a	38.8±1.35 ^c
T2	0.82±0.32 ^b	0.1±0.002 ^{ab}	0.47±0.008 ^{abc}	0.38±0.002 ^a	0.38±0.002 ^a	345±26.47 ^b
T3	1.47±0.00 ^a	0.12±0.002 ^a	0.53±0.003 ^a	0.82±0.003 ^a	0.38±0.002 ^a	70±5.08 ^c
T4	1.6±0.69 ^a	0.09±0.000 ^b	0.48±0.186 ^{abc}	0.5±0.000 ^a	0.38±0.002 ^a	30±1.00 ^c
T5	1.71±0.29 ^a	0.1±0.017 ^{ab}	0.43±0.618 ^{bc}	0.21±0.109 ^a	0.38±0.002 ^a	95.4±22.06 ^c

T6	1.27±0.18 ^a	0.1±0.007 ^{ab}	0.41±0.037 ^c	0.48±0.002 ^a	0.38±0.002 ^a	676.6±42.70 ^a
T7	1.41±0.33 ^a	0.12±0.008 ^a	0.52±0.031 ^{ab}	0.78±0.002 ^a	0.42±0.003 ^a	54.8±6.62 ^c
LSD	0.27	0.02	0.02	NS	NS	8.8

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 40% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30 mushroom compost + 30% peat moss

The different growing media had a significant influence across all microminerals observed (Table 4). The highest concentration of Fe with 37.79 mg kg⁻¹ was obtained on berries cultivated on media containing 40% coir, 20% zeolite, and 40% mushroom compost. A combination of coir, mushroom compost, and peat moss had the highest Zn concentration of 6.27 mg kg⁻¹. This study showed a significantly high Mn concentration (42.09 mg kg⁻¹) in berries cultivated on media with 40% coir, 20% zeolite, and 40% peat moss. In comparison, the lowest concentration of 8.13 mg kg⁻¹ was obtained on media combination with 60% coir and 40% mushroom compost. The fruit B concentration varied from 4.73 to 6.32 mg kg⁻¹ and the highest concentration was obtained in combination with 60% coir plus 40% peat moss. Aluminium concentration varied for treatments; however, the lowest concentration was obtained on media with 60% coir plus 40% peat moss. Berry fruits cultivated on a combination of coir, zeolite, and mushroom compost had the highest Cu concentration.

Table 4. Influence of growing media of the micro minerals of blueberry fruits

Growing media	mg/kg					
	Fe	Zn	Mn	B	Al	Cu
T1	20.12±0.34 ^{bc}	4.83±0.20 ^{ab}	27.78±2.83 ^b	6.21±0.234 ^a	7.95±0.85 ^a	0.69±0.008 ^{abc}
T2	19.1±0.59 ^{bc}	5.29±0.24 ^{ab}	26±2.50 ^b	4.73±0.212 ^b	7.93±0.26 ^a	1.2±0.355 ^{ab}
T3	16.24±1.26 ^c	5.4±0.32 ^{ab}	8.13±0.35 ^c	5.02±0.171 ^b	8.54±0.95 ^a	0.56±0.323 ^{cd}
T4	23.92±1.91 ^b	4.43±0.12 ^b	20.51±2.54 ^c	6.32±0.091 ^a	5.14±0.34 ^b	0.58±0.321 ^{cd}
T5	37.79±5.40 ^a	5.92±0.78 ^a	17.92±1.18 ^{cd}	4.85±0.008 ^b	7.44±0.47 ^a	1.31±0.281 ^a
T6	16.53±1.62 ^{bc}	5.63±0.68 ^{ab}	42.09±0.96 ^a	6.14±0.227 ^a	8.96±0.71 ^a	0.89±1.492 ^{bc}
T7	17.5±1.29 ^{bc}	6.27±0.28 ^a	14.12±1.08 ^d	6.01±0.268 ^a	7.44±0.49 ^a	0.46±0.465 ^d
LSD	0.29	0.4	5.89	0.12	2.3	0.1

T1- 100% coir, T2- 80% coir + 20% zeolite, T3- 60% coir +40% mushroom compost, T4- 60% coir + 40% peat moss, T5- 40% coir + 20% zeolite + 40% mushroom compost, T6- 40% coir + 20% zeolite + 40% peat moss, T7- 40% coir + 30 mushroom compost + 30% peat moss

The correlation analysis is presented in Table 5 below. The results show that the correlation varied from positive to negative and weak. A strong positive correlation was observed between the following elements: P & N, K & P, N & Zn, P & Zn, Mg & Zn, Na & Mn, and Cu & Zn (.752, .547, .590, .775, .528, .728, .533 respectively) at p<0.01. P and Zn had the highest significant correlation of .775 across all minerals investigated. Several minerals in the study had a moderate to low negative correlation, except for the correlation between B & Mn and Al & Mn.

Table 5. Correlation analysis of the twelve mineral elements in blueberry 'Legacy'

Elements	N	P	K	Ca	Mg	Na	Fe	Cu	Zn	Mn	B
P (%)	.752**										
K (%)	.403*	.547**									
Ca (%)	.117	0.087	-.265								
Mg (%)	.289	.452**	.364*	.141							
Na (mg/kg)	-.078	.125	-.294	-.185	-.025						
Fe (mg/kg)	.112	-.295	-.295	.237	-.084	-.282					
Cu (mg/kg)	.313	.341*	.022	.241	.104	.379*	0.145				
Zn (mg/kg)	.590**	.775**	.427*	.187	.528**	.203	-.171	.533**			
Mn (mg/kg)	-.302	-.312	-.373*	-.110	.060	.728**	-.137	.253	-.034		
B (mg/kg)	-.103	-.279	.003	-.122	.314	-.042	-.173	-.517**	-.176	.430**	
Al (mg/kg)	-.296	-.009	-.176	.049	-.134	.315	-.123	.032	.156	.160	-.128

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level

DISCUSSION

Data from the present study indicated that the twelve mineral elements were influenced by the different growing media used. The highest concentration of nitrogen was obtained in treatment with coir, zeolite, and mushroom compost; this can be related to the physical and chemical properties of the three media and nitrogen uptake efficiency (Noble *et al.*, 2024; Tuckeldoe *et al.*, 2023). However, it must be noted that zeolite does not directly contribute to the concentration of nitrogen or any other element, as its main function is to retain water and act as a carrier of the minerals in mineral uptake (Jarosz *et al.*, 2022).

Additionally, nitrogen availability in *Vaccinium* species enhances renewal, overall production, and flower bud initiation and development for the following season, especially on deciduous blueberry types (Sandler & DeMoranville, 2008). Phosphorus content was observed on the berries. However, the quantities were lower than all macro-minerals investigated. This is because phosphorus is an element that is not easily taken up by the plant, even if it is available in the substrate. These findings align with those of Kingston *et al.* (2020), where two blueberry cultivars were evaluated, and phosphorus had the lowest concentration across all measured macro elements. The highest potassium percentage was obtained in the treatment containing coir and mushroom compost. Potassium is regarded as one of the macronutrients critical for blueberry plants as it facilitates the movement of calcium and magnesium in the xylem vessel (Moraes *et al.*, 2021). A significantly higher sodium concentration was obtained from berries grown in 40% coir, 20% zeolite, and 40% peat moss; this can be strongly associated with the high sodium available in the growing media before planting (Table 1). The sodium percentage of 30.23 was obtained.

The growing media combination containing 40% coir, 20% zeolite, and 40% mushroom compost, generally, half of the microminerals assessed iron, zinc, and copper, respectively. This trend was also observed in nitrogen concentration on the macro minerals, which relates to the physical and chemical properties of these growing substrates. Treatment 6, containing coir, zeolite, and peat moss, had the highest manganese concentration across all treatments. These findings agree with those of (Ochmian *et al.*, 2009) mineral composition of blueberry production.

Results from the Pearson correlation analysis showed a strong positive correlation between P and Zn of .775, which indicates an increase of each of these elements and the other increases. Research conducted on field crops indicates that increased phosphorus increases the availability and uptake of zinc in plants. These elements are most deficient in most substrates (Sánchez-Rodríguez *et al.*, 2021; Zhu *et al.*, 2001).

The authors further elaborate on the benefits of these elements in the overall growth and increased yield of various crops. A strong linear relationship between P and N was observed at a 0.01 significant level, indicating an influence of each of these elements. According to Peterson *et al.*, (1988), the nitrogen source also influences the uptake of blueberry plants, as the correlation between phosphorus and NH_4 tends to increase the availability of phosphorus compared to NO_3 .

CONCLUSION

The increase in fresh blueberry consumption worldwide, mainly due to health benefits, has necessitated the demand for improved production to supply the demand. However, intensive research is necessary as the production of blueberries is affected by various factors, such as climatic conditions and management practices, to maximize fruit quality and yield. Varying results were obtained in this study; however, a treatment combination with 40% coir, 20% zeolite, and 40% mushroom compost improved most of the microminerals investigated. The use of the growing media in combination has the potential to improve the berry fruit's nutritional content.

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Data Availability Statement:

Data is stored on a Data Management Plan Tool, a platform the institution (CPUT) provides for data storage, preservation, and sharing. Data included in this paper will be made available online upon request.

Ethical Clearance:

Ethical clearance for this research study was granted by the CPUT Faculty Research Ethics Committee.

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ASSESSMENT OF PRESERVATION TECHNIQUES AMONG VEGETABLE MARKETERS IN IBADAN METROPOLIS OF OYO STATE, NIGERIA

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ABSTRACT

Vegetables are a major source of income and overcoming micronutrient deficiencies. The study objectives were to identify the major vegetables offered for sale, determine the preservation techniques, and assess the determinants of vegetable loss among marketers in Ibadan Metropolis of Oyo State, Nigeria. A multistage sampling technique was used to select a total of 125 vegetable marketers in five markets across five local government areas in the study area. The data for the study were analysed using descriptive statistics, and multiple regression analysis. Test of significance was carried out at 5% level. The study revealed that common vegetables among the marketers included tomato (47.2%), scotch bonnet pepper (47.2%), and jute leaf (39.2%). The preservation techniques employed by the marketers included the use of baskets and jute sacks. With an average postharvest loss of 5.82%, regression analysis revealed that education level, marketing experience, weather conditions, and access to market stalls accounted for 47.0% of postharvest losses among vegetable marketers. The study concluded that the sellers had a low adoption rate of improved storage and preservation techniques. It is recommended that the marketers be supported by the policy makers and relevant stakeholders to have better access to improved technologies for the storage and preservation of vegetables.

Keywords: Preservation technology, vegetable marketers, multiple regression, postharvest losses.

INTRODUCTION

Background to the study

Fresh fruits and vegetables are very important sources of vitamins that are essential for a healthy human diet (Chidi, 2012). In sub-Saharan Africa, vegetables are a significant component of households' diet and constitute the best resources for overcoming micronutrient deficiencies (Oluoch *et al.*, 2009). Vegetables are a natural source of food that can supply the majority of nutrients especially minerals, vitamins, and crude fibre required by the body. They are rich in and are comparatively cheaper sources of vitamins and minerals (Thamburaj & Narenda, 2001). To achieve nutritional security, households must consume enough vegetables (Udoh & Etim, 2006) which according to Chan (2025) is an important part of a healthy diet. Hence, the need for vegetables in household diet at all times in adequate quantities and quality. They must also be safe for consumption at prices that must be within the range of the consumers' budget. Vegetable production constitutes an important part of Nigeria's economy. Vegetables comprise all categories of plants whose leaves, fruits or roots are acceptable and used as vegetables by urban and rural communities through custom, habit and tradition (FAO 1998, Ambrose-Oji, 2009). Some common indigenous vegetables in Nigeria include *Ugu* (*Telfairia occidentalis*), water leaf (*Talinum triangulare*), bitter leaf (*Vernonia amygdalina*), Green (*Amaranthus caudatus*), *ukazi* (*Gnetum africanum*) cucumber, garden egg, carrot, Cabbage, and onion (Firdaus & Gunawan, 2012). According to Thamburaj and Narenda (2001), the production of vegetables contribute about 25% of the total agricultural exports of the country.

Vegetables provide smallholder farmers with much higher income and more jobs per hectare than staple crops as well as serve as foreign exchange earning to their growing countries (AVRDC 2006). The quality and nutritional value of fresh produce is affected by post-harvest handling and storage conditions (Sabani *et al*, 2006). As such, vegetables are usually harvested when the plant is fresh and high in moisture. This high vegetable moisture makes their handling, transportation and marketing a peculiar problem particularly in the tropics as they must be preserved using appropriate methods that will prevent the growth of bacteria, fungi or any other micro-organisms or retard the oxidation of fats so as to prevent them from spoilage and risk of foodborne diseases (LaBorde 2022).

Vegetable marketing is a complex phenomenon due to its perishable nature, seasonality and bulkiness Adenuga *et al.* (2013). Even though heavy losses are encountered in crop production, it is significant to mention that losses in fruits and vegetables between rural production and town consumption in the tropics are as high as 50% (Oyeniran, 1988). According to Verma and Singh (2004), the overall losses in vegetables can be up to 25 percent of total production.

Vegetables are perishable crops, proper and scientific storage, packaging, transport and handling technologies are not adequate and hence, considerable amount of produce is wasted. The vegetable crops because of their moisture content are inherently more liable for deterioration in quality and quantity especially under tropical conditions. Moreover, they are biologically active and carry out transpiration, respiration, ripening and other biochemical activities, which contribute for deterioration in quality of the produce. The extremely perishable nature of vegetables results in inability on the part of producer to manage supply in the markets. Furthermore, the large distance between the production area and the market, as well as the sub-optimal post-harvest technology and management (including the method of picking/plucking/digging/ harvesting, grading, packing, storing and transporting), a large proportion of vegetables is lost or spoiled at various stages of post-harvest activities. Severe losses occur because of poor transportation facilities, lack of know-how, poor management and improper market facilities or due to careless handling of the produce by farmers, market intermediaries and consumers (Gauraha & Thakur, 2008; Singh *et al.*, 2008).

According to Food and Agriculture Organisation (FAO, 2004), in developing countries postharvest losses of fruits and vegetables are more serious than those in well developed countries. The handling procedures used in technologically advanced countries to reduce post-harvest losses are not fully recognized in less developed countries. According to FAO (2004), storage, packaging, transporting and handling technologies for perishable crops like fruits and vegetables are practically non-existent in developing countries, hence considerable amount of produce are lost. According to Tyler and Gilman (1979), the multiple effect of post-harvest loss include loss in the resources such as labour needed to produce the crop, and the livelihood of the individuals involved in the production process. Post-harvest loss tends to prevent adequate supply of and accessibility to fresh agricultural produce, thereby causing an increase in the price of such produce. Also, the extent of loss that occurs among retailers within the markets due to lack of appropriate storage facilities and the effectiveness of the various methods they employ to reduce the loss is uncertain as there is a dearth of data in this regard.

The assessment of storage methods among vegetables marketers would help in identifying the factors responsible for losses. This in turn would help in developing proper measures required at different stages to prevent/reduces such losses to increases the availability of vegetables for domestic consumption and export purposes. This study is therefore, generally aimed at assessing the storage methods and post-harvest losses among vegetable marketers in Oyo state of Nigeria. Consequently, several of the natives and residents in Oyo states and communities in Nigeria are involved in the vegetables marketing subsector of the nation's economy.

The study, therefore, seeks to provide answer to the following questions;

- i. What are the major vegetables among marketers in the study area?
- ii. What are the various storage methods employed by the vegetable marketers in the study area?
- iii. What are the determinants of vegetable loss among marketers in the study area?

The broad objective of this research is to assess the storage methods and post-harvest losses among vegetable marketers in the study area. Thus, the specific objectives are to:

1. identify the major vegetables offered for sale by vegetable marketers in the study area;
2. determine the various storage methods employed by the vegetable marketers in the study area; and
3. assess the determinants of vegetable loss among marketers in the study area.

MATERIALS AND METHOD

The Study Area

The study was conducted in Ibadan metropolis, the capital of Oyo State, Nigeria. The metropolis is composed of 11 Local government areas, comprising six at the outskirts and five at the centre. The latter are: Ibadan South East, Ibadan North East, Ibadan North West, Ibadan South West, and Ibadan North Local Government Areas. The map of Ibadan metropolis is as presented in Fig. 1.

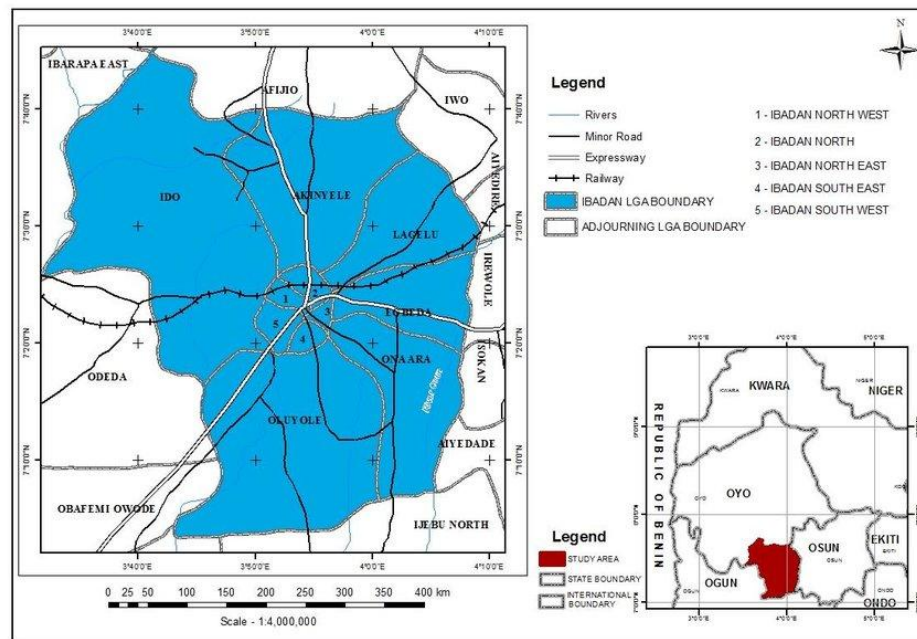


Fig 1: Map of Ibadan Metropolis, Oyo State, Nigeria

Ibadan is located between longitude $7^{\circ}20''$ and $7^{\circ}40''$ East of the Greenwich meridian and between latitude $3^{\circ}55''$ and $4^{\circ}10''$ North of the equator. The city is in the equatorial rain forest belt and has a land area of between 445 and 455km² with an estimated population of 1,991,367 persons according to the 1991 population census. Ibadan metropolis is an important commercial centre and it comprises of people of different cultural and socio-economic backgrounds. It has an annual rainfall of 1,250mm – 1,800mm distributed averagely for nine months with moderate temperatures that ranges between 27°C and 40°C with a relative humidity of about 75% to 90%. It falls within Latitude $3^{\circ}E$ and $5^{\circ}E$ of the Greenwich Meridian. It is the capital city of Oyo State and falls within the rainforest zone of Nigeria, where the occupation of Majority of the rural dwellers are purely agrarian.

Sources of Data

Primary data was used for the study. This was collected through the use of structured questionnaires to be administered to the vegetable marketers. The questionnaire was designed to collect information including the socio-economic characteristics (such as age, sex, household size and years of experience and other information) in order to fulfill the objectives of the study.

Sampling Procedure and Sample Size

Multistage Sampling Method was used to select the required samples for the study. The first stage involved the random selection of five local government areas in Oyo State which have large markets for vegetable marketers. The second stage involved a random selection of one market each from the five local government area. The third stage was a random selection of 25 vegetable marketers from the five markets, giving a total of 125 respondents for the study.

Analytical Techniques

Descriptive Statistics

Descriptive statistical tools were used for objective one and two that is, major vegetables among vegetable marketers and the storage methods respectively. Tools such as means, frequency distribution and percentages were used.

Regression Analysis

Regression analysis was used for objective three; that is to determine the vegetable loss among the marketers this was accomplished with the use of multiple regression model.

The regression model is specified as:

$$Y = f(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, \dots, \mu) \quad (1)$$

Where:

Y = percentage of the vegetable loss (%)

X₁ = Age of vegetable marketers (years)

X₂ = Education levels of vegetable marketers (years)

X₃ = Marketing experience of vegetable marketers (years)

X₄ = Household size of the vegetable marketers (number)

X₅ = Household income of vegetable marketers (R)

X₆ = Transportation cost (R)

X₇ = Perceived weather condition (dummy; 1 for adverse and 0 for otherwise)

X₈ = Unavailability of market stalls (dummy; 1 for inadequate and 0 for otherwise)

μ = Error term (which is assumed to have zero mean and constant variable)

Cob-Douglas functional form was fitted for the study as follows:

Double log function

$$\log Y = a + b_1 \log x_1 + b_2 \log x_2 + b_3 \log x_3 + b_4 \log x_4 + b_5 \log x_5 + b_6 \log x_6 + b_7 \log x_7 + b_8 \log x_8 + \mu \quad (2)$$

Where:

a = Constant

b₁, b₂, b₃, b₄, b₅, b₆, b₇, b₈ = Regression Coefficients

X₁, ..., X₈ = as previously defined

μ = Error term

The test of significance was carried out at 5% level

Likert Scale

The 5-point Likert scale was used to determine the challenges faced by the vegetable marketers major.

The response to various constraints was scored in a way that the response indicating the most severe constraint is given the highest score (5). The responses were measured as follows:

Extremely severe = 5, Severe = 4, Moderately severe = 3, Mildly severe = 2, Not a problem = 1

RESULTS AND DISCUSSION

Socioeconomic Characteristics of the Respondents

The socioeconomic characteristics of the vegetable marketers include age, gender, marital status, educational status, marketing experience, household size and household income.

Details of the socioeconomic characteristics of the vegetable marketer's area as presented in Table 1.

Table 1: Socioeconomic characteristics of vegetable marketers (N= 125)

Socio economic characteristics	Frequency	Percentage	Mean
Age (years)			
30 and below	14	11.2	43.33
31-40	32	25.6	
41-50	42	33.6	
51-60	32	25.6	
Above 60	5	4.0	
Gender			
Male	30	24.0	
Female	95	76.0	
Religion			
Islam	106	84.8	
Christianity	19	15.2	
Marital Status			
Single	26	20.8	
Married	71	56.8	
Divorced	16	12.8	
Widowed	12	9.6	
Educational Status			
No Formal education	30	24.0	8
Primary Education	27	21.6	
Secondary Education	50	40.0	
Tertiary	18	14.4	
Household size (Numbers)			
≥5	7	5.6	11
6-10	46	36.8	
≤10	72	57.6	
Marketing experience			
≥10	41	32.8	17
11-20	22	17.6	
≤20	62	49.6	
Household Income			
≤100,000	71	56.8	
100,001-200000	28	22.4	
200,001-300,000	8	6.4	
300,000 and above	18	14.4	

The majority of the respondents (76%) were females while 24% were males, showing that females are more involved in the marketing of vegetables in the study area. This is consistent with Abdulsalam-Saghir et al. (2006) that marketing of agricultural products are synonymous with women Nigeria. About one-third (33.6%) of the marketers were between 41 and 50 years, while 25.6% comprised each of respondents aged between 31 – 40 and 51 to 60 years. Only 11.2% were below the age of 30. The average age of the marketers in the study area was 43.3 years. This indicates a good supply of an agile workforce in vegetable marketing in the study area.

The marital status results showed that most of the marketers were married (56.8%) while 20.8% were single or divorced. This could have an implication on post-harvest losses in vegetable marketing since married marketers are likely to have access to more family labour especially for harvesting. The results also showed that the majority (40%) of vegetable marketers possessed secondary education; those with

no formal education were 24%, 21.6% had primary education while 14.4% had tertiary education. The vegetable marketers in the study area also spent an average of eight years in school. This statistic showed that most of the farmers had low education. This could be a contributory factor to high post-harvest losses in vegetable marketing because only marketers who had appreciable level of education or training can appreciate and use most of the post-harvest technologies available.

Furthermore, the results of the present study showed that the majority (49.6%) of the farmers had above 21 years of marketing experience while 32.8% had below 10 years' experience in vegetable marketing while 17.6% had experience between 11 and 20 years. The average years of marketing experience is 17 years. This could also have an effect on post-harvest losses in vegetable marketing. The years of experience in vegetable marketing might also be responsible for various methods and knowledge used in the preservation of vegetables among the farmers. The majority (56.8%) of the vegetable marketers earned less than ₦100,000.00. On the other hand, 22.4% of the respondents earned between ₦100,001.00 and ₦200,000.00 while 14.4% of them earned above ₦300,000.00 per annum. The majority (57.6%) of the vegetable marketers had households of more than 11 members while 36.8% had between 6 and 10 household members while 5.6% had less than 5 household members. The respondents also had an average household size of 11.

Major Vegetables among Marketers

This section showed the distribution of respondents according to the major type of vegetables among marketer which include jute leaf, plumed cockscomb, African spinach, fluted pumpkin leaf or green, bitter leaf, tomato, scotch bonnet pepper, cayenne pepper, ball pepper, and okro. This is as presented in Table 2 which showed the distribution of respondents based on the major types of vegetable marketed.

Table 2: Distribution of Respondents based on vegetables marketed

Vegetables	Frequency	Percentage
Jute leaf (<i>Corchorus olitorius</i>)	49	39.2
Plumed cockscomb (<i>Celosia argentea</i>)	48	38.4
African spinach (<i>Amaranthus cruentus</i>)	46	36.8
Fluted pumpkin leaf (<i>Telfairia occidentalis</i>)	19	15.2
Bitter leaf (<i>Veronia amygdalina</i>)	4	3.2
Tomato (<i>Lycopersicon esculentum</i>)	59	47.2
Scotch bonnet pepper (<i>Capsicum chinense</i>)	59	47.2
Cayenne pepper (<i>Capsicum annum</i>)	38	30.4
Ball pepper (<i>Capsicum annum</i> L.)	24	19.2
Okra (<i>Abelmoschus esculentus</i>)	12	9.6
Onions (<i>Allium cepa</i>)	42	33.6

The majority (94.4%) of the respondents marketed tomato and scotch bonnet pepper. On the other hand 39.2% of the respondents marketed jute leaf, while 38.4% marketed plumed cockscomb. Similarly, 36.8% of the respondents marketed african spinach, while 33.6% and 30.4% marketed onions and cayenne pepper, respectively. Other vegetables marketed included ball pepper, fluted pumpkin leaf, okra and bitter leaf.

Storage Methods Employed by the Vegetable Marketers

This section discusses the various storage and preservation methods employed by vegetable marketers which include baskets packaging, jute sack, fibre sack, Refrigeration, wooden crates, dew, spreading and sun-drying in the study area. This is presented in Table 3 which showed the distribution of the respondents according to the storage methods for vegetables among the marketers.

Table 3: Distribution of the Respondents according to the Storage Methods

Methods	Leafy vegetables		Fruit vegetables		Root vegetables	
	Frequency	%	Frequency	%	Frequency	%
Basket Packaging	42	33.6	64	51.2	43	34.4

Jute Sack	9	7.2	44	35.2	25	20
Fibre Sack	2	1.6	5	4	4	3.2
Refrigeration	0	0	2	1.6	1	0.8
Wooden Crates	0	0	2	1.6	0	0
Dew	10	8	0	0	0	0
Spreading	4	3.2	7	5.6	0	0
Sun drying	0	0	0	0	11	8.8

The results show that 33.6% of the respondents uses baskets for packaging their leafy vegetables, 7.2% uses jute sacks, 8% kept their vegetables under the dew while 3.2% spread their leafy vegetables on plane surfaces. The results showed that 51.2% used baskets to package their vegetables, 35.2% jute sacks, 5.6% spread their fruit vegetables on a plane surface to avoid spoilage, while 4% used fibre sacks for storage and preservation. This finding was supported by Yimenu et al. (2024) which reported that spreading on the flour is a major storage and preservation technique for agricultural produce.

The present results also showed that 34.4% of the marketers used baskets for packaging their root vegetables, 20% jute sacks, 8% employed sun drying while 3.2% employed fibre sacks. There is also no standard method of storage in the area because of unavailability of storage facilities and lack of basic knowledge on the practices. The only way by which some of the marketers stored their produce was in the use of baskets.

Determinants of Vegetable Loss among Marketers

This section discussed the determinants of vegetable loss during marketing which includes age of respondents, educational level, marketing experience, household size, household income, transportation cost, perceived weather condition and availability of marketing stalls. Details of the percentage of vegetable loss and factors affecting the vegetable loss are presented in the Table 4 and 5 respectively.

Table 4: Distribution of Respondents Based on Percentage of Vegetable loss

Vegetable lost (%)	Frequency	Percentage	Mean
≤5	61	48.8	5.82
5.01-10	50	40	
≥10	14	11.2	
Total	125	100	

From Table 5 48.8% had vegetable loss of less than 5% of the total vegetable marketed, 40% of the marketers lost between 5% and 10% of vegetables during marketing while 11.2% suffered more than 10% loss of their total vegetables. The mean percentage of vegetable loss among the marketers is 5.82%. This study is line with the findings of Abolade and Meludu (2020) that the majority of the value chain actors experienced loss during postharvest handling.

Table 5: Factors affecting vegetable losses

Variables	Coefficient	T value	P-value
(Constant)	10.184	4.140	0.00
Age of respondents	0.002	0.032	0.975
Educational Level	-0.187*	-2.144	0.034
Marketing experience	-0.224*	-2.442	0.016
Household size	-0.165	-0.341	0.734
Household income	0.053	0.109	0.914
Transportation cost	-0.108	-1.501	0.136
Perceived weather condition	0.131	1.759	0.081
Unavailability of Market stalls	0.254*	2.735	0.007

F value	12.74
R ²	0.470

The regression analysis carried out to determine the influence of some factors on the percentage of vegetable lost during marketing. A multiple linear regression analysis was carried out which gave an empirical result which was subjected to F-test. The value of the F-statistics was found to be significant at 5%. This implies that all explanatory variables (independent) had a joint impact on the dependent variable.

The effect of all the independent variables; age (years), educational level (years), marketing experience (years), household income (naira), transportation cost (naira), household size (number), weather condition and market stalls on the dependent variable (percentage of vegetable lost) tested were significant at 5% level of probability with coefficient of determination (R²) of 0.47.

The coefficient of educational level and marketing experience are negatively significant at 5% while market stalls are positively significant at 5%. This shows that a 5% increase in the number of years spent in school decreases the quantity of vegetables lost during marketing by 18.7%. Also, a 5% increase in the marketing experience decreases the quantity of vegetables lost during marketing by 22.4%. Unavailability of market stalls increases the quantity of vegetables lost during marketing by 25.4%.

CONCLUSION AND RECOMMENDATIONS

Conclusion

The study concluded that with the use of baskets and jute sacks, there was inadequacy in the major method of storage and preservation among the vegetable marketers. This, in addition to the socioeconomic condition of the marketer, makes vegetable to be susceptible to spoilage and loss which was perceived to be worsened by weather condition and unavailability of market stalls, high storage cost, and inadequate market stalls. This could therefore lead to reduction in the availability of vegetables and access among the populace.

Recommendations

Based on the research findings, the following recommendations are proposed:

- Public and private partnership should be deployed to providing infrastructural facilities especially market stalls, which may help in storing of the leftover vegetable produce and also to reduce the rodent infestation
- The government should put in place the necessary platforms to encourage the use of effective methods of storage and preservation methods among vegetable marketers to ensure all year round supply. In this regard, financial institutions should be made to support the vegetable marketers with fund to increase capital for their business as well as access the necessary preservation equipment. Similarly, extension services should be rendered to the vegetable marketers to educate them on appropriate storage and preservation techniques.

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GENETIC GAIN ON AGRONOMIC AND MALTING QUALITY TRAITS AMONG SELECTED BARLEY CULTIVARS IN THE WESTERN CAPE PROVINCE, SOUTH AFRICA

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ABSTRACT

This study evaluates the genetic gains in nine barley cultivars released between 2004 and 2020, focusing on agronomic performance and malting quality traits. Field trials were conducted during the 2023 growing season at Caledon (high rainfall) and Heidelberg (low rainfall). In Caledon, the highest yield was achieved by Malgas (S20) at 6.17 t ha⁻¹, while in Heidelberg, Malgas yielded 4.50 t ha⁻¹. Genetic improvements were evident in ear density, as Bitou (S19) produced 516 ears m⁻² at a lower plant density (8 plants m⁻¹) compared to older Nemesia (S04), which produced 416 ears m⁻² at 9 plants m⁻¹. Recent cultivars from SABBI, such as Kadie (S16) and Malgas (S20), exhibited reduced plant heights of 63 cm versus 73–75 cm in older cultivars like Disa (S06) and Agulhas (S09), indicating successful incorporation of dwarfing traits. Trends in total nitrogen content varied, with Caledon showing a positive correlation with release year ($y = 0.0088x - 16.167$) and Heidelberg a negative correlation ($y = -0.0045x + 10.872$). Kernel plumpness improved over time, with Bitou (S19) reaching 95.82% in Caledon and 96.97% in Heidelberg, while screenings decreased significantly at both sites. This study underscores the vital role of barley breeding in enhancing yield and quality, warranting continued efforts under diverse climatic conditions.

Keywords: Malting barley, genetic gain, grain yield, malting quality

INTRODUCTION

The development of malting barley is essential as global warming increasingly affects growing conditions (Monteiro *et al.*, 2020; Simon *et al.*, 2023; Grigorieva *et al.*, 2023). Weather and soil conditions significantly influence malting barley yield (Bartosiewicz & Poręba, 2019). Optimal cultivars exhibit strong agronomic traits and superior malting quality. Increased investment in breeding programs is essential for genetic improvement, ensuring stable yields and high malt quality. Higher grain yield correlates with shorter stems, a higher harvest index, and more ears and kernels per plant (Cossani *et al.*, 2022). Genetic progress depends on germplasm diversity and the heritability of key traits (Monteiro *et al.*, 2020).

Barley breeding at SABBI in South Africa began over two decades ago, focusing on reducing plant height, improving disease resistance, and enhancing grain yield and malting quality. However, the impact of genetic gain on yield and quality remains unreported. The breeding program relies solely on internal data, while studies elsewhere indicate annual yield increases of 0.4%–1.1% due to genetic improvements and better management (Cossani *et al.*, 2022; Yadav *et al.*, 2021). However, management contributions have declined as environmental and economic constraints limit chemical inputs (Abeledo *et al.*, 2003).

Barley (*Hordeum vulgare* L.) is essential for malt production, requiring strict standards for moisture content, protein levels, and kernel uniformity (O'Donovan *et al.*, 2011). Its role in brewing has made it an industrial crop of interest to researchers and farmers (Rani & Bhardwaj, 2021). Advances in breeding have identified genetic markers for improved malt traits, including enzymatic activity and starch composition, though high yield often correlates with undesirable traits like increased protein content (Zhang *et al.*, 2021; Trubacheeva & Pershina, 2021). Climate change and reduced genetic diversity necessitate novel breeding strategies, integrating traditional and modern genetic techniques to optimize both yield and malt quality (Wenzl & Carling, 2020). This study evaluates genetic gains in grain yield and key agronomic and malting characteristics across nine barley cultivars.

MATERIALS AND METHODS

Trial Site and Establishment

Nine winter barley cultivars (Table 1) were planted during the 2023 growing season. Field trials were established in two locations within the Western Cape Province: Caledon (34° 17' 35" S, 19° 30' 30" E) and Heidelberg (34° 08' 54" S, 20° 44' 45" E). Both sites are rainfed with sandy loam soils. Cultivars were planted under optimal conditions during the 2023 planting season. The Heidelberg trial was sown on May 5, 2023, and harvested on November 6, 2023. The Caledon trial was sown on May 20, 2023, and harvested on November 17, 2023.

Rainfall and temperature data for 2022, 2023 and the five-year average

During the 2023 growing season, temperatures and rainfall patterns varied between Caledon and Heidelberg. At Caledon, minimum temperatures ranged from 6.8°C in July to 14.6°C in December, while maximum temperatures varied between 15.5°C in July and 26.7°C in November. In Heidelberg, minimum temperatures ranged from 6.06°C in July to 14.84°C in December, with maximum temperatures between 16.32°C in July and 27.57°C in November. Compared to the 2022 season, both locations experienced slightly lower minimum temperatures in most months, while maximum temperatures showed variability, with notable increases in November. Rainfall fluctuated across the growing season, with monthly totals differing from both the 2022 season and the five-year average, reflecting seasonal climatic variations at both sites.

Experimental Designs

Trial Layout and Management

The field trials were conducted using a randomized complete block design (RCBD). Plots were established with a five-tine no-till deep blade plot planter. Each trial consisted of three replications per entry, with individual plots measuring 1.25m in width, 25cm in inter-row spacing, and 5m in length. Five rows were planted per plot, with a seeding density of 140 seeds per square meter adjusted based on the thousand kernel weight (TKW). All seeds were planted untreated. Fertilization was applied according to the rainfed areas rotation system, with individual recommendations based on soil analyses from both locations. Two types of fertilizers were used throughout the growing season. Alpha 36 fertilizer was applied at planting, followed by a first top dressing with YarabelaTM CAN S at the 6-7 leaf stage. A second top dressing with YarabelaTM CAN S was applied at the flag leaf stage, except in Heidelberg.

Table 1: Detailed overview of cultivar characteristics, seeding reequipments and plots for sandy loam trial

Cultivar	Year of release	Organization	TKW(g)	Seeds/m ²	Kg/Ha(g)	Grams/plot(g)	Plot area (m ²)	Soil type
Erica	2004	*SABBI	28	140	49	43	5 x 1.25	Sandy loam
Nemesia	2004	SABBI	33	140	58	51	5 x 1.25	Sandy loam
Disa	2006	SABBI	36	140	63	55	5 x 1.25	Sandy loam
Agulhas	2009	SABBI	34	140	60	53	5 x 1.25	Sandy loam
Hessekwa	2012	SABBI	41	140	72	63	5 x 1.25	Sandy loam
Elim	2014	SABBI	45	140	79	69	5 x 1.25	Sandy loam
Kadie	2016	SABBI	40	140	70	61	5 x 1.25	Sandy loam
Bitou	2019	SABBI	46	140	81	71	5 x 1.25	Sandy loam
Malgas	2020	SABBI	41	140	72	63	5 x 1.25	Sandy loam

Abbreviations: SABBI = South African Barley Breeding Institute; TKW = thousand kernel weight

Pest management

Pest management included weed, insect, and fungal control. Weed management combined manual removal, mowing, and herbicides. Pre-planting, Trifluralin 480 EC (2000 ml ha⁻¹) and Makhro Paraquat (3000 ml ha⁻¹) were applied, followed by post-sowing Boxer (3000 ml ha⁻¹) and Bonanza 500 SC (150 ml ha⁻¹). Broadleaf weeds were treated 7 weeks after planting with Brush-off (3.5 g ha⁻¹), Quelex (50 g ha⁻¹), 400MCPA (750 ml ha⁻¹), and Wetcit Oro (100 ml per 100 L), while Ryegrass was controlled with Axial (200 ml ha⁻¹). Trials were maintained with Makhro Paraquat and manual weeding. Fungicide and insecticide were applied twice: Ceriax (800 ml ha⁻¹) and Pyrinex 480 EC (750 ml ha⁻¹) at the 5-6 leaf stage, then Miravis (800 ml ha⁻¹) and Pyrinex 480 EC (750 ml ha⁻¹) at the flag leaf stage. Pyrinex 480 EC was chosen for its cost-effective control of barley pests.

Data Collection

Plant parameters

Plant height was measured at full ear maturity using a tape measure. At the end of grain growth, plants were harvested by hand in one-meter sections at soil level. Harvested plants were separated to determine plants per square meter and tillers per plant. The number of plants per meter was converted to plants per square meter using the following formula:

$$\text{Plants m}^{-2} = \frac{\text{plants per m}}{0.25}$$

The number of tillers per meter was converted to determine tillers per plant using the following formula:

$$\text{Tillers plant}^{-1} = \frac{\text{tillers per m}}{\text{plants per m}}$$

Grain yield

At the end of the growing season, barley ears from trial plots were harvested and threshed with a Wintersteiger Delta combine harvester. The cleaned grain was weighed, and both yield (kg ha⁻¹) and yield gain (%) were calculated using the following formulae:

$$\begin{aligned}\text{Grain yield (t/ha)} &= \left(\frac{\text{Sample weight (kg)} \times 10000}{1.25 \times 5} \right) \div 1000 \\ \text{Yield gain (\%)} &= \left(\frac{\text{New variety (t ha}^{-1}) \times \text{Old variety (t ha}^{-1})}{\text{Old variety (t ha}^{-1})} \right) \div 100\end{aligned}$$

Data Analysis

The nitrogen content was measured using a Foss Infratec 1221 whole grain analyser, with comprehensive grading performed via a Steinecker apparatus. Kernel plumpness and screenings were assessed using >2.5 mm and <2.0 mm sieves, respectively. A 100 g sample of rubbed, unscreened barley was manually cleared of stones and screened with 50 strokes along the sieve slots. Data analysis was conducted in RStudio (Version: 2023.09.1+494) with results evaluated by ANOVA at a 5% significance level.

RESULTS

Genetic gain on grain yield

Statistical analysis in Caledon revealed a significant yield difference ($p < 0.05$) between older and newer cultivars, indicating that genetic gain improves grain yield. Older cultivars like Erica (S04, 2004) yielded 3.92 t ha⁻¹, whereas Malgas (S20, 2020) reached 6.17 t ha⁻¹, with no significant differences among Bitous, Kadie, Elim, Hessekwa, and Agulhas. In Heidelberg, no significant differences ($p < 0.05$) in grain yield were observed among the cultivars planted (Figure 1).

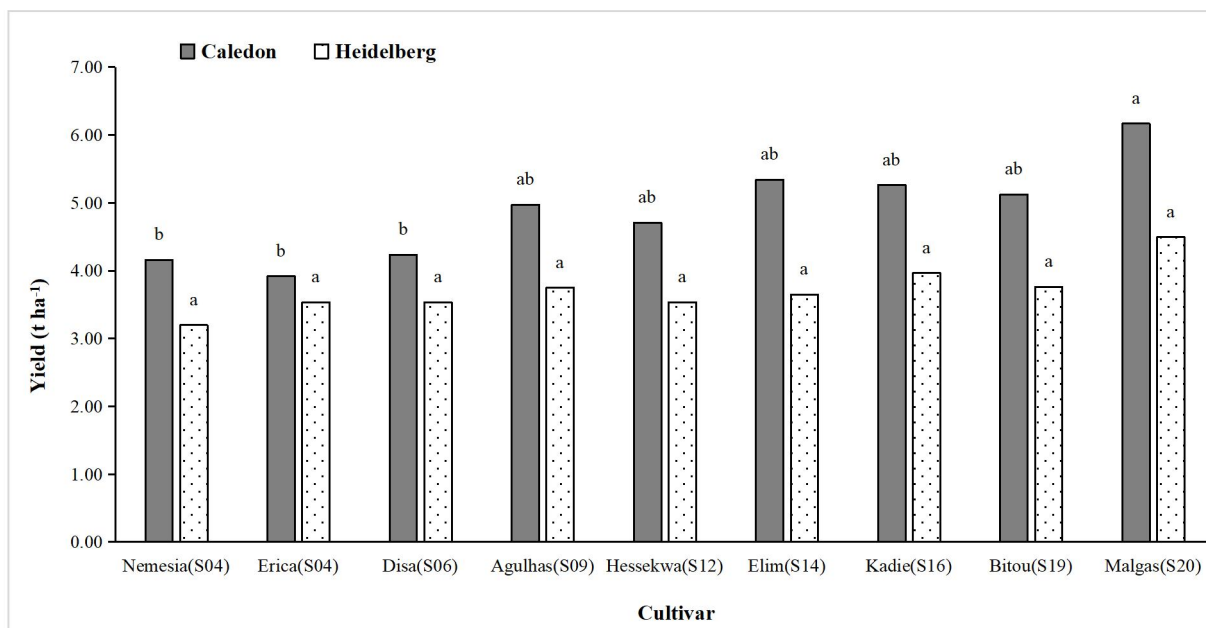


Figure 1: Grain yield of barley cultivars released in different years at SABBI, where S04 (2004), S06 (2006), and subsequent labels indicate the release year of each cultivar. Means with the same letter are not significantly different ($p < 0.05$).

Genetic gain on plant height

In both locations, genetic improvement significantly affected plant height ($p < 0.05$). In Caledon, older cultivars were taller, while in Heidelberg no clear trend was observed (Figure 2).

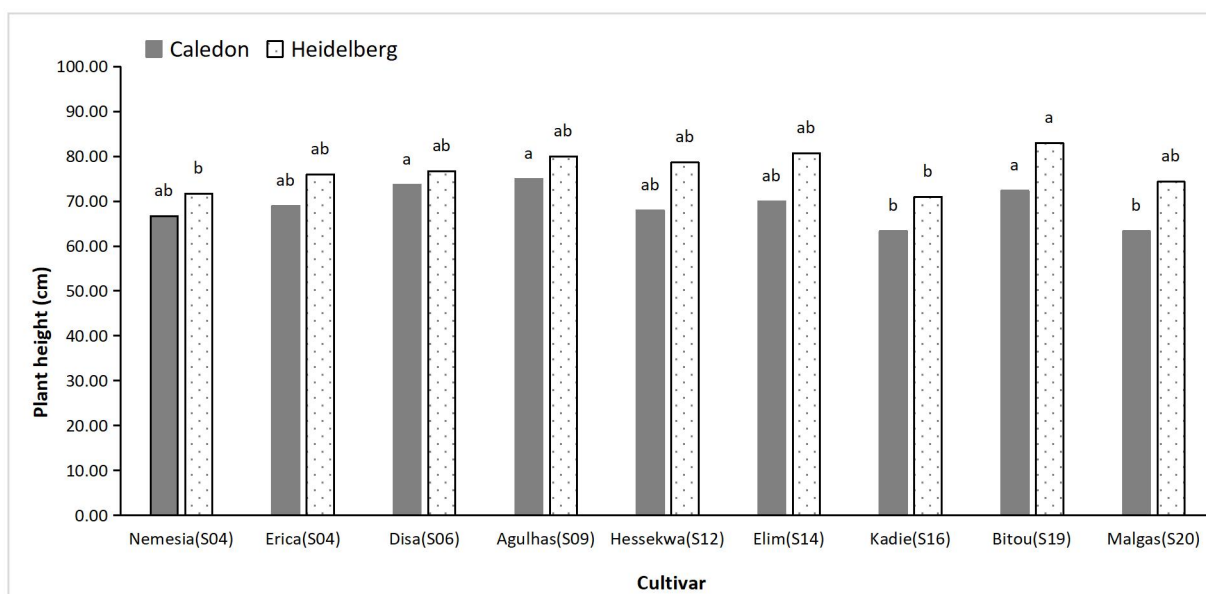


Figure 2: Plant height of barley cultivars released in different years at SABBI, where S04 (2004), S06 (2006), and subsequent labels indicate the release year of each cultivar. Means with the same letter are not significantly different ($p < 0.05$).

Genetic gain on number of plants per meter square

The different cultivars released over various years showed a significant effect ($p < 0.05$) on plant density (plants m^{-2}) in Caledon. Recently released cultivars exhibited higher plant densities, with 'Malgas' (released in 2020) having the highest plant count across both localities. The highest plant densities were observed in cultivars released from 2014 to 2020, while the lowest densities were noted in cultivars released between 2004 and 2012. In contrast, no significant differences ($p < 0.05$) in plant density (plants m^{-2}) were detected among the nine cultivars in Heidelberg.

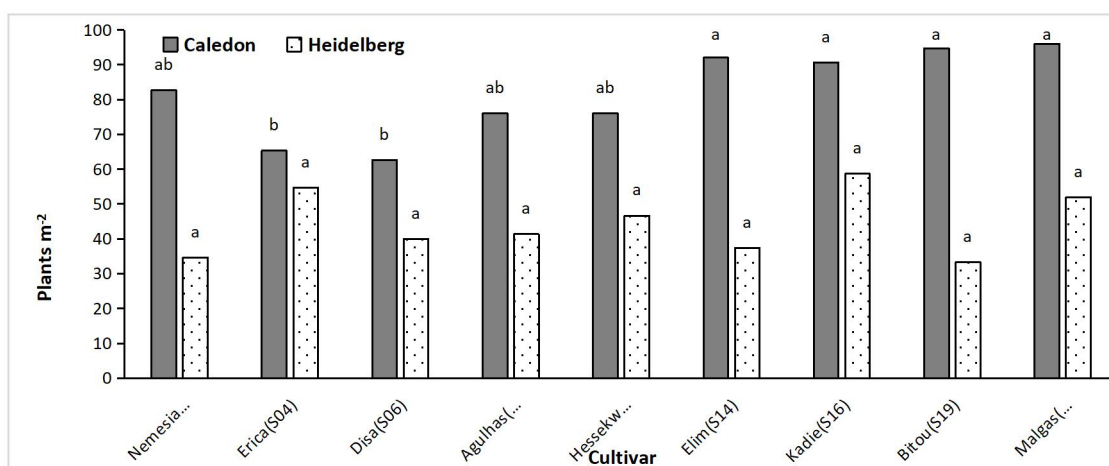


Figure 3: Mean plant density (plants m⁻²) for nine barley cultivars across two localities, where S04 (2004), S06 (2006), and subsequent labels indicate the release year of each cultivar. Means with the same letter are not significantly different ($p < 0.05$)

Effect of genetic gain on number of ears per meter square

In Caledon, analysis revealed significant differences ($p < 0.05$) in ear density, with older cultivars producing fewer ears than newer ones. No difference was found among cultivars from 2004 to 2006, but a significant contrast emerged between 2006 ('Disa') and 2014 ('Elim'), with no further differences among cultivars from 2014 to 2020. In Heidelberg, ear density remained consistent across cultivars.

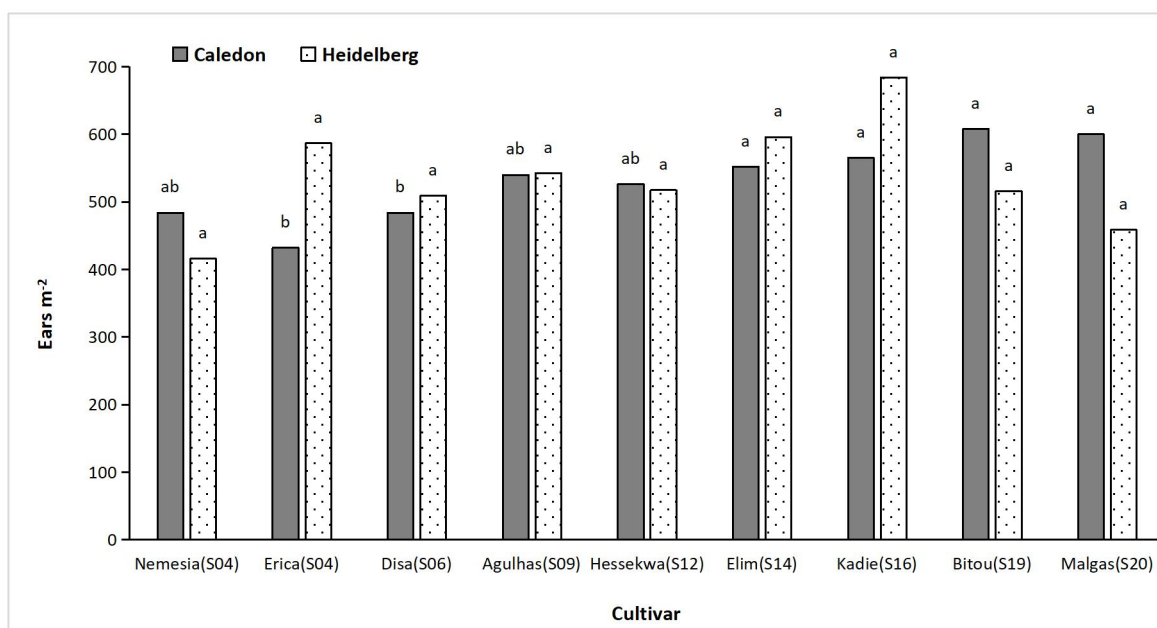


Figure 4: Effect of genetic gain on ear density (ears m⁻²) for nine cultivars released in different years and grown in two localities, where S04 (2004), S06 (2006), and subsequent labels indicate the release year of each cultivar. Means with the same letter are not significantly different ($p < 0.05$).

Genetic Gain Relationship Analysis For Caledon And Heidelberg

Relationship between grain yield and plants per square meter

Grain yield positively correlated with plant density in Caledon and Heidelberg, with genetic yield gains linked to higher plant density (Figures 5 and 6)

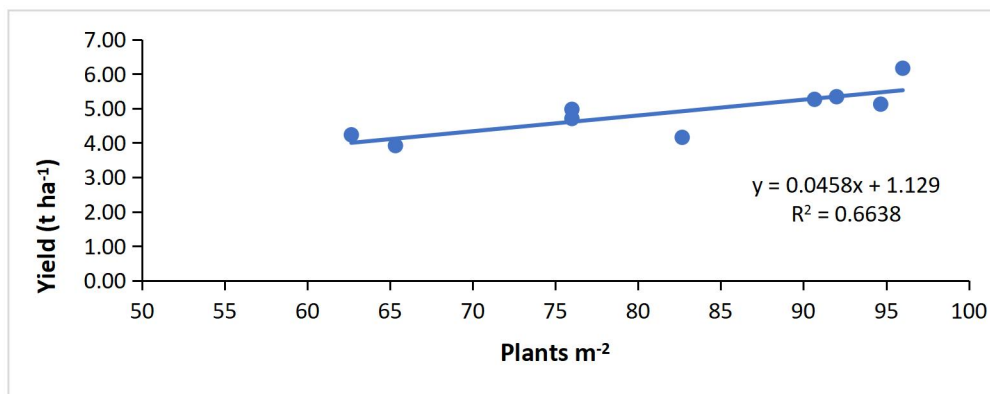


Figure 5: Relationships between grain yield and plant m⁻² of barley cultivars released in different years, planted in Caledon.

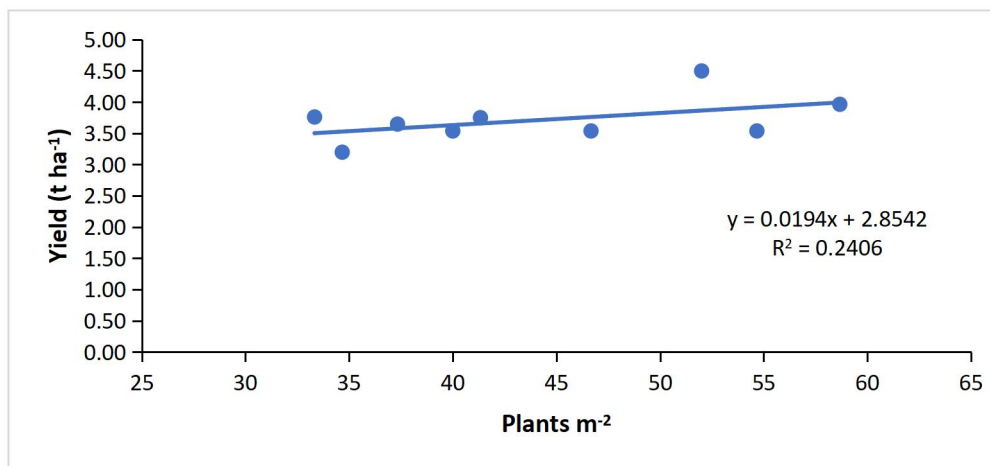


Figure 6: Relationships between grain yield and plant m⁻² of barley cultivars released in different years, planted in Heidelberg

Relationship between grain yield and ears per meter square

Grain yield correlated positively with ears m⁻² in Caledon (Figure 7) and modestly in Heidelberg (Figure 8), indicating higher yields with increased ear density.

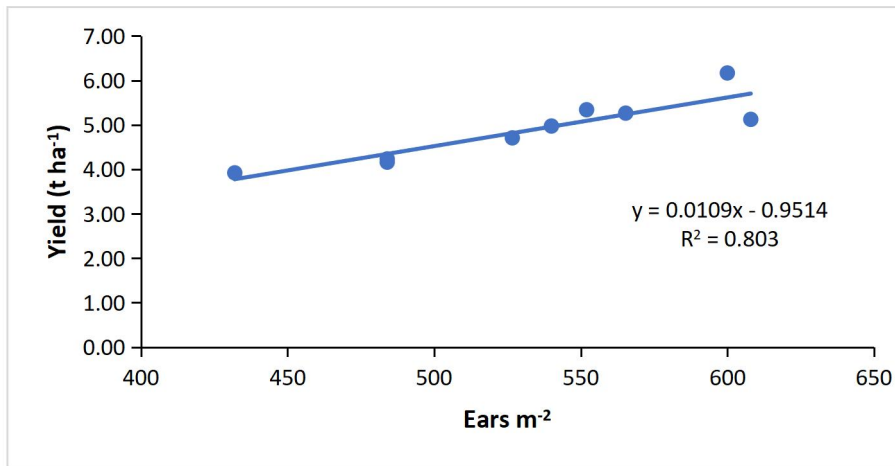


Figure 7: Relationships between grain yield and ears m⁻² of barley cultivars released in different years, planted in Caledon.

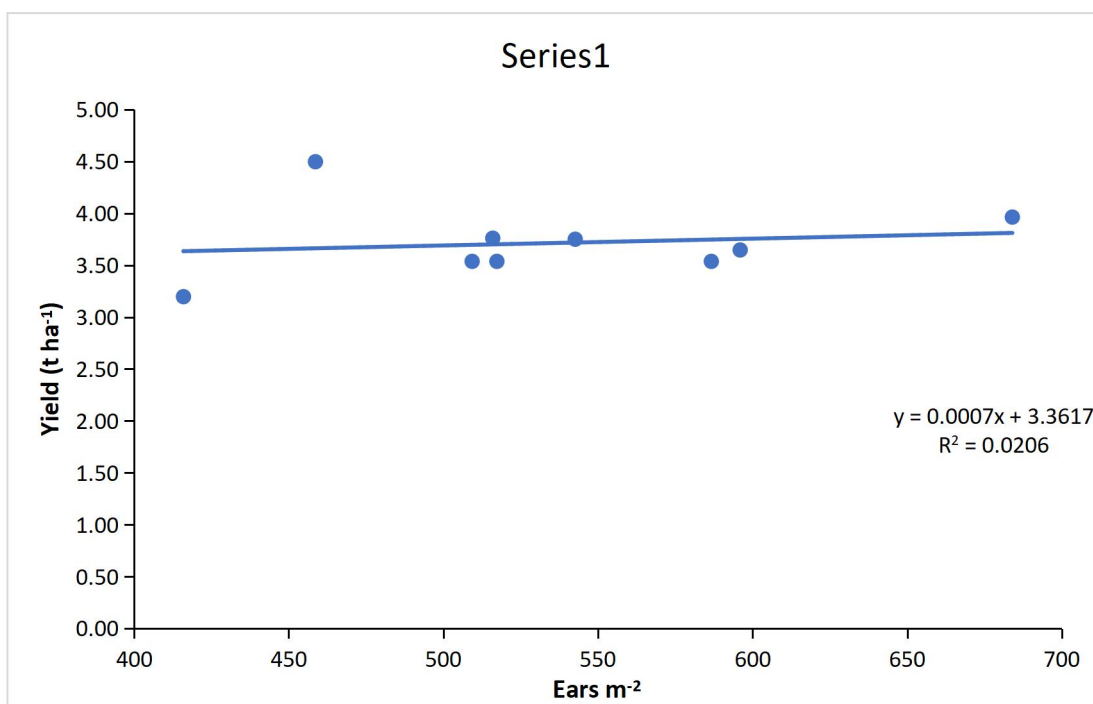


Figure 8: Relationships between grain yield and ears m⁻² of barley cultivars released in different years, planted in Heidelberg

Genetic gain on total nitrogen

There was a positive correlation between TN and years of release of cultivars in Caledon (Figure 9), whilst there was a negative correlation observed in Heidelberg (Figure 10).

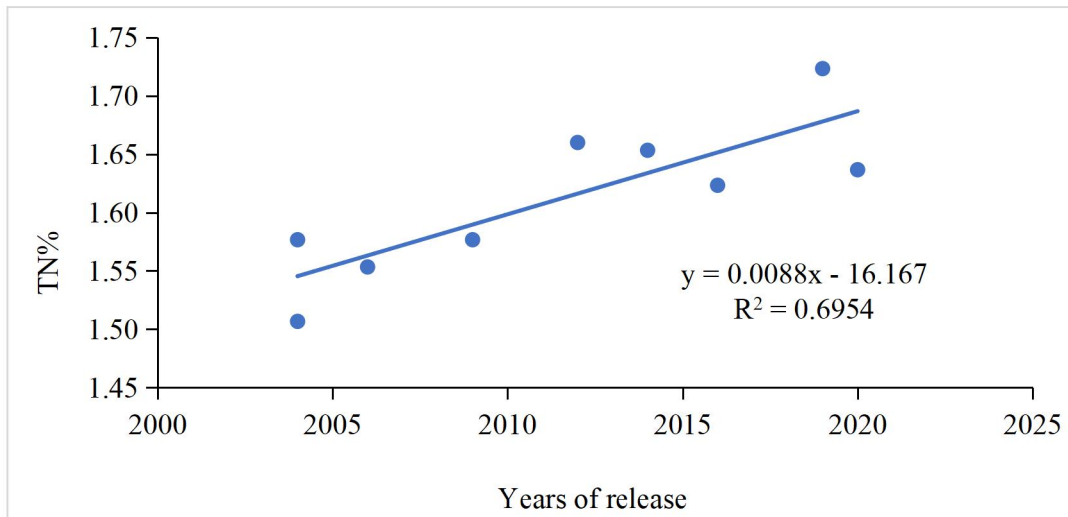


Figure 9: Relationships between kernel total nitrogen and year of introduction of nine cultivars of spring barley planted in Caledon

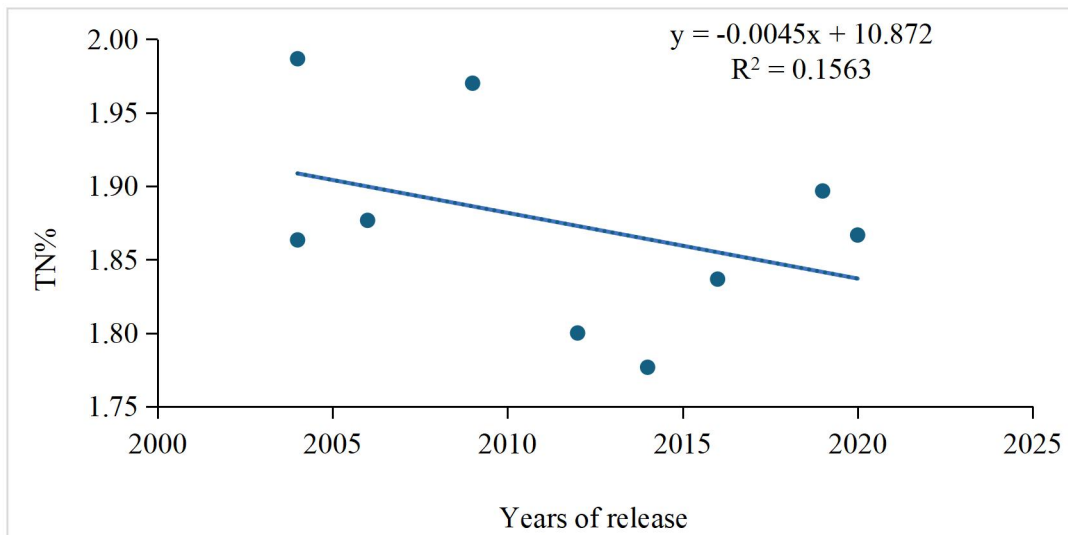


Figure 10: Relationships between kernel total nitrogen and year of introduction of nine cultivars of spring barley planted in Heidelberg

Genetic gain on plumpness

There was a positive correlation between plumpness and years of release of cultivars in both locations (Figures 11 and 12).

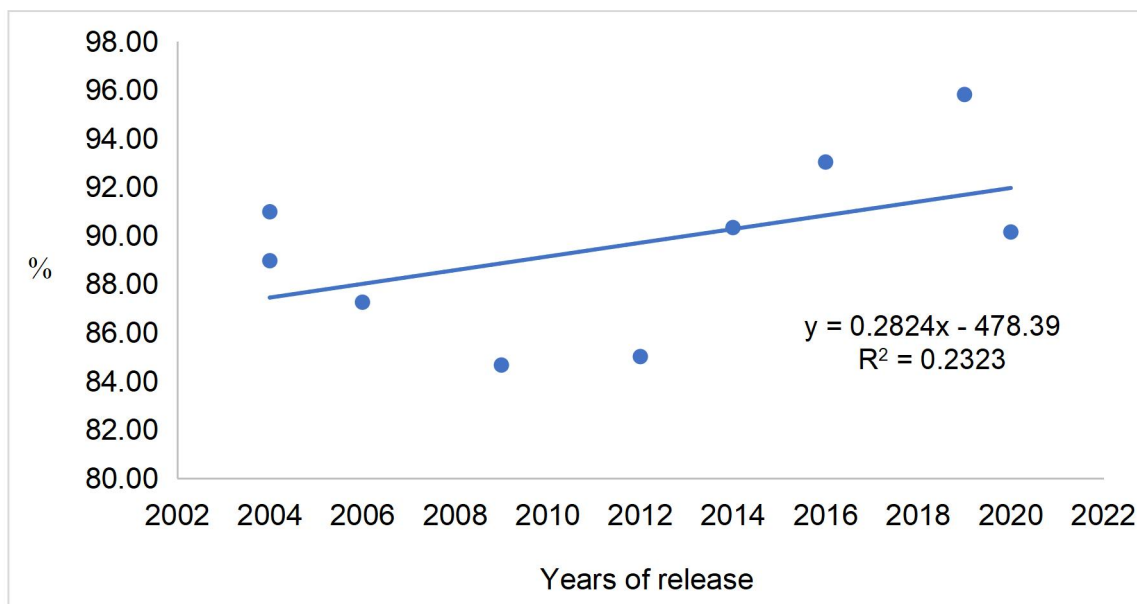


Figure 11: Relationships between kernel plumpness and year of introduction of nine cultivars of spring barley planted in Caledon

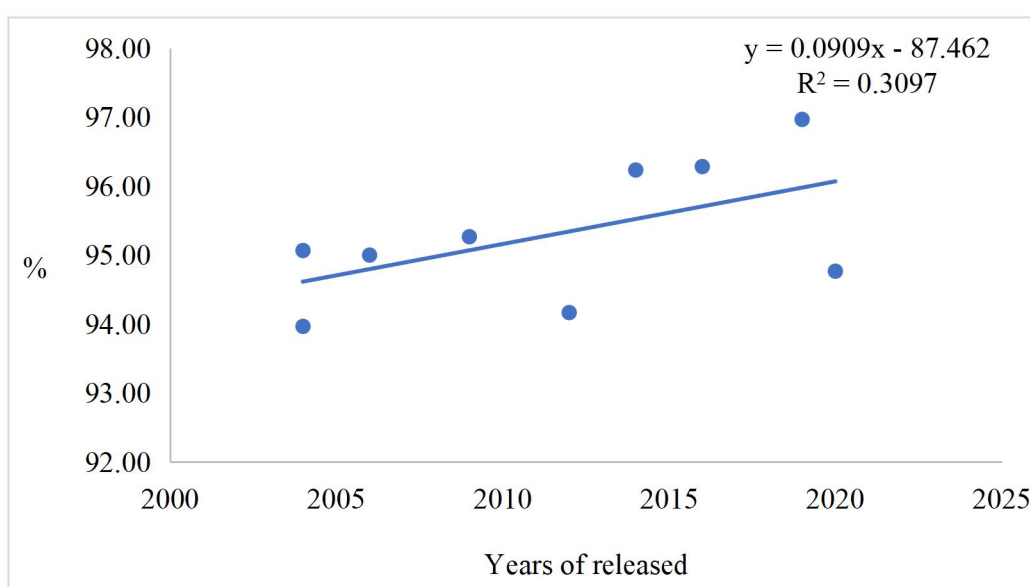


Figure 12: Relationships between kernel plumpness and year of introduction of nine cultivars of spring barley planted in Heidelberg

Genetic gain on screenings

The correlation between screenings and the year of cultivar release in Caledon and Heidelberg was negative (Figures 13 and 14). This indicates a significant genetic improvement in newer cultivars, as evidenced by reduced screenings. Since high-quality malts require minimal screenings, this reduction reflects advancements in cultivar breeding.

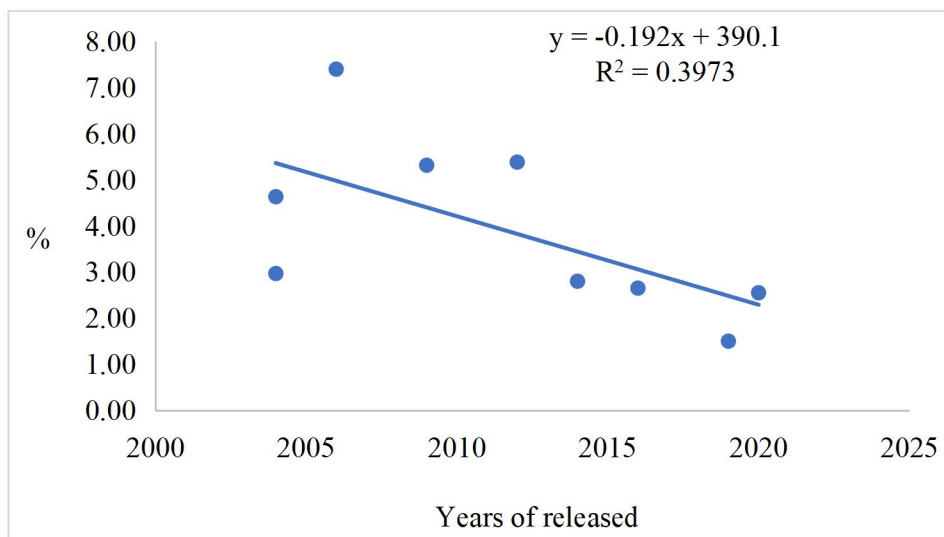


Figure 13: Relationships between screenings and year of introduction of nine cultivars of spring barley planted in Caledon

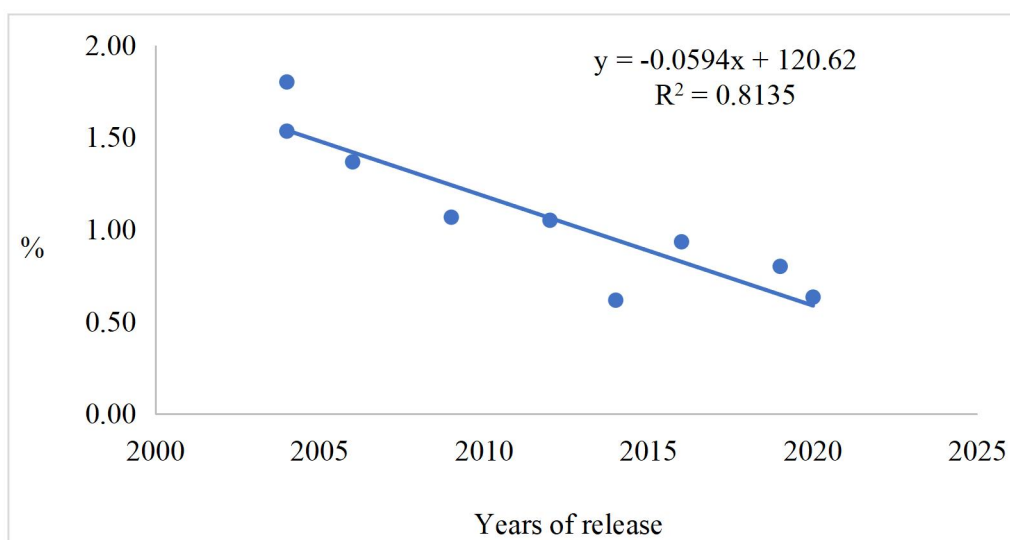


Figure 14: Relationships between screenings and year of introduction of nine cultivars of spring barley planted in Heidelberg

DISCUSSION

Weather conditions on plant establishment and grain yield

Effective plant establishment is essential for high yield, as it significantly influences key yield components (Simon *et al.*, 2023; Grigorieva *et al.*, 2023). Rainfall exceeded the 5-year average and 2022 levels at both locations. In Caledon, approximately 120 mm in June promoted tillering and high yield (6.17 t ha⁻¹ for 'Malgas' versus 3.92 t ha⁻¹ for 'Erica'), while Heidelberg benefited from above-average rainfall in May and June. However, heavy September rains (210 mm in Caledon, 60 mm in Heidelberg) caused lodging and lower yields, with rainfall and temperature fluctuations throughout the season influencing overall performance.

Genetic gain on grain yield of different barley cultivars released in different years

Genetic gains in Caledon (2004–2020) ranged from 0% to 20%, while Heidelberg showed 0–20% improvement (2004–2020), indicating continuous yield progress. Studies report yield increases of 9–51% (Fekadu *et al.*, 2011), 3% per plant (Lalić *et al.*, 2010), and annual gains of 0.25–0.27 t ha⁻¹ (Bulman *et al.*, 1993) or 20 kg ha⁻¹ (Abeledo *et al.*, 2003). Grain yield remains a key indicator of barley genetic progress (Abeledo *et al.*, 2003; Rodrigues *et al.*, 2020; Cossani *et al.*, 2022).

Genetic gain on plant height

Barley breeding at SABBI has reduced plant height, with older cultivars (e.g., Disa, 73 cm; Agulhas, 75 cm) being taller than newer ones (e.g., Kadie, 63 cm; Malgas, 63 cm), suggesting dwarfing gene incorporation (Rodrigues et al., 2020). Eshghi et al. (2011) highlighted high heritability for height and grain yield. In Heidelberg, no clear height reduction trend emerged, though shorter plants, like Malgas (63 cm, 6.17 t ha⁻¹), outyielded taller ones, such as Erica (76 cm, 3.20 t ha⁻¹). Height declined at 1.0 cm per year (Rodrigues et al., 2020), but excessive shortening may reduce photosynthetic efficiency and increase disease risk (Lalić et al., 2010; Akgun, 2016).

Genetic gain on grain yield components

Grain yield increases in this study are primarily driven by higher plant density, more ears per square meter, and genetic improvements in ears per plant and kernels per ear. Cultivars with greater tillering capacity produce more ears, enhancing yield potential. Newer cultivars generally exhibit higher ear densities than older ones, with Bitou and Malgas (2019–2020) reaching 94–96/m² in Caledon, compared to 65/m² for the older Erica. In Heidelberg, despite Bitou having the lowest density, it outperformed the 2004 Nemesia in tiller and ear production, demonstrating genetic improvements across environments. Previous studies show mixed trends, with Fekadu et al. (2011) reporting significant variation in ears per plant, while Abeledo et al. (2004) observed improvements in modern cultivars. Other research (Bulman et al., 1993; Lalić et al., 2010) suggests selection criteria like Q12 can increase ears per plant by 4%, though overall yield component trends remain variable across studies.

Genetic gain on total nitrogen

South African malting barley must contain 1.5–2.0% total nitrogen, with premium quality set at 1.56–1.85%. In our study, modern cultivars showed higher nitrogen levels (1.51–1.90%). These findings highlight concerns that older cultivars may have suboptimal nitrogen levels, posing challenges for breweries. Genetic improvement programs, including marker-assisted selection to incorporate protein QTLs (Trubacheeva & Pershina, 2021), have been crucial in optimizing nitrogen content and enhancing malt quality (Luo et al., 2019; Rani et al., 2021).

Genetic gain on plumpness

Caledon trials showed a positive correlation between kernel plumpness and cultivar release year, with newer cultivars achieving higher plumpness (Rani et al., 2021). Malting barley requires at least 80% plumpness for quality (Fox et al., 2008), as uniform kernels aid water uptake and modification (Kumar et al., 2013). In Caledon, Bitou (S19) and Kadie (S16) reached 95.82% and 93.03%, compared to 84.67% for Agulhas (S09), an 11.15% difference. Similarly, in Heidelberg, Bitou (S19) and Kadie (S16) had 96.97% and 96.28% plumpness, while Erica (S04) and Hessekwa (S12) were lower at 93.97% and 94.17%, showing a 3.88% variation. These results confirm consistent genetic improvements in kernel plumpness (Kumar et al., 2013).

Genetic gain on screenings

In both locations, a significant ($p < 0.05$) negative correlation was found between screenings and cultivar release year, indicating a gradual reduction over time (Rodrigues et al., 2020; Fekadu et al., 2011; Abeledo et al., 2003). In Caledon, Disa (S06) and Hessekwa (S12) recorded the highest screenings at 7.04% and 5.38%, while Bitou (S19) and Malgas (S20) had the lowest at 1.50% and 2.55% - a 4.85% decline from 2006 to 2020. In Heidelberg, Nemesia (S04) and Erica (S04) showed the highest screenings (1.53% and 1.80%), compared to Elim (S14) and Malgas (S20) at 0.62% and 0.63%, a 1.17% decline from 2004 to 2020. Breeding methods likely contribute indirectly to these improvements by enhancing overall plant health, grain quality, and uniformity.

CONCLUSION

Grain yield is driven by plant density, ear density, and rainfall. Caledon's higher rainfall resulted in consistently greater yields than Heidelberg. Newer cultivars (2016–2020) outperformed older ones, with Malgas achieving 6.17 t ha⁻¹ in Caledon and 4.50 t ha⁻¹ in Heidelberg. In Heidelberg, despite lower plant density, Bitou showed higher ear density, reflecting genetic improvements. Quality also improved in newer varieties, with enhanced grain nitrogen content, greater kernel plumpness (e.g., Bitou at 96.4%), and reduced screenings (e.g., Malgas at 0.63%). Future research should optimize breeding for these quality traits and investigate nitrogen's impact on malting quality.

Acknowledgment

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ROLE OF MEDIATION IN ADDRESSING FOOD SECURITY, HEALTH, AND WELLNESS IN NIGERIA: A COMPREHENSIVE APPROACH TO SUSTAINABLE SOLUTIONS

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ABSTRACT

Food security, health, and wellness are interlinked domains crucial for global well-being, and addressing these issues through mediation offers a holistic approach to sustainable and equitable solutions. This study focuses on Nigeria, exploring how mediation can effectively resolve conflicts and promote collaboration among stakeholders to improve food security and public health. The problem statement highlights significant disparities in food distribution and access in Nigeria, leading to malnutrition and poor health outcomes, which mediation can address by fostering cooperative relationships and inclusive dialogues. The methodology involved qualitative and quantitative research, including surveys and interviews. Key findings include improved communication between agricultural producers, policymakers, and consumers; the development of inclusive policies that integrate food security with public health initiatives; effective conflict resolution regarding resource allocation; and increased community engagement in crafting tailored solutions to local needs. Based on these findings, several recommendations are proposed: integrating mediation into policy frameworks to ensure collaborative and sustainable solutions; strengthening stakeholder networks to facilitate ongoing dialogue and cooperation; investing in training programmes for mediators to equip them with the skills necessary to address the complex dynamics of food security and health; and promoting community-based mediation programmes to empower.

INTRODUCTION

Nigeria is the most populous country in Africa with over 200 million inhabitants.¹ Unfortunately, the "Giant of Africa" faces challenges in ensuring food security, health, and wellness for its rapidly growing population.² The concept of food security, as defined by the Food and Agriculture Organisation (FAO), includes four key dimensions: availability, access, utilisation, and stability.³ In Nigeria, these dimensions are severely compromised as a result of poverty, majorly and other factors including climate change, political instability, and inefficient agricultural practices.⁴ The country's agricultural sector, which employs approximately 70% of the workforce, has struggled to keep pace with population growth.⁵ This backdrop has led to a negative reliance on food imports and vulnerability to global market fluctuations.

Adebayo and Ojo believe that the challenges of food security in Nigeria are inextricably linked to the health and wellness of its population.⁶ Malnutrition, particularly among children and women of reproductive age, remains a pressing concern.⁷ According to UNICEF, Nigeria has the second-highest burden of stunted children in the world, with a national prevalence rate of 32% for children under five,

¹Abubakar, I., et al., 'The Lancet Nigeria Commission: investing in health and the future of the nation.' (2022) *The Lancet*, 399(10330), 1155.

²See Sohn, I., 'Why Is Nigeria The "Giant of Africa" Still Poor?' (2020) *The Journal of Applied Business and Economics*, 22(5), 11-41.

³Clapp, J., Moseley, W. G., Burlingame, B., and Termine, P., 'The case for a six-dimensional food security framework.' (2022) *Food Policy*, 106, 102164.

⁴Ayinde, I. A., et al., 'Food security in Nigeria: impetus for growth and development.' (2020) *J. Agric. Econ*, 6, 808-820.

⁵Dauda, R. S., 'Poverty and economic growth in Nigeria: Issues and policies.' (2016) *Journal of Poverty*, 21(1), 61-79.

⁶Adebayo, P. F., and Ojo, E. O., 'Food security in Nigeria: An overview.' (2012) *European journal of sustainable development*, 1(2), 199.

⁷Kuku-Shittu, O., et al., *Child malnutrition in Nigeria: evidence from Kwara State* (Vol. 33., Intl Food Policy Res Inst., 2016) p.32.

with severe impact on cognitive development, educational outcomes, and future economic productivity.⁸ Moreover, Philip and Kolawole found that the double burden of malnutrition is increasingly evident, with rising rates of obesity and non-communicable diseases coexisting with undernutrition, particularly in urban areas.⁹ It needs mentioning that the health sector in Nigeria faces inadequate infrastructure, shortage of healthcare professionals, and limited access to quality healthcare services, especially in rural areas. The relationship between food security and health is therefore evident in the cycle of poverty, malnutrition, and disease that affects millions of Nigerians¹⁰. Food insecurity leads to compromised immune systems, making individuals more susceptible to illness, while poor health in turn affects productivity and economic stability, further exacerbating food insecurity.

In the context of Nigeria's food security and health challenges, mediation can be elixirs that will smooth relationship and cooperation among government agencies, agricultural producers, food distributors, healthcare providers, community leaders, and international organizations. Mediation process create a neutral ground for these actors to voice their concerns, share perspectives, and work towards common goals while bridging the gap between policy formulation and grassroots implementation to ensure that interventions are culturally appropriate and locally owned. Mediation assists in conflict resolution, especially in areas where resource scarcity and competition over land and water rights exacerbate food insecurity. In Nigeria's Middle Belt region, for instance, conflicts between herders and farmers have had devastating impacts on agricultural productivity and community well-being.¹¹ When effectively employed, mediation can facilitate dialogue between these groups and promote sustainable land-use agreements and improved food security outcomes. As for the health sector, Mediation's potential can facilitate inclusive dialogue and collaboration between traditional healing practices and modern medicine, address community mistrust in health interventions, and improve communication between healthcare providers and patients.

This paper posits that mediation, when strategically applied and integrated into existing frameworks, can be a nostrum for addressing the interconnected challenges of food security, health, and wellness in Nigeria. Through qualitative and quantitative data, this paper will shed light on the potency of mediation in addressing Nigeria's food security and health challenges, and the role of mediation as a more holistic, inclusive, and sustainable approach.

CONCEPTUAL REVIEW

Food security and its dimensions

The concept of food security, initially introduced during the World Food Conference in 1974 with a primary focus on food availability, has expanded to include multiple dimensions that reflect the nature of ensuring adequate nutrition for all.¹² The most widely accepted definition, established by the Food and Agriculture Organisation (FAO) at the 1996 World Food Summit, states that food security exists "when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life."¹³ From this definition, there are four key dimensions of food security that can be identified. They are: availability, access, utilisation, and stability. Food availability is the physical presence of food in sufficient quantities, which is influenced by factors such as agricultural production, food imports, and distribution systems.¹⁴ Access emphasizes the ability of individuals and households to obtain food, taking into

⁸Amoo, T. B., and de Roos, B., 'Stunting and Its Risk Factors in Under Age Five Children in Ogun State, Nigeria: A Cross-Sectional Study.' (2021) *International Journal of Healthcare and Medical Sciences*, 7(4), 76-86.

⁹Philip, F. A., and Kolawole, O. E., 'Patterns and Predictors of Childhood Undernutrition in Nigeria From 2008-2018: A Pooled Data Analysis.' (2022) *Gender and Behaviour*, 20(4), 20701-20714.

¹⁰G Ese, A., 'The Role of Food and Nutrition in Achieving Sustainable Developmental Goal 2030 Through Food Security in Nigeria.' (2022) *Alexandria Science Exchange Journal*, 43(2), 33-38.

¹¹See Yamusa, P. M., *The Root Causes of the Upsurge in Farmer-Herder Conflict Case Study on Middle-Belt Nigeria* (Doctoral dissertation, Master's thesis, Near East University, 2022); Akov, E. T., 'The resource-conflict debate revisited: Untangling the case of farmer-herdsman clashes in the North Central region of Nigeria.' (2017) *African Security Review*, 26(3), 288-307.

¹²Clapp, J., Moseley, W. G., Burlingame, B., and Termine, P., 'The case for a six-dimensional food security framework.' (2022) *Food Policy*, 106, 102164.

¹³Malaysia, P., 'Food security: concepts and definitions.' (2010) *Journal of Community Health*, 16(2), 2.

¹⁴Ibid.

account both economic and physical barriers, and it acknowledges that the mere presence of food does not guarantee its accessibility to all segments of the population.¹⁵ Utilization as the third dimension focuses on food's nutritional value and how the body makes the most of various nutrients.¹⁶ This dimension lays emphasis on food safety, nutritional quality, and the physiological ability to absorb and metabolise nutrients, while also considering factors such as clean water, sanitation, and health care, which are crucial for proper food utilization. The fourth dimension of food security which is stability underscores the importance of consistent access to adequate food over time.¹⁷ This dimension addresses the vulnerability of food security to short-term shocks (such as economic or climatic crises) and long-term trends (like seasonal food scarcity).

Health and wellness in relation to food security

The relationship between food security and health is bidirectional because food security status has an impact on health outcomes and health status, which influence an individual's ability to achieve food security.¹⁸ Chronic food insecurity is associated with stunting, wasting, and micronutrient deficiencies in children, which can have lifelong impacts on physical and cognitive development.¹⁹ For adults, food insecurity can increase the risk of diabetes, hypertension, and cardiovascular diseases.²⁰ This association is partly due to food-insecure individuals' tendency to rely on energy-dense but nutrient-poor foods, which are often more affordable and accessible. This is especially prevalent in Nigeria and the Sub-Sahara Africa.²¹ Research by Coffino et al has shown that food insecurity is associated with higher levels of stress, anxiety, and depression.²² This relationship is particularly pronounced in mothers, who often sacrifice their own nutritional needs for their children.²³ Pregnant women experiencing food insecurity are at higher risk of gestational diabetes, excessive weight gain, and iron deficiency anaemia, which can lead to adverse birth outcomes like low birth weight and preterm delivery.²⁴ Moreover, food insecurity during early childhood can have long-lasting effects on physical, cognitive, and socio-emotional development.²⁵ In relation to wellness, which is the physical, mental, and social well-being, adequate nutrition is fundamental.²⁶ As per Hung et al., proper nutrition as a result of food security can improve physical health, cognitive function, emotional well-being, and social interactions.²⁷ On the contra side, food insecurity can disrupt family dynamics, affect academic and work performance, and limit social participation, with severe implications for wellness.²⁸

Theory and Practice of Mediation

Mediation, as a form of alternative dispute resolution, involves a neutral third party who facilitates communication and negotiation between conflicting parties to reach a mutually acceptable

¹⁵Whiteford, S., and Ferguson, A. E., 'Social dimensions of food security and hunger: An overview.' (2019) *Harvest Of Want*, 1-21.

¹⁶Timmer, C. P., 'Behavioral dimensions of food security.' (2012) *Proceedings of the National Academy of Sciences*, 109(31), 12315.

¹⁷Leroy, J. L., et al, 'Measuring the food access dimension of food security: a critical review and mapping of indicators.' (2015) 36(2) *Food and nutrition bulletin*, 167.

¹⁸Pérez-Escamilla, R., 'Food security and the 2015–2030 sustainable development goals: From human to planetary health.' (2017) *Current developments in nutrition*, 1(7), e000513.

¹⁹Montenegro, C. R., et al., 'The pediatric global burden of stunting: Focus on Latin America.' (2022) *Lifestyle Medicine*, 3(3), e67.

²⁰Ibid.

²¹Bjornlund, V., Bjornlund, H., and van Rooyen, A, 'Why food insecurity persists in sub-Saharan Africa: A review of existing evidence.' (2022) *Food Security*, 14(4), 845-864.

²²Coffino, J. A., et al., 'Food insecurity among graduate students: Prevalence and association with depression, anxiety and stress.' (2021) *Public Health Nutrition*, 24(7), 1889-1894.

²³Ibid.

²⁴Natamba, B. K., et al., 'The association between food insecurity and depressive symptoms severity among pregnant women differs by social support category: a cross-sectional study.' (2017) *Maternal & child nutrition*, 13(3), e12351.

²⁵Ivers, L. C., and Cullen, K. A., 'Food insecurity: special considerations for women.' (2011) *The American journal of clinical nutrition*, 94(6), 1740S-1744S.

²⁶Hung, S. T., et al., 'Examining physical wellness as the fundamental element for achieving holistic well-being in older persons: review of literature and practical application in daily life.' (2023) *Journal of Multidisciplinary Healthcare*, 1889-1904.

²⁷Ibid.

²⁸Ibid.

resolution.²⁹ One of the fundamental theories in mediation is the transformative approach, developed by Bush and Folger.³⁰ This theory posits that the primary goal of mediation should be the empowerment of parties and the recognition of each other's perspectives, rather than solely focusing on reaching an agreement.³¹ According to the theory, an ideal mediation process is the one that emphasises personal growth and improved relationships between parties.³² The practice of mediation is typically laced with techniques and strategies. Active listening, reframing, and asking open-ended questions are fundamental skills employed by mediators to facilitate communication and understanding between parties.³³ The use of caucuses, or private meetings with individual parties, is a common practice that allows mediators to explore underlying interests and concerns that may not be expressed in joint sessions.³⁴ It needs to be mentioned that recent developments in mediation practice have seen the integration of technology, especially in light of global pandemics and increasing digitalization.³⁵ There is also a growing interest in the application of mediation principles to address multi-party conflicts, particularly those related to environmental issues, community development, and public policy. The growing scholarship on this subject matter demonstrates the importance and potency of mediation techniques in resolving complex, multi-stakeholder challenges in various domains. However, these do not form the focus of this paper.

Gaps in existing studies

Despite the growing body of literature on mediation, there is a gap in research that addresses the application of mediation to food security and health challenges. Existing studies on food security in Nigeria have primarily focused on quantitative assessments of food availability and access, agricultural productivity, and nutritional outcomes.³⁶ The potential role of mediation in resolving these crises remains underexplored. Furthermore, there is a lack of research on how mediation can be integrated into existing food security and health initiatives in Nigeria. Questions about the cultural appropriateness of various mediation techniques, the training requirements for mediators in this context, and the potential synergies between mediation and other intervention strategies remain unanswered.

Challenges of Food Security, Health, And Wellness in Nigeria

In spite of its vast agricultural potential and status as Africa's largest economy, Nigeria continues to battle severe food security crisis.³⁷ The current food security situation threatens the well-being of millions of its citizens, and according to recent data from the World Food Programme, an estimated 19.4 million Nigerians are food insecure, with this number projected to rise due to economic instability and insecurity.³⁸ The agricultural sector, which ought to ordinarily form the backbone of Nigeria's food security efforts, is plagued by low productivity, inadequate infrastructure, and limited access to

²⁹Pablo, J., 'Effectiveness of Mediation and Arbitration as Alternative Dispute Resolution Methods in Mexico.' (2024) *Journal of Conflict Management*, 4(1), 38-50.

³⁰Bush, R. A. B., and Folger, J. P., *The promise of mediation: The transformative approach to conflict*. (John Wiley & Sons, 2004) 15.

³¹Ibid.

³²Ibid.

³³Whatling, T., *Mediation skills and strategies: A practical guide*. (Jessica Kingsley Publishers, 2012) p.15.

³⁴Ibid.

³⁵Forliano, C., et al., 'Technological orientation and organizational resilience to Covid-19: The mediating role of strategy's digital maturity.' (2023) *Technological Forecasting and Social Change*, 188, 122288; Hirblinger, A. T., *Digital Inclusion in Mediated Peace Processes*. (Washington, DC: United States Institute of Peace, 2020) p.23.

³⁶Owoo, N. S., 'Demographic considerations and food security in Nigeria.' (2021) *Journal of Social and Economic Development*, 23(1), 128; Amare, M., et al., 'Study of the determinants of chronic malnutrition in Northern Nigeria: quantitative evidence from the Nigeria demographic and health surveys.' International food policy research institute (IFPRI) working paper 45 (September 2017). *Food and nutrition bulletin*, 39(2), 296-314; Adebayo, P. F., and Ojo, E. O., 'Food security in Nigeria: An overview.' (2012) *European journal of sustainable development*, 1(2), 199-199.

³⁷Wudil, A. H., et al., 'Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA).' (2022) *International Journal of environmental research and Public Health*, 19(22), 14836.

³⁸Wudil, A. H., et al., 'Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA).' (2022) *International Journal of environmental research and Public Health*, 19(22), 14836.

modern farming techniques.³⁹ Smallholder farmers that are the majority of agricultural producers struggle with limited access to credit, quality inputs, and reliable markets for their produce.⁴⁰ This results in suboptimal yields and significant post-harvest losses, the situation of which is further exacerbated by heavy reliance on rain-fed agriculture, which makes food production highly vulnerable to erratic weather patterns and climate change impacts.⁴¹

This pervasive issue of food insecurity breeds malnutrition in its various forms, which stunt individual and national development. According to Onoja and Adione, micronutrient deficiencies, often referred to as "hidden hunger," are widespread in Nigeria.⁴² These deficiencies are largely due to a lack of dietary diversity and quality, resulting from food insecurity and poor nutritional knowledge. The existence of food insecurity presents a serious challenge for public health interventions because malnutrition weakens the immune system, making individuals more susceptible to infections and less able to recover from illnesses. This is especially concerning in light of Nigeria's recent high burden of diseases such as cholera and tuberculosis.⁴³ It goes without saying that the mental health implications of food insecurity are often overlooked but are equally significant. Chronic stress associated with uncertainty about access to food can lead to anxiety, depression, and other mental health disorders, which take psychological toll on family, community cohesion, and overall societal well-being.

METHODOLOGY

This study employed a mixed-method approach to investigate the role of mediation in addressing food security, health, and wellness in Nigeria. The research design combined quantitative and qualitative techniques to capitalise on their respective strengths and provide a comprehensive understanding of the research questions. The study proceeded through two phases: a large-scale survey to gather broad quantitative data on food security, health status, and attitudes towards mediation; and in-depth interviews to gather qualitative data. Both sources of data are integrated to develop a holistic understanding. Ethical considerations included securing informed consent, maintaining confidentiality and anonymity, and offering debriefing sessions for interview participants.

RESULTS

Phase One: Surveys

The survey aimed to understand the role of mediation in addressing food security, health, and wellness in Nigeria. Targeting 100 respondents, the survey achieved an 86% response rate, distributed via Google Forms to national agricultural and health platforms on social media. The questionnaires were divided into five sections: the demographic information, food security status, health and wellness indicators, awareness of mediation, and experiences with food-related conflicts.

Interview

The researchers conducted six in-depth interviews with key stakeholders to explore mediation's role in addressing food security, health, and wellness in Nigeria. Interviews were conducted in varied formats, including in-person sessions, audio calls, and WhatsApp voice calls, each lasting less than 20 minutes.

One agricultural expert and farmer, when asked about his perception of the role mediation can play in resolving the food security crisis in Nigeria, stated that:

³⁹Tijani, S. A., *Extension paradigm shift: a drive for agricultural productivity and value addition in Nigeria*. (Ibadan University Press, Publishing House, University of Ibadan, Ibadan, Nigeria, 2021) p.119.

⁴⁰Abdulyakeen, A., 'Conflict Continuum and Food Security in Northwestern Nigeria: Reflections on Key Issues and Policy Recommendation.' (2022) *Studia Securitatis*, 16(2), 7-31.

⁴¹Begna, T., 'Major challenging constraints to crop production farming system and possible breeding to overcome the constraints.' (2020) *International Journal of Research Studies in Agricultural Sciences (IJRSAS)*, 6(7), 27-46.

⁴²Onoja, A. O., and Adione, A. A., 'Hidden hunger burden and policy responses in Nigeria: implications for attainment of the sustainable development goal' (2020) *Nigerian Agricultural Policy Research Journal (NAPReJ)*, 7(1), 12.

⁴³As of June 30, 2024, 2,102 suspected cholera cases have been reported in 33 states and 122 local government areas in Nigeria. Unfortunately, 63 fatalities have occurred since the year 2024 began. See Smith, S.I., 'Nigeria's cholera outbreaks: why they happen and are so hard to control' (The Conversation, June 26 2024). Online at: <https://theconversation.com/nigerias-cholera-outbreaks-why-they-happen-and-are-so-hard-to-control-233123>

"...The challenges farmers face in accessing markets and resources are immense. Mediation can be a game-changer in resolving disputes over land and water access, which are crucial for sustainable farming practices..."

A health professional in one of the federal hospitals in Nigeria responded to the same question with the following statement:

"...Food insecurity directly impacts public health outcomes, exacerbating issues like malnutrition and disease. Mediation could potentially improve community health by addressing food access disparities and enhancing healthcare services...."

A community leader from the Kwara State in North-Central Nigeria expressed his view as thus:

"...We have had issues between farmers and herders. Last year, cattle destroyed crops on several farms, leading to heated arguments and threats of violence. It was a tense situation that affected food production and community relations. We tried to resolve it through traditional means, but it was challenging to find a solution that satisfied everyone. Food-related conflicts disrupt our community's stability and progress. Mediation based on the little I know about it can offer a better approach to resolving these disputes because it will bring in a new dimension which is its collaborative approach. I believe if well framed, it can foster fostering unity and resilience among diverse stakeholders."

A government official from the Ministry of Agriculture in Kwara State stated that:

"...Our policies over the years have aimed to tackle food security and health challenges through strategic interventions. But I think mediation can be a great deal to revitalise our approach. I have attended several peace-building conferences and I have heard much about how mediation has the potential to strengthen governance and community engagement, ensuring effective implementation of these policies. In fact, I have had several conversations with farmers in the rural areas who think mediation could help them communicate better and resolve these recurring issues with the Fulani grazers before they escalate into bloody ones. Often, they told me that they do not know about new agricultural programmes or why certain decisions are made. If they had someone to facilitate discussions between us and them as the government, maybe they could express their needs better and understand our plans."

A representative of an NGO which is based in Osun State in South-Western part of Nigeria responded on the same question. The representative stated that:

"...At the grassroots level, we see firsthand the struggles communities face with food insecurity and health disparities. Mediation is a powerful ADR method but we have made little progress as a country in implementing it. If the government is serious, we are ready to work with them to see that mediation empowers communities to find sustainable solutions and advocate for their rights...."

A professional mediator that practices in Lagos State said:

"...Mediation is not just about resolving conflicts. Instead, it is about empowering parties to find common ground and sustainable solutions. In food-related disputes, impartiality and inclusivity are crucial for achieving long-term resolutions..."

Methodology

The respondents spanned various age groups, with 7 (8.1%) aged 18-30, 54 (62.8%) aged 31-45, 18 (20.9%) aged 46-60, and 7 (8.1%) aged 61 and above. The majority of respondents were male (71 respondents, 82.6%) compared to female respondents (15 respondents, 17.4%). Geographically, respondents were primarily from urban areas (66 respondents, 76.7%), with representation from North-Central Nigeria (43 respondents, 50.0%), South-East Nigeria (27 respondents, 31.4%), and South-West Nigeria (16 respondents, 18.6%). Education levels varied, with 12 respondents (14.0%) having primary education, 24 respondents (27.9%) secondary education, and 50 respondents (58.1%) tertiary education. Occupationally, 59 respondents (68.6%) were engaged in formal employment, while 27 respondents (31.4%) were in informal occupations.

Food Security Status

The survey highlighted significant food insecurity concerns among respondents. A majority of 69 respondents (80.2%) worried about running out of food, and 68 respondents (79.1%) reported being unable to afford balanced meals. Additionally, 49 respondents (57.0%) indicated their purchased food did not last due to financial constraints.

Health and Wellness Indicators

Respondents' perspectives on health and wellness were varied. While 36 respondents (41.9%) rated their health as fair and 32 respondents (37.2%) as good, 11 respondents (12.8%) reported poor

health. Access to healthcare was predominantly available, with 71 respondents (82.6%) confirming availability when needed. However, dietary habits were concerning, with only 13 respondents (15.1%) consuming fruits and vegetables daily.

Mediation Awareness and Perceptions

Mediation awareness was relatively low, with 60 respondents (69.8%) unfamiliar with the concept. Among those aware, 61 respondents (70.9%) agreed or strongly agreed that mediation could address food security issues, whereas perceptions on its role in improving health and wellness were more divided, with 28 respondents (32.6%) strongly disagreeing.

Experiences with Food-Related Conflicts

Food-related conflicts were prevalent among respondents, with 68 respondents (79.1%) reporting such experiences. These conflicts primarily included farmer-herder conflicts (72 respondents, 83.7%). Despite the prevalence, mediation was infrequently utilised, with only 15 respondents (17.4%) indicating its use in resolving food-related conflicts.

DISCUSSION

On mediation awareness and perception, the respondents' low awareness of mediation (69.8% unfamiliar) indicates a significant knowledge gap about alternative dispute resolution mechanisms in the context of food security. However, the positive perception among those aware (70.9% agreeing or strongly agreeing that mediation could address food security issues) aligns with scholarly perspectives on the potential of mediation in resolving resource-based conflicts.⁴⁴ This dichotomy between low awareness and positive perception among the informed indicates a need for targeted education and outreach programmes to increase understanding of mediation's potential in addressing food security challenges. In the same vein, the high prevalence of food-related conflicts (79.1% of respondents reporting such experiences), combined with the low utilization of mediation (only 17.4% indicating its use), signifies a significant opportunity for intervention. This finding corroborates existing literature on the underutilization of alternative dispute resolution mechanisms in resource conflicts in developing countries.⁴⁵ The community leader's account of farmer-herder conflicts also reiterates the potential for mediation to address not only immediate disputes but also underlying structural issues affecting food security.

The data has revealed a relationship between food insecurity, health outcomes, and the potential for mediation. The health professional's insight on the direct impact of food insecurity on public health aligns with established research on the health consequences of food insecurity.⁴⁶ Mediation no doubt has the potential to effectively address these interconnected issues, but there is a need for an integrated approach to food security and health policy, where this conflict resolution mechanism is properly implemented. The agricultural expert's comments on farmers' challenges in accessing markets and resources point to structural barriers in the food production system. This finding resonates with literature on the role of institutional factors in food security.⁴⁷ Mediation's potential in addressing these structural issues, as suggested by the professional mediator, indicates a possible expansion of mediation beyond interpersonal conflicts to systemic challenges in the food security landscape. The perspective of the NGO representative on mediation empowering communities to find sustainable solutions suggests that mediation could serve not only as a conflict resolution tool but also as a means of enhancing community agency in addressing food security and health challenges. Based on the government official's recognition of mediation's potential to strengthen governance and community engagement in policy implementation, it can be well submitted that mediation could play a role in bridging the gap between policy formulation and effective implementation in addressing food security and health challenges.

CONCLUSION

⁴⁴ Bush, R. A. B., and Folger, J. P. (see note 30 above).

⁴⁵ Rambo, S. O., 'African countries and the world trade organization dispute settlement mechanism; the challenges, constraints and the need for reforms' (Doctoral dissertation, University of Nairobi, 2014); Tudy-Jackson, J, 'Non-Traditional Approaches to ADR Processes That Engage African-American Communities and Africa-American ADR Professionals.' (2011) *Cap. UL Rev.*, 39, 921.

⁴⁶ Gundersen, C., and Ziliak, J. P., 'Food insecurity and health outcomes.' (2015) *Health affairs*, 34(11), 1830-1839.

⁴⁷ Barrett, C. B., 'Overcoming global food security challenges through science and solidarity.' (2021) *American Journal of Agricultural Economics*, 103(2), 422-447.

This paper has provided a comprehensive examination of the role of mediation in addressing food security, health, and wellness in Nigeria. The findings have underlined the intricate nature of these issues, which are marked by agricultural productivity, market access, climate change impacts, nutrition, health infrastructure, and water access. Despite the prevalent food insecurity and health disparities, the paper argued that mediation has a potential to transform this backdrop and effectively resolve these conflicts, while enhancing stakeholder cooperation, and fostering sustainable solutions. The evidence from the quantitative survey data and qualitative insights from interviews has indicated that mediation can significantly improve communication, build trust, facilitate collaborative problem-solving, which are crucial in resolving food security and wellness challenges and achieving sustainable solutions in Nigeria.

Recommendations and Implications for Policy and Practice

It is important to develop a National Mediation Policy that will integrate mediation approaches into sectoral policies so as to institutionalise mediation as a conflict resolution mechanism in food security and health contexts. This aligns with the growing recognition of Alternative Dispute Resolution (ADR) mechanisms in governance frameworks (Brown et al., 2019). While Part II of the Arbitration and Mediation Act ostensibly recognises mediation, there is a need for a more robust legal framework that would provide the necessary legitimacy and enforceability for mediated agreements. By embedding mediation within existing policy structures, Nigeria can create a more responsive and adaptive governance system capable of addressing food security and health challenges through collaborative problem-solving approaches.

It is also suggested that there should be established mediation units within key government agencies and that a National Mediation Institute should be created to promote sustainable institutional capacity for mediation. The integration of mediation courses into relevant university programmes will benefit interdisciplinary approaches in addressing societal challenges. This will also foster a cadre of skilled mediators with expertise in food security and health issues in Nigeria.

To improve the integration of mediation in the foregoing issues raised, it will be critical to establish multi-stakeholder platforms and develop digital networking tools which are critical for improving collaborative governance in the food security and health sectors. In the same vein, supporting community mediation centers with formal mediation integrated with traditional practices, and implementing school-based programs will be an effective grassroots approach to conflict resolution. Wertheim et al. believe that this approach will foster a culture of dialogue and peaceful conflict resolution from an early age.⁴⁸ These community-based initiatives can collectively build social capital and enhance community resilience in facing food security and health challenges.

Improving specialised training and mentorship will also enhance the use of mediation in resolving the foregoing issues. There should be targeted training programmes for different stakeholder groups. Mediator mentorship programmes should also be established for building a skilled and diverse mediation workforce. By tailoring training to specific stakeholder needs and providing ongoing support through mentorship, this recommendation can ensure the development of mediators who are well-equipped to navigate the intersections of food security, health, and conflict resolution.

⁴⁸Wertheim, E., Freeman, E., and Trinder, M., 'Enhancing relationships in school communities: Promoting cooperative conflict resolution and respect for cultural diversity in schools.' In *Peace psychology in Australia* (pp. 139-160). Boston, MA: Springer US.

CHEMICAL CHARACTERIZATION OF *PROTEA MADIENSIS* EXTRACT AND ITS ANTIDIABETIC ACTIVITY

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ABSTRACT

Protea madiensis, a flowering shrub belonging to the *Protea* genus (Proteaceae) found in southern Nigeria, is traditionally known for its ethnomedicinal properties in wound healing and antibacterial properties. This study aimed at investigating chemistry, and the inhibitory activity against α -glucosidase and α -amylase enzymes. The leaves of *P. madiensis* were air-dried, powdered and soaked in methanol to obtain the methanol extract. Column chromatography (CC) was used for the fractionation and the isolation of phytoconstituents. Four compounds were isolated and chemically characterized using spectroscopic techniques and some were identified using LC-MS. Compound **3** showed the highest inhibition of α -glucosidase with an IC_{50} value of 28.9 ± 2.8 μ g/mL. In contrast, fraction XIII showed inhibition for both α -glucosidase and α -amylase with IC_{50} of 32.7 ± 3.7 and 48.8 ± 6.2 μ g/mL respectively. This research has provided valuable clues for the further utilization of *P. madiensis* leaves as potent inhibitors of α -glucosidase with promising anti-diabetic activity.

Keywords: α -Amylase, α -Glucosidase, Antidiabetic, Phytochemicals, LC-MS

INTRODUCTION

Diabetes mellitus (DM) is an endocrine metabolic disorder characterized by abnormal levels of glucose in the bloodstream (Dirir *et al.*, 2022). Factors like oxidative stress, obesity, and sedentary lifestyles contribute to cell alterations. Type I requires insulin injections, while type II can be managed with synthetic antidiabetic agents. However, these drugs are limited due to low bioavailability, high production costs, and side effects (Etsassala *et al.*, 2020). Natural products have been found to have anti-diabetic potential. Inhibitors of α -glucosidase and α -amylase delay the breaking down of carbohydrates in the small intestine and diminish the postprandial blood glucose excursion. An effective means of lowering the levels of postprandial hyperglycemia is via α -amylase and α -glucosidase inhibitors (Kashtoh and Baek, 2023). Inhibitors of α -glucosidase and α -amylase isolated from medicinal plants can serve as an alternative drug with increased potency and fewer adverse effects than existing synthetic drugs (Kazeem *et al.*, 2013).

Protea madiensis Oliv. is a flowering shrub (3 to 6 m high) belonging to the family Proteaceae. The morphologic features of this plant have been described (Doutrelepont *et al.*, 1995). Not much is known of its medicinal uses. However, the root bark of *P. madiensis* is prepared in Rwanda to treat skin disease, hyperpigmentation, or for voluntary depigmentation (Kamagaju *et al.*, 2013) to cure diarrhea in Uganda (Beard, 1962). Nigerian traditional healers also prepare liquid extracts from fresh leaves, which are directly applied to wounds or burns to enhance their healing (Udegbumam *et al.*, 2012). The stem bark can be used to treat headaches, diarrhea, malarial fever, amenorrhea, and epilepsy. (Gadea *et al.*, 2022). In Cameroon, *P. madiensis* is traditionally used for carious teeth, hemorrhoids, sores, and eye worm diseases (Gadea *et al.*, 2022).

No previous report has been given on the anti-diabetic properties of *P. madiensis* nor the mechanism by which it exerts this effect. However, some species in the Proteaceae family exhibit anti-diabetic properties. For example, the leaves and flowers of *Oreocallis grandiflora* contain flavonoids and have the potential to be used in anti-inflammatory and diabetes treatments (Vinueza *et al.*, 2018). This study aimed to evaluate the effect of *P. madiensis* leaf extracts and isolated compounds on the activities of α -glucosidase and α -amylase.



Figure 1: Picture of *Protea madiensis* (Fischer *et al.*, 2010)

MATERIALS AND METHODS

Plant Materials

Fresh leaves of *P. madiensis* were collected from the Southern savanna area in the South-West region of Nigeria and authenticated by a qualified taxonomist at Ekiti State University, Ado-Ekiti, Ekiti State, Nigeria. A specimen with Voucher number UHAE-2023079 was deposited at the departmental herbarium for future reference.

Preparation of plant extract

The leaves were air-dried at room temperature and ground into powder. About 1kg of the powdered leaf sample was extracted with 90% methanol at 60 °C for two hours. The resulting extract was filtered, and the filtrate was concentrated on a rotary evaporator at 40 °C to obtain 110 g total extract. The extract was stored at – 20 °C until use.

Chemical and reagents

The 1D (¹H, ¹³C, and DEPT-135) and 2D NMR (COSY, HSQC, HMBC) spectra were recorded on Avance 400 MHz NMR spectrometer (Bruker, Rheinstetten, Germany) at 400 (¹H) and 100 (¹³C) MHz. Chemical shifts were reported in parts per million (ppm) and coupling constants (J) in Hz. Proton and carbon values are relative to the internal standard TMS and were acquired in CDCl₃ and DMSO. LC-MS and HRESI-MS were obtained on a Waters Synapt G2 mass spectrometer (Cone Voltage 15 V), which was operated in the negative and/or positive ion mode using direct injection. Column chromatography was performed using Sephadex (LH-20, Sigma-Aldrich) and silica gel 60 (70-230 mesh ASTM, Merck). TLC was performed on silica gel aluminium sheets (Silica gel 60 F₂₅₄, Merck) to monitor the fractions. Visualization was achieved with vanillin sulfuric acid reagent and heating to 105 °C.

Extraction and Fractionation of the total extract

A fraction of the total extract (80.0 g) was applied to a silica gel column and eluted using a gradient of hexane/EtOAc in order of increasing polarity. Fifty-five (55) fractions (500 mL each) were collected and combined according to their TLC profiles to yield thirteen main fractions labeled I-XIII.

Isolation of Pure Compounds

Main fraction VI (500 mg) was subjected to successive silica gel column using DCM:MeOH gradient (100:0, 95:5, 90:10, 85:15) elution, to yield a total 42 fractions. Fractions VI15-20 showed a white precipitate, which resulted in compound **1** (β-sitosterol) (3.8 mg). Fraction XI (176 mg) was subjected to successive Sephadex LH-20 columns using MeOH: H₂O (50:50), to produce compounds **2** (catechin) (7.2 mg) and **3** (epi-catechin) (8.7 mg). Fraction XIII (180 mg) was subjected to the Sephadex LH-20 column using MeOH: H₂O (70:30), and this yielded compound **4** (kaempferol glycoside) (10 mg).

Bioassays

α-Glucosidase inhibitory assay

The inhibitory activity of the plant extracts and isolated compounds against α-glucosidase from *Saccharomyces cerevisiae* was determined by slightly modifying the method reported by Kim *et al.* (2000) and Sarmadi *et al.* (2012). The reaction mixture of 50 μL of phosphate buffer (50 Mm, pH 6.8), sample (10 μL, 200 μg/mL), and 50 μL of α-glucosidase solution (1U/mL) was incubated at 37 °C for 15 minutes in a 96 well plate. After the initial incubation, 20 μL of 5 mM substrate, which was p-nitrophenyl-α-D-glucopyranoside (p-NPG), was added to the reaction mixtures in the 96 well plates and incubated at 37 °C for 20 mins. Then the enzymatic reaction was terminated by adding 0.1 M

sodium carbonate (Na_2CO_3) solution (50 μL). The enzymatic hydrolysis of the substrate was monitored by the amount of *p*-nitrophenol liberated in the reaction mixture at 405 nm using the AccuReader M965 Metertech (V1.11) spectrophotometer. Control without enzyme (C) was prepared by substituting enzyme with the phosphate buffer, while in control with enzyme (CE), DMSO, which is diluted to the same concentration as the samples, was used in place of the test samples. Acarbose at different concentrations was used as the positive control. All experiments were done in triplicates and the % inhibitory activity of the samples on α -glucosidase was calculated using equation 1. IC_{50} of samples with good inhibitions were determined as earlier described. The results were expressed as a percentage inhibition, calculated using Formula for (1).

$$\text{Inhibitory activity (\%)} = (1 - A/B) \times 100$$

where A is the absorbance in the presence of the test substance and B is the absorbance of the control.

α -Amylase inhibitory assay

The α -amylase inhibition assay was conducted according to the slightly modified standard method by Kim *et al.* (2000) and Sarmadi *et al.* (2012). In a 96-well plate, 50 μL of phosphate buffer (0.01 M, pH 6.9), 20 μL of porcine pancreatic α -amylase (2 U/mL) solution and the test samples (20 μL) were added and incubated at room temperature for 20 minutes. Afterwards, 20 μL of 1 % soluble starch was added to the well plates and incubated further for 30 minutes at room temperature after which the reaction was stopped by the addition of 90 μL of 3, 5-dinitro salicylic acid (DNS). The reaction mixture was placed in a boiling water bath for 10 minutes and the absorbance was read at 540 nm. Acarbose, at various concentrations, was used as a standard, and each experiment was done in triplicate. The percentage inhibitory activity of the α -amylase was calculated using equation 1.

Statistical analysis

Data were recorded and analyzed statistically using MedCalc for Windows, version 19 (MedCalc Software, Mariakerke, Belgium). Data was tested for normality and analyzed further using the independent t-test, repeated measures ANOVA, and one-way ANOVA. A P-value of less than 0.05 was considered significant. Dose response curves and IC_{50} values were generated using GraphPad Prism for windows, version 9.0.0 (121) (GraphPad Software, San Diego, US).

Results and Discussion

Four compounds (Figure 2) were isolated from different fractions of the *P. madiensis* crude extract. The structures were determined by comparing the 1D (^1H , ^{13}C , and DEPT-135) and 2D NMR (HSQC and HMBC) spectroscopic data to the reported ones from the literature. All the compounds are reported for the first time in this plant of study.

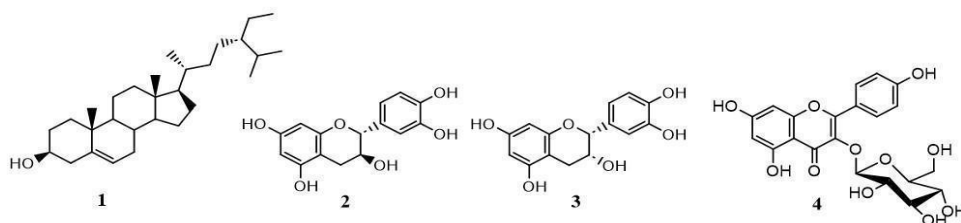


Figure 2: Chemical structure of compounds isolated from *P. madiensis*

Structural elucidation of the isolated compounds

The comparison of the NMR spectroscopic data with those previously published led to the structure elucidation of the isolated compounds as β -sitosterol (**1**) (Leon *et al.*, 2014), catechin (**2**) (Leon *et al.*, 2014; Masike *et al.*, 2019), epicatechin (**3**) (Leon *et al.*, 2014; Masike *et al.*, 2019), and kaempferol-3-O-glucoside (**4**) (Meng *et al.*, 2019).

α -Glucosidase and α -amylase inhibition assay

The MeOH extract and sub-fractions of *P. madiensis* were screened for their α -glucosidase and α -amylase inhibitory activity against α -glucosidase and α -amylase enzymes (Table 1). The preliminary screening was done at a working concentration of 100 $\mu\text{g/mL}$ of the samples. Among the fractions from the crude extract, IX, X, XI, XII, and XIII showed the highest inhibition against α glucosidase enzymes (98.7%, 99.4%, 99.6%, 84.6% and 97%), respectively. The MeOH extract showed a moderate inhibition of 61.7% (at 100 $\mu\text{g/mL}$) and compound **3** amongst the isolated compounds showed 98.5% inhibition as well. Acarbose was used as a positive control, and it showed an inhibition of 61% at 100 $\mu\text{g/mL}$. The same samples were screened against α -amylase, and sample XIII showed the highest inhibition (86.1%), whereas sample IX and the MeOH crude extract both showed a

moderate inhibition of 58.4 and 67.7%, respectively. Acarbose was used as a positive control, and it showed an inhibition of 90.8% at 100 µg/mL. Among the compounds isolated from *P. madiensis*, compound **3** showed the highest α-glucosidase inhibitory activity with IC₅₀ values of 28.9 ± 2.8 µM whereas other compounds showed weak to no inhibition (Table 1). Inhibition of α-glucosidase and α-amylase by the five fractions from the methanol extract of *P. madiensis* leaves were evaluated (Table 2). The IC₅₀ values for α-amylase and α-glucosidase inhibition were 20.25 ± 1.23 and 130.2 ± 1.8 for acarbose. The other fractions, such as MeOH crude, IX, X, XI, XII and XIII, showed IC₅₀ values of 51.1 ± 5.9, 53.1 ± 6.8, 30.4 ± 2.7, 47.8 ± 5.3, 51.9 ± 4.1 µg/mL and 32.7 ± 3.7 µg/mL on α-glucosidase respectively. The MeOH crude extract and IX showed a weak inhibition against α-amylase with IC₅₀ values of 187.9 ± 9.6 and 204.9 ± 12.9 respectively. The present study demonstrated a creditable inhibitory activity of fractions from leaves of *P. madiensis* on the carbohydrate metabolizing enzymes. This therapeutic approach can be advised to delay the availability of dietary carbohydrate substrate for glucose production in the gut.

Table 1. The IC₅₀ (µg/mL) values of different fractions and pure compounds from *P. madiensis*

Extracts/Compounds	a-glucosidase	a-amylase
MeOH Crude extract	51.1 ± 5.9	187.9 ± 9.6
OM-IX	53.1 ± 6.8	204.6 ± 12.9
OM-X	30.4 ± 2.7	nd
OM-XI	47.8 ± 5.3	nd
OM-XII	51.9 ± 4.1	nd
OM-XIII	32.7 ± 3.7	48.8 ± 6.2
1	Nd	nd
2	Nd	nd
3	28.9 ± 2.8	nd
4	30.9 ± 2.3	nd
Mixture (2+3)	31.6 ± 3.7	nd
Acarbose	130.2 ± 1.8	20.25 ± 1.23

nd: not determined.

LC-MS analysis of the active fractions of the leaves of *P. madiensis* led to the identification of sixteen constituents from the extracts. The identification of the constituents (compounds) was based on the peak area, retention time and molecular formula with the help of available mass spectra *m/z* databases such as Mass Bank of Europe & National Library of Medicine and related literature reviews. Table 2 shows the proposed compound name, mass (*m/z*), retention time and its molecular formula.

Table 2: Phytoconstituents identified from *P. madiensis* by LC-MS

Peak	Proposed compound	<i>m/z</i>	R _t (min)	[M-H] ⁺	Molecular formula	Crude	OM-IX	OM-X	OM-XI	OM-XII
1	Arbutin	273.1	3.79	[M+H] ⁺	C ₆ H ₁₂ O	+	-	-	-	-
2	Procyanidin B	579.2	4.61	[M+H] ⁺	C ₃₀ H ₂₆ O ₁₂	+	-	-	-	-
3	Dihydroferulic acid	197.1	5.32	[M+H] ⁺	C ₁₂ H ₁₂ O ₈	-	-	+	+	-
4	Floribol A/E	551.3	6.02	[M+H] ⁺	C ₃₆ H ₅₄ O ₄	+	-	-	-	+
5	Sinapic acid	225.2	7.93	[M+H] ⁺	C ₁₁ H ₁₂ O ₅	-	-	+	-	-
6	Icariside F ₂	403.2	7.77	[M+H] ⁺	C ₁₈ H ₂₆ O ₁₀	-	-	-	+	-
7	Lapachol	277.2	7.89	[M+Na] ⁺	C ₁₅ H ₁₄ O ₃	-	-	-	+	-
8	Glucogallic acid	333.2	8.90	[M+H] ⁺	C ₁₃ H ₁₆ O ₁₀	-	-	-	+	-

9	<i>p</i> -Hydroxybenzoyl calleryanin	445.2	8.64	[M+Na] ⁺ C ₂₀ H ₂₂ O ₁₀	-	+	-	-	-
10	Eximin	399.25	10.34	[M+Na] ⁺ C ₁₉ H ₂₀ O ₈	-	+	+	+	-
11	Rhamnocitrin-3-O-rutinoside	609.27	11.92	[M+H] ⁺ C ₂₇ H ₃₀ O ₁₅	+	-	-	-	+
12	Kaempferol-3-robinobioside	565.27	12.54	[M+H] ⁺ C ₂₇ H ₃₀ O ₁₅	-	-	-	-	+
13	Malvidin-3-coumaroyl-hexoside	639.28	12.72	[M+H] ⁺ C ₂₃ H ₂₅ O ₁₂	-	+	-	-	-
14	Kaempferol 3,7-Di-O-methyl-4'-O- -α-rhamnopyranosyl-(1→2)- β-glucopyranoside	623.28	12.82	[M+H] ⁺ C ₂₉ H ₃₅ O ₁₅	+	+	-	-	-
15	Pheophorbide b	607.29	13.13	[M+H] ⁺ C ₃₅ H ₃₄ N ₄ O ₆	+	+	-	-	-
16	Isorhamnetin dihexoside	3,7- 663.45	13.85	[M+H] ⁺ C ₂₈ H ₃₂ O ₁₇	+	+	+	+	+

CONCLUSION

Natural products continue to be viewed as valuable resources for discovering new drugs and are crucial to developing existing ones. The plant extracts' inhibition and activity may be attributed to the synergistic effect between the present compounds and the isolated pure compounds. *Protea madiensis* leaf extracts have potential applications as dietary supplements and a source for developing antidiabetic therapies. Additionally, further studies should be conducted to determine its mode of action.

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**DIRECT SPEECH-TO-SPEECH MULTILINGUAL LANGUAGE TRANSLATION MODEL USING
LONG SHORT-TERM MEMORY (LSTM): A PROPOSED MODEL**
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ABSTRACT

Nigeria's linguistic diversity presents communication barriers among ethnic groups, hindering effective dialogue, conflict resolution, and economic stability. This is particularly critical in healthcare, where language discrepancies can compromise patient representation and medication safety. This research proposes a novel approach to a multi-lingual speech translation system powered by deep bidirectional long short-term memory (DBLSTM) networks. The system will be trained on speech datasets collected from native speakers of three indigenous Nigerian languages. Following data pre-processing and feature extraction, a DBLSTM network will be trained to facilitate real-time speech translation. The resulting model will be integrated into a user-friendly mobile application with Python scripts. The system's effectiveness will be evaluated through speaking rate, speech naturalness, and WER. The successful implementation of this research has the potential to bridge communication gaps in the Nigerian health sector.

Keywords: speech translation, DBLSTM, generative AI, multilingual, Nigerian Language

INTRODUCTION

Nigeria is a multi-ethnic country with over 371 ethnic groups speaking over 525 languages (Omaka, 2021). Nigeria is one of the most ethnically and linguistically diverse countries in the world (Akindele, Olatundun & Akano, 2022). The three largest ethnic groups are the Hausa, Yoruba, and Igbo, but there are many other smaller groups, each with its own unique culture and language (Davis & Kalu-Nwiwu, 2001). Hausa was the most widely spoken local language in Nigeria, as it was used by more than 48 million people. The second most popular spoken language is Yoruba with approximately 39.5 million speakers, followed by Nigerian Pidgin, Igbo, and Fulfulde, which are recorded as 30 million, 27 million, and 22 million speakers respectively as illustrated in Figure 1 (Sasu, 2022).

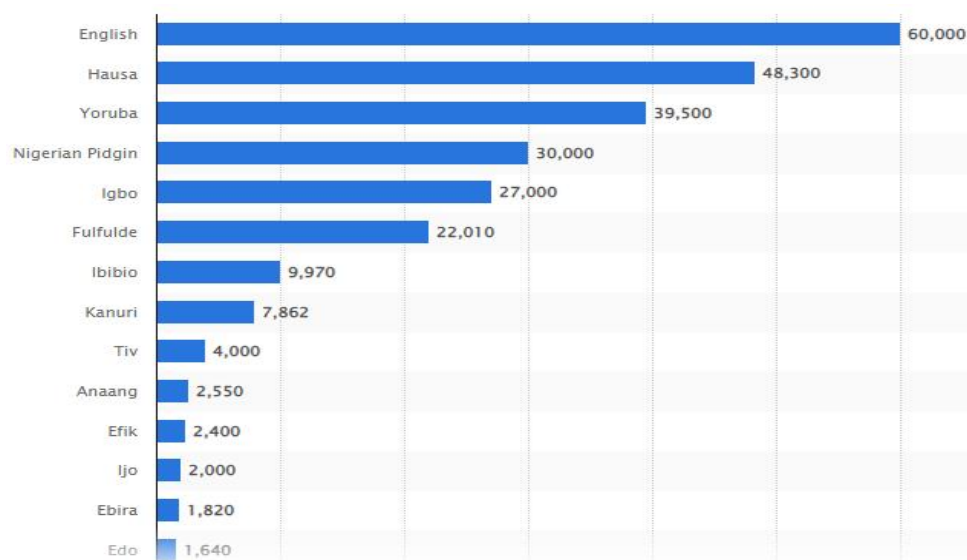


Figure 1: Statistical analysis of the languages spoken in Nigeria as of 2021, by number of speakers (Sasu, 2022).

This diversity of languages can be a barrier to communication and collaboration, especially in healthcare care, educational, commercial, and government settings. Language barriers are a significant challenge for Nigeria's diverse population, as people speak many different native languages. This can make it difficult for people to communicate with each other, which can lead to misunderstandings, grievances, and conflict. It can also make it difficult for people to access essential services such as healthcare and education. Language barriers also have a negative impact on the economy, as they can make it difficult for businesses to operate and for people to find employment. For example, language barriers can impact the economy and community stability in Nigeria as follows:

- i. A medical doctor may be unable to provide proper treatment to a patient if they cannot communicate with each other.
- ii. A trader may be unable to sell their goods to a farmer if they cannot speak the same language.
- iii. A teacher may be unable to teach their pupils effectively if they cannot speak the same language.
- iv. People may be reluctant to use public services if they cannot communicate with the staff.
- v. Businesses may be unable to operate effectively if their employees cannot speak the same language.

To overcome these challenges, it is important to invest in language education and to promote the use of translation and interpretation resources to create an environment where people from different language backgrounds feel respected and valued while the country's many different languages and cultures are respected and preserved.

Speech translation systems (STS) are a new technology that allows people who speak different languages to communicate with each other in real-time. Google and Microsoft are the leading companies in the development of STS, but their systems do not support Nigerian local dialects. Speech-to-speech translation is the process of instantly translating spoken words from one language to another. It works by combining three different technologies: automatic speech recognition (ASR), machine translation (MT), and text-to-speech (TTS). ASR transcribes the spoken words into a text format. MT translates the text from the source language to the target language. TTS converts the translated text back into speech.

The speech-to-speech translation is the process through which conversational spoken phrases are instantly translated and spoken aloud in another (second) language (Ajao et al. 2022; Ajao et al. 2023). This speech translation technology, called automatic speech recognition system (ASRS) enables various speakers of different languages to communicate fluently, sharing ideas, express the emotional feeling without much barriers (Alshamsi & Kepuska, 2020). The speech-to-speech translation model were integrated with three different technologies for the efficient performance in the

architecture, which includes automatic speech recognition (ASR), machine translation (MT) and voice synthesis (TTS). The automatic speech recognition component processes the voice in its original language, resulting in a text version that is translated to the target language by the MT component (Islam et al. 2018). At the end of the processing, the translated text is sent into the text-to-speech component which "speaks" the text in a synthesized voice (Duarte et al. 2014) as illustrated in Figure 2.

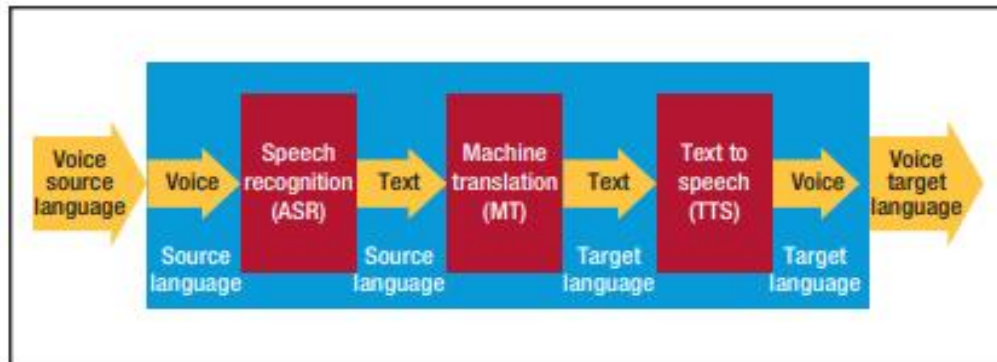


Figure 2: Machine translation (MT) components. (Source: Duarte, et al. 2014).

Speech translation is a promising technology that can overcome this language barrier. Speech translation systems allow people to communicate with each other in real time, even if they do not speak the same language. Deep learning-based speech translation systems have the potential to achieve high accuracy and fluency, especially when trained on large datasets of speech and text data (Singh et al. 2023). However, developing such systems for multilingual speech translation is a challenging task, especially for countries with a high diversity of languages like Nigeria. The dataset scarcity has made it difficult for extending the speech-to-speech language translation model for usefulness and conversation among the multi-ethnicity groups in Nigeria. Some of other problems are unclear word boundary of spoken language, multiple optional inputs, fewer grammar constraints of spoken language, and incorporating incoherence of spoken language. These identified problems have necessitated the research institute to organized the international workshop on spoken language translation model development and international consortium for research on speech-to-speech translation model (Etchegoyhen et al. 2022). STS is a valuable tool for many settings, such as medical facilities, schools, police stations, hotels, retail stores, and factories. So, the development of STS that can support Nigerian local dialects and would be a valuable contribution to the country. It would help to improve communication and understanding between people from different language backgrounds, and it would also make it easier for people to access services such as healthcare and education. It can help people to communicate and access services even if they do not speak the same language. It is important to develop STS that can support Nigerian local dialects. This would help to improve communication and understanding between people from different language backgrounds in Nigeria.

In this research, we propose a novel standalone expert system model for direct speech-to-speech multilingual language translation using deep long short-term memory (LSTM) autoencoders. Our proposed system is specifically designed for the multilingual spoken among the multi-ethnic population in Nigeria. This language translation model is experimented on a large dataset of speech and text data from the country's major ethnic groups and will truly serve everyone to provide solution of the data scarcity. It will also help to provide standard models for different languages translation, recognition and conversion in Nigeria, and provide efficient platform to evaluate the results for improvement.

Speech-to-speech multilingual language translation (S2S MT) is a challenging task that requires the ability to encode speech in one language, translate it into another language, and then synthesize speech in the target language (Gao et al., 2006). The design of end-to-end direct multilingual translation systems is an emerging natural language processing research field, with some of the following existing relevant literature.

Ìyàndá et al. (2014) developed a system for generating the phonemic transcription of Yoruba text. They collected and digitized standard Yoruba text data and corrected the orthography using the Tákádá text editor and Àkótó Yoruba software. They then recorded the corresponding speech data in a quiet environment using a noise-canceling microphone on a typical multimedia computer system

using the Speech Filing System software. The speech data was then analyzed and annotated using the PRAAT speech processing software.

Jia et al. (2022) present a neural direct speech-to-speech translation model that was trained using end-to-end. Translatotron 2 consists of a speech encoder, a linguistic decoder, an acoustic synthesizer, and a single attention module that connects them together. Experimental results on three datasets consistently show that Translatotron 2 outperforms the original Translatotron by a large margin on both translation quality (up to+ 15.5 BLEU) and speech generation quality and approaches the same of cascade systems. a simple method for preserving speakers' voices from the source speech to the Ttranslation speech in a different language. The proposed method can preserve each speaker's voice on speaker turns without requiring for speaker segmentation.

Liu et al. (2021) proposed a unified system for multilingual automatic speech recognition (ASR) and language identification (LID) using neural network and hidden Markov model (HMM) based models. This system addresses the multilingual speech recognition problem where the first speech recognition module contains one language, and the language is identified at the utterance level. The second instance considers multiple languages in the same speech stream and requires dynamic language switching. The LID and ASR modules are combined in real time to complement each other. The enhanced LID module achieves an accuracy of 99.3%, and the multilingual ASR system achieves an accuracy of 92.4%.

This proposed S2S translation system consists of two main components: a speech recognition component and a machine translation component. The speech recognition component is used to convert speech input into a sequence of text tokens. The machine translation component is used to translate the text tokens into the target language. This system will be evaluated on a variety of multilingual speech translation tasks involving the major ethnic groups in Nigeria and the expected results will outperform the state-of-the-art in the area of unique local language translation and recognition.

MATERIALS AND METHOD

The initial stage is to collect a large corpus of parallel text and speech data in the eight languages listed as follows: English, Nupe, Fulfude, Gwari, Ilaje, Igbo, Yoruba, and Hausa. This consists of the same speech utterances in the eight aforementioned languages. The data will be collected by recording Native speakers among young people and old people that will represents the patient in the hospital and adults in urban and rural areas as the best approach to collect high-quality parallel speech data. Extensive dataset will be acquired to cover a wide range of individuals multiethnicity language spoken from sources such as doctors, professional native speakers and so on, especially in the medical domains. The collected dataset will be preprocessed to reduce noise and unify the format for speech encoding as presented in Figure 3. This preprocessing will include tasks such as:

- i. Cleaning and transcribing the data, which involves removing noise from the recordings and transcribing the speech
- ii. Aligning the data by finding the corresponding sentences in the eight aforementioned languages.
- iii. Splitting the data into training, development, and testing. The training set will be used to train the model, the development set will be used to evaluate the model during training, and the test set will be used to evaluate the model after training.

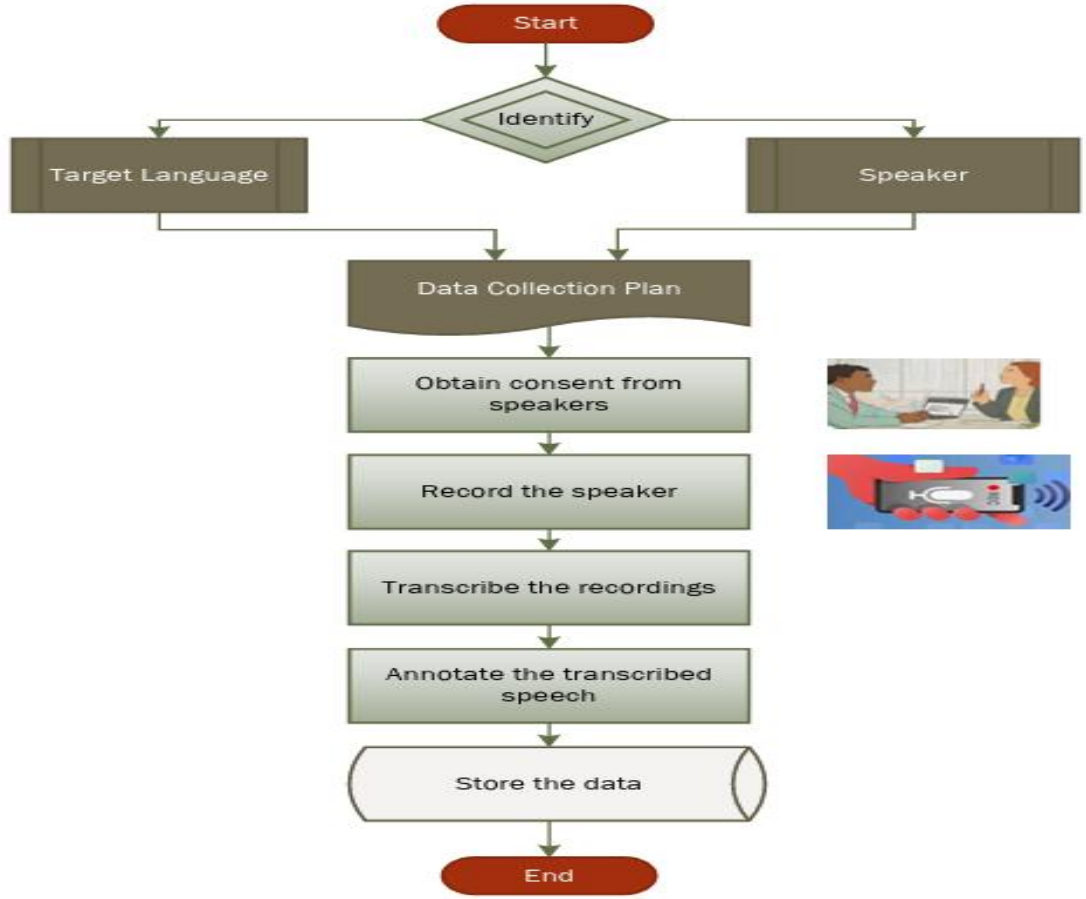


Figure 3. The flowchart of speech-to-speech data spectrogram

The LSTM autoencoder model is trained on the preprocessed data. This model is trained to learn the statistical relationships between words and phrases in different languages. The system model includes new candidate generated, the activation function using tanh, the input gate, the forget gate and the output which can be expressed mathematically as given in Equations 1-5. The mathematical model for the encoder and decoder unit of the system is given in Equations 6-10.

$$C^{N<t>} = \tanh(W_c[a^{<t-1>}X^{<t>}] + b_c, \quad (1)$$

$$\Gamma_u = \sigma(W_u\{A^{<t>}, X^{<t>}\} + b_u \quad (2)$$

$$\Gamma_f = \sigma(W_f\{A^{<t>}, X^{<t>}\} + b_f \quad (3)$$

$$\Gamma_o = \sigma(W_o\{A^{<t>}, X^{<t>}\} + b_o \quad (4)$$

$$\text{output} \begin{cases} c^{<t>} = \Gamma_u * c^{N<t>} \\ a^{<t>} = \Gamma_o * c^{<t>} + \Gamma_u * c^{<t-1>} \end{cases} \quad (5)$$

Encoder Unit:

$$h_t = f(x_t, h_{t-1}, c_{t-1}) \quad (6)$$

$$c_t = g(x_t, h_{t-1}, c_{t-1}) \quad (7)$$

Decoder Unit:

$$y_t = h_t \quad (8)$$

$$h_t = f(y_t, h_{t-1}, c_{t-1}) \quad (9)$$

$$c_t = g(y_t, h_{t-1}, c_{t-1}) \quad (10)$$

where:

- x_t is the input vector at time step t
- h_t is the hidden state at time step t
- c_t is the cell state at time step t
- y_t is the output vector at time step t
- f and g are non-linear functions, such as the sigmoid or tanh function

The encoder of the system takes the input vector x_t and produces a hidden state h_t and a cell state c_t . The decoder then takes the hidden state h_t and produces an output vector y_t . The goal of the model is to minimize the reconstruction error between the input vector x_t and the output vector y_t . The encoder takes the input vector x_t and produces a hidden state h_t and a cell state c_t . The hidden state h_t represents the learned features of the input vector x_t , while the cell state c_t stores long-term information about the input sequence. The encoder consists of three gates: the input gate, the forget gate, and the output gate. These gates control how the hidden state h_t and the cell state c_t are updated. The input gate controls how much of the input vector x_t is added to the cell state c_t . The forget gate controls how much of the previous cell state c_{t-1} is forgotten. The output gate controls how much of the hidden state h_t is output from the encoder.

The decoder takes the hidden state h_t and produces an output vector y_t . The output vector y_t represents the reconstructed input vector x_t . The decoder consists of two gates: the input gate and the output gate. These gates control how the hidden state h_t is updated and how the output vector y_t is produced. The input gate controls how much of the previous hidden state h_{t-1} is added to the current hidden state h_t . The output gate controls how much of the hidden state h_t is output from the decoder.

The following is an algorithm for a bidirectional long short-term memory (LSTM) model for direct speech-to-speech multilingual language translation:

Algorithm for Direct Speech-To-Speech Multilingual Language Translation Model using Bidirectional Long Short-Term Memory (LSTM) Model

$x = (x_1, x_2, \dots, x_T)$ – Input sequence

$y = (y_1, y_2, \dots, y_T)$ – Output sequence

Connectionist temporal, $P(K, t|x) = \frac{\exp(y_t^K)}{\sum_{K'} \exp(y_t^{K'})}$

The output layer contains a single unit for each of the transcription label

$a = (a_1 \dots a_T) \rightarrow CTC \text{ alignment}$

$B \rightarrow$ Operator that remove blank space and repeated labels

$B(a - bc - -) = abc = B(- - a - bc)$

$P_r(z|x) = \sum_{a \in B^{-1}(x)} P_r(a|x)$

$z = (z_1 \dots z_T) \rightarrow target \text{ sequence}$

$CTC(x) = -\log P_r(z|x) \rightarrow Objective \text{ function}$

+Expected Transcription Loss

$L(x) = \sum_x P_r(z|x) L(x|z) \text{ real valued transcription}$

$$L_x \approx \frac{1}{N} \sum_{i=1}^N L(x, B(a^i)), a^i \sim P_r(a|x)$$

$$\frac{\partial \log P_r(a|x)}{\partial \log P_r(t|x)} = \frac{\delta a, k}{P_r(K, t|x)}$$

$$\nabla_{xf(x)} = f(x) \nabla_x \log f(x)$$

$$\frac{\partial L(x)}{\partial P_r(k, t|x)} = \sum_a \frac{\partial P_r(a|z)}{\partial P_r(k, t|x)} L(x, B(a)) = \sum_a \Pr(a|x) \frac{\partial \log P_r(a|x)}{\partial P_r(k, t|x)} (L(x, B(a)))$$

$$\frac{\partial L_x}{\partial \Pr(k, t|x)} \approx \frac{1}{N} \sum_{i=1}^N L(x, B(a^{i,t,k}))$$

$$a^i \approx P_r(a|x)$$

$$a_t^{i,t,k} = a_t^i \forall t \neq t, a_t^{i,t,k} = K$$

$$\frac{\partial L(x)}{\partial y_t^2} \approx \frac{P_r(K, a|z)}{N} \sum_{i=1}^N (L(x, B(a^i)) - z(a^i, t))$$

$$z^i(a^i, t) = \sum_x \Pr(k', t|x) L(x, B(a^{i,t,k'}))$$

Decoding algorithm beam search

Initialise $B \leftarrow \{\phi\}; P_r(\emptyset, 0) \leftarrow 1$

for $t = 1 \dots T$ **do**

$\hat{B} \leftarrow$ the W is the most probable sequences in B

$B \leftarrow \{ \}$

for $y \in \hat{B}$ **do**

if $y \neq \emptyset$ **then**

$P_r^*(y, t) \leftarrow P_r^*(y, t-1) P_r(y^t, (a|x))$

if $\hat{y} \in \hat{B}$ **then**

$P_r^*(y, t) \leftarrow P_r^*(y, t) + P_r(y^*, \hat{y}, t)$

$P_r^-(y, t) \leftarrow P_r^-(y, t-1) + P_r(-, (a|x))$

Add y to B

for $k = 1 \dots K$ **do**

$P_r^-(y+k, t) \leftarrow 0$

$P_r^*(y+k, t) \leftarrow P_r(K, y, t)$

Add $(y+K)$ to B

Return: $\max y \in B P_r^*(y, T)$

An expert system-based mobile application program interface will be developed as a third-party system that can ease the interaction between the two parties of different language spoken such as the case of medical personnel and the patient in the hospital. Also, as the case may be in the police station where the expression of suspect information is required to be captured for further investigation. This mobile expert system development can be achieved using python language, HTML, Javascript, and structured query language (SQL) for both front-end and back-end design. The complete expert system framework which comprises the integration of objectives 1, 2, 3, and 4 into the architecture as presented in Figure 4.

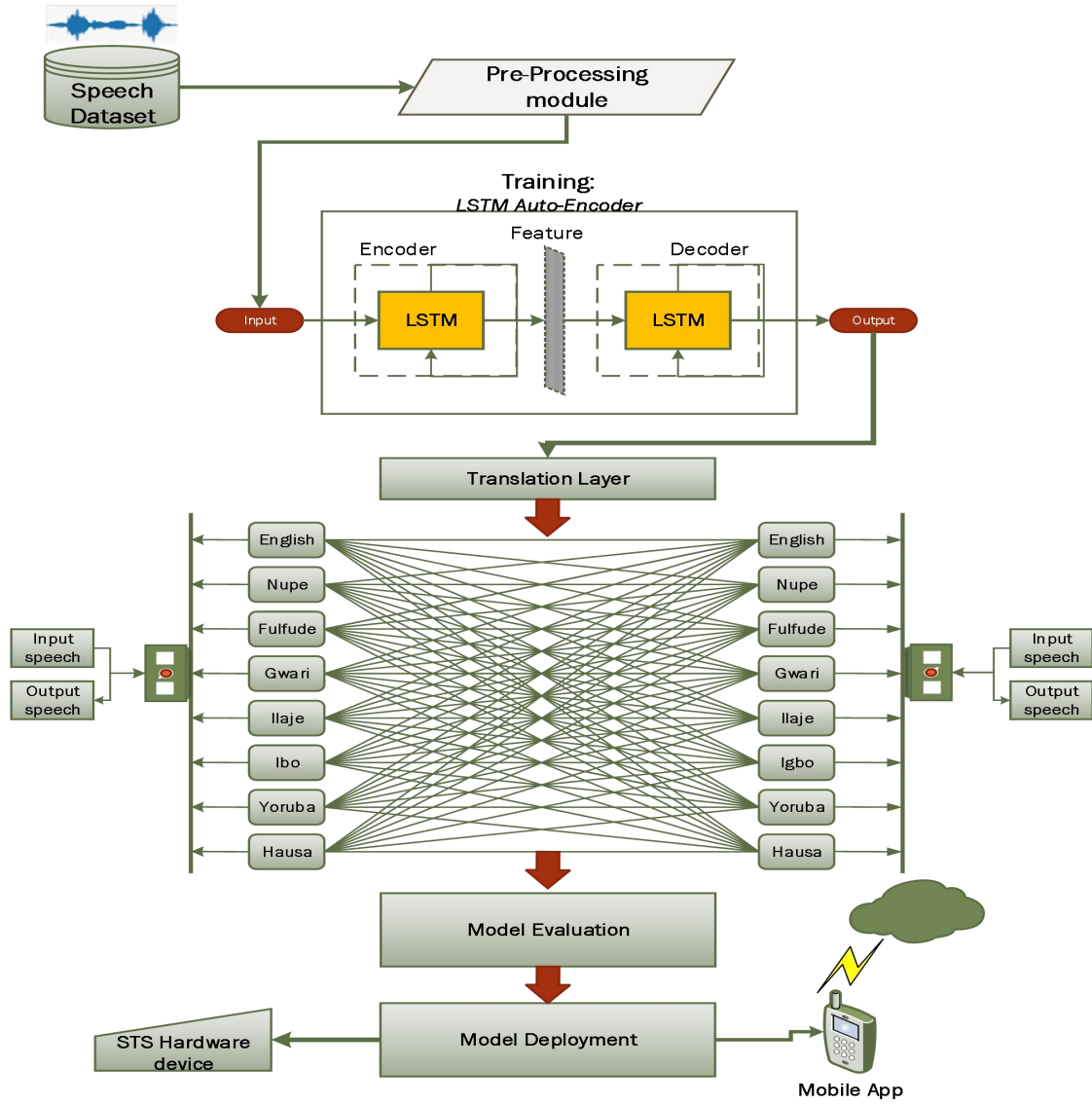


Figure 4. Complete system architecture

The developed system shall be evaluated using standard metrics such as translation accuracy, speech sensitivity, precision, fluency, and naturalness. Also, metrics such as speed, Word Error Rate and Character Error Rate will be used as the performance evaluation metrics as shown in Equation 11-16.

$$\text{Speech naturalness} = \frac{\text{Average rating of human listeners}}{5} \quad (11)$$

$$\text{Speech naturalness} = \frac{\text{Weighted sum of objective measures}}{\text{Total weight}} \quad (12)$$

$$\text{Weighted sum of objective measures} = (\text{Measure 1} \times \text{Weight 1}) + (\text{Measure 2} \times \text{Weight 2}) + \dots + (\text{Measure N} \times \text{Weight N}) \quad (13)$$

Where:

- Measure i is the value of the i-th objective measure.
- Weight i is the weight of the i-th objective measure.

The weights can be assigned based on the importance of each objective measure

$$\text{Speaking rate (WPM)} = \frac{\text{Total number of words in the translated speech}}{\text{Duration of the translated speech (in minutes)}} \quad (14)$$

$$\text{WER} = \frac{\text{Number of insertions} + \text{Number of deletions} + \text{Number of substitutions}}{\text{Total number of words in the original text}} \quad (15)$$

$$\text{Accuracy} = \frac{\text{Number of correctly translated words}}{\text{Total number of words in the original text}}$$

(16)

RESULTS

The research will provide a solution to the national challenge of multilingual diversity in Nigeria with multi-ethnic groups by offering a third-party language translation system to eliminate language barriers among numerous ethnic groups. This proposed approach will allow for increased collaboration and engagement among people of various ethnicities and languages. These potential impact in terms of social, economic, and technological values include:

- i. Improved communication and understanding: The research can aid in the removal of language barriers and the improvement of communication and understanding between people from various cultures. Also, increased collaboration, innovation, and social cohesiveness can result from it.
- ii. Cultural heritage preservation: It can help to preserve and promote cultural heritage by digitizing and translating traditional stories, songs, and other cultural items into numerous languages.
- iii. Improved access to information and services: It can let people access information and services in their native language, no matter where they live.
- iv. Increased commerce and investment: The research can assist companies in expanding into new markets and increasing trade and investment. This has the potential to spur economic growth and employment creation.

CONCLUSION

In conclusion, this research proposes a novel approach to direct speech-to-speech multilingual language translation using Deep Long Short-Term Memory (LSTM) Autoencoders. By leveraging the power of deep learning and the ability of LSTMs to capture sequential dependencies, this model aims to achieve significant advancements in the field of natural language processing. The proposed system is expected to offer several benefits, including enhanced accuracy, real-time translation capabilities, and multilingual support. By addressing the limitations of existing methods, this research has the potential to revolutionize how people communicate across language barriers and foster greater global understanding. Future research directions could explore the integration of attention mechanisms, the use of larger datasets, and the adaptation of the model to specific domains such as medical or legal translation. Additionally, investigating the ethical implications of language translation technology is crucial to ensure its responsible and beneficial use.

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Informed Consent Statement: All the speech will be collected on the basis of the consent of the recorder

Data Availability Statement: Dataset gathered will be published on a platform that could serve as test bed for other researchers in the area.

Ethical Clearance: Ethical clearance will be obtained from the ethical committee of the health sector

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PREPARING NOVICE TEACHERS FOR THE REALITY OF THE CLASSROOM: A COMPARATIVE STUDY BETWEEN SOUTH AFRICA AND INDIA

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ABSTRACT

Preparing novice teachers for the realities of the multilingual classroom is a challenge, not only in South Africa, but across the world. This paper compares the experiences of English pre-service teachers in India and South Africa and their professional development as part of their transition into the classroom. Future teachers are to be equipped with the necessary knowledge, skills, and attitudes to succeed in today's dynamic teaching profession. Along with a core curriculum, project-based learning, technology integration and supervised teaching practice are essential elements in any teacher education programme. Not only lecturers, but also other stakeholders which include parents, students, alumni, advisory boards, school principals and officials from the department of education associated with both institutions, advised on intervention programmes which emphasised essential teaching skills such as lesson planning, instructional delivery, technology integration, assessment, and differentiated instructional strategies which cater to the diverse needs of learners. Data was collected via document analysis and interviews to determine the success of the current programmes and to reflect on the way forward. Activity Theory was used to identify inherent contradictions and boundaries in the collaboration between all participants. The findings show the importance of including stakeholders in the planning of the curriculum to ensure the successful transition of novice teachers into the classroom.

Keywords: activity theory, collaboration, language teachers, multilingualism, stakeholders, teacher education

INTRODUCTION

India, being one of the BRICS countries, is a very important partner for South Africa to collaborate with. There are many similarities between South Africa and India, with historic links between the two countries. However, unlike South Africa, the economy in India seems to be thriving, despite their 1.3 billion population. This paper compares the preparation of student teachers for multilingual classrooms in South Africa and in India. During their undergraduate studies, novice teachers are provided with knowledge, skills, and attitudes to start their careers in teaching. This paper looks at how teachers are prepared in two institutions of Higher Education, one a University of Technology in South Africa, and the other, a Private University in India. The study originated as part of a collaboration between the two institutions to explore practice and learn from each other in a supportive environment of collaborative research and knowledge exchange.

This collaboration started during an international faculty exchange visit of lecturers from the Faculty of Education at an institution in South Africa, to a private university in the north of India. International collaboration and hosting of international scholars, which exposes staff and students to lecturers and scientists from across the world, enhances critical thinking and dialogue, and is a priority at both these institutions. Two English lecturers collaborated to explore differences and similarities in the preparation of novice teachers for the realities of the classroom, which is a challenge, not only in South Africa, but also in India. The purpose of the study was to explore practices at both institutions, give students an opportunity to share their experiences as undergraduate students, and to learn from fellow students in a different country. The main research question was "*How are teachers prepared for the classroom in South Africa, versus India, and what can we learn from one another?*"

The elements included in the curricula of both institutions are based on current research on teacher education. According to Shulman (1986), "Pedagogical Content Knowledge" has been pivotal in teacher education, highlighting the necessity of combining content expertise with effective teaching methods to ensure successful teacher preparation. This perspective aligns with Grossman (1990), who found that teachers with strong content knowledge are better equipped to develop engaging and effective lessons, underscoring the importance of comprehensive subject matter training in pre-service programs. Similarly, Freeman and Johnson (1998) argue for a reconceptualization of the knowledge base for language teacher education, emphasising the integration of teachers' personal practical knowledge with theoretical foundations to create contextually relevant and responsive preparation programs. There is a need for high-quality teacher education programs that integrate strong content knowledge, pedagogical skills, and extensive practice to improve student outcomes

and educational equity (Darling-Hammond, 2006). It is important to reflect on how teachers are prepared for the classroom to ensure that teacher preparation is relevant and of the required quality, as is recommended by Ball, Thames, and Phelps (2008) who stress the importance of specialised content knowledge in teaching.

The strong focus on practice teaching that combines theory and practice at both institutions, is grounded in research. Smith and Sela (2005) emphasise the importance of practicum experiences for English teachers, advocating for structured support and feedback from experienced mentors to develop practical skills and confidence. Integrated programs that bridge theory and practice, offer student teachers opportunities to apply their knowledge in real classrooms with mentor guidance (Zeichner, 2010). Additionally, professional development workshops focusing on pedagogical skills as part of student teachers' preparation to go out on teaching practice sessions at schools, enhance their preparedness for diverse classroom settings (Richards, 2011), which strengthen the integration of coursework and practice teaching, especially when teaching specific skills such as reading literacy (Barends & Nel, 2017).

The study aimed to explore students' challenges at both institutions and to identify similarities and differences. Farrell (2007) identifies challenges faced by novice English teachers, such as classroom management and lesson planning, suggesting that mentorship and support systems are vital for a smooth transition into the profession. Teacher preparation programmes should be tailored to the specific context, including local educational policies and cultural norms (Borg & Alshumaimeri, 2012). Lastly, challenges posed by rigid prescriptive documents such as Annual Teaching Plans (reference), assessment-focused teaching, and inconsistencies in the Curriculum and Assessment Policy Statement (CAPS) in South Africa (Department of Basic Education, 2011) and the Curriculum Framework provided by the National Council for Teacher Education in India (National Council for Teacher Education, 2024) highlights a gap between theoretical training and real-world application, affecting new teachers' ability to effectively implement critical pedagogical approaches in English classrooms. These important trends in education were also identified by Nkealah and Simango (2023) in similar studies and guided the study and interview questions used in the discussion with students in the study.

METHODOLOGY

The study followed a qualitative case study approach, where two lecturers from the two institutions collaborated to compare the preparation of student teachers who will be teaching English in secondary schools (grade 8 to 12) in their respective countries (B Ed SPFET). This is the first phase to a longitudinal collaboration and exchange of knowledge between these two institutions. Data on the two programmes and experiences of students, was collected via a document analysis of the guidelines and curricula of the two institutions, as well as a small focus group interview with ten students in their third and fourth years of study at both institutions (five students from each institution). An open invitation to participate in the study, was sent to all third- and fourth year students at both institutions who are studying to become English teachers in secondary schools (grade 8 to 12). Ten students volunteered to participate in the study.

Document analysis

Curriculum documents which are used to plan and present courses in teacher education from the two institutions in this study were discussed and compared by the researchers. These documents included subject offerings, an overview of content and the lay out of the different programmes.

Interviews

The ten students in their 3rd and fourth years of study at both institutions, were invited to a joint MS Teams meeting. They were asked to comment on challenges and best practices they have experienced during their undergraduate years of study. They were also invited to come up with suggestions on the way forward. Random sampling was used, as an open invitation was sent to all students majoring in English in both faculties to join in the discussion, and the first five students from each institution who responded to the invitation, were invited to join the focus group interview session. The responses and input from the students created an opportunity for students to interact and to discuss ways to enhance teacher preparation through further collaboration. As seen in Table 1, two of the students from South Africa were not English majors but enrolled for two English year courses as part of their degree. The other three students from South Africa all majored in English. The five students from India were all majoring in English.

Table 1: Participants and disciplines

Code	Studying	Majors
SA1	PhD, BEd SPFET completed	English; CTS
SA2; SA4	BEd SPFET 4	English; Engineering graphic design; Afrikaans
SA3; SA5	Bed SPFET 3	Maths literacy, Computers science, English to 2 nd year
IN1, IN2	4 Year Integrated B A B Ed._ Semester 7	English Literature, Political Science, History
IN3	4 Year Integrated B A B Ed._ Semester 7	English Literature, Political Science, History
IN4	4 Year Integrated B A B Ed._ Semester 3	English Literature, Economics, Geography
IN5	4 Year Integrated B A B Ed._ Semester 3	English Literature, Political Science, Geography

The interview questions (Table 2) were grounded in Activity Theory, which was used as a lens to compare the preparation of teachers in these two institutions. Five questions were posed to students, as seen in Table 2 below.

Table 2: Interview questions

Interview questions		Activity theory element
1	What are the requirements to be an English teacher in your country and educational system?	rules
2	What activities, technology and methods were you taught to use in your teaching of English during your time at university, but your lecturers?	tools
3	Describe how your internships or practice teaching sessions are done and the role of your mentor teacher and school where it is done	community
4	Have you attended workshops or lectures by other stakeholders, apart from your lecturers. Comment on such interventions	division of labour
5	How can we better prepare you to be an English teacher? Suggestions or recommendations?	outcome

RESULTS AND DISCUSSION

Both the document analysis and interview data were analysed with a strong focus on the differences and similarities between the two programmes. Activity theory was used to identify the rules, tools, community, division of labour and outcomes, as these were the most significant elements for this pilot study. The researchers compared the B Ed SPFET programme guidelines (rules) provided by both institutions, which show several similarities. Both programmes are based on allocated credits. However, in South Africa, the credits determine the notional hours to be spent on the course. One credit is seen as equivalent to ten notional hours, which implies the minimum number of hours a student is expected to spend on the course. In India, one credit constitutes 15 contact hours. There is a minor difference in the allocated credits per course. In the programme selected from South Africa a BEd degree requires 460 credits and the BEd degree in India is 200 credits. There is a similar number of hours required to complete the degree successfully.

In India, teaching degrees (e.g. integrated BSc BEd. and BA BEd.) are approved by a national body, called the National Council for Teacher Education (NCTE). Education in India is the responsibility of both the Central and State Government. All prospective schoolteachers need to write a Teacher Eligibility Test (TET), which is a proficiency test for teachers before being appointed in schools. Teachers who teach learners in the senior grades, need e.g. a BSc BEd and an MSc degree in the discipline, or a BA BEd and MA.

Although English is the lingua franca of India, it is a second language for most citizens. English is a compulsory subject for all students. The Institute for Teacher Training and Research at this specific institution in India annually meets with their Advisory Board and stakeholders to discuss the curriculum before implementing the next four-year degree cycle, where necessary changes are made to keep the qualification relevant and sought after. Classes are normally small, with a maximum of 50 students in each course, with access to Smartboards and Internet. The curriculum makes a distinction between content and pedagogy. Compulsory subjects are included in the curriculum to enhance the professional development of students and develop a strong value system, such as *Peace and Value education, Design Thinking and Creativity, Human values, Ethics and Life skills, Computer programming, Industrial internship, AI and applications, Environmental Science and Waste management* and *ICT skills* which include *AR and VR* (Augmented reality and Virtual reality).

In South Africa, students can study a BEd degree or a B degree, followed by a teaching diploma (PGCE). All degrees are approved by the South African Qualification Authority (SAQA) and regularly verified by audits done by the Council of Higher Education (CHE). This is the same as in India where all teaching qualifications are approved by the National Council for Teacher Education (NCTE). It is mandatory qualification for all teachers in India. After completing the B Ed degree students can pursue a Master's degree in Education (M Ed) in both countries. All requirements for teacher education in South Africa are available in the *Minimum Requirements for teacher Education Qualifications* (MRTEQ) (South Africa, 2015). Appointment of teachers is done via the Department of Basic Education (DBE). There is no final national test before entry into the teaching profession, but prospective teachers have to be verified and registered with the South African Council for Educators (SACE), which is a professional body that manages Professional Development and inculcation of a Code of Ethics for all educators (SACE, nd). Similarly, all teachers in India must be registered to the Central Board for Secondary Education (CBSE), or the State Board of Education (SBE) for each specific state. Both the Central Government and the State Government can register teachers.

Although English is the lingua franca of South Africa, it is also a second language for most citizens in South Africa (Stats SA nd). English is a compulsory subject in most schools but in the early grades the focus is on mother tongue learning and teaching.

At this specific institution in South Africa, Advisory Board meetings are held on a quarterly basis, whereas in India these meetings are held twice a year with all stakeholders involved in the first meeting, and only academics in the second meeting. In South Africa, classes in the B Ed programme are generally large, (up to 160 students), but in the electives classes are between ten and 100 students on average. The curriculum distinguishes between content and pedagogy, although the focus is on the integration of these two subjects. Compulsory subjects such as *Education, Professional Studies and Teaching practice*, are included in the curriculum where similar core values are taught. Students also attend classes in venues with Smartboards and Internet access, as is the case in India.

There are several similarities between the curricula of the institutions in the study. Both institutions have a strong focus on applied knowledge for the school and classroom. There is a similar percentage of time allocated to content knowledge, pedagogical content knowledge and applied practical knowledge overall, although the curriculum is organised differently. The focus at both institutions is on the core subjects of *Education, Professional knowledge, and Research*.

This paper focused specifically on the preparation of English teachers. Both institutions offer English as a content subject as well as English methodology or pedagogy, with similar credits allocated to these courses. The courses at the South African institution are offered as year courses whereas in India they are semester courses. The option of semester courses gives students more possibilities for electives with diversified and varied content which is an advantage for the students in India. An interesting difference in the selection of content for the English course, is that the South African institution focuses on South African and African literature, whereas the course in India includes Indian literature, as well as American literature choices for prescribed readings. Both courses have a strong element of English grammar and communication skills and require of students to show critical awareness of language usage in different texts and contexts, with an emphasis on the different genres, including poetry, drama and novel. The South African institution has a stronger emphasis on preparing students to teach in indigenous languages, as with specific reference to the socio-political and historical context and complexity of the South African multilingual context.

There is a slight difference in the teaching of English methodology or pedagogy in that this is a separate five credit subject in the South African institution, from 1st to 4th year, whereas in India it is taught as general pedagogy courses with professional soft skills in the first and second year, with reference to the students' specific subject choices (*Teaching-Learning Process, Theories of learning, Psychology of learners, Classroom management, Curriculum Development, Philosophical and Sociological basis of Education, Inclusive Education, Guidance and Counselling, Assessment for learning, Educational Research, Global Trends In Education, Gender School and Society, Educational Technology, Statistics in Education*). In India, there is a strong focus on ICTs in Education, including understanding ICT tools, and preparing E Lesson Plans. In their second-year students in India are prepared for the classroom by participating in micro and - macro teaching. Here they are taught how to prepare lessons, with a focus on micro-specific teaching skills of seven minutes, focusing on different lesson elements, such as the lesson introduction, how to explain new content, illustrate lessons, how to recap, how to reinforce new knowledge, stimulus variation, and assessment. These elements are eventually combined into one macro lesson, which is applied to their own discipline. Macro lessons include body language, use teaching aids, explain topics, and blackboard writing skills.

In the 3rd year students focus specifically on the pedagogy of English. In the fourth year the focus is on the beginner English teacher as students are exposed to a mixture of knowledge and integrated learning which includes work-directed theoretical learning, approaches to teaching English and the relationship of English with other subjects (Language across Curriculum). The course offered in India focuses largely on methods of teaching English poetry, prose and grammar. There is a focus on the three-language model in India which includes a regional language (e.g. in Gujrat - Gujrati; Punjab - Punjabi), their national language (Hindi) and English as a second language. In the institution in India the Language of Learning and Teaching (LoLT) is English, whereas in the institution in South Africa it is English and Afrikaans. Teaching skills are reinforced, focusing on English as a subject. Assessment forms an integral part of the course with types of formative and summative assessment and setting assessment tasks, especially integrating ICT in English Teaching.

In the South African institution most of the general teaching topics are addressed in two different subjects called *Professional Studies* and *Education*. English methodology is taught as a five-credit year course from year one to year four, with a focus on the South African Curriculum (CAPS) and classroom techniques for language learning and literary appreciation. In their third year, South African students design lessons to study the use of texts and assessment strategies. They have to develop the skill of explaining and correcting language errors. In their fourth year there is also an introduction to basic research skills as students are expected to design and apply research instruments, such as questionnaires and interpret results.

There is a difference in practice teaching between these institutions. In the specific South African institution in the study, students go on four weeks of teaching practice at local schools from their first year onwards, whereas in India students go out to schools in their third year (semester 6) for a pre-internship of 2 weeks, and then in their fourth year (semester 7) for a full six months' internship. They have the option to extend this internship as student assistants at the schools and complete their last semester online. About 30% of students opt to do this. A very interesting similarity at both institutions, is that students participate in a credit-bearing service-learning intervention. In the South African institution this forms part of the 3rd year curriculum when students tutor English for 15 to 20 hours at a nearby correctional service centre for young adults, or at a children's home near campus. The focus of these projects is reading and English proficiency. At the HE Institution in India, students participate in a *Socially Relevant Project* where they go out into communities and participate in projects to enhance literacy, health, and technology in communities. Students work in groups and are expected to participate in selected programmes offered at sites in the area, where they assist with eg literacy campaigns for schools in rural areas or assisting women in nearby villages with basic skills. Students spend at least 15 days on projects, at times convenient to them. Both institutions enrich their curriculum for the students by including guest speakers who offer workshops and share current topics with the students. These workshops in South Africa are hosted by senior officials from the Department of Education, or experts such as school principals or union members. In India these workshops are offered by different experts in Education. Activity Theory was used to analyse the process and identify differences and similarities. The findings show the importance of including external stakeholders in the planning of the curriculum to ensure the successful transition of novice teachers into the classroom.

CONCLUSION

The collaboration between these two institutions, lead the way to collaborative online seminars for undergraduate, as well as postgraduate students, where students could share the same platform to discuss student-led research initiatives. Student interactions enhance a culture of inquiry and critical thinking, and they were surprised at the similarities in their programmes. One participant pointed out “to know your content in English and have the desire to teach and make a difference, those are the only vital points that any teacher should have” which was echoed by all, pointing the way forward to more student interactions.

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Data Availability Statement: The recording of the interview and transcript has been stored in a repository.

Ethical Clearance: Ethical clearance for investigating the professional development of student teachers was granted through the Ethics Committee from CPUT. The interviewees agreed that their input could be shared and completed the necessary consent forms.

Conflicts of Interest: The authors are senior lecturers at the two institutions respectively and are both involved in management. This study provides an opportunity to explore the need for curriculum renewal at both institutions and to share relevant information with both Faculties of Education.

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ADAPTING MOODLE FOR EFFECTIVE ENGLISH FOR SPECIFIC PURPOSES (ESP) INSTRUCTION IN UNDER-RESOURCED TVET COLLEGES

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ABSTRACT

This paper investigates the integration of Moodle, a Learning Management System (LMS), for teaching English for Specific Purposes (ESP) in Technical and Vocational Education and Training (TVET) colleges in South Africa. The study aims to address the gap in understanding how Moodle can be tailored to meet the specific needs of ESP lecturers in under-resourced environments. Using a combination of theoretical frameworks, including the Technology Acceptance Model (TAM) and Constructivist Learning Theory (CLT), the paper explores barriers such as limited digital literacy, inadequate infrastructure, and insufficient institutional support. Data were gathered through a comprehensive review of academic literature and policy documents. The findings reveal that digital literacy and targeted training programs are crucial for successful Moodle adoption, and institutional support plays a key role in overcoming challenges. The paper concludes with recommendations for developing a tailored Moodle framework that can enhance ESP instruction in TVET settings. Future studies should focus on the long-term impact of these interventions and the scalability of the proposed framework across diverse educational contexts. Further studies should examine long-term pedagogical and institutional impacts of such frameworks and scalability across varied post-school education and training contexts.

Keywords: collaborative learning; digital capacity building; educational technology; lecturer training; online education

INTRODUCTION

This paper investigates the integration of Moodle, an LMS, for teaching English for Specific Purposes (ESP) at TVET colleges, which were formerly known as Further Education and Training (FET) colleges. ESP refers to the teaching of English that is tailored to the specific linguistic, communicative, and professional needs of students in specialised fields. Unlike general English instruction, ESP focuses on industry-specific vocabulary, discourse structures, and practical language applications essential for workplace. This study addresses the gap in how Moodle can be adapted to meet the specific needs of ESP lecturers in under-resourced environments (Mpungose, 2020; Mohammadi et al., 2021). Although Moodle is effective for collaborative learning (Shalatska et al., 2023; Prasetya, 2021), its underutilisation in TVET institutions stems from a lack of customised frameworks, technical infrastructure, institutional support, and digital literacy (Raban & Mayisela, 2022; Uziak et al., 2018). Developing a tailored framework could enhance digital literacy and pedagogical strategies, aligning technology with institutional goals (Prasetya, 2021; Simon et al., 2024).

There is limited knowledge on how Moodle can be adapted to the specific challenges faced by ESP lecturers in TVET colleges (Raban & Mayisela, 2022), as existing theories like the Technology Acceptance Model (TAM) and Constructivist Learning Theory (CLT) are mainly applied in better-resourced contexts, such as universities (Davis, 1985; Prasetya, 2021). Challenges such as limited internet access, lack of technical support, and minimal training hinder Moodle's practical implementation in TVET settings (Mohammadi et al., 2021; Mpungose, 2020). CLT supports collaborative learning, crucial for ESP, while TAM explains how perceptions of ease of use affect adoption (Sarfo & Yidana, 2016; Rosli et al., 2022). Applying both frameworks can help develop a Moodle-based LMS tailored to the unique needs of TVET ESP lecturers, addressing barriers like digital literacy and infrastructure (Prasetya, 2021; Bosman et al., 2021).

Despite this, there remains limited knowledge about how Moodle can be specifically adapted to the unique challenges faced by ESP lecturers in TVET colleges (Raban & Mayisela, 2022). This gap exists because existing theories on LMS integration, such as the Technology Acceptance Model (TAM) and Constructivist Learning Theory (CLT), have primarily been applied in contexts with better digital infrastructure, such as universities, and do not fully account for the challenges present in TVET settings (Davis, 1985; Prasetya, 2021). These challenges include limited internet access, lack of technical support, and minimal training on how to use LMS platforms effectively in language teaching (Mohammadi et al., 2021). As a result, despite the theoretical potential of Moodle to enhance ESP instruction, its practical implementation in these settings has been hindered by contextual barriers (Mpungose, 2020).

To address this gap, the theoretical concepts that may help solve the problem include CLT) and the Technology Acceptance Model (TAM). CLT emphasises active, collaborative learning, which is central to the design of Moodle and its potential to support language learning in ESP contexts (Sarfo & Yidana, 2016; Prasetya, 2023). Meanwhile, TAM provides a framework for understanding how lecturers' perceptions of Moodle's ease of use and usefulness influence their adoption and integration of the platform (Davis, 1985; Rosli et al., 2022). These frameworks, when applied together, offer a conceptual basis for developing a Moodle-based LMS that is tailored to the needs of ESP lecturers in TVET institutions. By addressing the current challenges of digital literacy, infrastructure limitations, and pedagogical support, these theories can guide the creation of a more effective LMS framework (Prasetya, 2021; Bosman et al., 2021)

Research Questions

This study addresses gaps in tailoring Moodle as an LMS for ESP in TVET colleges. The following research questions guide the investigation:

1. What are the specific needs of English lecturers for teaching with a Moodle-based LMS in TVET colleges?
2. What resources, policies, and support mechanisms are available for using a Moodle-based LMS in TVET colleges?
3. What are the design principles for developing a Moodle-based LMS for English lecturers in TVET colleges?

Literature Review

The integration of an LMS like Moodle in educational contexts, especially in TVET institutions, has been a growing focus. Despite its potential to enhance learning, several challenges persist, particularly in teaching ESP. This literature review explores Moodle's role, the barriers to its adoption, the significance of digital literacy, the importance of institutional support, and how design principles can enhance its use in TVET settings for ESP instruction.

Moodle as a Learning Management System in Education

LMS platforms have become central to modern education, with Moodle standing out as a highly adaptable and widely used system. Its open-source structure allows for extensive customisation, making it ideal for institutions with varied educational needs (Asar, 2024).

However, barriers to effective Moodle implementation persist, particularly in resource-constrained environments like TVET colleges. Challenges such as insufficient technical infrastructure and inadequate lecturer training limit the platform's effectiveness (Raban & Mayisela, 2022; Uziak et al., 2018). These barriers highlight the need for institutional strategies tailored to the specific needs of TVET lecturers and learners, particularly those teaching and learning ESP.

The Role of Digital Literacy in LMS Adoption

A key factor in Moodle adoption in TVET settings is lecturers' digital literacy, which is often lacking in under-resourced environments, limiting their ability to use advanced features (Mpungose, 2020; Mohammadi et al., 2021). The Technology Acceptance Model (Davis, 1985) explains that perceived ease of use and usefulness are crucial to LMS adoption. Lecturers, especially in developing countries, struggle with using Moodle due to limited digital skills despite understanding its benefits (Mpungose, 2020; Prasetya, 2021). Targeted training is essential to improve digital literacy and enable effective use of Moodle in ESP instruction (Prasetya, 2021; Mohammadi et al., 2021), as its potential remains underutilised without such support.

Institutional Support and Policy Frameworks

Institutional support is critical for successful LMS adoption in TVET settings, as inadequate resources and unclear policies hinder effective teaching with platforms like Moodle (Simon et al., 2024). Many TVET institutions lack coherent digital learning policies, forcing lecturers to rely on informal methods, leading to inconsistent Moodle use (Mpungose, 2020). Effective policies must address both technical and pedagogical needs, providing training and technical support to help lecturers use Moodle efficiently (Simon et al., 2024). Additionally, policies should focus on governance, quality assurance, and continuous professional development to ensure effective LMS integration (Mohammadi et al., 2021).

Affordances of Moodle for ESP Instruction

Moodle's affordances, or the features that make it particularly useful for specific educational tasks, are highly relevant for ESP instruction. As a platform, Moodle supports the integration of language-specific tasks such as vocabulary building, collaborative writing, and peer feedback, which are essential for teaching ESP (Shalatska et al., 2023). Features like discussion forums and glossaries

allow students to engage in tasks that mimic real-world language use, which is a key aspect of ESP instruction (Prasetya, 2021).

Despite the pedagogical potential of Moodle, its affordances are often underutilised in TVET institutions due to the challenges previously discussed, such as limited digital literacy and institutional support (Raban & Mayisela, 2022; Uziak et al., 2018). For Moodle's affordances to be fully realised in ESP instruction, lecturers need adequate training and support to use these tools effectively (Prasetya, 2023).

Design Principles for Moodle-Based Systems

The successful implementation of Moodle in TVET institutions requires a set of design principles that cater to the specific needs of both lecturers and learners. Instructional design models such as ADDIE (Analysis, Design, Development, Implementation, Evaluation) and SAMR (Substitution, Augmentation, Modification, Redefinition) highlight the importance of aligning digital tools with specific learning outcomes (Wienand et al., 2024). For Moodle to be effective in ESP instruction, these principles must focus on promoting collaboration, interactivity, and learner autonomy while being flexible enough to accommodate varying levels of digital literacy among lecturers.

However, as Elias (2010) notes, many institutions fail to fully utilise Moodle's features due to a lack of training and support. In Elias' study, only a small portion of Moodle's accessibility features were implemented in educational settings, highlighting the need for institutions to provide more comprehensive training programs for lecturers. Without this support, the full potential of Moodle's design principles cannot be realised.

Comparative Analysis of LMS Platforms

While Moodle is known for its flexibility and open-source nature, other LMS platforms like Blackboard and Canvas offer specific advantages; Canvas excels in user-friendliness, while Blackboard is strong in administrative features (Salah & Thabet, 2021). Moodle's customisation makes it ideal for resource-limited TVET environments, but institutions with better infrastructure may prefer Blackboard or Canvas (Asar, 2024). Additionally, Sakai and Brightspace are also in use at South African higher education institutions. Sakai, an open-source LMS, has been implemented at institutions such as the University of Cape Town (UCT) and North-West University (NWU), valued for its modularity and integration with institutional digital ecosystems (University of Cape Town, 2023). Brightspace, developed by D2L, has been adopted by UCT as part of its transition to a more modern, adaptive learning environment, emphasising accessibility and advanced analytics (D2L, 2022). Despite these differences, Moodle's flexibility and support for collaborative learning make it especially effective for ESP instruction in TVET settings (Shalatska et al., 2023).

Literature review conclusion

The literature underscores Moodle's potential as a flexible LMS, particularly suited for ESP instruction through its collaborative tools and constructivist design (Shalatska et al., 2023; Prasetya, 2021). However, challenges like low digital literacy, insufficient training, and inadequate institutional support hinder its effective adoption in TVET colleges (Mpungose, 2020; Raban & Mayisela, 2022). To fully realise Moodle's potential, there must be targeted training programs, clear institutional policies, and customised design principles that accommodate lecturers' specific needs (Mohammadi et al., 2021; Simon et al., 2024). Addressing these issues will enhance Moodle's usability, ultimately improving ESP instruction and contributing to educational advancement in resource-limited environments (Prasetya, 2021; Uziak et al., 2018).

METHOD

The methodology employed focuses on identifying, reviewing, and analysing relevant literature to build a comprehensive understanding of the current state of Moodle's implementation, barriers, and solutions in the context of TVET education. This section outlines how the material for this conceptual paper was sourced, the inclusion and exclusion criteria applied, how data was cleaned, and the analytical approach used to develop the framework.

Data Collection: Finding Material to Analyse

The study collected theoretical and practical sources on Moodle integration in TVET for ESP instruction by searching databases like Google Scholar, JSTOR, and ERIC using terms such as "Moodle integration in TVET" and "barriers to LMS adoption" (Davis, 1985; Prasetya, 2021). Policy documents, including the National Plan for Post-School Education and Training (NPPSET) (DHET, 2023a) and the 2024 Teaching and Learning Plan (DHET, 2023b), were also reviewed to understand external factors like institutional support and policy alignment (Mohammadi et al., 2021). Document analysis assessed how institutional policies and resources influenced Moodle adoption, revealing gaps between mandated policies and classroom practices (Raban & Mayisela, 2022). This phase helped align theoretical insights with practical challenges in TVET settings.

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria for the materials were designed to ensure the relevance and applicability of the literature to the research questions.

Theoretical and Empirical Studies: Both conceptual frameworks and empirical case studies were included to balance the theoretical development of the proposed framework with practical insights into Moodle's adoption.

Geographical Relevance: Literature focusing on LMS implementation in developing countries or under-resourced environments was prioritised, particularly studies set in South Africa or similar contexts (Mpungose, 2020; Raban & Mayisela, 2022).

Studies focusing on LMS platforms other than Moodle, such as Blackboard or Canvas, were excluded unless they provided valuable comparative insights (Salah & Thabet, 2021). Additionally, research from highly resourced educational contexts, like top-tier universities in developed countries, was omitted, as these studies did not address the infrastructural challenges faced by TVET institutions in South Africa. To maintain relevance, studies using Moodle in non-educational contexts, such as corporate training, were also excluded to focus solely on pedagogical strategies within TVET environments.

Handling data gaps and overabundance of data

When specific studies on Moodle in TVET were lacking, the scope was expanded to include research on Moodle in higher education and low-resource environments, with insights from developing countries used to address common challenges like digital literacy and institutional support (Prasetya, 2021). Conversely, when an abundance of literature was found, inclusion criteria focused on studies with strong empirical support and those frequently cited, especially on language learning, digital literacy, and institutional policy (Creswell, 2007).

Data cleaning

Once the relevant literature was gathered, the next step was to organise and clean the data. This process involved categorising the studies according to their thematic relevance, focusing on three core areas: digital literacy and lecturer training, institutional policies and support, and Moodle's pedagogical affordances for ESP instruction. Using thematic coding, each study was tagged with key themes such as "technical barriers," "constructivist learning," "digital literacy," "institutional policy," and "formative assessment."

Table 1: Thematic categorisation of studies

Study	Thematic Category	Key Themes	Tagged Themes
Mpungose (2020)	Barriers to Adoption	Digital Literacy	Technical Barriers
Mohammadi et al. (2021)	Barriers to Adoption	Digital Literacy	Digital Literacy
Prasetya (2021)	Pedagogical Affordances	Constructivist Learning	Formative Assessment
Sarfo & Yidana (2016)	Pedagogical Affordances	Constructivist Learning	Formative Assessment

Table 1 shows that studies like Mpungose (2020) and Mohammadi et al. (2021) were categorised under barriers to adoption, focusing on digital literacy, while Prasetya (2021) and Sarfo & Yidana (2016) were grouped under pedagogical affordances. This organisation aligned the material with the research objectives and highlighted unique perspectives for deeper analysis (Creswell, 2007; Scherer et al., 2019).

Data analysis

Following Creswell's (2007) method, the data were first grouped into broad themes like digital literacy, institutional support, and Moodle's role in ESP instruction, then divided into more specific subcategories for detailed analysis. Within-theme analysis identified recurring issues like the need for digital literacy training (Mpungose, 2020; Mohammadi et al., 2021) and policy gaps (Simon et al., 2024). Cross-theme comparison showed that digital literacy challenges were compounded by poor institutional support (Raban & Mayisela, 2022), while Moodle's benefits were underutilised due to insufficient training (Prasetya, 2021).

Advantages and disadvantages

This approach allows for a systematic analysis of both theoretical and empirical studies, offering a holistic view of barriers to Moodle adoption in TVET settings (Creswell, 2007; Scherer et al., 2019). However, relying on existing literature limits real-world insights and lacks primary data, which could provide stronger evidence of Moodle's impact (Prasetya, 2021; Mpungose, 2020). Moreover, data selection may have inadvertently excluded some valuable studies.

Conclusion of the methodology

In sum, this methodology provides a structured approach to understanding how Moodle can be better integrated into ESP instruction in TVET institutions. By drawing from a broad array of literature and using systematic methods for inclusion, exclusion, and analysis, the study offers insights into the key factors affecting Moodle adoption. While the conceptual nature of the study limits its empirical evidence, the findings derived from existing literature provide a strong foundation for future research and practical application.

DISCUSSION OF FINDINGS

The study used a holistic case design (Creswell, 2007) to analyse Moodle adoption for ESP instruction, framed by the NPPSET, 2024 Teaching and Learning Plan (T&L) Plan, and APP (DHET, 2023a; DHET, 2023b; DHET, 2023c).

Key Finding: Importance of Digital Literacy

Digital literacy is crucial for successful Moodle adoption, as lecturers with better digital skills were more confident in using the platform (Mpungose, 2020; Mohammadi et al., 2021). This aligns with the Technology Acceptance Model (Davis, 1985), which highlights ease of use as key to adoption.

Institutional support and policy alignment

Institutions with strong policy support, like the APP (DHET, 2023c), showed higher Moodle adoption, especially with continuous professional development (Simon et al., 2024; Prasetya, 2021).

Resistance to Moodle integration

Resistance often stemmed from poor infrastructure and lack of digital literacy, hindering Moodle adoption (Karishma & Raghuwaiya, 2022; Mpungose, 2020).

Common themes

The need for targeted technical and pedagogical training emerged as a key theme, supported by the NPPSET and T&L Plan, emphasising lecturer development for e-learning (DHET, 2023a; DHET, 2023b).

Assertions

Digital literacy and institutional support are critical for Moodle adoption, with targeted training and infrastructure improvements essential for success (Raban & Mayisela, 2022; Mpungose, 2020).

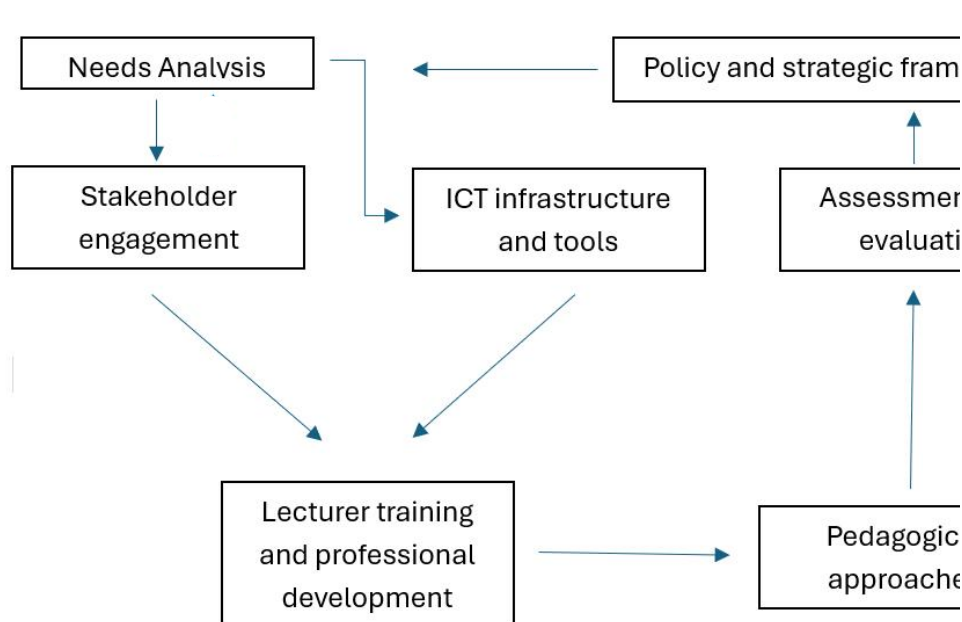
Conclusion of findings

In conclusion, the findings from this conceptual study underscore the intertwined roles of digital literacy, institutional support, and policy alignment in fostering Moodle adoption for ESP instruction in TVET settings. The use of both within-case and cross-case thematic analysis provided comprehensive insights into the factors that influence Moodle's adoption. By drawing on national policies, such as the NPPSET and the 2024 Teaching and Learning Plan Framework, this study highlights the importance of aligning institutional strategies with broader educational goals to achieve widespread and effective Moodle adoption.

Recommendations

This section presents a design-based framework for implementing Moodle at a TVET college, specifically aimed at enhancing ESP instruction. The framework, represented in Figure 1, builds on institutional needs, policy alignment, and existing literature. It addresses key challenges identified in previous studies (Mpungose, 2020; Prasetya, 2021) and integrates Moodle's functionalities to improve teaching practices. Each element of the framework follows a logical progression, and the continuous loop reflects the iterative nature of the process, ensuring that each stage informs and

strengthens the next.



The framework starts with a needs analysis to identify digital literacy levels and infrastructure gaps, forming the foundation for all subsequent actions (Mpungose, 2020). This is followed by targeted stakeholder engagement, ensuring alignment with institutional objectives and securing

Figure 1: Design-based framework for Moodle implementation

commitment from key parties such as lecturers, students, and administrators (Raban & Mayisela, 2022). Once engagement is secured, the next step is ensuring ICT infrastructure readiness, including stable internet and digital devices, which is essential for successful Moodle integration (Prasetya, 2021). Lecturer training is then prioritised, enabling educators to effectively use Moodle's tools in their teaching practices (Mohammadi et al., 2021). The training is followed by the implementation of collaborative, student-centered pedagogical approaches that enhance language acquisition (Prasetya, 2021). Continuous assessment and evaluation are critical for monitoring progress, refining infrastructure, and adjusting training programs based on real-time outcomes (Simon et al., 2024). Finally, policy and strategic alignment with institutional and national frameworks, such as the NPPSET and the 2024 Teaching and Learning Plan, ensures that Moodle adoption is sustainable and embedded within broader educational goals (DHET, 2023a; DHET, 2023b).

CONCLUSION

The design-based framework presented in this paper offers a structured, iterative approach to Moodle implementation in TVET colleges for ESP lecturers. As illustrated in Figure 1, the framework integrates key elements—needs analysis, stakeholder engagement, ICT infrastructure, lecturer training, pedagogical approaches, and continuous assessment—in a way that each phase informs the next. The strategic placement of the arrows and the continuous loop emphasise the adaptive nature of the framework, ensuring sustained improvements and responsiveness to evolving needs.

My new contribution to the field is this integrated, feedback-driven framework that connects lecturer training, ICT infrastructure, and pedagogical approaches in a continuous cycle of improvement. This model advances the existing literature by providing a comprehensive, scalable solution for Moodle implementation, particularly in under-resourced TVET settings. This is a significant contribution because it moves beyond isolated interventions and presents a sustainable model that adapts to institutional needs over time.

Recommendations for Future Practice

For practitioners, this framework offers clear, actionable recommendations:

- Ongoing needs analysis: Regularly assess digital literacy and infrastructure gaps to ensure that Moodle continues to meet institutional and lecturer needs.
- Stakeholder Engagement: Foster continuous collaboration between lecturers, administrators, and IT teams to ensure the effective use of Moodle and address any barriers promptly.
- Enhanced ICT infrastructure: Prioritise reliable internet and digital devices as foundational elements for successful Moodle implementation.

- Continuous Lecturer Training: Develop flexible, ongoing training programs that evolve with technological advancements and pedagogical demands.

Recommendations for Future Research

Future research can build on this framework by exploring:

- Longitudinal impact studies: Conduct long-term studies to evaluate the sustained impact of this framework on teaching outcomes and Moodle adoption.
- Comparative studies across institutions: Adapt and compare the framework in different TVET contexts, exploring its scalability and flexibility across various institutional environments.
- Pedagogical innovations: Investigate how specific Moodle features contribute to innovative teaching practices in ESP instruction, particularly in collaborative and blended learning models.

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POSTHUMANISM AND ACTOR-NETWORK THEORY: EXPANDING PERSPECTIVES IN EDUCATIONAL TECHNOLOGY RESEARCH

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ABSTRACT

Educational technology research often relies on human-centric perspectives, neglecting the complex interactions and interdependencies between humans and technology. Posthumanism and Actor-Network Theory (ANT) provide alternative frameworks to explore educational technology from a largely unexplored socio-technical perspective. This conceptual-methodological paper offers a theoretical reflection on a study that employed posthumanism and ANT to uncover the complexities that extend beyond human-centred views of educational technology. By focusing on these theoretical principles, the paper aims to enhance the effectiveness and relevance of educational technology interventions. ANT's socio-technical approach, which neither privileges social nor technical aspects, is particularly useful for examining the entangled relationships that defy simple distinctions between human and technology. Although ANT does not prescribe specific research tools, it offers novel approaches for studying the dynamic interplay between humans and technology in educational contexts. By adopting ANT as ontology rather than just a theoretical framework, this study encourages researchers to consider technology and humans as co-constitutive, shaped equally by their context and interactions. Future educational technology should adopt posthumanism and ANT to challenge traditional academic paradigms and foster more holistic, inclusive approaches.

Keywords: Anthropocentrism; education; information and communication technology (ICT); ontology; research methodology

INTRODUCTION

Educational technology research often overlooks the intricate interactions and interdependencies between humans and technology, treating them as separate entities rather than interconnected elements of a broader socio-technical system. However, Posthumanism and Actor-Network Theory (ANT) provide alternative frameworks for understanding these relationships in complex educational contexts. By moving beyond human-centred perspectives, these approaches reveal the entanglements between human and non-human actors, offering deeper insights into the dynamics of educational technology. This conceptual-methodological paper explores the potential of posthumanism and ANT in uncovering the hidden complexities of educational technology research, highlighting their value in fostering more nuanced and inclusive theoretical perspectives.

Problem statement

The field of educational technology remains largely under-theorised (Hew et al., 2019; Schad et al., 2021), with much of the existing research relying on human-centric frameworks that prioritise human agency while overlooking the complex, reciprocal interactions between humans and technology. This anthropocentric focus often results in linear, deterministic models that fail to capture the intricate socio-technical entanglements shaping educational experiences. To develop a more comprehensive understanding of the role of Information and Communication Technology (ICT) in education, researchers must embrace a socio-technical perspective - one that acknowledges the agency of both human actors and technological entities (Hicks et al., 2020). Such an approach moves beyond simplistic cause-effect relationships and instead foregrounds the co-constitutive nature of human-technology interactions in educational environments. Despite its potential, this perspective remains largely underexplored within educational technology research (Ferrante, 2017). This conceptual-methodological paper seeks to contribute to this emerging discourse by examining how posthumanism and ANT can provide the theoretical tools necessary to uncover these overlooked complexities.

Literature review

A critical examination of the existing body of knowledge in educational technology research forms the foundation of this study. By reviewing key theories, frameworks, and methodologies this literature

review aims to identify gaps, limitations and emerging trends in the field. Understanding the evolution of educational technology research and the theoretical perspectives that have shaped it will allow for a deeper exploration of under-theorised areas. This review not only highlights the current state of research but also sets the stage for the application of alternative theoretical perspectives to further advance the understanding of socio-technical dynamics in educational technology.

ANT - Recognizing the agency of technology

ANT offers a framework that challenges the traditional human-centric view of social organisation, arguing that both human and non-human actors possess agency in shaping socio-technical networks (Latour, 2005; Tatnall, 2019). ANT does not prioritise the social over the technical; instead, it recognises that technology, like human actors, has the capacity to influence outcomes within a network. This perspective allows for a more nuanced understanding of how technology plays an active role in shaping educational practices and experiences. Furthermore ANT's adaptability makes it more versatile than traditional methodologies, enabling researchers to uncover hidden complexities in interconnected systems (Rowan and Bigum, 2003). While ANT has found wide application in disciplines such as sociology and technology, its uptake within educational research has been relatively limited (Fenwick and Edwards, 2010).

ANT – A socio-technical approach in educational technology research

ANT's socio-technical approach is particularly relevant to the study of educational technology, as it frames human and non-human elements as mutually shaping and influencing each other (Kipnis, 2015; Matthews, 2021). This approach considers technology not merely as a tool but as an active participant in shaping educational outcomes alongside human actors, such as teachers and learners. The application of ANT in educational technology research (Figure 1), varies depending on the epistemological stance, with differences emerging between interpretivist or posthumanist perspectives (Cordella and Shaikh, 2003; Sackstein, 2021). While interpretivist approaches have been more widely employed, ANT holds significant potential when viewed through a posthuman lens, offering a more dynamic and interconnected understanding of educational technology that challenges traditional boundaries between humans and technology.

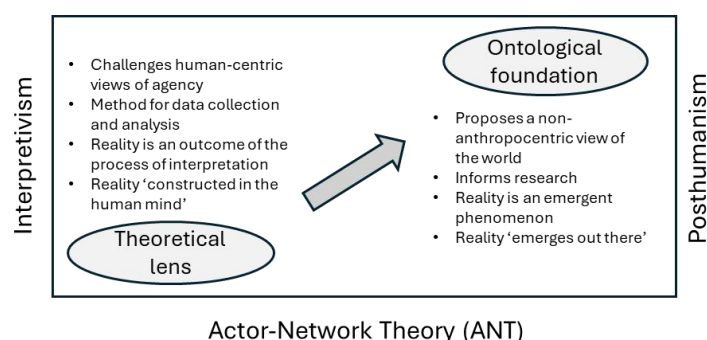


Figure 1: ANT: Theoretical lens or ontological foundation

MATERIALS AND METHODS

This paper draws on a phenomenological study that applied posthumanism and ANT to explore the patterns of technology-mediated interaction between secondary school teachers and learners during the COVID-19 pandemic (Kennedy and Cronjé, 2023; Kennedy, 2024). This study employed a qualitative survey design to explore how teachers appropriated ICT in their teaching practices before, during, and after the pandemic, with particular focus on the role of access in shaping their interactions. The survey included questions on teachers' experiences with the transition to emergency remote teaching (ERT), their technological-pedagogical knowledge, and their access to and use of ICT in daily teaching. To ensure ethical compliance and confidentiality, the survey featured a consent statement, and responses were collected anonymously. A total of 22 teachers from government schools participated in the study, providing valuable insights into the evolving role of technology in education.

ANT was applied as a theoretical lens (Figure 2) to explore the complex and dynamic relationships between teachers, learners, and technology in the context of the COVID-19 pandemic. By framing these interactions as part of a socio-technical network, ANT allowed for an exploration of how human and non-human actors mutually influenced and shaped educational experiences. This approach provided deeper insights into the ways in which technology was not merely a passive tool but an

active participant in the teaching and learning process, restructuring pedagogical practices and communication dynamics in both expected and unexpected ways.

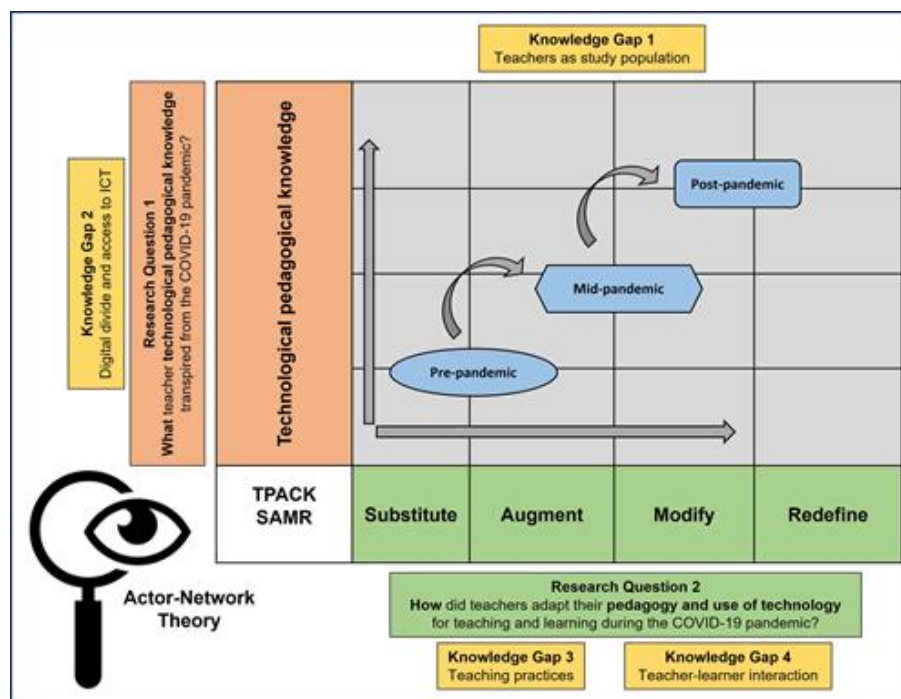


Figure 2: Theoretical and conceptual framework

In the absence of specific prescribed research methods within ANT, a structured approach was developed to guide its application in this study. The following steps (Figure 3) were undertaken to explore the complex interactions between teachers, learners and technology during the pandemic through an ANT-informed perspective.

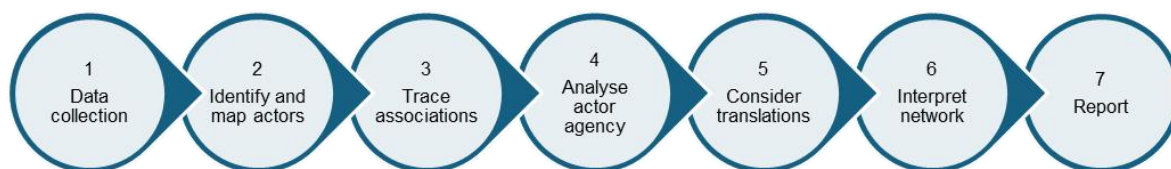


Figure 3: Steps in applying ANT

The process began with data collection and mapping, where relevant data was gathered to understand teachers' experiences and a network diagram was created to visually represent the different actors involved. The next step, identifying actors, involved recognizing both human and non-human entities, ensuring that technological tools, digital platforms, and institutional structures were considered alongside teachers and students. Once actors were identified, tracing associations examined how these actors interact, highlighting the relationships and dependencies within the network.

A critical aspect was analyzing actor agency, which involved assessing how different actors influence and shape the network. This step explored power dynamics, revealing the extent to which technology mediates interactions and restructures traditional educational roles. Translation was then considered, focusing on how actors align their interests and negotiate their roles to ensure effective engagement in technology-mediated learning.

In the interpretation phase, patterns of interaction, power dynamics, and challenges related to access and engagement were examined. This step highlighted common barriers and successful strategies in technology adoption and integration. The final stage, reporting, structured the research

findings into a coherent academic format, including an introduction to the research context, a methodology section detailing the data collection and actor identification process, and a findings section that presents the network diagram and discusses actor agency. The analysis section interpreted these findings through ANT concepts, such as translation and power shifts, while the conclusion summarized key insights, discussed policy implications, and suggested future research directions. This structured approach ensured a comprehensive application of ANT, allowing for a nuanced exploration of the complex socio-technical entanglements in crisis-driven educational settings.

RESULTS

The actor-network diagram (Figure 4) was developed to visually represent the key actors (both human and non-human) within the network, trace the connections between these actors, and illustrate the complex relationships and interactions that shape the use of ICT in education.

Despite the growing body of research on ICT in education, many existing studies fail to account for the broader socio-cultural, economic and institutional factors that shape technology adoption and use. However, this study reaffirms that access to and use of ICT is not merely a matter technological availability but is deeply embedded within social, cultural and educational contexts (Czerniewicz and Brown, 2005). In South Africa, these contextual influences are particularly significant, as diverse socio-economic conditions, varying levels of digital infrastructure, and institutional policies all play a role in determining how ICT is integrated into school environments (Sadeck et al., 2020).

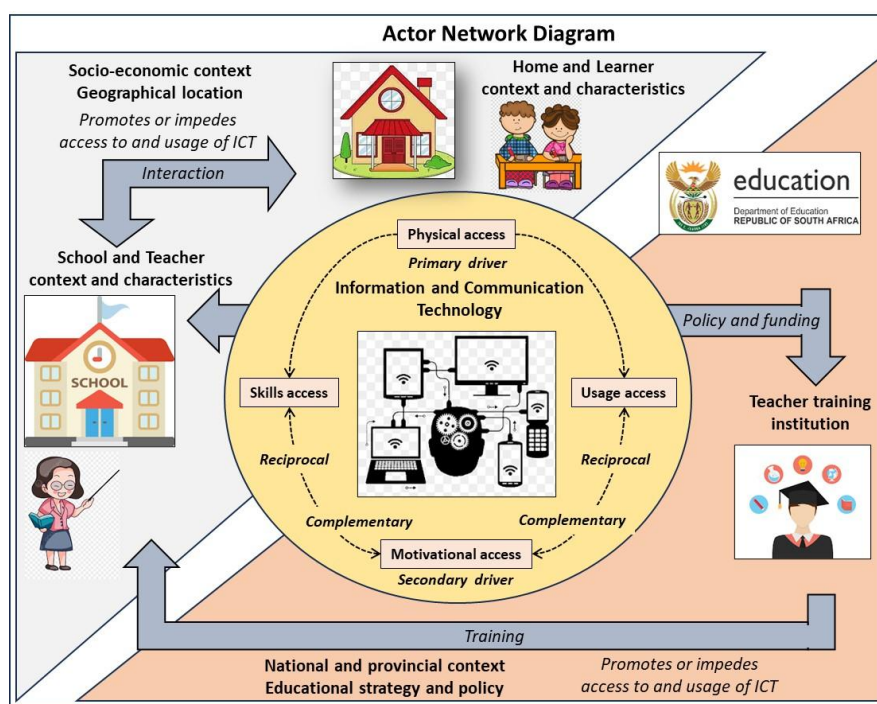


Figure 4: Actor-network diagram

To address these contextual complexities, this study proposes the Context-Aware ICT Appropriation (CAIA) model, illustrated in Figure 5, as a theoretical framework for understanding ICT integration in schools. The term CAIA (pronounced KA-ya) is inspired by the Zulu word "kaya", meaning homestead or village, which conveys the idea of a sustainable, community-driven approach to ICT implementation. This linguistic and cultural connection underscores the model's emphasis on local context, collective knowledge, and shared responsibility in shaping technology adoption in educational settings.

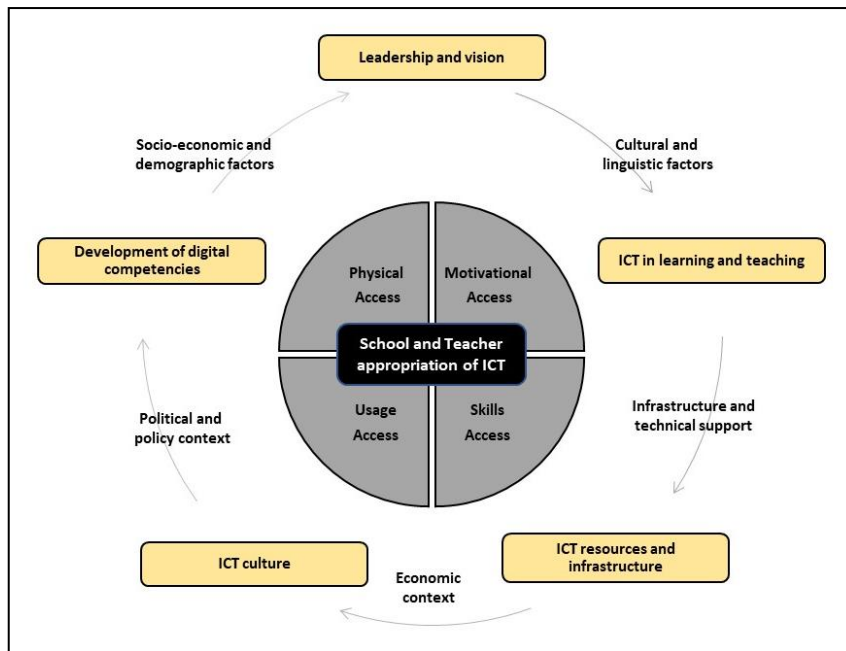


Figure 5: The Context-Aware ICT Appropriation (CAIA) model

The CAIA model aims to provide a holistic framework that enables schools to assess their strengths, challenges and contextual needs in relation to technology integration. By applying this model, educational institutions can develop ICT strategies that are contextually responsive, adaptable, and sustainable. Rather than imposing a one-size-fits-all approach, the CAIA model advocates for inclusive, context-sensitive planning, ensuring that ICT implementation projects are not only technically viable but also socially embedded and educationally meaningful.

By bridging theoretical insights with practical application, the CAIA model serves as a valuable tool for policymakers, educators, and researchers to enhance the long-term effectiveness of ICT integration in diverse educational environments.

DISCUSSION

The application of posthumanism and ANT in educational technology research significantly broadens the theoretical and methodological toolkit available to scholars. By shifting from human-centred perspectives, these approaches enable researchers to explore technology-mediated educational environments in a more holistic, context-sensitive, and socially responsible manner. The inclusion of non-human actors in educational research fosters a more nuanced understanding of how technologies, institutional policies, infrastructures, and socio-cultural factors interact to shape learning experiences.

However, it is equally important to acknowledge the challenges and limitations associated with the use of ANT in educational research (Ferrante, 2017). One of the primary concerns is that ANT does not prescribe a specific research method or provide a standardised framework for network analysis. This methodological openness, while valuable in fostering flexibility, also raises the question of how to effectively study non-human actors without imposing human-centred interpretations. Since non-human entities lack direct agency in communication, the researcher needs to carefully “listen” to and “speak” on behalf of these entities. Researchers must thus decide how to represent their roles, influences, and interactions within the network. This inevitably introduces a level of subjectivity, as human researchers must act as mediators or interpreters on behalf of non-human artifacts.

Another challenge is that research using ANT tends to focus on analysis and description rather than producing practical guidelines or operational solutions. While this approach offers rich theoretical insights, it may create a disconnect between researchers and educational practitioners, particularly those who seek actionable strategies for integrating ICT into schools. The lack of prescriptive outcomes can make it difficult to translate ANT-based research into policy recommendations or pedagogical frameworks that can be readily applied in educational settings.

Despite these challenges, critical reflection on posthumanism and ANT does not diminish their value; rather, it enhances their applicability by encouraging researchers to develop methodological innovations that bridge theory and practice. Future research should explore hybrid methodological approaches that combine ANT's conceptual depth with practical frameworks for educational technology implementation. By doing so, posthumanism and ANT can contribute not only to advancing theoretical discussions but also to shaping more inclusive, adaptable, and sustainable educational technologies.

CONCLUSION

Posthumanism and ANT challenge traditional academic paradigms, offering a novel and dynamic approach to studying educational technology. By using ANT as an ontological foundation, rather than merely an interpretative theoretical lens, researchers can move beyond human-centred frameworks and instead explore how humans and technologies co-evolve within complex socio-technical networks. This relational perspective acknowledges the agency of both human and non-human actors, leading to a deeper and more nuanced understanding of how ICT shapes and is shaped by educational practices.

Despite its relative underutilization in educational research, posthumanism and ANT provide a powerful framework for rethinking technology-mediated learning environments. Their application not only stimulates and revitalizes the debate on education (Ferrante, 2017) but also opens new avenues for examining the intricate interplay between technology, pedagogy, and institutional structures.

To fully harness the potential of these socio-technical perspectives, future educational technology research should actively integrate posthumanist and ANT-informed methodologies. Doing so will contribute to the development of context-sensitive, inclusive, and forward-thinking educational technology practices, ensuring that ICT integration aligns with the evolving needs of learners, educators, and institutions in an increasingly digital world.

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Data Availability Statement:

The raw data supporting the conclusions of this paper will be provided by the authors upon request, without undue reservation.

Ethical Clearance:

Ethical clearance for the referenced study was secured from the Faculty of Informatics and Design Research Ethics Committee of the Cape Peninsula University of Technology (CPUT) and the Western Cape Education Department (WCED).

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No conflicts of interest are to be declared.

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A CONCEPTUAL FRAMEWORK FOR ENHANCING SUSTAINABLE CONSTRUCTION PRACTICES AMONG SMME'S IN SOUTH AFRICA

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ABSTRACT

This study presents a scoping review of factors influencing the adoption of sustainable construction practices in Africa with a particular focus on SMMEs in South Africa's construction industry based on an analysis of 21 studies from across the continent. The review identifies financial considerations such as high upfront costs, limited access to affordable financing, and the availability of economic incentives as key barriers to adoption. Government incentives and policies also emerge as significant, not only for their direct impact but also for their indirect influence on client demand by shaping perceptions of cost and economic viability. The study proposes a conceptual framework that maps the relationships among these factors, offering practical insights for academics, practitioners, and policymakers seeking to promote sustainable construction practices, particularly among South African construction SMMEs.

Keywords: sustainable construction practices, adoption, scoping review, small, medium and micro enterprises

INTRODUCTION

A sustainability-focused construction industry is a potential crucial partner in achieving the United Nations' Sustainable Development Goals (Gade, Larsen & Selman 2021). The construction industry possesses the potential to contribute towards achieving the Sustainable Development Goals (SDGs) related to sustainable cities and communities (SDG 11), responsible consumption and production (SDG 12), climate action (SDG 13) and life on land (SDG 15) (Pizzi, Caputo, Corvino & Venturelli, 2020). Despite this potential, conventional construction consumes a significant amount of energy (38% of global energy production), contributes to pollution, and emits 35% of carbon dioxide gas emissions (Fitriani & Ajayi, 2022; Ahmed, Sayed, Asran & Nosier, 2021). Conventional construction uses fossil fuels during material production, transportation, and construction. In addition, conventional construction consumes 25% of potable water and 30% of natural resources as raw materials (Fitriani & Ajayi, 2022). The production of traditional construction materials, such as concrete and steel, requires significant energy consumption (Fitriani & Ajayi, 2022). In addition, construction sites often have inadequate waste management, which produces 30% of global waste (Fitriani & Ajayi, 2022). Construction waste releases harmful pollutants into the soil and water bodies, damaging the surrounding ecosystems. The net result is that conventional construction is associated with environmental degradation and greenhouse gas emissions. This negative consequence of conventional construction, coupled with the increasing demand for infrastructure, underscores the urgent need for sustainable construction practices (Zulu, Zulu, Chabala & Chunda 2022).

Sustainable construction practices are intractably linked with sustainable development (Tokbolat, Karaca, Durdyev & Calay, 2020). Sustainable development occurs when a society fulfils its present needs while safeguarding the capacity of future generations to meet its own needs (WCED 1987). Sustainable construction practices are a construction process that incorporates the basic themes of sustainable development (Fei et al., 2021). Sustainable construction practices create infrastructure using environmentally responsible and resource-efficient processes throughout an infrastructure's lifecycle (Department of Public Works, 2018). Sustainable construction practices are also called green construction, green building or sustainable building (Department of Public Works, 2018). On its part, sustainable construction practices are a narrower concept focusing on the specific actions and strategies employed during the construction phase to achieve sustainability goals. Thus, sustainable construction practices are a subset of sustainable construction.

Governments worldwide, including the South African government, recognise the importance of sustainable construction practices (Department of Public Works, 2018). This realisation is reflected in the pervasiveness of sustainable construction policies and certifications that are being enacted. In South Africa, the Green Building Council of South Africa (GBCSA) has managed green building certifications since its establishment in 2007. Duplessis (2015) asserts that sustainability issues are dealt with by the standards established by the South African Bureau of Standards (SABS) for construction projects, such as road and bridge construction. However, it is unclear how the adoption of sustainable construction practices works from a process standpoint (Ahmed et al., 2021; Marsh, Brent & de Kock, 2021; Akinshipe, Oluleye & Aigbavboa, 2019). This lacunae in the literature seems to affect the development of frameworks and policies that promote sustainable construction practices. This is particularly pertinent for construction SMMEs as they have fewer resources and experience than their larger competitors (Marsh, Brent & de Kock, 2020).

The study proposes a conceptual framework of factors influencing the adoption of sustainable construction practices by South African construction SMMEs. The study will achieve this by conducting a scoping literature review on the enablers or barriers to African construction companies adopting sustainable construction practices. The study adopts this approach, given the limited literature on African construction companies adopting sustainable construction practices and hiatus by South African construction SMMEs (Marsh et al., 2020). South Africa has the Green Building Council and national standards, which are stronger institutional structures, but many African nations struggle to promote sustainable construction practices (Marsh et al., 2020). Unlike their counterparts in Ghana and Zambia, SMMEs in South Africa face challenges in implementing sustainable construction practices (Ametepey, Aigbavboa & Ansah, 2015).

The scoping review will be guided by the following research questions: (1) What are the facilitators or barriers to the adoption of sustainable construction practices by African construction companies? (2) What are the relationships among the enablers/barriers to the adoption of sustainable construction practices by African construction companies? Understanding the issues raised by the research questions is crucial for the development of sustainable construction practices. South African construction SMMEs represent a sizeable percentage of the South African construction industry. Thus, there is a need for targeted interventions that specifically target these construction SMMEs if sustainable construction practices are to become ingrained throughout the South African construction industry.

MATERIALS AND METHODS

The scoping review process adhered to the five-step methodological framework proposed by Arksey and O'Malley (2005). Initially, the study delineated research questions to shape the search strategies and selection of pertinent studies. Subsequently, searches on Scopus and Web of Science were performed using the keywords "sustainable OR green AND construction practices," "adoption," and "barriers OR facilitators OR enablers OR drivers OR challenges," resulting in 344 documents. In the third step, relevant studies were chosen based on inclusion criteria, origin from an African country, publication in English, and format as a journal article or conference paper. Review articles and articles in the press were excluded. This process yielded 51 documents. The titles and abstracts of these articles were then assessed for relevance to sustainable construction practices, narrowing the field to 21 documents. The fourth step involved thoroughly examining the full texts to extract key information like the study's country, sample size, publication year, research methods, and significant findings. Finally, the collected data were systematically analysed to create a narrative synthesis of the factors influencing the adoption of sustainable construction practices in the African construction industry. The relevance of these factors to SMMEs was examined, and their interrelations were explored to formulate a conceptual framework that could explain the adoption of sustainable construction practices by South African construction SMMEs.

RESULTS

Although the study targeted all African countries, relevant publications emerged from only four African countries, as shown in Figure 1. There were nine publications from Nigeria, five from South Africa, four from Ghana, two from Zambia, and one was a two-country study that compared findings from South Africa and Nigeria.

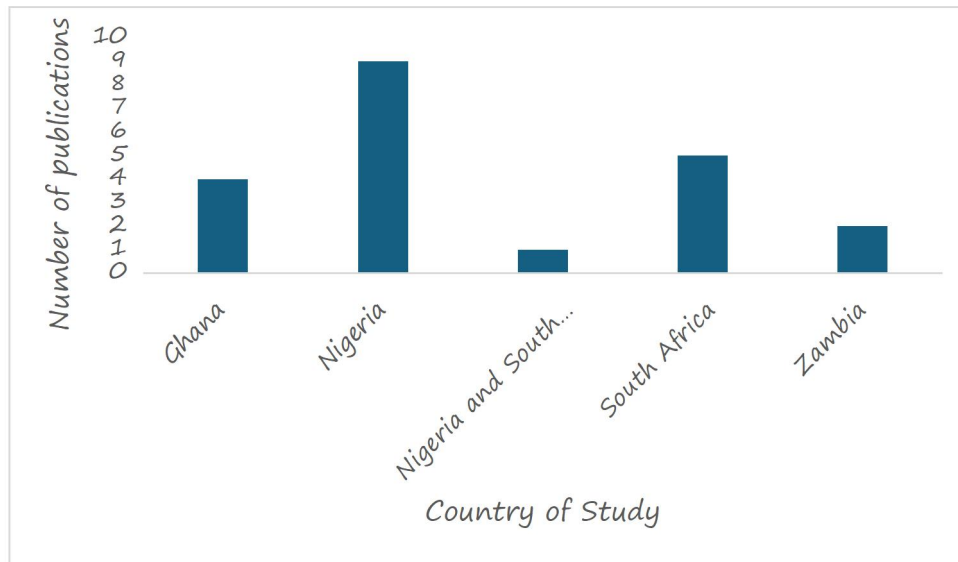


Figure 1. Number of publications from 2014 to 2024

Figure 2 shows the number of publications per year from 2015 to 2024. There was one publication in 2015 and three in 2018. The publications in each year that followed were: four publications in 2019, two publications in 2020, five publications in 2021, two publications in 2022, two publications in 2023 and two publications in 2024. There were no publications in 2016 and 2017.

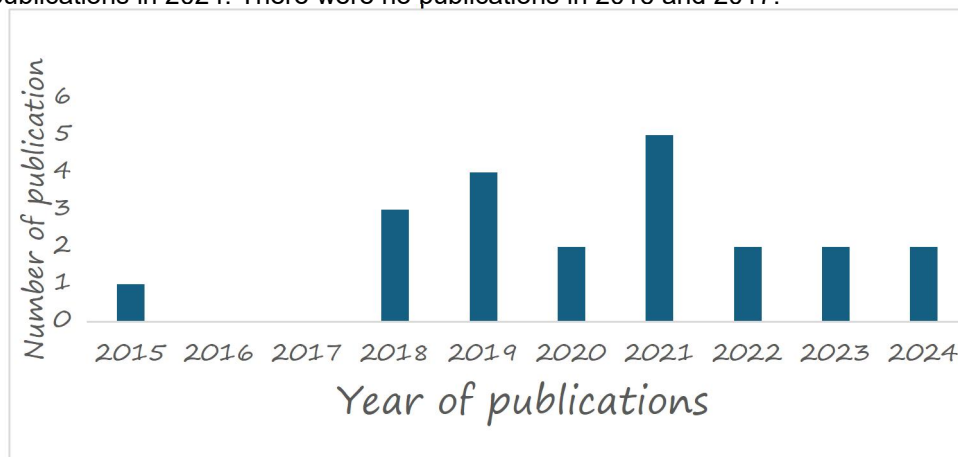


Figure 2. Number of publications from 2014 to 2024

Most of the studies collected data using surveys. Fourteen studies were surveys. These studies analysed their finding using descriptive statistics, with most reporting mean item scores. The sample size for these studies ranged from 44 to 281. There was one study that had a pilot with 20 respondents. Two studies used interviews. These had smaller sample sizes ranging from 4 to 15 respondents. The studies that used interviews used thematic analysis to uncover prominent factors. Five studies followed mixed methods; mostly sequential interviews followed by surveys. The studies focused on built environment professionals, interviewing or surveying architects, engineers, quantity surveyors, project managers, and construction managers.

In investigating what influences the adoption of sustainable construction practices, the studies focused on the challenges, enablers and factors impacting the adoption. Table 1 summarises these factors and the key findings from the studies.

Table 1: Key factors from the study

Factor/challenge/enabler	Main findings from the selected studies	References
Economic and cost perceptions	Sustainable construction materials and implementation are perceived as expensive, leading to fears of higher investment costs. Mitigation through financial incentives, tax breaks, and clear ROI communication is suggested.	de Beer & Kajimo-Shakantu 2023a; Osuizugbo et al., 2021; Okoye 2021; Marsh et al., 2021; Oguntona et al., 2019a; Amusan Lekan et al., 2019; Akinshipe et al., 2019; Aghimien, Aigbavboa, Oke & Musenga 2018; Ametepey et al. 2015; Djokoto, Dadzie & Ohemeng-Ababio 2014
Government incentives and policies	Government support through legislation, codes, and standards is crucial for adopting sustainable construction. Enforcement mechanisms, such as rewards and penalties for compliance, are necessary to drive sustainable practices.	de Beer & Kajimo-Shakantu 2023b; Zulu et al., 2022; Osuizugbo et al., 2021; Aghimien et al., 2018; Aghimien et al., 2019; Amusan Lekan et al., 2019; Oguntona et al., 2019; Darko & Chan, 2018; Ametepey et al. 2015; Djokoto et al. 2014
Attitude towards sustainable construction	Construction professionals and stakeholders are not keen to change how they have operated for a long time to implement sustainable construction (resistance to change). A lack of awareness of sustainable construction's benefits, including economic benefits, influences the attitude. Awareness of sustainable construction practices can change attitudes toward sustainable construction.	Maqbool et al., 2022; Okoye 2021; Aghimien et al., 2018; Ametepey et al., 2015
Client Demand and Preferences	The lack of demand for sustainable construction practices by clients impacts adoption. Clients' awareness of the benefits, including lifecycle costs, is essential. The inclusion of sustainability clauses in contracts can drive compliance.	Akinshipe et al., 2019; Babalola & Harinarain, 2024; De Beer, 2023; Djokoto et al., 2014; Okoye, 2021; Osuizugbo et al., 2021; Tunji-Olayeni, Kajimo-Shakantu & Osunrayi 2020; Tunji-Olayeni, Kajimo-Shakantu & Ayodele 2024
Knowledge of sustainable construction practices	There is inadequate knowledge about sustainable materials, practices, and technologies. This gap can be addressed through training, workshops, and continued professional development to enhance the adoption of sustainable practices.	Aghimien et al., 2019; Akinshipe et al., 2019; Ametepeya et al., 2015; Amusan et al., 2015; De Beer, 2023; Oguntona et al., 2019; Tunji-Olayeni et al., 2020; Tunji-Olayeni et al., 2024
Industry Norms and Practices	The construction industry tends to prioritise initial costs over long-term benefits like operational efficiency. sustainability is often seen as an additional, rather than integral, aspect of construction projects. The construction industry tends to favour economic over environmental considerations, which significantly hampers the adoption of sustainable practices. construction is heavily influenced by traditional practices, which prioritise cost over sustainability.	Daniel, 2018; Okoye et al., 2021; De Beer, 2023; Aghimien et al., 2018; Babalola and Harinarain, 2024; Tunji-Olayeni et al., 2024
Resource Efficiency and Waste Management	Waste management is one of the key sustainable construction practices. Environmental footprint of construction activities can be minimised through water conservation, the use of environmentally preferable products, and optimising processes to reduce waste and energy consumption. Life cycle costing is a key to for sustainable construction.	de Beer & Kajimo-Shakantu, 2023b; Maqbool et al., 2022; Zulu et al., 2022; Tunji-Olayeni et al., 2020; Oguntona et al., 2019a; Ametepey et al., 2015

DISCUSSION

The selected studies illustrate that the factors influencing sustainable construction practices are deeply interconnected. The interconnections among the factors depicted in the conceptual framework presented in Figure 3.

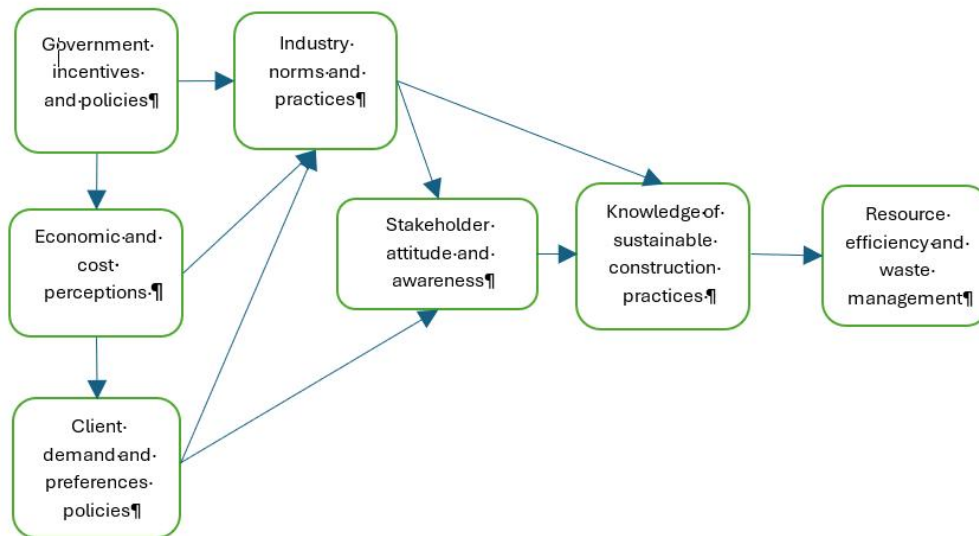


Figure 3. A conceptual framework linking various factors that influence the adoption of sustainable construction practices

Government incentives and policies (Figure 3) are crucial in shaping both the economic outlook and cost-related perceptions surrounding sustainable construction. Tools like tax incentives, subsidies, and grants help ease concerns about high initial costs, making green building projects seem more financially feasible. Without such support, these upfront expenses often remain a major deterrent (Zulu et al., 2022; de Beer & Kajimo-Shakantu, 2023). When governments champion sustainability efforts, the perceived risks decline, encouraging more participation from clients and industry professionals. Economic perception also directly influences market demand. When clients recognise sustainable construction practices as a wise long-term investment, their interest naturally grows. Clear communication around the financial upsides is critical to building client confidence (Akinshipe et al., 2019; Babalola & Harinarain, 2024).

Stakeholder mindsets are largely shaped by their understanding of sustainable methods. A limited knowledge base often leads to hesitation and a preference for conventional practices (Aghimien et al., 2019; Tunji-Olayeni et al., 2020). Targeted education and skills training can help shift this mindset and encourage openness to innovative, sustainable solutions. Additionally, industry norms carry significant weight in influencing behaviour. Traditionally, the construction sector leans toward short-term cost-cutting rather than long-term sustainability (Daniel et al., 2018; de Beer & Kajimo-Shakantu, 2023a). However, mounting pressure from policy-makers and increasingly eco-conscious clients can challenge these norms and promote a greener way forward (Maqbool et al., 2022).

Professional knowledge also plays a vital role in managing resources efficiently and minimising waste. Those with a solid grasp of sustainable techniques are better equipped to implement impactful environmental strategies (Oguntona et al., 2019a; Maqbool et al., 2022). Closing the knowledge gap is, therefore, essential to raising the bar for sustainability in construction projects. Ultimately, government policies can spark widespread change by encouraging the industry to pivot from purely cost-driven models toward more sustainable practices (Zulu et al., 2022; de Beer & Kajimo-Shakantu, 2023a). Likewise, consistent client demand for greener solutions can push the sector to embrace these practices as standard procedures (Akinshipe et al., 2019; Babalola & Harinarain, 2024).

CONCLUSION

This study explored key factors influencing the adoption of sustainable construction practices by SMMEs in Africa, with a particular focus on South Africa. The evidence highlights two dominant drivers: government incentives and policies, and client demand and preferences. These factors shape the adoption of sustainable practices by influencing industry norms, stakeholder awareness, and

perceptions of cost and value. Importantly, the review finds that government interventions do more than set standards - they indirectly shape market demand by reframing the economic narrative around sustainability. Practically, the framework provides policymakers with a targeted tool to design more effective sustainability strategies for the construction SMME sector. It points to the need for integrated approaches that combine regulation with incentives, market stimulation, and capacity-building initiatives. For South African SMMEs, in particular, sustainable construction will depend on accessible training, financial support mechanisms, and procurement practices that reward sustainability. By aligning policy instruments with the operational realities of SMMEs, governments can accelerate the shift toward sustainable construction across the continent. Theoretically, the study contributes a consolidated view of fragmented literature, mapping the interplay between institutional support and market dynamics in the construction SMME space. It offers a conceptual framework that situates SMMEs within broader policy and market systems, identifying where leverage points exist for enhancing sustainable adoption.

To support the adoption of sustainable construction practices among African SMMEs, particularly in South Africa, policymakers should prioritise financial interventions that reduce the high upfront costs and improve access to affordable financing options. Tailored economic incentives and sustainability-linked procurement policies could further encourage uptake. Future research should empirically test the proposed conceptual framework across diverse African contexts to validate its applicability and identify regional or sector-specific nuances. Longitudinal studies and case-based investigations could also provide deeper insights into how financial, policy and market dynamics evolve over time to influence sustainable practice adoption in the construction SMME sector.

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THE IMPACT OF DIGITAL COMMUNICATION TECHNOLOGIES ON THE DEVELOPMENT OF THE FILM INDUSTRY IN SOUTH AFRICA

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ABSTRACT

The advancement of digital communication technologies have had a significant impact on the development of South Africa's film industry. These technologies have transformed several facets of the film industry, including production, distribution, marketing, and audience engagement. This research examined the impact of digital communication technologies on the development of the South African film industry. Existing literature on the phenomenon reveals that most nations have adopted digital technologies, which has improved prospects for the film industry's value chain. Virtual servers, for instance allow the South African film industry to distribute its films to a larger audience via digital streaming platforms, while reducing transportation and storage costs. The research followed a qualitative approach. Interviews were conducted with ten film experts based on their involvement and expertise in the South African film industry. The findings revealed that the South African film industry has fully embraced digital technology, shifting from analogue to digital filming. The research further highlighted compelling facts regarding the advantages of digital technology for the South African film industry in showcasing their work to a broader geographic audience. Further research is recommended in several segments of the film industry, particularly regarding the factors that influence audience consumption behaviour among the digital native generation.

Keywords: Digital streaming platforms, Filmmaking, Netflix, Over-the-top services, Showmax

INTRODUCTION

In recent decades, the emergence of digital technologies has transformed multiple facets of filmmaking, such as production, distribution, and consumption. Digital communication technology is significantly impacting the global film industry, altering the sector's value chain, notwithstanding its considerable growth. The South African telecommunications industry, as noted by Muthivhi (2022), has been at the forefront of adopting advanced digital technologies to enhance the efficacy of communication services. The proliferation of digital communication technology has transformed communication methods, leading to the emergence of new practices across all digital platforms. The integration of digital technologies in the South African film industry has been shaped by global influences, notably globalisation, which has also impacted employee relations (Mpabanga 2022). The rapid progression of digital technologies has generated new prospects for both amateur and auteur filmmakers.

The South African film industry, in particular, has undergone significant transformation in recent years due to the impacts of digitisation. The film industry in South Africa has benefited from digitisation by the lowering of production costs, enabling new distribution models, and enhancing global reach. Digitisation has created opportunities for independent filmmakers, diversified storytelling, and increased the visibility of the South African film industry on the global stage. It has further redefined the filmmaking landscape in South Africa by making the production and distribution of films more accessible (Kearney 2021). Historically, South Africa's film industry faced numerous challenges, including limited funding and infrastructure. Traditional film production often required significant investments in equipment, set design, and logistics. However, the evolution of digital technology has dramatically reduced many of these barriers. Filmmakers can now create high-quality films using affordable digital cameras and editing software (Kearney 2021). This accessibility has sparked

creativity and innovation among filmmakers, allowing them to produce diverse narratives that reflect South Africa's rich and complex societal fabric (Kearney 2021).

The emergence of OTT streaming services has also changed the distribution model within the industry. OTT services such as Netflix, Showmax, and Amazon Prime have started investing in South African content (Mahony 2022). This has provided filmmakers with critical international exposure and the potential for financial returns. OTT services began producing their own content, rather than relying solely on the efforts of others, following the immense popularity of their own shows and films. The integration of streaming services into the fabric of South African cinema illustrates a shift from traditional box office models to digital consumption (Mahony 2022). According to Mbombo and Muthambi (2022), digital technologies have provided viewers with the convenience of accessing and consuming content through the use of a touch screen or button. The rapid advancement in internet connectivity, in conjunction with the proliferation of mobile devices that are optimised for digital media consumption, has enabled consumers to access their desired media content from anywhere at any time (Mbombo 2021). This trend reflects a broader global movement in which audiences increasingly prefer to view films online. Consequently, digitisation fosters a more extensive reach for South African films, allowing them to resonate with both local and international audiences.

Rationale

Digitalisation and industrialisation have afforded South Africa opportunities to enhance efficiency, transform processes, and integrate supply chains across various sectors, including the film industry (Andreoni et al. 2021). Mbura (2022) claims that the global film industry has seen substantial alterations due to technological advancements, resulting in a digital disruption that has reshaped its dynamics and developmental trajectories. Nonetheless, digital technologies exert a far-reaching impact that beyond the film industry, influencing sectors such as fashion and education. For example, individuals adept in digital technology typically prefer to browse fashion magazines in digital format on mobile devices for ease, as opposed to reading paper versions (Mbombo & Muthambi 2022). In conjunction with globalisation, the COVID-19 epidemic has expedited the integration of digital tools and platforms in South Africa's education system, as a means of responding to the crisis (Mhlanga & Moloi 2020).

The influence of digital communication technologies on the development of the South African film industry is substantial, impacting both filmmaking processes and additional sectors. The advent of novel filmmaking techniques is profoundly altering filmmakers' artistic choices about form and content development (Panda 2019). Winstead (2023) observes that the increasing accessibility and affordability of sophisticated digital filmmaking equipment do not, by themselves, empower major studios to produce higher-quality films at lower costs. Moreover, it indicates that filmmakers lacking the substantial resources of major production companies will have much enhanced opportunity to participate in the art. The digitalisation of the film industry has unequivocally equalised opportunities, allowing marginalised voices, formerly silenced through financial limitations, to attain recognition (Winstead 2023). The film industry in South Africa is significantly benefiting from digital communication technology, which offers a vital advantage in the filming, editing, distribution, marketing, and viewing of films. Due to digitisation, significant progress has been made in practically every aspect of filmmaking.

Problem statement

The film industry, once defined by celluloid and theatrical release, is now undergoing a radical transformation due to technological advancements, presenting both opportunities and challenges for filmmakers, distributors, and audiences, requiring a deeper understanding of these changes. Streaming services and on-demand platforms have fundamentally altered how audiences consume films, leading to a decline in traditional cinema viewing and a rise in home entertainment. Digital communication technologies have revolutionised filmmaking, from pre-production planning to post-production editing, but also raise questions about the future of film distribution and exhibition. The rise of technology has created new opportunities for independent filmmakers but also poses challenges for established players who must adapt to a rapidly changing landscape. The film industry must adapt to the changing technological landscape, including training and education for professionals, to ensure its continued relevance and success.

Knowledge gap and scope

This research addresses a critical knowledge gap by investigating the impact of digital communication technologies on the development of the South African film industry, especially following the COVID-19 pandemic, which hastened the shift of numerous sectors to digital platforms. This research is unique as it explicitly investigates the advancements in the value chain of low-budget films in South Africa. Consequently, the research tackles a substantial knowledge deficit that is often neglected. Although foresight studies and technical impact studies are frequently carried out across several industries, they are seldom employed in the low-budget film sector (Iden et al. 2017). The author is unaware of any research that investigates the impact of digital communication technologies on the evolution of the South African film industry, particularly concerning low-budget films and including the entire value chain of the industry. Previous research has focused mainly on the distribution component of the value chain (Kehoe & Mateer 2015), trends in technological innovation (Protogerou et al. 2016; Benghozi et al. 2015), the internet as a disruptive force (Fang & Xiong 2020), and the consistently transforming film industry (Grundström 2018).

Research objectives

Digital communication technologies have consolidated their position in the film industry, resulting in an extraordinary shift in audio-visual content production, exhibition, distribution, and consumption. As a result, the digital viewing platforms have become the film industry's dominant infrastructure and economic model. It is in consideration of the prevalent changes that the objective of this research is to:

- examine the impact of digital communication technologies on the development of the South African film industry.

The research puts forward a convincing argument on how digital communication technologies have had and continue to have an impact on transforming the South African film industry and as a result completely revolutionising it.

Critical analysis of previous studies

The evolution of the global film industry

In the two decades, the film industry has significantly advanced as a result of digital technology. Technology is evolving, roles are shifting, and new skills are required daily (Bosman 2017). The advent of digitalisation and advancements in film aesthetics have brought about a substantial change in the emphasis of cinematic storytelling, changing the narrative's primary attention from traditional storytelling elements to special effects and action sequences. This transition has resulted in a shift in audience focus from characters to visuals, leading to a greater emphasis on the plot rather than the characters themselves. The shift has further resulted in audiences experiencing heightened appreciation for the visual aspects of contemporary films.

According to Wang (2011), the film industry's perpetual technological advancements have had a substantial impact on the history of film. These advancements have included the transition from silent to sound films, the transition from black and white to colour images, the development of three-dimensional (3D) films, and the ongoing transition to virtual reality (VR) films. Such technological advancements have attracted audiences to cinemas (Domínguez et al. 2020; Rhaïem & Amara 2021; Tiberius & Hauptmeijer 2021). Similarly, the advancement of home cinema technology has rapidly grown, posing competition to traditional movie theatres. Faster internet connections enable high-resolution movie streaming, which presents a challenge to traditional theatre distribution (Hadida et al. 2021; Zhu 2001) and the mainstream television sector (Schauerte et al. 2020). Technological advancement in the production process and digitisation in post-production have made it easier for independent filmmakers to expand internationally and enter new markets.

Kafidoff (2023) posits that the manner in which films are produced and distributed is one of the most significant developments in global trends, as it is not constrained by the conventional studio system. Digital streaming services have enabled the production and distribution of a wider range of specialised content as a result of the availability of digital communication technologies. Kafidoff (2023) adds that digital technologies have allowed the film industry to take more risks on independent filmmakers and ideas that may have been difficult to procure funding or distribution through traditional means. Independent film producers are able to visualise and convey their narratives to audiences through digital streaming platforms as a result of digital communication technologies. In addition to expediting production schedules and reducing expenses, digital communication technologies are revolutionising the promotion and distribution of films (Winstead 2023). Additionally, the phenomenal

growth of social media has authentically expanded the global market. This implies that filmmakers can promote their films to individuals worldwide at a minimal to no cost by utilising social media (Winstead 2023). This shift has allowed films to reach a wider audience by making it easier to distribute them to various places, thereby increasing the market for film producers (Shalihah et al. 2023).

The film industry has experienced a significant transformation, with digitisation playing a critical role in the transformation of various aspects of film production and distribution (Shalihah et al. 2023). In order to adapt to the evolving landscape, the traditional theatrical windows have been diminished, and the availability of streaming services has been expanded, leading to the digital distribution revolution (Su 2022). The film industry's entire value chain has been altered by the influence of digitalisation, which has led to increased efficiency, accuracy, and realism (Tang 2024). Consequently, the visual effects and overall quality of films have been enhanced (Tu 2024). According to Tu (2024), digital media art has become an essential component of film and television production, providing a wide range of methods for creative expression and the creation of visual effects.

The transformation of the film industry in Africa

The film industry in Africa is undergoing a significant transformation characterised by growing trends such as heightened global acclaim, a rise of distinct narrative styles, and the use of state-of-the-art technologies. Klaassen and Ibrahimova (2022) argue that the increasing availability of digital technologies, the accessibility of digital film equipment, and the rise of digital streaming platforms are enabling a new generation of African filmmakers to emerge. The advent of the digital era offers the film industry in Africa a chance to exploit digital platforms, OTT streaming services, and creative distribution models. The transition to digital filmmaking has provided filmmakers on the continent with a greater number of opportunities to present a more inclusive and diverse image of Africa to global audiences and new markets. The appeal of African narratives to investors, primarily in the United States and China, has been confirmed by the global attention that Africa is receiving (Onyango 2021).

Klaassen and Ibrahimova (2022) note that the Nigerian film industry, also known as “Nollywood”, represents this expansion, producing approximately 2,500 films annually. In recent years, the Nigerian film industry has garnered significant attention from scholars globally (Miller 2016; Lobato 2010; Larkin 2005 & Haynes 2016). This fascination is primarily attributable to the low-budget production and distribution style of Nollywood. However, Ajibade (2013) and Becker (2013) argue that the success of Nollywood is primarily due to the relativity of the stories that are conveyed to audiences in the African continent and the African diaspora. The development of Nollywood is closely linked to the emergence of digital technologies. These developments have transformed multiple aspects of the industry, encompassing production, distribution, advertising, and exhibition. In her essay titled “*Digital Disruption: Technological Innovation and Global Film Circulation*”, Iordanova (2012) shares that new technologies fundamentally challenge the traditional distribution model. Conventional filmmaking frequently encountered limitations, like limited resources and access to sophisticated equipment; yet, digital tools have democratised the filmmaking process in Nollywood, allowing a broader spectrum of artists to participate in the market and produce superior content. Hanmakyugh (2024) believes that the introduction of digital technology has both optimised production methods and improved the quality of films produced.

Asheolge (2023) notes that Nollywood has undergone many distribution routes, like VHS, VCDs, and movie theatres, each presenting its own unique challenges. Simon (2021) states that iROKOTV, created in 2010, is considered the initial digital platform for distributing Nollywood films. Simon (2021) further shares that multiple online streaming services have emerged in Nigeria with the aim of disseminating Nollywood films to both local and global viewers. The emergence of online streaming services have indeed afforded Nigerian filmmakers novel opportunities to engage audiences locally and internationally. The transition from conventional cinema releases to digital platforms facilitates instant access to films (Hanmakyugh 2024). Nollywood now has the opportunity to distribute its films on international streaming platforms such as Showmax and Netflix (Asheolge 2023). As a result, Nollywood no longer just serve domestic audiences but also extends its international reach, a vital element in its development as the second-largest film producer globally.

The transformation of the South African film industry

The South African film industry is a developing and esteemed business that is globally acclaimed and renowned for its competitiveness. It accurately depicts the multifaceted history, customs, and socioeconomic obstacles of the nation. It stimulates the generation of employment, encourages innovative forms of self-expression, and has a significant influence on the overall economic state of the country. Tuomi (2005) claims that the South African film industry has a substantial impact on the transfer of technology and the enhancement of the country's skill set, while also generating a noteworthy amount of foreign exchange. The industry has social and political implications since it disseminates ideas, information, and encourages discussion (Tuomi 2005). Following the democratic elections in 1994, as a result of calls for industry restructuring, the National Film and Video Foundation (NFVF) was founded in 1999. South Africa has since welcomed an assortment of filming projects, including large-scale motion pictures and commercials (Le Sueur 2022). In addition to captivating narratives and exceptional cinematography, the industry is a dynamic ecosystem that fosters economic development and cultural enrichment.

The globalisation of the film industry has had a diverse impact on South Africa (Madara 2018). For instance, South Africa capitalised on this experience and established a flourishing local film industry (Madara 2018). Globalisation has enabled the industry to create films that emphasise its neglected histories and regional narratives for a global audience. Film production companies are presented with a plethora of opportunities to contribute to a diverse variety of films when foreign filmmakers travel to South Africa to shoot their films (Le Sueur 2022). This international recognition has a direct impact on the South African film industry. Moreover, filmmakers from both domestic and foreign countries are taking advantage of the country's distinctive and diverse locations, low production costs and low exchange rate, which make it less expensive to make a movie in South Africa than in Europe or the United States (Ncoyo 2014).

Brand South Africa claims that the nation's thriving and expanding film industry has improved its standing abroad and resulted in significant collaborations between Hollywood producers and local filmmakers. Building on a cluster of creative industries in the public and private sectors focused on Cape Town specifically, the film industry in South Africa contributes to job creation and skill development (Barnard & Tuomi 2008). Based on a number of factors, Evans (2009) expresses that Cape Town appears to be deserving of the title of primary creative city in the country. Tomaselli (2013) conveys that international filmmakers frequently shoot in Cape Town in particular because of the city's top-notch studios, inexpensive cost, variety of shooting locations, excellent infrastructure for services, including well-trained crews, upscale hotels that are in high demand, and summer's long, sunny days. Cape Town can thus be considered a "Local Hollywood" according to Goldsmith et al. (2010). Furthermore, according to a report on the creative industries commissioned by the Department of Labour (Creative Industries Report 2008), the Western Cape's film and television sector generated R2.5 billion in economic activity between 2003 and 2004, while Gauteng's sector only generated R1.3b.

Collins et al. (2016) claim that the South African film industry is a significant component of the country's small but well-established creative sector. The industry has made substantial advancements in technology, adopting state-of-the-art technologies and inventive narrative strategies. South African filmmakers are progressively delving into genres such as science fiction, horror, and animation, thus broadening the range and attractiveness of their cinematic creations. This technological innovation not only improves the calibre of domestic films but also places them in a competitive position on the international scene. The digitisation of South Africa's film industry signifies a crucial transformation to augment creativity, accessibility, and economic development. It signifies a substantial transition that mirrors overarching global trends while simultaneously tackling distinct local challenges.

Global trends demonstrate that advancements in technology have transformed film production and distribution, enabling South African filmmakers to access wider audiences both locally and globally (Snowball et al. 2018). The integration of high-definition cameras and digital editing tools has enhanced film quality and rendered production more economical for filmmakers. The shift from analogue to digital technologies has allowed filmmakers to produce, distribute, and exhibit films with more efficiency and cost-effectiveness. This transition has enhanced accessibility for emerging filmmakers from historically marginalised communities who previously encountered obstacles to accessing production resources (Moyer-Duncan 2021). Leveraging on digital media, these creatives

get access to broader audiences, thus fostering a more inclusive film culture. Furthermore, digitisation has been instrumental in the emergence of independent cinema in South Africa.

The spread of digital filmmaking equipment has substantially reduced production costs, enabling independent producers to explore storytelling without the limitations of conventional funding sources (Botha 2012). The shift to digital media markedly improves the distribution and visibility of South African films. The emergence of OTT streaming platforms like Showmax and Netflix has created new opportunities for local filmmakers to access international viewers. This transition is especially crucial in a post-apartheid era, where the South African film industry has been endeavouring to portray diversified narratives and perspectives. Digitisation democratises access to content, enabling independent filmmakers to present their work without relying solely on traditional cinema distribution methods (Moyer-Duncan 2021).

The emergence of digital streaming services

The advent of digital streaming services has brought about a significant upheaval in the global film and entertainment industries, leading to both prospects and obstacles for future studies (Soares 2024). Digital streaming services have transformed the availability of films and have also changed consumer behaviour, as they can now access a wide range of films. According to Gaustad (2019), digital streaming services have greatly expedited the digital revolution, enabling wider access to movies beyond the confines of conventional cinemas. Due to technological improvements in the digital realm, digital streaming services have experienced a surge in popularity (Alforova et al. 2021; Fan 2024). Moreover, their success has been greatly impacted by the existence of improved networks with higher bandwidth (Aguayo et al. 2018). Therefore, they exert a significant influence on the economic growth of various sectors, including the film industry in South Africa. Their impact extends beyond individual consumption patterns, as demonstrated by the findings of Ruddin and Jamalullail (2022). Digital streaming services are crucial in the digital age and are often linked to Industry 4.0 (Ruddin & Jamalullail 2022).

The shift towards digital subscriptions has exposed consumers to novel features, benefits, and constraints (Echauri 2023). The participation of digital service providers has significantly transformed the framework of copyright management organisations and the remuneration of producers (Towse 2020). The competition among streaming providers has increased due to technological improvements, resulting in the widespread availability of streaming services (Mohammad et al. 2021). The rise of streaming media consumers and mobile devices has greatly aided the advancement of mobile multimedia applications, leading to increased availability of digital streaming services (Bang et al. 2006). Streaming services have had an impact on how consumers make decisions, prompting research to focus on the elements that drive subscription and referral behaviours (Barata & Coelho 2021). In addition, the management and distribution of films on streaming services have become crucial in order to enhance user involvement and generate income (Morgan 2019; Aguiar & Waldfogel 2021). This technological and cultural upheaval has not only altered how films are consumed but has also revolutionised the financial strategies of content producers (Gaustad 2019).

The film industry has undergone a significant transformation as streaming platforms have acquired popularity, as noted by Chatterjee (2023). A new era of on-demand content consumption has been introduced as a result of the disruption of traditional television and film distribution strategies (Chatterjee 2023). The proliferation of streaming services has enabled the viewing of films on a diverse array of devices, such as smartphones, tablets, and smart televisions. Sharma (2022) concurs, asserting that there is currently a significant demand for over-the-top (OTT) video streaming content and services. Gengan (2023) states that the COVID-19 epidemic has opened up new opportunities for the South African film industry in the online sphere, as individuals are increasingly utilising the internet. The development of the film industry has facilitated the viewing of films on OTT platforms, including Showmax, Netflix, Amazon Prime, and YouTube. This has facilitated the viewing of films by consumers from any location and at any time, while also offering new opportunities for independent filmmakers to expand their audience.

The accessibility and convenience that streaming services offer have significantly influenced film consumption patterns (Chatterjee 2023). Viewers are no longer subject to the constraints and predetermined schedules of conventional broadcast networks (Chatterjee 2023). Gengan (2023) declares that the online video-on-demand (VOD) industry is anticipated to continue to significantly influence international cinema entertainment in the future. The convergence of technology has led to

the emergence of the digital cultural industry, which has fundamentally transformed the film industry. This convergence has facilitated groundbreaking advancements in the creation and dissemination of films, heralding a new epoch in the industry. However, the influence of digital innovation is not restricted solely to the film industry, but also encompasses multiple sectors that are experiencing digital change (Musostova et al. 2023). Digitalisation refers to the transition from analogue technology to digital advancements, which promotes the development of creative and knowledge-driven economies (Musostova et al. 2023). The digital revolution has had an impact on the characteristics of corporations, resulting in significant alterations in the structure and administration of businesses (Birkinshaw 2018).

MATERIALS AND METHODS

This research aimed to analyse the impact of digital communication technologies on the development of the film industry in South Africa. Therefore, the researcher adopted an exploratory research design using semi-structured interviews. The exploratory research design makes it clear that the aim of the research is not to offer certain conclusions on the phenomenon, but makes an effort to give empirical data in a field where there have not been many studies done before (Brown 2006). In accordance with Burns and Grove (2003), exploratory research is done to gain fresh insights, uncover novel notions, and increase awareness of a topic. Based on the positivism philosophical assumptions adopted for the research, a qualitative research approach was most suited. A research approach, according to Chetty (2016), is a plan that moves from generalisations to particular techniques for gathering, analysing, and interpreting data. Saunders et al. (2009) states that the purpose of qualitative research is to understand, describe, and translate a social phenomenon.

Population and sampling strategy

To establish the validity of the research and to further understand how digital communication technology has influenced the development of the South African film industry, a purposive sampling was used. Purposive sampling is also known as selective or judgmental sampling, and it indicates a team of professionals or subjects who offer the most insightful responses to the study's questions (Silverman 2004). Higson-Smith and Bless (1995) state that purposive sampling is based on the researcher's assessment of the specifications of the necessary sample. Silverman (2004) maintains that a case is specifically picked for purposive sampling because it best represents a characteristic or method that is relevant to the subject at hand. The purposive sampling approach was chosen to guarantee that the sample comprised individuals capable of offering the most insightful and pertinent information regarding the state of the film industry in South Africa. Furthermore, the researcher successfully reached out to persons who fulfilled the criteria to contribute to the study, which was very crucial for time efficiency. Thus, for the purpose of this research, film experts such as producers, directors, writers, and film editors were purposively selected as an appropriate representative group of South African filmmakers. **Sampling size**

Creswell (2013) defines a sample size as the total number of participants in the study. When determining an appropriate sample size for this study, the author focussed on the attainment of data saturation. A qualitative sample size needs to be adequate to collect enough data to adequately explain the phenomenon and meet the study's objective. The use of certain sample techniques, such as the purposive sampling technique, as in the case of this paper, is what is referred to as the sampling frame. When more people are added but no fresh perspectives are generated, data saturation occurs (Morse 2015). According to Guest et al. (2006), most qualitative research evidently reaches data saturation with a sample size of twelve people. To achieve data saturation, Creswell (1998) recommends a sample size of five to twenty-five participants, whereas Morse (1994) recommends that the sample size be at least six. Using the above guidelines, the research achieved data saturation with a sample size of ten participants.

Data collection and analysis

This research employed semi-structured interviews to gather data. This enabled the author to engage in direct dialogue with members of the film industry. This research sought to evaluate the extent to which digital communication technologies have influenced and continue to influence the development of the South African film industry. In order to achieve this objective, interviews and meetings were conducted with South African film experts. Karlsson (2007) shares that conducting interviews is the most effective method of acquiring data. The interviews made it simpler for participants to reveal additional details regarding the current state of the South African film industry and how technology has aided the sector.

The thematic analysis method was employed to analyse the data. The analysis of the data was qualitative in nature, as only qualitative information was collected. Henning (2004) claims that data analysis necessitates a methodical approach and the ability to articulate a thorough understanding of the facts in writing. This process involves the transcription, transcript reading, theme finding, theme evaluation, and theme conflict detection, and it is a methodical organisation and combining of research data (Polit & Hungler 1995). It is also a means of conveying the structure, direction, and significance of the volume of data collected (Marshall & Rossman 1999). The research was conducted in accordance with Braun and Clarke's (2006) six-phase thematic analysis methodology. Braun and Clarke (2006) outline a six-phase thematic analysis process that encompasses the following: getting familiar with data, initial coding, generating themes, validity and reliability of themes, defining and naming the themes, and finally interpretation and reporting of the findings.

RESULTS

The objective of this research was to examine the impact of digital communication technologies on the development of the South African film industry. To address this objective, the paper had to address the following research question:

- How have digital communication technologies impacted the development of the South African industry?

The data was presented thematically based on the nature of the research and the research topic. The purpose of this was to arrange the data collected from South African film practitioners in a sequential manner. Table 1 below presents the themes that emerged during the data analysis process as well as their relevancy to the research.

Table 1: Themes that emerged from the data analysis

Themes	Relevance
Digital migration	Participants view the shift from analogue to digital filmmaking as a major development in the South African film industry.
Greater accessibility	Participants shared that digital technologies have afforded many individuals to have access to the film industry in terms of jobs and accessibility to tools for producing content.
Viewing convenience	Participants observed that advancements in digital technology have made it possible for audiences to conveniently access and watch films at any time and location, hence indicating the evident development in the film industry.

The themes that emerged as shown in table 1 are presented below with verbatim responses written in italics. Moreover, the participant from whom the verbatim response was taken is identified and referred to using brackets and line numbers. Thus, results for theme 1 are presented in Table 2 below.

Table 2: Results for theme 1

Theme 1:	Verbatim quotes:
Digital migration	<i>"...when I started out like you would literally send the videotape to SABC or Mnet or even DSTV back then, they would go and like upload that tape, but for the longest time now at least 10 years you just basically WeTransfer it to them, using a similar kind of service, that's also completely digital..."</i> (Participant G: 1145-1149).
	<i>"...2010, they were still mainly shooting on film, but by 2011, literally everyone was shooting on digital, and film wasn't even really an option anymore..."</i> (Participant G: 1129-1130).
	<i>"...the cloud services and the fact that a lot of the films and TV series are now digital, you don't have to have the actual film anymore. You can just transfer it. In the old days, you had to take your hard drives..."</i> (Participant F: 974-976).
	<i>"...so, it has changed in a way that it's very much less analogue, less delivering of hard drives and assets on physical devices, and now everything's remote, online, on servers, so seeing that progression has been very interesting because since the pandemic happened, it's almost overwhelming..."</i> (Participant B: 275-

South Africa has experienced significant advancements in film technology in the past two decades. The ability to transform the entire process of filmmaking into a digital format is one of the most significant advancements facilitated by digital communication technology. Participants asserted that the South African film industry has fully transitioned to digital technology, eliminating the option to choose between shooting on film or digital. Initially, physical cassettes were given to corporations like SABC and MultiChoice, but the shift to digital technology has simplified the process of delivering video. The utilisation of cloud computing in the field of filmmaking, together with its capacity to remotely store and retrieve vast quantities of data, stands out as a major technological breakthrough within the South African film industry. Participants said that in the past, South African filmmakers were required to store the footage on tangible storage devices, such as hard drives, and physically carry them to different locations. The South African film industry was compelled to transition from analogue to digital due to a variety of factors, including financial and accessibility concerns. The findings underscored that anyone who possesses a digital camera or a mobile phone has the potential to become a film producer or at least claim to be one. Table 3 below presents results for theme 2.

Table 3: Results for theme 2

Theme 2:	Verbatim quotes:
	<i>"...it made film making accessible to most people, whereas in the past, it was a very exclusive group of people where it is now with your cell phone you can make a film, ...and therefore, stories that we would never have heard, creativity in people that would never have had the opportunity has become possible. Those guys would never have had that ability to do something unless digital had become a thing..."</i> (Participant E: 831-836).
	<i>"...people were feeling that there was a red tape, it was not easy to get into the industry..."</i> (Participant D: 650-651).
	<i>"...I think it has positively evolved in terms of inclusivity, in terms of training and development of South African citizens that are not only White..."</i> (Participant A: 4-5).

In light of the increased availability of films through the internet and across digital platforms, digital communication technology has made it easier for individuals to access and view films. This has allowed more individuals to see movies and increased the South African industry's overall reach. The results demonstrated a substantial increase in inclusivity within the South African film industry compared to its previous state. Participants discussed the concept of "accessibility" within the framework of the film industry's current efforts towards diversity. The film industry's accessibility also encompasses the right to intellectual property for the creations and innovations of every producer. Furthermore, this accessibility is denoted in relation to employment opportunities, the development of the sector to be more inclusive, the capability for viewers to digitally access films, and the opportunity to reach a global stage and audience. Streaming platforms such as Showmax, Netflix, Amazon Prime, and others have enabled the viewing of films on various devices, including smartphones, tablets, and smart TVs. This has afforded South African filmmakers with novel opportunities to reach a wider audience, while simultaneously facilitating convenient access to films for consumers. Table 4 below presents results for theme 3.

Table 4: Results for theme 3

Theme 3:	Verbatim quotes:
Viewing convenience	<i>"... we are no longer confined to TV 1, 2 and 3 and Bob TV. I am no longer confined to linear broadcasting, so it means therefore, I can watch whatever I want, whenever I want, right..."</i> Participant J: 157-1578).
	<i>"...I mean the LSM between 18 maybe to say 30 years is different...if they don't feel your show, if they feel like it's not relevant, they have options.... So, viewership is also wide because you are not like channelled to only watching</i>

	<i>SABC. We have variety now, like Showmax...Netflix, we have...eVOD...there are so many platforms...So, the audience obviously have changed...” (Participant D: 703-709).</i>
	<i>“...people's viewing habits have changed, we don't wait for things, all of that is there...” (Participant C: 587-588).</i>
	<i>“...I mean, the audiences have grown and they're no longer domestic....” (Participant J: 1543).</i>

Digital technologies have had a substantial impact on both the distribution and consumption of films. The expanded opportunities for South African independent filmmakers have facilitated broader accessibility of films for audiences, regardless of their location or preferred viewing time. The rise of on-demand viewing has caused a shift in viewer behaviour, giving viewers with new types of viewing experiences. On account of the rising existence of streaming platforms, it was noted that the capacity to reach audiences and meet them where they are, has altered dramatically. This has created a market for South African films that would otherwise struggle to get widespread distribution and presentation. The OTT service's accessibility across time and geography gives viewers the freedom to watch the desired content, also makes it perceived as more desirable than traditional media.

DISCUSSION

Digital migration

The results indicate that the introduction of digital communication technologies has substantially facilitated the development of the South African film industry. The industry has gradually transitioned from analogue to digital recording technology over the past two decades. This transition was inevitable due to a variety of factors, such as the film viewing convenience and accessibility concerns of the industry. According to scholarly discourse, the big film studios and other distributors need to adapt to new forms of distribution and consider adjusting the system owing to convergence, digitalisation, and their responsibilities as makers of films (Kerrigan 2010). The film industry in South Africa is now significantly more accessible to individuals and filmmakers who have limited financial resources than major production companies. This has facilitated the democratisation of filmmaking in South Africa, rendering it more accessible to independent filmmakers than ever before. This implies that South African independent filmmakers can circumvent the industry's traditional gatekeepers and enjoy a higher degree of artistic expression and creative freedom with less cost. Every advancement in the South African film industry has brought the sector closer to producing more persuasive films, which in turn makes for a more pleasurable viewing experience.

The research further highlighted the development of the South African film industry in terms of the affordability of equipment used to shoot content. Digital cameras have largely replaced film cameras due to their ability to capture higher-quality photographs at a reduced cost. To some extent, anyone who owns a digital camera or a mobile phone has the potential to become a filmmaker or assert their status as a content producer. Digital editing software has also supplanted conventional movie editing equipment, facilitating more precise and efficient editing. Thus, affordable digital video editing software enable South African amateur filmmakers or content creators to effortlessly complete tasks that previously required the physical cutting and splicing of film reels. The digital format facilitates the simultaneous capture and modification of images, thereby accelerating and optimising the post-production process. Independent filmmakers in South Africa can now generate high-quality films at a fraction of the cost of traditional filmmaking.

Nevertheless, the digital transformation has not been limited to digital tools and procedures; South African independent film producers are now able to distribute their films to the general public through online channels like YouTube and other social media platforms. A film can be made more accessible to a broader audience by ensuring that it reaches millions of people through a successfully executed social media strategy. According to Viljoen-Stroebel (2022), digital technology have disrupted traditional industry norms and procedures. The development of digital film technology and data compression, which allow for the digital capture, modification, storage, transportation, and presentation of films, has been one of the most significant advancements in the film industry (Stump 2014). Digital communication technology has further revolutionised film storage, simplifying the process of managing and transferring films to South African theatres and broadcasting companies.

According to Stump (2014), digital film technology and data compression, which enable the digital filming, editing, storage, transportation, and presentation of films, were among the most significant advancements of the past few decades. The transition from professional camera equipment to mobile phones during the production stage represents a new phase in this technological advancement (Stump 2014).

Greater accessibility

The advent of digital filmmaking has presented filmmakers with an unprecedented number of opportunities and possibilities. Digital communication technologies have simplified the process of obtaining all the necessary knowledge for breaking into the South African film industry by allowing individuals to utilise digital resources. The research discovered that, prior to the emergence of digital technology, south African filmmakers were subjected to exploitation by major corporations. Now they are no longer limited to relying on large television broadcast corporations like MultiChoice and SABC, as digital technologies have enabled them to retain intellectual property rights to their productions. A report from CIGS (1998) emphasises this point, asserting that local films are not widely distributed both within and outside of South Africa due to issues with the SABC, limited intellectual property rights for South African filmmakers, low production budgets, difficult access to foreign markets (CIGS 1998), and a lack of local theatrical releases (NFVF 2010).

The South African film industry's accessibility is a multifaceted issue that is influenced by economic, social, and cultural factors. The significance of policy frameworks in the development of a post-apartheid film industry has been underscored by the National Film and Video Foundation of South Africa (Botha 2003). The issue of accessibility in the South African film industry is not restricted to creative aspects; it also includes economic factors, such as the influence of organisational changes on local opportunities (Tuomi 2007). The industry's ability to address systemic deficiencies in education systems and provide employment opportunities is crucial for the enhancement of inclusivity and accessibility. Furthermore, the necessity of a comprehensive strategy to enhance accessibility in the sector is emphasised by the importance of stakeholder inclusion, human capital, and film policy in industry development (Botha 2003; Kleynhans 2006; Ngobese 2023). South Africa's film industry is a contested space in terms of industry structure, with a variety of factors that influence its competitiveness and development (Tomaselli 2013).

The research also underscored the South African film industry's accessibility in terms of global viewership of locally produced films. The study's findings also highlighted the significant impact of digital communication technology on the South African film industry, particularly in terms of cost-efficiency and ease of accessibility. According to Mulla (2022) viewers are driven to continue watching OTT videos due to pull factors such as affordability, a wide variety of material, and convenient accessibility. The OTT service is preferable to conventional media because it offers accessibility in terms of both time and geography, allowing users to easily access the desired content (Shin & Park 2021). The factors that attract people to choose OTT over other forms of entertainment media include cost-effectiveness (Bhullar & Chaudhary 2020), the ability to access a wide range of content (Bhattacharyya et al. 2022), convenient access to content through various devices and at any time (Mulla 2022), availability of both global and local content (Nagaraj et al. 2021), and the collaborative nature of digital streaming services (Shin & Park 2021).

Viewing convenience

The paper highlighted the various exceptional digital streaming alternatives available to South African filmmakers, enabling them to reach a wider audience while maintaining control over their intellectual property rights. Digital platforms like Netflix and Showmax have transformed the South African film industry by granting South African filmmakers the opportunity to reach a wider audience and compete globally, in addition to their local market. Motsaathebe (2018) observed that the South African film industry experienced a substantial shift starting in 2004, marked by the release of highly successful films like *"Yesterday"*, *"Jerusalem"*, and *"Tsotsi"*, which gained recognition on the global platform. In addition to the internet, audiences can access a range of content via other platforms, including television and digital media. Kehoe and Mateer (2015) have noted that audience behaviours regarding the internet are changing as individuals allocate time for internet access and consumption of digital material. The conventional approaches to business in the South African film industry have been challenged by the digital revolution. This change has empowered consumers with greater

control over media and has made filmmaking equipment more accessible and affordable for inexperienced filmmakers. They are now able to produce and distribute media on their own thanks to this. According to Stump (2014), the development of digital film technology and data compression has been one of the most important advancements in recent decades. This technology enables films to be produced, altered, saved, transmitted, and displayed digitally. The current technical advancement involves a transition from using professional camera equipment for filming throughout production to utilising cell phones.

The study emphasised that digital technologies have had a substantial impact on the distribution and consumption of films. The improved opportunities for South African independent filmmakers have facilitated more accessibility for audiences, enabling them to see films from any place and at any time. In addition to promoting services such as television, digital technology has caused a change in attitudes and a restructuring of consumers' daily habits (Roca et al. 2016). Furthermore, it was observed that the use of digital technologies has allowed filmmakers to engage with their intended audiences. In recent years, digital technology has caused a significant change in audience viewing habits, granting viewers unprecedented control over content, beyond any previous generation. Currently, South African viewers have a variety of options for watching content, the flexibility to choose where to watch it, and the freedom to decide when to watch it. Audiences are no longer compelled to physically go to their nearby cinema in order to watch a movie. The advent of digital communication technology has significantly facilitated the dissemination of South African films through online and digital platforms like Showmax and eVOD. The emergence of new distribution methods, such as streaming services and video on demand, has fundamentally changed the movie-watching habits of South Africans. The advancement of digital technology has expanded the toolset available to South African filmmakers, allowing them to choose the most suitable tools and procedures for their productions (Piccirillo 2011).

The South African film industry has undergone a significant transformation in every part of its value chain due to the advent of digital technology. This has had a profound and extensive influence on the development of the South African film industry. As the industry progresses rapidly, it is clear that the dynamic interplay between technology and creativity will shape the sector's future in ways that are beyond our imagination. The findings indicate that digital technology has had a substantial influence on independent film production in several ways. The most prominent effect is the transition from analogue to digital, followed by the increased accessibility of the industry and the convenience of viewing films.

CONCLUSION

Digital technology has profoundly transformed the film industry, particularly since the 1960s, when it began to radically change the nature of film production and distribution. This study explored the impact of digital communications technologies on the development of the film industry in South Africa. This technological development transformed the sector in several phases, from silent to sound and from black and white to colour and 3D, thus increasing the narrative powers of filmmakers. The shift from analogue to digital film production has been facilitated by the development of digital media technology. The advent of digital cameras marked a crucial shift, making digital film the predominant production method, replacing the analogue approaches that prevailed until the turn of the millennium. The shift to digital platforms has further resulted in completed films being distributed as large files, extending the reach of the sector to a wider audience and enabling individuals to earn a living from content creation. The advent of digital technology has had a profound impact on film production, distribution and consumption. The South African film industry has therefore experienced a major digital revolution which has transformed the entire value chain of the medium. The process of producing films has become more efficient, cheaper and easier to access, making them more accessible to a wider audience. Filmmakers who exploit this evolution experience improved audio-visual quality, which increases consumer interest and satisfaction. The integration of digital technology has increased market opportunities and production capacity, which has led to an increase in film consumption rather than the decrease that some might have expected in the face of rapid technological progress. There have also been advances in film marketing which go beyond traditional approaches, as new digital technologies require precise targeting of specific consumers. Social media have democratised the ability of those with access to the internet to distribute their films and content via digital platforms.

Moreover, the advent of digital technology has enhanced the operational structure of the film industry by fostering stronger interconnectivity between the various sectors, accelerating the process from pre-production to distribution. In addition, the COVID-19 pandemic has led to a boom in online streaming, creating new opportunities and increasing the demand for cinemas to build a strong online presence. The advent of digital streaming services has fundamentally changed the way people consume films, leading to major changes in economic structures, cultural sustainability and consumer behaviour. Digital streaming services have also made films available to new audiences that may not have had the opportunity to see them in cinemas. Digital technology has greatly improved the ability of individuals to express their thoughts about the latest film, leading to faster response times. The digital transformation has the potential to profoundly transform film education and training, affecting curricula, pedagogy and accessibility. The shift from traditional film stock to digital workflow has democratised film production, allowing students and individuals to experiment and create content with greater ease and accessibility. This availability has broadened participation, bringing in different voices and perspectives that were previously precluded by the high costs of film production. Therefore, this study also recommends a future study with a focus on the impact of digital transformation on education and training.

Informed Consent Statement: The participants received an invitation letter detailing the protocols of the study and its intended purpose. Prior to the start of the interviews, they were provided with a consent form to sign and made certain that they understood the study's purpose and their role in it.

Data Availability Statement: Data is available from the author.

Ethical Clearance: Permission to carry out the research was sought and obtained from the University of Johannesburg.

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THE POTENTIAL ROLES OF ARTIFICIAL INTELLIGENCE IN ENHANCING FORMAL EDUCATION

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ABSTRACT

The deployment of Artificial Intelligence (AI) in education aims to enhance teaching and learning processes, offering transformative potential through personalized instruction and improved educational outcomes. AI applications, such as intelligent tutoring systems, virtual mentors, adaptive learning platforms, educational games, virtual reality simulations, and automated grading systems, have garnered significant attention in the educational field. These technologies promise to improve student engagement, provide tailored learning experiences, and alleviate many administrative burdens for educators. This paper explores the potential roles of AI in formal education, beginning with an overview of traditional teaching methods and tools. The study is carried out through a review of literature and research on the integration of AI into formal education. A comparison between Computer-Aided Instruction (CAI) and AI-based teaching and learning highlights the advancements AI brings to the educational landscape. Despite its many benefits, however, AI also presents challenges related to ethics, privacy, and equity, which must be addressed. AI's impact on formal education is diverse and far-reaching, making AI techniques and tools essential for achieving UNESCO's fourth Sustainable Development Goal which zeros in on quality education for all. As AI technology continues to evolve, collaboration among stakeholders—including governments, educators, students, and parents—is crucial to harness its potential while mitigating associated challenges

Keywords: Computer-aided-Instruction, Digital Technology, Intelligent Tutoring Systems, Sustainable Development Goal, Virtual Reality

INTRODUCTION

Formal Education and Artificial Intelligence

Formal education refers to the structured, systematic learning process that typically occurs within an organized institution, such as schools, colleges, and universities. It follows a predefined curriculum, often leading to the award or attainment of recognized qualifications, degrees, or certifications (Johnson and Majewska, 2022). Formal education is characterized by its emphasis on standardized learning objectives, assessments, and instructional methods, with the goal of imparting knowledge, skills, and competencies to learners.

Formal education encompasses a wide range of activities aimed at facilitating learning within structured settings such as schools, colleges, and universities. These activities include but are not limited to classroom instructions, lectures, tutorials, assignments and homework, examinations and assessment. (Nitko and Brookhart, 2020). These activities collectively contribute to the holistic development of students within the formal education system, fostering intellectual, social, and personal growth.

Artificial intelligence (AI) refers to the development of computer systems that can perform tasks that typically require human intelligence. These tasks include learning, reasoning, problem-solving, perception, understanding natural language, and interacting with the environment. AI encompasses various techniques and approaches, including machine learning, natural language processing, computer vision, robotics, and expert systems (Ghosh and Arunachalam, 2021). AI has significantly impacted many areas of life including formal education by enhancing learning experiences, improving learning outcomes and administrative efficiency as well as facilitating wider and easier access to education. Popular algorithms used in AI include supervised and unsupervised learning algorithms, reinforcement algorithms, deep learning algorithms and so on.

Highlights of the impact of AI in enhancing formal education are not common knowledge. This study provides a cursory overview of AI's impact on formal education as well as some of the challenges facing the integration of AI into education.

Review of traditional teaching and learning methods and tools

Traditionally, before the advent of digital technology, several methods have been employed for teaching and learning. The methods include lecture methods (Major et al., 2016), demonstration methods (Joyce et al., 2014), discussion methods, tutorial methods and others.

Traditional Audio-Visual Aids

To effectively impart the required knowledge to learners, a variety of audio-visual teaching and learning aids have been employed. Traditional audio-visual teaching and learning aids encompass a range of tools and techniques used to enhance the educational process by engaging multiple senses. They combine sound and visuals to enhance classroom experiences. Common examples of traditional teaching aids are Chalkboards/Whiteboards, Overhead Projector, Slide Projector, Audio Recording, Charts, Graphs and Diagrams.

Textbooks and Printed Materials have long been a core component of education, providing students with in-depth information and structured learning. Printed materials like worksheets, handouts, and reference guides offer supplementary resources for practice, specific topics, or revision. These traditional teaching aids have been widely used for decades and continue to be valuable tools in various educational settings. However, they also have limitations, particularly in terms of interactivity, adaptability, and reliance on physical materials. With the advent of digital technology, newer audio-visual aids offer enhanced capabilities and overcome some of these limitations.

Newer Audio-Visual Aids

Newer audio-visual teaching and learning aids utilize digital technologies to significantly enhance educational experiences, catering to diverse learning styles and preferences. Interactive Whiteboards (IWB), Document Cameras, Virtual Reality (VR) and Augmented Reality (AR) (Huang and Liang, 2017), Online Video Platforms (like YouTube, Khan Academy, and TED-Ed), and Podcasts and Audiobooks (Makina, 2020) are some examples of newer teaching and learning aids. These newer audio-visual teaching aids offer innovative ways to engage learners, promote active participation, and cater to diverse learning preferences. However, their effectiveness depends on thoughtful integration into instructional design and pedagogical practices.

Pre-AI Tools and Techniques

Prior to the present hype about AI, there already existed what is still called computer-aided instruction (CAI) or Computer-assisted learning (CAL) which is still in use today. Computer-Aided Instruction (CAI), also known as Computer-Assisted Instruction, refers to the use of computers and software

applications to deliver educational content and facilitate learning. It encompasses a variety of instructional methods and tools designed to enhance the teaching and learning process. CAI provides the following benefits among others (Usman and Madudili, 2020): interactive learning, self-paced learning, adaptive learning, immediate feedback, improved accessibility for learners with diverse needs and backgrounds and many more.

The enablers of CAI are the CAI tools and software which essentially are programs or platforms that use computers to help people learn. They can be used to deliver instruction, provide practice exercises, assess learning, and more. CAI tools have been a valuable supplement to traditional classroom instruction, allowing students to learn at their own pace and in a more engaging way. Examples of CAI enablers are Drill and Practice (e.g. Math Blaster (ages 6-12), Tutorial Software (e.g. Khan Academy (for all ages), Simulation Software (e.g. Flight Simulator (for all ages), Educational Games (e.g. Minecraft Education Edition (for ages 6-18), Learning Management Systems (LMS)(e.g. Moodle (for all ages), Authoring Tools (e.g. Articulate Storyline (for all ages) and many more.

Moodle is a free and open-source LMS that is used by millions of educators around the world. Moodle allows instructors to create and deliver online courses, track student progress, communicate with students, and provide online assessments. Its flexible design makes it suitable for a wide range of educational settings. Articulate Storyline is a popular authoring tool that allows educators and trainers to create professional-looking eLearning courses. Storyline offers a variety of features for creating interactive content, including quizzes, simulations, and branching scenarios.

Potential Roles of Artificial Intelligence (AI) In Formal Education

There is no doubt that AI is revolutionising education by making learning more engaging, accessible, and effective for learners of all ages and backgrounds. By harnessing the power of AI, educators can unlock new opportunities to enhance student engagement, improve learning outcomes, and prepare learners for success in the digital age. Possible roles of Artificial intelligence (AI) in formal education include but are not limited to the following:

1. **Personalized Learning:**
AI can facilitate personalized learning experiences tailored to individual students' needs and preferences (Hughey, 2020). Research from Carnegie Learning (2019) found that their AI-driven math software, MATHia, led to double the learning gains compared to traditional methods over one academic year.
2. **Adaptive Instruction and Feedback:**
AI-powered tutoring systems can provide adaptive instruction and feedback to students.
3. **Automated Grading and Feedback:**
AI can automate the grading process and provide immediate feedback to students. A study conducted by Stanford University in 2023 showed that AI-based essay graders, like ETS's e-Rater, have an accuracy rate of 96% compared to human graders, with the added benefit of providing immediate feedback (Standford, 2023).
4. **Content Creation and Curation:**
AI can assist in generating educational content and curating resources for educators (Haider and Rigby, 2016).
5. **Virtual Teaching Assistants:**
AI-powered virtual assistants can support teachers and students in various tasks (Munshi and Al Khoori, 2018). The AI teaching assistant, called Squirrel Learning, in China has been reported to have reduced remediation time by 40% while increasing student test scores by an average of 12% (Yixue Group 2014).
6. **Predictive Analytics for Student Success:**
AI can analyze data to predict student outcomes and provide early intervention. It has been reported that Purdue University's Course Signals project showed that AI-based early intervention systems helped reduce dropout rates by 21% over three years by identifying at-risk students (Anazia, 2021).
7. **Enhanced Accessibility and Inclusion:**
AI technologies can improve accessibility for students with disabilities (Müller and Tomlein, 2018). Tuteria (Nigeria) uses AI to improve access to education for marginalized communities. A pilot with visually impaired students in Lagos State reported an 80% improvement in academic participation and a 40% boost in comprehension rates after integrating AI tools like text-to-speech technologies (Johnson and Davis, 2024).
8. **Data-Driven Decision-Making:**

- AI can support data-driven decision-making processes in educational institutions.
9. Virtual Reality and Simulations:
AI-driven virtual reality and simulations can create immersive learning environments.
 10. Educational Gaming:
AI-powered educational games can engage students and promote learning (Clark et al., 2016).

These roles of AI in formal education are convincingly impactful. Without any doubt, AI techniques and tools will be indispensable in achieving the fourth UNESCO Sustainable Development Goal (SDG); that is “ensuring inclusive and equitable quality education and promote lifelong learning opportunities for all” (United Nations, 2023).

Available AI Tools for Teaching and Learning

AI tools for teaching and learning are becoming increasingly prevalent, offering personalized, adaptive, and interactive educational experiences. Below is a brief description of some available AI tools

Intelligent Tutoring Systems (ITS):

ITSs leverage AI algorithms to provide personalized instruction, feedback, and guidance to learners. They adapt to individual learning styles and paces, offering customized learning paths (Carnegie Learning, 2019).

Chatbots and Virtual Assistants

Chatbots and virtual assistants use natural language processing (NLP) to converse with learners, answer questions, provide explanations, and offer support in real-time (Serban, et al. 2017).

Automated Grading and Feedback Systems AI-powered systems automatically grade assignments, quizzes, and assessments, providing instant feedback to students. They may use machine learning algorithms to analyze and evaluate student responses (Singh, et al., 2017).

Adaptive Learning Platforms

Adaptive learning platforms use AI algorithms to analyze learner data and dynamically adjust content, activities, and assessments based on individual progress and performance (Baker 2016).

Content Recommendation Systems:

Content recommendation systems use AI techniques like collaborative filtering and content-based filtering to suggest relevant learning materials, resources, and courses to users (Ricci et al., 2015).

These AI tools represent a growing trend in education toward leveraging technology to support and enhance teaching and learning experiences. However, their effectiveness depends on thoughtful integration into instructional design and pedagogical practices.

Roles of AI in Academic Research

As artificial intelligence tools continue to evolve, their potential to transform academic research is becoming increasingly apparent. From facilitating comprehensive literature reviews and identifying hidden research gaps to analysing massive datasets and visually presenting complex information, AI is empowering researchers to tackle tasks once thought insurmountable (Wang & Wang 2024). Here are some roles of AI in academic research.

1. Data Analysis and Mining

AI techniques such as machine learning and data mining are used to analyze large datasets, uncover patterns, and extract valuable insights. AI algorithms can identify correlations, trends, and anomalies in research data, facilitating hypothesis generation and knowledge discovery (Achuthan 2016). Turnitin, a widely used plagiarism detection software, employs AI algorithms to compare students' submitted documents against a vast database of academic content and identify instances of plagiarism.

2. Natural Language Processing (NLP):

NLP techniques enable computers to understand, interpret, and generate human language. In academic research, NLP is used for tasks such as literature review, information extraction, summarization, and semantic analysis. (NLP) (Sodhar and Buller 2020).

3. Knowledge Discovery and Representation

AI systems can automatically discover and represent knowledge from unstructured data sources such as text documents, images, and multimedia content. This facilitates the creation of knowledge graphs, ontologies, and semantic networks to organize and share research findings (Shekan, Abdulkadium and Jabir 2021).

4. Predictive Modeling and Simulation

AI-based predictive modelling techniques are used to forecast future outcomes, simulate complex systems, and optimize experimental designs. AI algorithms can predict phenomena in various domains such as climate science, healthcare, and materials science (Hirschberg and Manning 2015).

5. Automated Experimentation and Discovery.

AI-driven automation tools enable researchers to conduct experiments, analyze results, and generate hypotheses at scale. Autonomous systems can explore vast search spaces, identify promising research directions, and accelerate the pace of discovery.

6. Robotics and Automation

AI-powered robots and automation systems are used in scientific research for tasks such as laboratory experimentation, sample handling, and data collection. Robotics enables remote sensing, exploration of hazardous environments, and high-throughput experimentation (Khatib 2016):

These roles demonstrate the diverse applications of AI in academic research, spanning data analysis, natural language processing, knowledge discovery, predictive modelling, automation, and robotics. AI technologies contribute to advancing scientific understanding, driving innovation, and addressing complex research challenges across disciplines.

Computer-Aided Vs AI-Based Learning and Teaching

Both computer-aided learning (CAL) and AI-based learning are two approaches to employing technology to enhance education, however, they differ in some respects. Table 1 shows the comparison between the two approaches.

Table 1: Comparison between CAL and AI-based Learning Approaches

Feature	Computer-aided Learning and Teaching	AI-based Learning and Teaching
Technology	Basic computer programs (e.g., drill & practice)	AI algorithms & machine learning
Teacher's Role	Central (uses CAL tools to enhance delivery)	Teacher as guide and mentor with AI handling many instructional tasks
Feedback	Limited feedback options, may be pre-programmed	Can offer dynamic and adaptive feedback
Overall Focus	Supports existing curriculum with technology	Can potentially revolutionize how learning is structured
Personalization	Limited personalization, usually through pre-set options	High level of personalization using adaptive algorithms
Content Delivery	Pre-programmed and static content	Dynamic content delivery based on learner's needs and progress
Interactivity	Moderate interactivity, often through quizzes and multimedia	High interactivity with real-time adjustments and interactive simulations
Adaptation to Learner's Pace	Limited adaptability to learner's pace	High adaptability, continuously adjusting to learner's pace
Flexibility in Teaching Methods	More rigid in teaching methods due to pre-set programs	Flexible teaching methods tailored to individual learning styles
Examples	Educational software, multimedia presentations	Intelligent tutoring systems, AI-driven educational platforms (Carnegie Learning, 2015)

Contrasting AI-based and Computer-aided Assessment in Education

AI-based and computer-aided assessments are two approaches to evaluating learners' knowledge and skills using technology, but they differ in their underlying methodologies and capabilities. Below is a comparison of the two approaches.

Distinguishing Factors	CAL assessment	AI-based Assessment
Methodology	Computer-aided assessment typically uses pre-defined rules and criteria.	AI-based assessment relies on advanced AI techniques to analyze and evaluate learners' performance
Capabilities	Computer-aided assessment systems may be limited to administering and scoring structured tasks	AI-based assessment systems can provide adaptive feedback, personalized recommendations, and insights into learners' performance based on sophisticated algorithms,
Complexity	whereas computer-aided assessment is more suitable for administering and scoring structured tasks with clear criteria.	AI-based assessment can handle complex and subjective tasks such as essays and open-ended questions (Digital Learning Institute, 2023)

Challenges of Adopting AI In Formal Education

While AI in formal education presents numerous opportunities, such as personalized learning and efficient administration, it is also beset with a number of challenges; including, but not limited to the following:

- AI systems require student data to personalize learning, but this raises concerns about student privacy and ownership of that data (Williamson 2019)
- AI algorithms can perpetuate and even worsen existing biases, leading to unfair treatment of certain groups of students (O'Neil 2016).
- The use of AI in education raises ethical issues, such as the transparency of AI systems and the accountability for decisions made by AI (Floridi and Cows 2019).
- There's a concern that AI might replace teachers, diminishing their role in the classroom.
- Not all schools have the resources to implement AI effectively. This could compound the educational gap between well-funded and poorly funded institutions.

The above are just a few of the challenges facing AI in education. These challenges, when carefully addressed, will enable the potential of AI to be harnessed to provide a more effective and equitable learning environment for all.

CONCLUSION

In this study, traditional teaching and learning tools and methods were briefly reviewed followed by the improvement brought about by Computer-aided learning (CAL). The transformative impacts of AI on formal education were highlighted with sample case studies. The comparison of CAL and AI-based teaching and learning brought into light the many advancements and innovations AI has brought to the education sector. From the highlights, it should not be difficult to infer that AI tools and techniques will be an indispensable means for achieving the fourth SDG of UNESCO, which zeros in on quality education for all. To reap the many pervasive impacts of AI in formal education, stakeholders in education (Government, teachers, learners and parents), especially in developing countries, have important roles to play by collaborating to mitigate against the challenges associated with the use of AI in education.

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RAISING CLIMATE CHANGE AWARENESS IN NIGERIAN LOWER BASIC SCHOOLS BY ADDRESSING CHALLENGES AND PROMOTING CLEAN, SUSTAINABLE ENVIRONMENTS

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ABSTRACT

This study investigates the effectiveness of climate change education among middle basic school pupils in Nigeria, highlighting the urgent need for enhanced awareness and understanding of environmental issues. The main purpose is to identify challenges and propose strategies for improving climate change education. A mixed-methods research design was employed, utilizing structured questionnaires for pupils and unstructured questionnaires for teachers to gather qualitative and quantitative data. Data analysis involved inferential statistics and thematic analysis to interpret the findings. Results revealed a significant knowledge gap, with 64% of pupils demonstrating low awareness of climate change concepts. The study concludes that comprehensive teacher training, resource allocation, and culturally relevant curricula are essential for effective climate education. Recommendations include developing a standardized climate change curriculum, initiating grant programs for educational resources, and engaging communities in hands-on sustainability projects to foster a generation equipped to address climate challenges.

Keywords: Climate Change Education, Teacher Training, Environmental Awareness, Resource Allocation and Sustainability Practices

INTRODUCTION

Climate change stands as one of the most significant challenges of our time, with far-reaching effects that touch every aspect of life, including the environment, economy, and social systems. In Nigeria, the consequences of climate change are particularly pronounced, manifesting through extreme weather events, rising temperatures, and shifting rainfall patterns. These changes profoundly affect agriculture, water resources, public health, and overall human livelihoods (Moyinoluwa, 2013). Despite the critical threat that climate change poses, there is a troubling lack of awareness among lower basic school pupils in Nigeria, a gap that threatens the long-term sustainability of the country's development.

Lower basic school pupils in Nigeria are children typically aged 6 to 9 years, who are enrolled in the first three years of primary education. This stage is foundational, as it significantly influences a child's academic trajectory and overall development. According to Salami (2016), early education in Nigeria is essential for fostering cognitive and social development, as it introduces pupils to literacy, numeracy, and environmental awareness—key areas that shape their future learning experiences. In the context of the Nigerian education sector, basic school pupils are crucial because they represent the starting point of formal education. Okebukola (2015) emphasizes that the early introduction of vital concepts, such as environmental sustainability, can have lasting effects on pupils' attitudes and behaviors. This makes them an ideal demographic for instilling awareness about critical issues like climate change, which is essential for nurturing informed and responsible future citizens.

However, one of the most striking issues facing this crucial demographic is the low level of awareness regarding climate change among young learners. Despite their importance in the educational system, many pupils in Nigeria's basic education system have only a superficial understanding of climate change concepts, such as global warming, deforestation, and pollution. This limited awareness was highlighted in a study by Akpomi and Vipene, (2016), which found that many pupils confuse climate change with everyday weather variations, revealing a significant gap in their comprehension of the subject. The roots of this problem lie in several factors, with the inadequate integration of climate change education into the primary school curriculum being one of the most significant.

In many Nigerian schools, environmental education is not prioritized, with climate change topics receiving only cursory attention, if at all. As noted by Bosah (2013), the current educational framework often treats environmental education as a peripheral subject, leading to a lack of depth in teaching important topics such as climate change. This lack of emphasis means that pupils are not exposed to the critical knowledge they need to understand the causes, effects, and potential solutions to climate change. The situation is further exacerbated by a shortage of educational resources—textbooks, visual aids, and interactive materials—that could help make climate change a tangible and understandable issue for young learners. Nwankwo and Eze (2012) highlight that many schools lack the necessary instructional materials to effectively teach environmental concepts, leaving teachers with limited tools to engage students on this critical issue. Without adequate resources, the already minimal coverage of climate change topics becomes even less effective, further hindering pupils' understanding of the environmental challenges facing their generation.

The role of teachers in this context cannot be overstated. As the primary conveyors of knowledge, teachers are crucial in shaping pupils' understanding of climate change. However, many teachers at the lower basic level in Nigeria lack the necessary knowledge and training to effectively teach climate change topics. Research by Dupigny-Giroux, (2008) underscores this issue, showing that many teachers possess only a rudimentary understanding of climate change, limiting their ability to convey the subject's complexities to their pupils. Furthermore, some teachers hold misconceptions about climate change, viewing it as a natural occurrence that human activities do not influence, which further complicates their ability to educate students accurately.

The challenges faced by teachers in promoting climate change awareness in Nigeria are multifaceted, reflecting a combination of systemic, educational, and socio-cultural barriers. One significant obstacle is the lack of professional development opportunities focused specifically on climate change education. Research by Igu et al (2023) indicates that many Nigerian teachers have not received formal training on integrating climate change topics into their teaching practices, resulting in a

significant gap in knowledge transfer. This lack of training leaves educators ill-equipped to effectively communicate the complexities of climate change to their students, which is crucial for fostering a generation that is both aware of and responsive to environmental issues.

Schools in Nigeria often face significant challenges due to the lack of infrastructure and resources necessary to support effective climate change education. As highlighted by Offorma, (2010), many educational institutions in the country are under-resourced, with limited access to the tools and materials that can make climate change concepts accessible and engaging for students. This scarcity of resources leaves teachers without the means to implement interactive and impactful lessons, which is crucial for enhancing the effectiveness of climate change education.

Promoting a clean and sustainable environment is essential in addressing the challenges posed by climate change, and raising awareness among lower basic school pupils is a critical step in this direction. By instilling environmentally responsible behaviors at a young age, education can play a vital role in shaping future generations' attitudes towards environmental stewardship. Educating pupils about the importance of protecting natural resources, reducing waste, and minimizing carbon footprints can have a profound impact on both the environment and society. For instance, a study by Ogunbode and Arnold (2014) found that environmental education programs in schools positively influence pupils' attitudes and behaviours toward the environment, leading to increased participation in eco-friendly activities.

Moreover, promoting clean and sustainable environments within schools not only fosters environmental responsibility but also helps build resilience against the impacts of climate change. Pupils who are aware of these challenges are better equipped to adopt practices that mitigate their effects. This resilience is particularly important in Nigeria, where many communities are vulnerable to environmental changes. For example, understanding the importance of water conservation can empower pupils in drought-prone areas to adopt practices that alleviate the impact of water scarcity. By addressing these gaps in education and resource availability, schools can better prepare students to tackle the pressing issues of climate change and contribute to a more sustainable future.

Given the current challenges faced in Nigerian schools due to inadequate resources and the limited integration of climate change education into the curriculum, it is clear that there are significant barriers to effectively raising awareness among lower-basic school pupils. The scarcity of educational tools and the sociocultural resistance to environmental change further complicate efforts to promote a clean and sustainable environment (Nepraš, et al, 2022). This situation underscores the urgent need for a strategic approach to enhance climate change education and foster environmentally responsible behaviours from a young age.

Addressing these challenges necessitates a thorough investigation into the specific gaps and needs within the educational framework. Therefore, this research aims to explore the following questions:

- a. What is the current level of understanding among lower basic school pupils in Nigeria regarding the relationship between climate change and sustainable environmental practices?
- b. How do resources and infrastructure in Nigerian schools hinder the teaching of climate change and sustainability concepts to lower basic pupils?
- c. What challenges do Nigerian teachers face when integrating climate change education that promotes sustainability into their lower basic school curricula?
- d. How do local cultural practices and attitudes impact the effectiveness of climate change education in promoting sustainable behaviours among lower basic school pupils in Nigeria?

MATERIALS AND METHODS

This study employed a mixed-methods approach to investigate climate change awareness among middle basic school pupils in Nigeria and to address the challenges faced by teachers in delivering climate change education. The research design integrates both quantitative and qualitative methodologies. The study targets two distinct groups, middle basic school teachers and pupils. The teacher population comprises of teacher from the metropolis of Ilorin, which is a composition of three local government areas. There are a total of 67 public basic schools in the metropolis with a total population of 216 teachers and 32 were sampled from 16 purposively sampled schools. There a total

of 918 pupils in the 16 sampled basic schools in the metropolis, and a stratified sampling procedure was adopted to divide the pupils into level, and so basic 5 and 6 pupils were sampled, from all the schools there are a total of 281 basic 5 and 6 pupils and a simple random sampling procedure of lucky dip was adopted in the selection of 216 pupil for the study.

A researcher's designed questionnaires was the only instrument used to elicit the needed data for this study. The questionnaires were in both quantitative and qualitative form. For teachers, an unstructured questionnaire was utilized. This open-ended format allows teachers to express their experiences. For pupils, a structured questionnaire was used. Data collection was conducted in two phases. For teachers, the unstructured questionnaires were distributed electronically through google form. All ethical considerations were adhered to. For pupils, the structured questionnaires were administered during school hours with the assistance of their teachers. The data analysis involved both quantitative and qualitative methods.

RESULTS

The findings of this study are presented as follows

Research Question 1: What is the current level of understanding among lower basic school pupils in Nigeria regarding the relationship between climate change and sustainable environmental practices?

To answer this question a clear benchmarks for categorizing pupils' knowledge levels as **high, medium, or low**, was first established, this was based on the questionnaire responses. A point-based system was employed, where each correct response is awarded one point. The total score for each pupil is then converted into a percentage, reflecting their overall understanding of climate change and sustainable environmental practices. Those scoring between:

- 0% and 39% = low
- 40% to 69% = Medium
- 70% or above = high

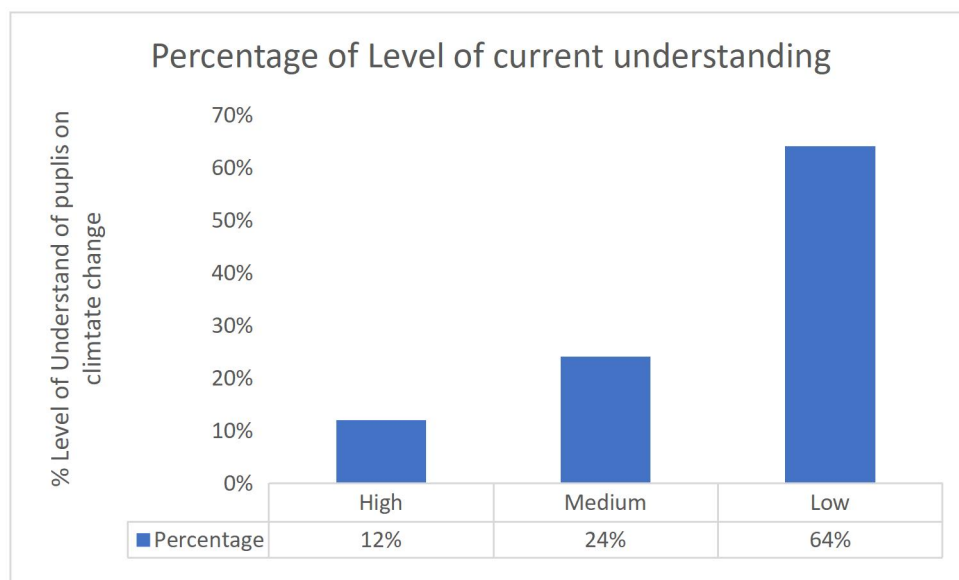


Fig.1. % of current level understanding among lower basic school pupils' climate change and sustainable environmental practices

The distribution of pupils' understanding of climate change and sustainable environmental practices reveals that 64% of the 216 pupils are categorized as having low knowledge, it is evident that the majority lack a basic understanding of these crucial concepts. Only 12% of the pupils demonstrate a high level of awareness, indicating that a small fraction is well-informed and capable of applying this

knowledge in real-world situations. The 24% with medium knowledge suggest that while some pupils have a general understanding, there are still gaps that need to be addressed. This skewed distribution underscores the urgent need for enhanced educational interventions focused on climate change and environmental sustainability. Schools must prioritize integrating these topics into the curriculum more effectively, ensuring that all pupils, particularly those currently at a low knowledge level, can develop a comprehensive understanding and engage in environmentally friendly behaviors.

Research Question 2: How do insufficient resources and infrastructure in Nigerian schools hinder the teaching of climate change and sustainability concepts to lower basic pupils?

The analysis followed a structured thematic approach to identify key challenges related to resources and infrastructure in Nigerian schools. The process began with transcribing unstructured data, ensuring a thorough understanding of participants' responses. In the initial coding phase, key phrases and patterns related to resource limitations and infrastructure challenges were identified.

Following this, the researcher developed six major themes: educational materials, where a lack of textbooks and visual aids hindered climate education; teacher training, which was insufficient for teaching sustainability concepts; classroom facilities, where overcrowding and poor ventilation created unfavorable conditions; technology access, which remained limited; funding challenges, due to low government support; and policy implementation, where weak enforcement of climate education policies further hindered effective teaching.

To enhance clarity, the data interpretation and representation step involved structuring these thematic findings into a mind map (Figure 2). This visual representation illustrated connections between key challenges, providing a comprehensive overview of resource gaps in climate education and emphasizing the urgent need for improvements in school infrastructure and learning materials.

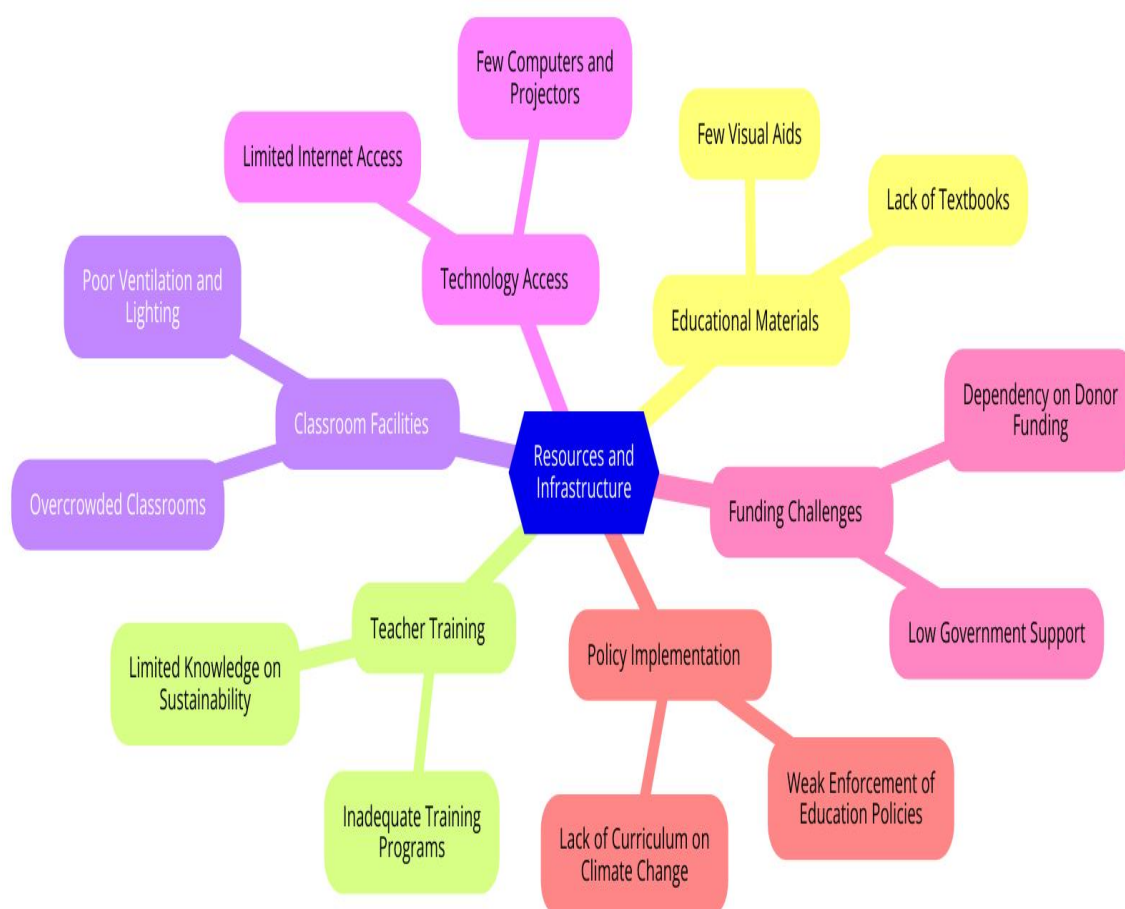


Fig. 2: Mind map diagram illustrating the theme "Resources and Infrastructure"

Figure 2 presents a mind map illustrating the theme "Resources and Infrastructure" related to climate change education in Nigerian schools. The central node emphasizes the critical role that adequate resources and infrastructure play in effective teaching. Six primary branches detail specific aspects, such as the availability of educational materials, teacher training, classroom facilities, and access to technology. Each branch is further broken down into sub-branches that highlight particular challenges, such as insufficient textbooks, lack of visual aids, and inadequate training for teachers. This visual representation underscores the urgent need for improvements in resources to enhance climate change education and promote sustainability among pupils.

Research question 3: What challenges do Nigerian teachers face when integrating climate change education that promotes sustainability into their lower basic school curricula?

A thematic analysis was conducted to identify teachers' challenges in integrating climate change education. First, data elicited were transcribed and organized. Key phrases were coded into broad categories, leading to six major themes: inadequate training, limited resources, curriculum constraints, misconceptions, assessment gaps, and weak policy support. The findings were structured into a mind map (Figure 3), illustrating connections between challenges.

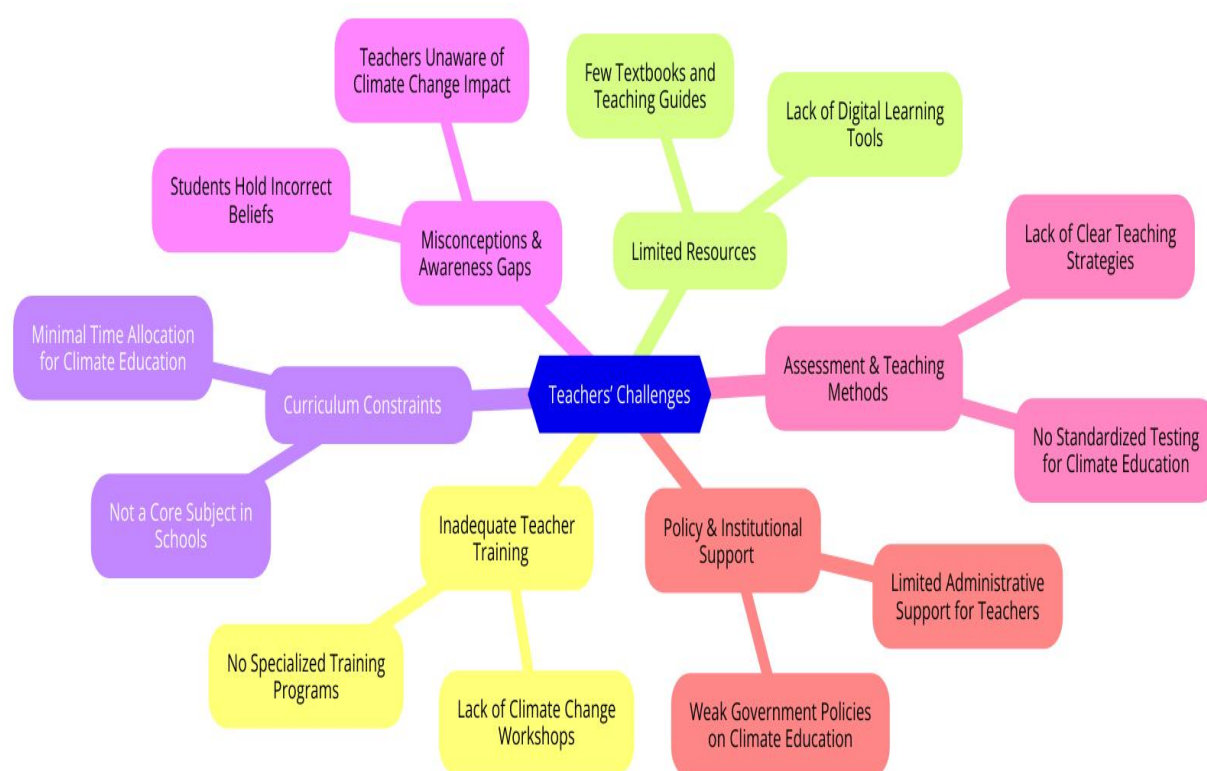


Fig. 3: Mind map diagram illustrating the theme "Teachers' Challenges"

Figure 3 illustrates a mind map focused on the theme "Teachers' Challenges" in integrating climate change education into lower basic school curricula in Nigeria. The central node highlights the various difficulties teachers encounter, which are crucial for understanding the barriers to effective climate education. Six primary branches detail specific challenges, such as inadequate training, limited resources, and misconceptions about climate change. Each branch is further subdivided into sub-challenges, providing a comprehensive view of the obstacles teachers face. This visual representation emphasizes the need for targeted professional development and resource allocation to empower educators in effectively teaching climate change and sustainability concepts.

Research Question 4: How do local cultural practices and attitudes impact the effectiveness of climate change education in promoting sustainable behaviors among lower basic school pupils in Nigeria? Findings from a thematic analysis revealed that: The researcher identified, analyzed, and interpreted patterns in the data using thematic analysis. The process began with data familiarization, where interviews were transcribed, and focus group notes were organized. Initial readings were conducted to identify key phrases related to cultural influences on climate education. Next, in the initial coding stage, key phrases related to cultural attitudes and education challenges were highlighted and grouped into broad categories. This step allowed for the identification of recurring themes.

The researcher then developed six major themes: Traditional Environmental Stewardship, which included indigenous conservation practices; Community Engagement, which highlighted the role of local leaders; Religious Influences, which focused on faith-based perspectives on climate change; Generational Knowledge Transfer, which emphasized how elders passed down sustainability values; Resistance to Modern Science, which reflected skepticism towards scientific explanations; and Integration into School Curriculum, which addressed challenges in incorporating cultural perspectives into formal education.

Finally, in the data interpretation and representation phase, the findings were structured into a mind map (Figure 4) to visually illustrate the connections between cultural practices and climate education. This representation highlighted key barriers and provided a comprehensive understanding of how cultural beliefs shaped students' learning experiences.

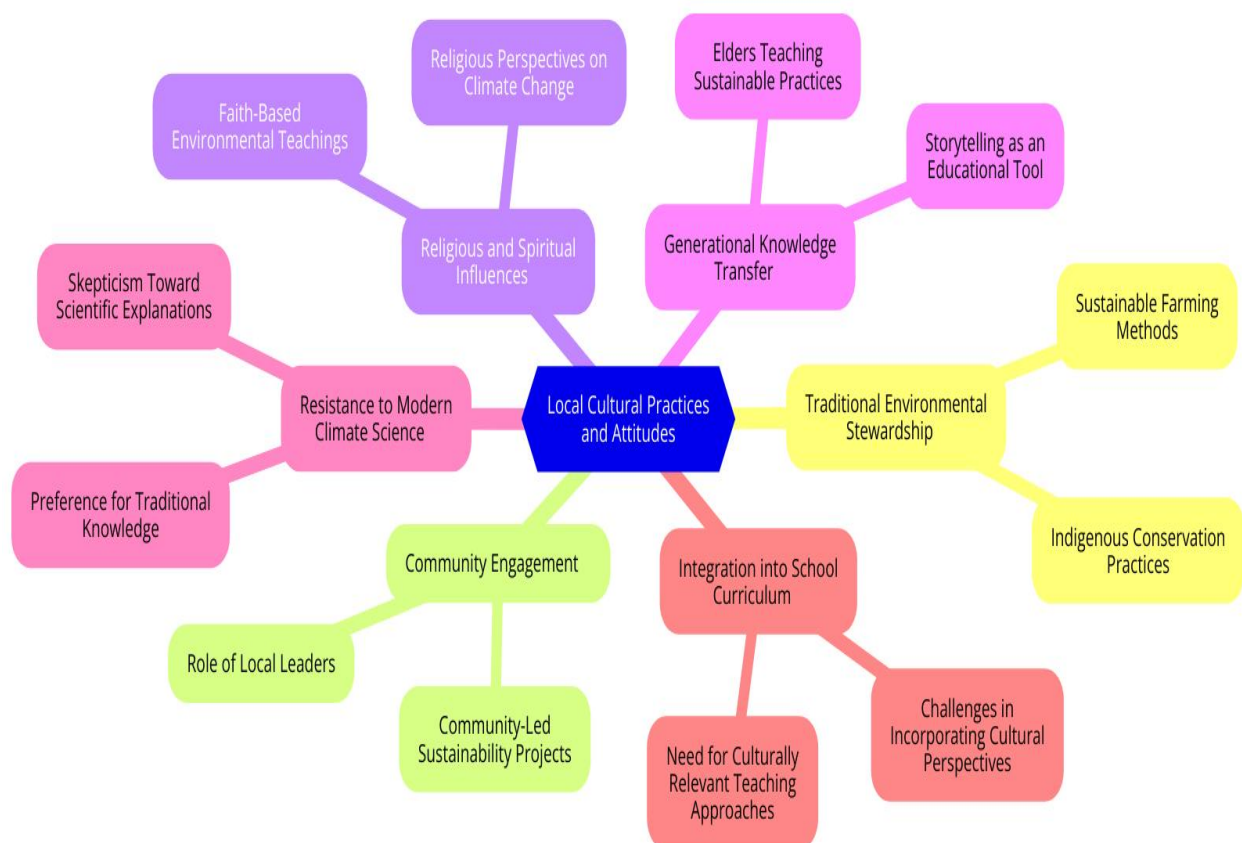


Fig. 4: Mind map diagram illustrating the theme "Local Cultural Practices and Attitudes."

Figure 4 presents a mind map that explores the theme "Local Cultural Practices and Attitudes" and their impact on climate change education among lower basic school pupils in Nigeria. The central

node connects to six primary branches, each representing different aspects of how cultural beliefs and practices influence educational effectiveness. These branches may include traditional views on environmental stewardship, community engagement in sustainability efforts, and the role of local customs in shaping attitudes towards climate change. The sub-branches provide specific examples and insights, highlighting the importance of integrating cultural context into climate education to foster more effective learning and promote sustainable behaviours among students.

DISCUSSION

The findings of this study underscore the pressing need for enhanced climate change education among middle-basic school pupils in Nigeria. The data reveals that a significant portion of pupils—64%—are categorized as having low knowledge regarding climate change and its implications. This alarming statistic highlights the inadequacy of current educational interventions and the urgent need for a comprehensive strategy to raise awareness and understanding of climate issues among young learners. The lack of awareness poses a long-term threat to the sustainability of Nigeria's development, as future generations may not be equipped to address the environmental challenges they will inevitably face.

Research by Salami, (2016) supports these findings, indicating that many teachers at the middle basic level possess only a rudimentary understanding of climate change. This limited knowledge significantly hampers their ability to convey the complexities of the subject to their pupils. Teachers are the primary conveyors of knowledge, and their understanding of climate change is crucial for fostering an informed and environmentally responsible generation. The study reveals that many educators hold misconceptions about climate change, viewing it as a natural occurrence unaffected by human activities. Such misconceptions further complicate their ability to educate students accurately, leading to a cycle of misinformation and misunderstanding.

In addition to the knowledge gap among teachers, the study highlights the critical issue of insufficient resources and infrastructure in basic schools in Ilorin metropolis. Offorma, (2010) emphasizes that many educational institutions are under-resourced, lacking the necessary tools and materials to effectively teach climate change concepts. This scarcity of resources leaves teachers without the means to implement interactive and engaging lessons, which are essential for enhancing the effectiveness of climate change education. The findings suggest that the lack of educational resources exacerbates the already minimal coverage of climate change topics in the curriculum, further hindering pupils' understanding of the environmental challenges facing their generation.

The challenges faced by teachers in promoting climate change awareness are multifaceted, reflecting a combination of systemic, educational, and socio-cultural barriers. One significant obstacle is the lack of professional development opportunities focused specifically on climate change education. Moyinoluwa (2013) indicates that many Nigerian teachers have not received formal training on integrating climate change topics into their teaching practices. This gap in professional development leaves educators ill-equipped to effectively communicate the complexities of climate change to their students, which is crucial for fostering a generation that is both aware of and responsive to environmental issues.

Moreover, the study reveals that local cultural practices and attitudes significantly impact the effectiveness of climate change education. The findings suggest that cultural beliefs can either facilitate or hinder the promotion of sustainable behaviours among pupils. This aligns with the work of Ogunbode and Arnold (2014), who found that environmental education programs that consider local cultural contexts are more successful in influencing positive attitudes towards sustainability. Understanding the cultural dynamics at play is essential for developing educational interventions that resonate with students and their communities.

The implications of these findings are profound. To effectively raise awareness and understanding of climate change among lower basic school pupils, a multifaceted approach is necessary. First and foremost, there is a critical need for enhanced teacher training programs that focus specifically on climate change education. By equipping educators with the knowledge and skills necessary to teach this complex subject, schools can foster a more informed and engaged student body. Professional

development opportunities should be prioritized to ensure that teachers are well-versed in the latest climate science and pedagogical strategies.

CONCLUSION

The findings of this study highlight the urgent need for a strategic approach to climate change education in Nigeria. By addressing the challenges identified—such as the knowledge gap among teachers, the lack of resources, and the influence of cultural attitudes—educators can better prepare students to tackle the pressing issues of climate change. This preparation is essential for fostering a generation that is not only aware of environmental challenges but also equipped to contribute to a more sustainable future. The integration of comprehensive teacher training, improved resource allocation, and culturally relevant educational practices will be key to achieving these goals and ensuring that future generations are prepared to face the realities of climate change. On the basis of this, the following recommendations were proffered:

- a. There is the need for the Nigerian Ministry of Education to create a standardized curriculum focused on climate change and sustainability for lower basic schools, incorporating local environmental issues and interactive activities.
- b. A grant programme should be initiated to provide financial support for schools to acquire educational resources related to climate change, including textbooks, visual aids, and technology.
- c. Basic schools need to engage pupils and local residents in hands-on projects, such as tree-planting campaigns and clean-up drives, integrating these activities into the curriculum to apply classroom concepts practically.
- d. There is the need for a nationwide campaign be launched to raise awareness among parents, teachers, and students about the importance of climate change education, utilizing workshops and media outreach to encourage community participation and sustainable practices.

Acknowledgements: The staff of the sampled basic schools are highly acknowledged

Informed Consent Statement:

Data Availability Statement:

Ethical Clearance: All ethical considerations were adequately adhered to.

Conflicts of Interest: There is no conflict of interest.

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ASSESSMENT OF HEAVY METALS IN GROUNDWATER AND ASSOCIATED HEALTH RISKS IN ILORIN METROPOLIS, NIGERIA

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ABSTRACT

Heavy metal contamination of groundwater poses significant health risks to communities that depend on these water sources. This study aims to evaluate the sources and potential health hazards of heavy metals in groundwater samples from Ilorin, Nigeria. Atomic absorption spectrometry was used to analyze manganese (Mn), iron (Fe), calcium (Ca), cobalt (Co), and nickel (Ni) in water samples collected from five locations in Ilorin metropolis: Oke-ose, Oja Oba, Adewole, Oloje, and Tanke. The results indicate that, with the exception of cobalt and nickel, the concentrations of all heavy metals studied were higher during the dry season compared to the rainy season. The Hazard Index (HI) calculated for water samples taken during the rainy season in all areas exceeded 1, indicating significant non-carcinogenic health risks. Furthermore, the incremental lifetime cancer risk (ILCR) for the water samples was found to range from level 1 to level 11, based on the Delphi method of classification, with values falling within the acceptable range of 1.00×10^{-6} to 1×10^{-4} . These findings highlight the potential health hazards associated with heavy metal contamination in Ilorin's groundwater, emphasizing the urgent need for measures to mitigate these risks and protect consumer health in the affected areas. The study shows the importance of regular monitoring and implementing effective water treatment solutions to ensure safe drinking water for the local population.

Keywords: Health risk assessment, Physicochemical parameters, potentially toxic elements, Seasonal variation, Water quality

INTRODUCTION

Water plays an important role in human life. It is essential for the survival of industry, agriculture, and humans. The healthy water ecosystem is depended on the physico-chemical and biological characteristics Increase in industrialization, urbanization, agriculture activity and various human

activities has increased the pollution of surface water and ground water (Bhalme and Nagarnaik, 2012). Water is one of nature's most frequently distributed and abundant compounds. . In total, there is 1,400 million billion litres of water, but most of this water is not used for drinking purpose, because 97% is sea water and only 3% is fresh water, out of which 2% is lodged in the polar ice caps and glaciers, only 1% water is available for portable use (Khalid *et al.*, 2011). Human use of ground water is dependent on the quality of the surrounding water. (Jafari *et al.*, 2008). The importance of ground water in human life cannot be overstated. Water is spoiled as a result of industrialization and urbanization (Nagamani, 2015) for agricultural uses. In rural areas, ground water is investigated, particularly in areas where other sources of water, such as a river, a dam, or a canal, are insufficient. Ground water has become increasingly polluted as a result of human activities during the last two decades. .

An adequate supply of safe and portable water assists in preventing the spread of gastrointestinal diseases, supports domestic and personal hygiene, and improves the standard of living (Ike & Ugodulunwa, 1999). Human activities are rapidly increasing the amount of industrial, domestic, and agricultural waste in ground water reservoirs (Aremu *et al.*, 2011). Similarly, a rise in anthropogenic activity affects both the amount and quality of water, and any pollution, whether physical or chemical, produces changes in the quality of the receiving water body. (Aremu *et al.*, 2011).

MATERIALS AND METHODS

Study Area and Map of Study Area

Ilorin is situated approximately between latitudes 8.5 (8 30°N) and longitude 4.6 (4 33°E). Ilorin was built as a residential, industrial and agriculture city. The ground water from the wells also serves as a source of drinking water in the study area. The terrain in the study area is generally flat, low lying and riddled with an intricate system of ground water channels. This area is located mainly within wooded savannah and characterized by an average temperature range between 30 and 36°C and generally the area is marked by two climatic seasons, the dry and wet seasons with an intervening cold and harmattan from December to January and an annual rainfall range between 1,000 and 1,500 mm. This area is marked by high industrial activities. Coordinate was taken in each study area. **Figure 1** and **Table 1** show the locations where samples were collected. There are 5 locations altogether (Okoro *et al.*, 2012b).

Location of Selected Wells and Boreholes in the Study Area

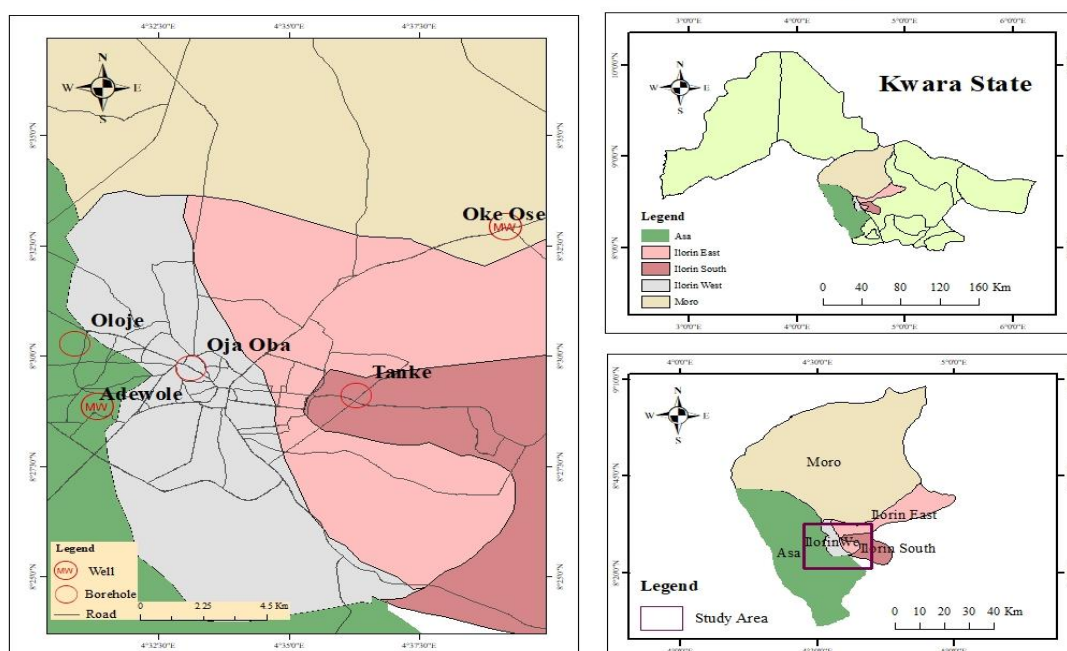


Figure 1: Map of study area and sampling points

Table 1: Table showing study areas, coordinates and activities around the locations

S/N	Areas	Water	Coordinates	Activities
1.	Adewole	Well	8.480799, 4.522245	School
2.	Oke Ose	Well	8.548622, 4.652528	Residential
3.	Tanke	Boreholes	8.484868, 4.604908	Residential
4.	Oja Oba	Boreholes	8.495224, 4.552007	Market
5.	Oloje	Boreholes	8.504353, 4.514927	Motors spare part dealers

Sample Collection

Ground water samples was randomly collected from 5 sampling sites in triplicate from 5 different locations of Ilorin Kwara state, Nigeria. Well water was taken from Adewole and Oke Ose and Borehole water was taken from Oloje, Tanke and Oja Oba during raining season and dry season. Distilled water was labelled separately and served as control. Each sample container was first rinsed with a small amount of water sample before the sample were collected. Each borehole was allowed to run for 1 minute at each sampling site to remove any externally induced contamination. Sterilized 1 liter bottles was used to collect the water sample at each sampling site and filled to the brim, leaving an air space of 2.5 cm. The bottles were marked for identification using the labels for each samples collected. The bottles were then transported to the laboratory in an insulated box to prevent external factors like high temperatures from changing some of the water parameters.

Chemical and Reagents

Analytical grade reagents and distilled water was used throughout the study. The apparatus and glassware were washed with detergent and thoroughly rinsed with distilled water and oven drying.

Pre-treatment of Sampling Bottles

All bottles were soaked in a bowl containing 0.1 M nitric acid for 24 hours, and then washed with detergent and rinsed thoroughly with clean water, and finally rinsed with distilled water. Then the bottles were allowed to dry before use (Okoro et al., 2012a).

Digestion and Heavy Metal Analysis

10 mL water samples were transferred to a beaker. 2 mL of concentrated HNO_3 and 6 mL of concentrated HCl was added. The sample was covered with Aluminium foil and heated on a hot plate at 90 to 95 °C until the volume is reduced to 50 mL by evaporation, the beaker was removed and allow to cool, then 50 mL distilled water was added into it and the sample was filtered to remove insoluble material, the samples was transferred into 100 mL samples bottles. The digested sample was subjected to Atomic Absorption Spectrophotometry for total metal concentration in the samples. The following metals was analyzed for Mn, Fe, Ni, Co and Ca in the samples.

Physicochemical Parameters

Each sample was analyze for relevant physicochemical parameters, which includes temperature, pH, electrical conductivity, total dissolved solids (TDS), at the site of collection of the water samples according to internationally accepted procedure and standard methods (APHA, 1994).

Instrumentation

The elemental analysis was done using Bulk Scientific Atomic Absorption Spectrophotometer Model 210, Fisher scientific (Bulk Scientific, E Norwalk, CT, USA).

Statistical Analysis

Data was subject to analysis of variance and significant means was separated by Duncan multiple range tests using the procedure of SAS (2002). All data was represented using Microsoft Excel and One-way analysis of variance (ANOVA) was used for comparison of the different group results IBM SPSS statistics for windows version XXVI (2019).

Health Risk Assessment

Human health risk assessment is a method of calculating the potential health consequences of exposure to carcinogenic and non-carcinogenic substances. In the risk assessment process, there are four basic steps: hazard identification, assessment of exposure, toxicity/dose-response

assessment, and then characterization of risk (USEPA, 2001). The aim of hazard identification is to basically examine pollutants that are present in a specified location, their concentrations, and spatial distribution. Assessment of exposure is mainly to evaluate the intensity, frequency, and length or period of human exposures to the contaminants (i.e. HMs). In this research, the assessment of exposure was done by calculating the average daily intake (ADI) of the HMs identified through ingestion, inhalation and dermal contact by the inhabitants. Dose-response assessment evaluates the toxicity due to exposure intensities of the HMs. A carcinogen potency factor known as cancer slope factor (SF), and a non-carcinogenic threshold called reference dose (RfD), are the two vital toxicity indices employed. Risk characterization helps predicts the probable cancerous and non-cancerous health risks the general populace in the study area are exposed to, by incorporating all the information collected to work out quantitative estimates of cancer risks and hazard indices.

The average daily intake (ADI) (mg/kg/day) for non-carcinogens through ingestion and dermal contact exposure pathways were calculated as recommended by USEPA, (2001).

For ingestion pathway,

$$ADI_{\text{ing-water}} = \frac{C_w \times \text{IngRw} \times EF \times ED}{BW \times AT}$$

where $ADI_{\text{ing-water}}$ is the average daily intake of heavy metals from water ingestion (mg/kg-day), C_w is the concentration of heavy metal in water sample, BW is body weight of the exposed individual, ED is the lifetime exposure duration (year), IngRw is the ingestion rate of soil and water particles (mg/day or L/day), EF is the exposure frequency (day/year), and AT is time period over which the dose is averaged (day).

For Dermal pathway,

$$ADI_{\text{derm-water}} = \frac{C \times SA \times KP \times AF \times ABS \times ET \times EF \times ED}{BW \times AT}$$

where SA is the exposed skin surface area (cm^2), KP is the permeability constant of the skin, ABS is the skin absorption factor, ET is the exposure time.

The Non-Carcinogenic Risk Assessment

Target Hazard Quotient (HQ) is the ratio of the protracted average daily intake (ADI) to the reference dose (RfD) of a particular heavy metal (HM) (USEPA, 2001), is used to estimate or assess the non-carcinogenic risk. The target hazard quotient (THQ) adopts a level of exposure called the reference dose (RfD), which is known as the daily absorption rate that is projected to have no significant risk of adverse health effects, over about 70-years lifetime. The formula is given by USEPA to be;

$$THQ = \frac{ADI}{RfD}$$

Where ADI is the average daily intake of a single toxic element and RfD is the chronic reference dose for the element (mg/kg-day) (USEPA 2001; Orosun *et al.*, 2020). If the Target Hazard Quotient is greater than 1, then there's heavy likelihood of adverse health effect to the exposed population. However, if the target hazard quotient is less than 1 then there's no likelihood of adverse health effects.

The hazard index (HI) is defined as the total sum of HQ obtained for different pathways. To evaluation the human health risks through more than a single heavy metal, the hazard index (HI) was established as (USEPA, 2001):

$$HI = \sum HQ$$

The Carcinogenic Risk Assessment

The carcinogenic risk assessment is used in the estimation and determination of the possibility of a population acquiring cancer of any kind after exposure to carcinogen. Incremental Lifetime Cancer Risk (ILCR) is estimated as the incremental probability of a person developing cancer over a period of time due to exposure to HMs (Orosun *et al.*, 2020). The formula is given as;

$$ILCR = ADI \times SF$$

where ILCR is the probability of an individual exposed to carcinogenic HMs to develop cancer over a period of time. ADI (mg/kg/day) and SF (mg/kg/day) are the average daily intake and the carcinogenic slope factor respectively. For cancer risk, only the known human carcinogens (Pb, Ni, Cr, Cd, and As) were considered. Cancer risk greater than 1×10^{-4} are considered high as they pose higher cancer risk while values below 1×10^{-6} are considered not to pose any cancer risk to humans; the

acceptable range is between 1×10^{-4} and 1×10^{-6} . The risks values are categorized in to 7 levels based on the Delphii method (Orosun *et al.*, 2020).

RESULTS AND DISCUSSION

Statistical Analysis for Metals Across Locations

In this study, Ilorin township water was monitored seasonally for a period of one year. The investigation was carried out on heavy metal concentrations, their distribution in different locations, and compares the effects of seasonal variation on heavy metal concentrations. The results of heavy metal analysis in this study are summarized in Tables 2 to 6.

Analysis for Manganese (Mn) in different locations

Table 2: Seasonal means of Mn concentrations at different location in Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
Mn	Oke Ose	3.06±0.15	2.80±0.21	2.93±0.22
	Oja Oba	2.81±0.14	3.44±0.68	3.13±0.56
	Adewole	3.14±0.53	0.06±0.005	1.60±1.72
	Oloje	0.36±0.019	0.054±0.01	0.21±0.17
	Tanke	0.12±0.02	0.089±0.01	0.11±0.02
	Mean seasons	1.90±1.52	1.29±1.69	
	CV%		97.5%	
	p≤0.05		***	***
	Interaction(p≤0.05)		***	

From Table 2, Manganese is a metalloid which occurs in the elemental state to a small extent; its concentration at all locations ranged from 0.11 ± 0.02 to 3.13 ± 0.56 µg/L. Location 2 (Oja Oba) recorded the highest concentration of 3.13 ± 0.56 µg/L which are above the WHO (2010) recommended standard value of 0.4 which may be as a result of human activities like steel production and mining in such area when compared with the work carried out by Orosun *et al.* (2020) in his work carried out on automobile sparepart and recycling market in Ilorin, Nigeria where the concentration of Mn ranges from 0.02-0.06 µg/L., also in a work carried out by Mebrahtu and Zerabuk (2011) on drinking water from urban areas of the Tigray Region, Northern Ethiopia where in Mikelle the concentration of Mn ranges from 0.031-0.038, it could be seen that all locations contains high concentration hence more polluted and poses greater risk which may be as a result of human activities like steel production and mining in such area. While the lowest concentration of 0.11 ± 0.02 µg/L was recorded in location 5 (Tanke). The highest concentration value for Manganese was recorded in dry season.

The order of increasing seasonal values is dry < rainy as summarized in Table 2 and Figures 2 and 3. Figure 2 also showed that there is no presence of outlier in the data. Furthermore, from the two-way analysis of variance computed shows significant variations of $P (\leq 0.05)$ were found in Seasonal, Location and Interaction effect. The coefficient of variation (CV) is 97.5%.

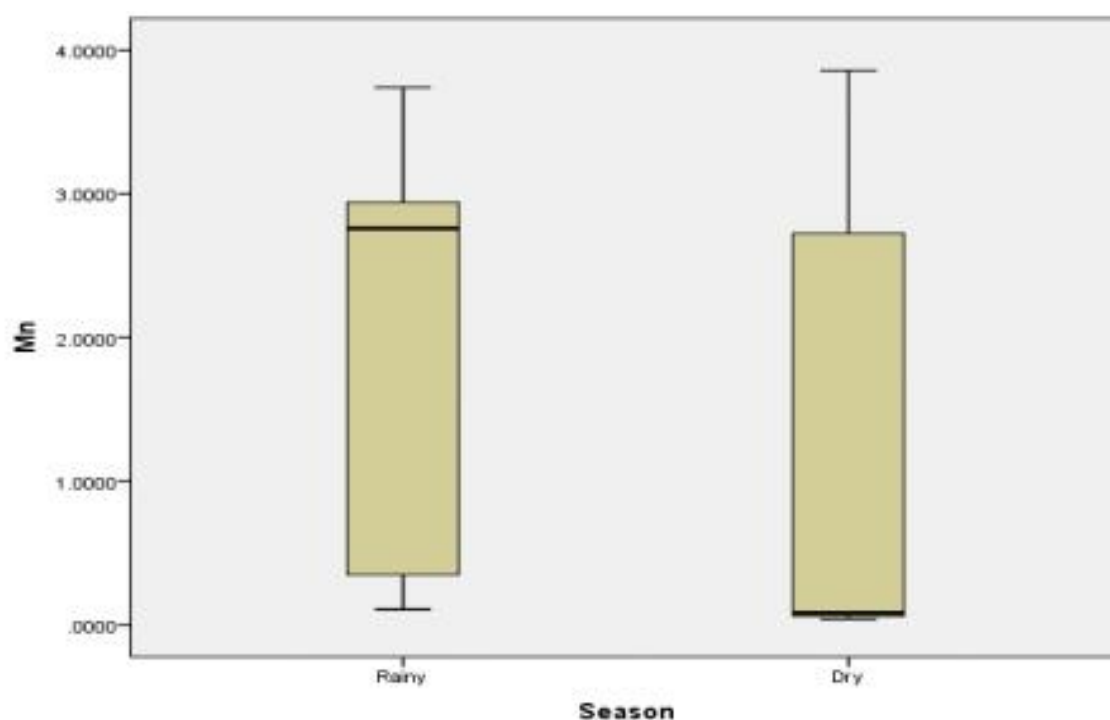


Figure 2: Box and Whisker plot for the annual spread of Mn concentrations seasonally

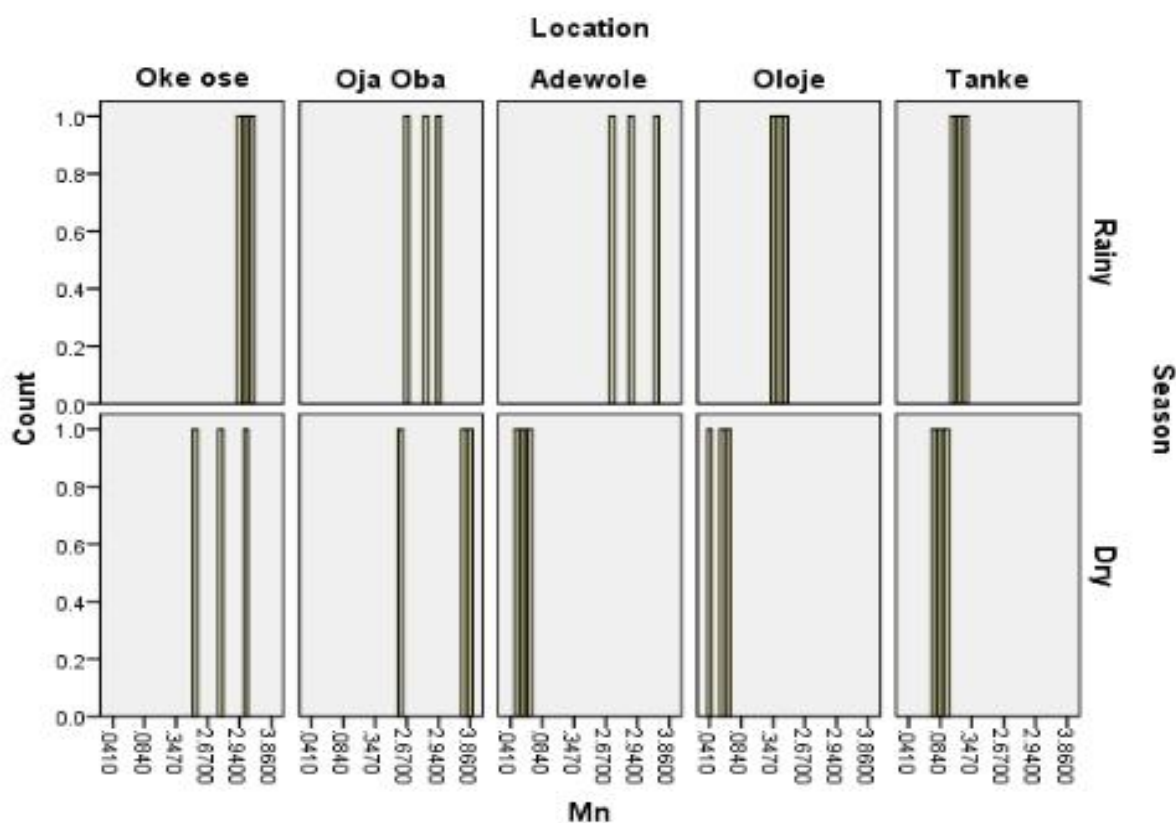


Figure 3: Bar chart for the seasonal spread of Mn concentrations in seasonally

Analysis for Iron (Fe) in different locations

Table 3: Seasonal means of Fe concentrations at different location in Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
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Fe	Oke Ose	2.83±0.27	3.85±0.22	3.34±0.60
	Oja Oba	4.09±0.21	2.72±0.24	3.41±0.78
	Adewole	3.03±0.16	0.72±0.29	1.88±1.28
	Oloje	0.71±0.19	0.37±0.12	0.54±0.24
	Tanke	2.73±0.56	0.49±0.04	1.61±1.28
	Mean seasons	2.68±1.23	1.63±1.57	
	CV%		97.60%	
	p≤0.05		***	***
	Interaction(p≤0.05)		***	

Looking at Table 3 critically, it was observed that Fe concentration at all locations ranged from 0.54±0.24 to 3.41±0.78 µg/L. Location 2 (Oja Oba) still recorded the highest concentration of 3.41±0.78 µg/L which are above the WHO recommended standard and of 0.5µg/L, when compared with a work carried out Orosun et al 2020 the concentration of Fe ranges from 0.03- 0.07, and in a work carried out by Okoro (2019) on Techniques for the assessment of water quality in okun river ilorin Nigeria the concentration of Fe ranges from 2.64- 9.65, it can be seen Okun river is highly polluted and poses more risk which may be as a result of human/Anthropogenic activities while the lowest concentration of 0.54±0.24 µg/L was recorded in location 4 (Oloje). The highest concentration value for Fe was recorded in rainy season with mean value and SD of 4.09 ± 0.21. The order of increasing seasonal values is dry < rainy as summarized in Table 3 and Figures 4 and 5. Figure 4 also revealed that there is presence of mild outliers in the rainy season data. Furthermore, from the two-way analysis of variance computed, significant variations of P (≤ 0.05) were found in Seasonal, Location and Interaction effect of the two factors. The coefficient of variation (CV) is 97.6%

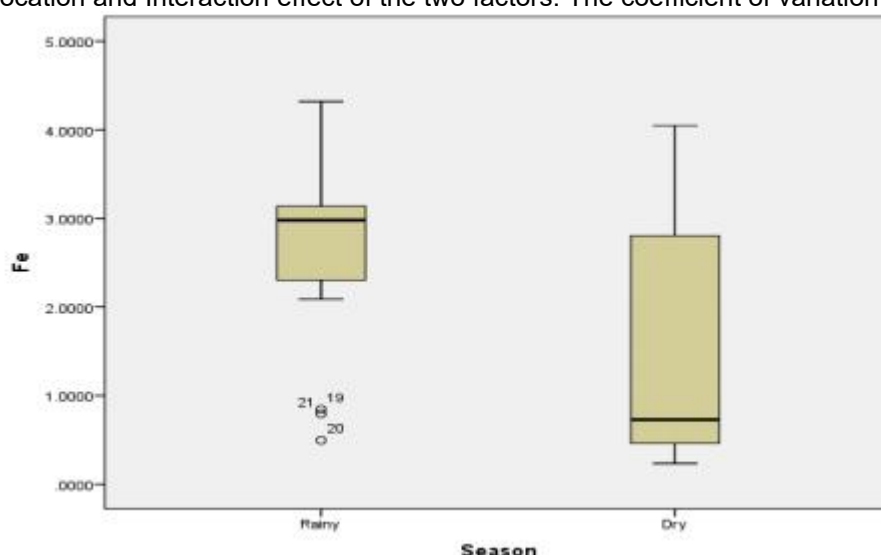


Figure 4: Box and Whisker plot for the annual spread of Fe concentrations ground water samples in Ilorin

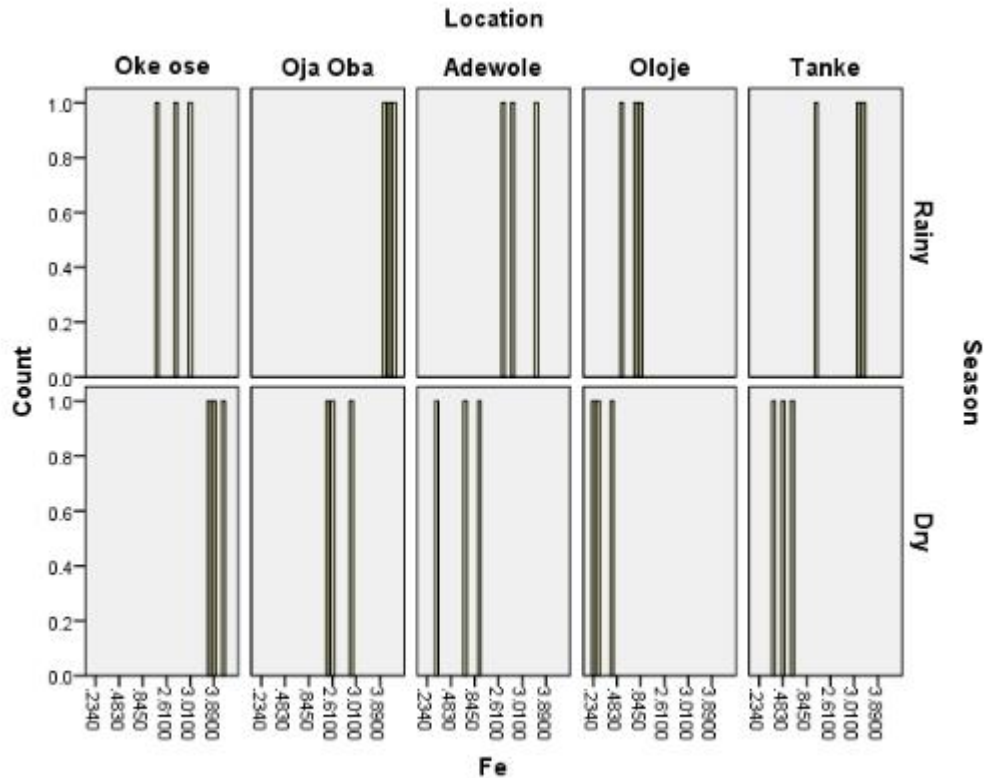


Figure 5: Bar chart for the seasonal spread of Fe concentrations in ground water samples collected from different locations in Ilorin

Analysis for Calcium (Ca) in different locations

Table 4: Seasonal means of Ca concentrations at different location in Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
Ca	Oke Ose	40.73±4.19	44.40±4.20	42.57±4.25
	Oja Oba	53.17±5.54	46.2±5.12	49.68±6.11
	Adewole	40.33±0.68	17.15±4.59	28.74±13.03
	Oloje	40.28±11.97	11.60±7.21	25.94±18.02
	Tanke	12.95±2.09	19.78±9.70	16.37±7.30
	Mean seasons	37.49±14.79	27.83±16.23	
	CV%		88.8%	
	p≤0.05		***	***
	Interaction(p≤0.05)		***	

Table 4 critically shows that Ca concentration at all locations ranged from 16.37±7.3 to 49.68±6.11 µg/L. Location 2 (Oja Oba) recorded the highest concentration of 49.68±6.11 µg/L while the lowest concentration of 16.37±7.30 µg/L was recorded in location 5 (Tanke). The highest concentration value for Ca was recorded in the rainy season, with a mean value and SD of 53.17±5.54. The value reported are below the WHO recommended standard value of 75µg/L (WHO, 2010).

The order of increasing seasonal values is dry < rainy as summarized in Table 4 and **Figures 6 and 7**. **Figure 6** also revealed that there is a presence of mild outliers in the rainy season data. Furthermore, from the two-way analysis of variance computed, significant variations of P (≤ 0.05) were found in Seasonal, Location and Interaction effect of the two factors. The coefficient of variation (CV) is 88.8%.

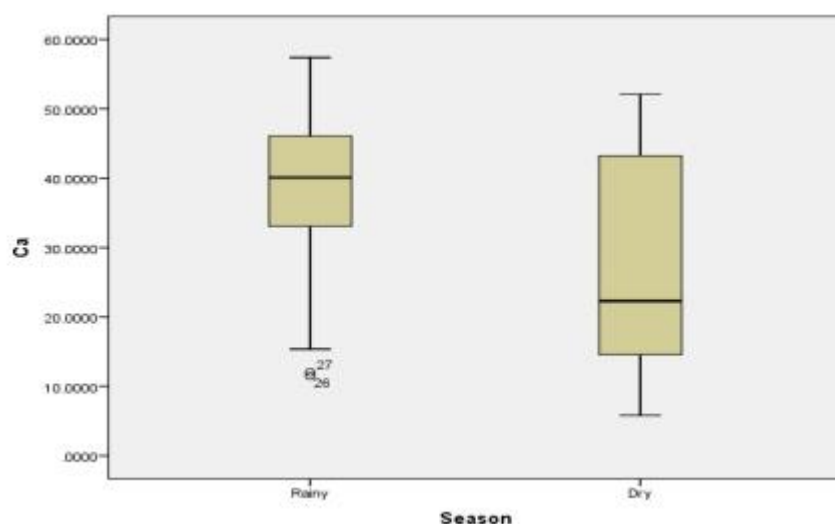


Figure 6: Box and Whisker plot for the annual spread of Ca concentrations in ground water samples collected from Ilorin

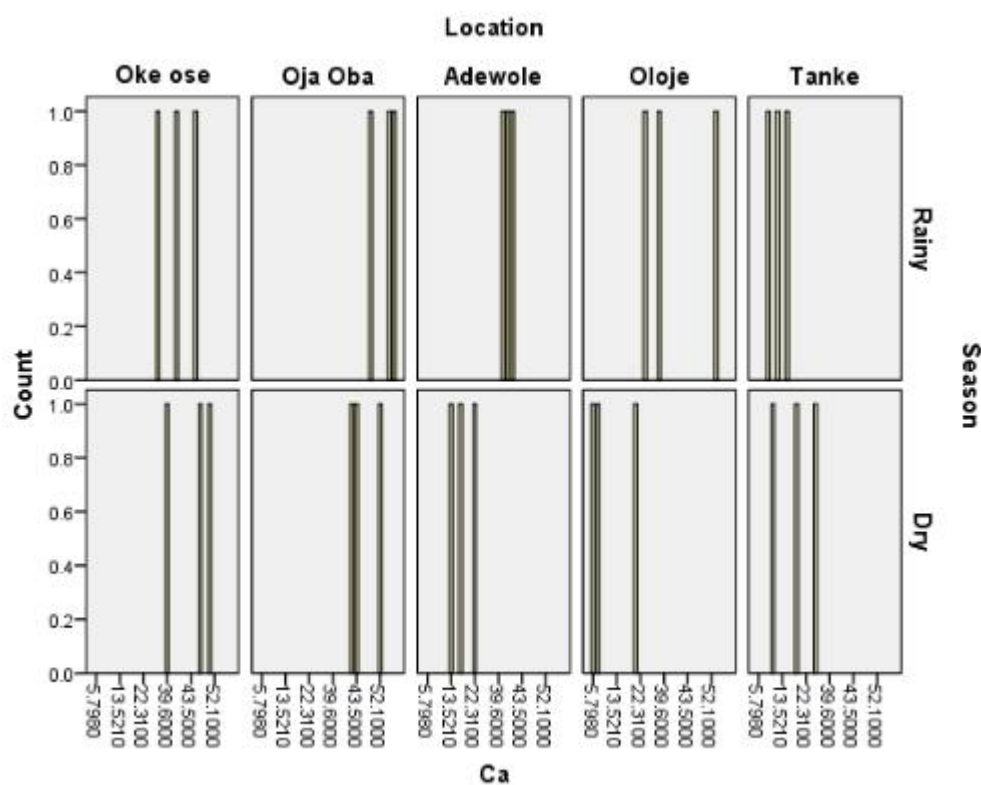


Figure 7: Bar chart for the seasonal spread of Ca concentrations in ground water samples collected from Ilorin

Analysis for Cobalt (Co) in different locations

Table 5: Seasonal means of Co concentrations at different location in Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
Co	Oke Ose	0.25±0.06	0.12±0.04	0.18±0.08
	Oja Oba	0.06±0.03	0.15±0.06	0.11±0.06
	Adewole	0.19±0.08	0.0003±0.0006	0.095±0.12
	Oloje	0.0003±0.0006	0.0007±0.0006	0.0005±0.00054

Tanke	0.0007±0.0006	0.0007±0.0006	0.0007±0.0005
Mean seasons	0.1002±0.11	0.05±0.07	
CV%		88.2%	
p≤0.05		***	***
Interaction(p≤0.05)		***	

From Table 5, Cobalt is also a metalloid which occurs in the elemental state to a small extent; its concentration at all locations ranged from 0.0005 ± 0.00054 to 0.18 ± 0.08 µg/L. When compared with the work carried out by Mebrahtu and Zerabuk (2011) in their work carried out on drinking water from urban areas of the Tigray Region, Northern Ethiopia wherein Co ranges from 0.011-0.03, Location 2 (Oja Oba) recorded the highest concentration of 0.18 ± 0.08 µg/L while the lowest concentration of 0.0005 ± 0.00054 µg/L was recorded in location 4 (Oloje). The highest concentration value for Co was recorded in the rainy season at Oke Ose. Co values reported were below the detection limit of 1µg/L. The order of increasing seasonal values is dry < rainy, as summarized in Table 5 and Figures 8 and 9. Figure 8, which is a box plot, also revealed that there is no presence of outliers in the data. Furthermore, from the two-way analysis of variance computed, significant variations of P (≤ 0.05) were found in Seasonal, Location and Interaction effect. The coefficient of variation (CV) is 88.2%

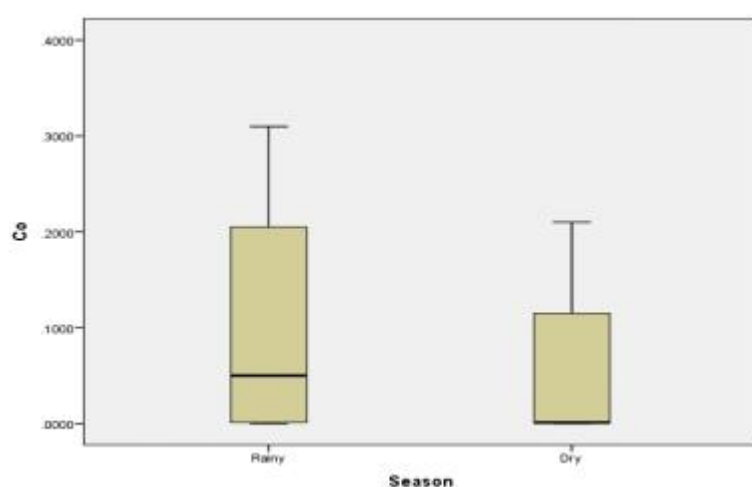


Figure 8: Box and Whisker plot for the annual spread of Co concentrations in ground water samples collected from Ilorin

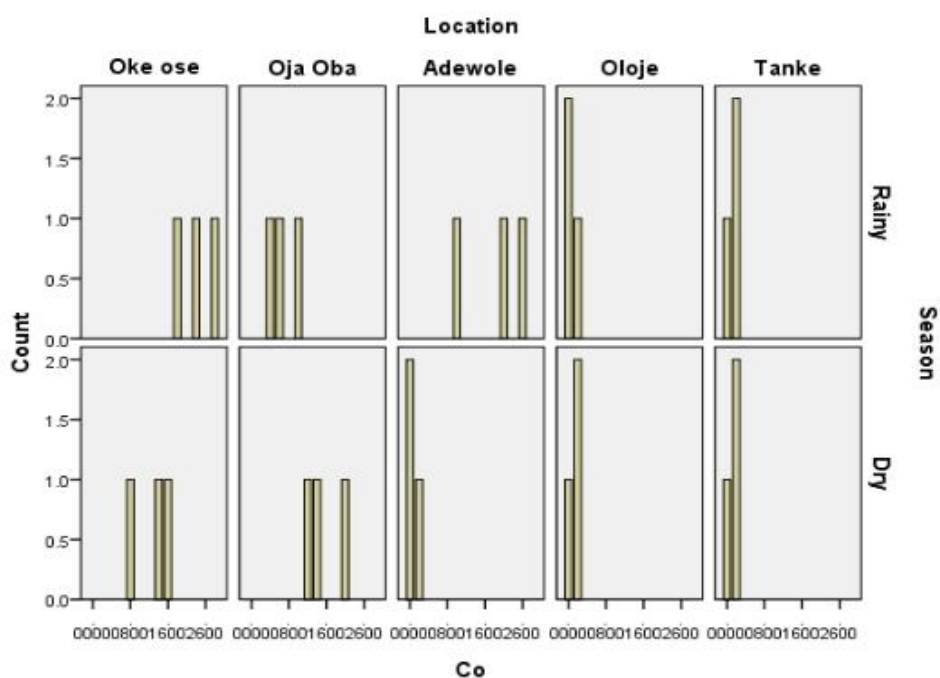


Figure 9: Bar chart for the seasonal spread of Co concentrations in ground water samples collected from Ilorin

Analysis for Nickel (Ni) in different locations

Table 6: Seasonal means of Ni concentrations at different locations in Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
Ni	Oke Ose	0.14±0.04	0.11±0.03	0.13±0.03
	Oja Oba	0.063±0.065	0.10±0.02	0.083±0.05
	Adewole	0.09±0.01	0.0007±0.0006	0.0003±0.0006
	Oloje	0.0003±0.0006	0.0003±0.0006	0.0003±0.0005
	Tanke	0.0003±0.0006	0.0007±0.0006	0.0005±0.00055
	Mean seasons	0.058±0.06	0.042±0.057	
	CV%		86.1%	
	p≤0.05		NS	***
	Interaction(p≤0.05)		***	

Table 6 showed that Ni concentration at all locations ranged from 0.0003±0.0005 to 0.13±0.03 µg/L. When compared with the work carried out by Odebunmi et al., (2014) in his work carried out on trace metals level of drinking water sources in part of Osun state Nigeria where the concentration of Ni ranges from 0.02-0.06, also in a work carried out by Mebrahtu and Zerabuk (2011) the concentration of Ni ranges from 0.033-0.041. It can be seen that Location 1 (Oke Ose) recorded the highest concentration of 0.13±0.03 µg/L while the lowest concentration of 0.0003±0.0005 µg/L was recorded in locations 3 and 4. The highest concentration value for Ni was recorded in the rainy season with a mean value and SD of 0.14±0.04, which is within the WHO standard value of 0.07µg/L (WHO, 2010). The order of increasing seasonal values is dry < rainy, as summarized in Table 6 and Figures 10 and 11. Figure 10 also revealed that there is no presence of outliers in the seasonal data. Furthermore, from the two-way analysis of variance computed as given in Appendix 1 (Table App5), significant variations of P (≤ 0.05) were found in Location and Interaction effect of the two factors, but not significant (NS) in Season. The coefficient of variation (CV) is 86.1%

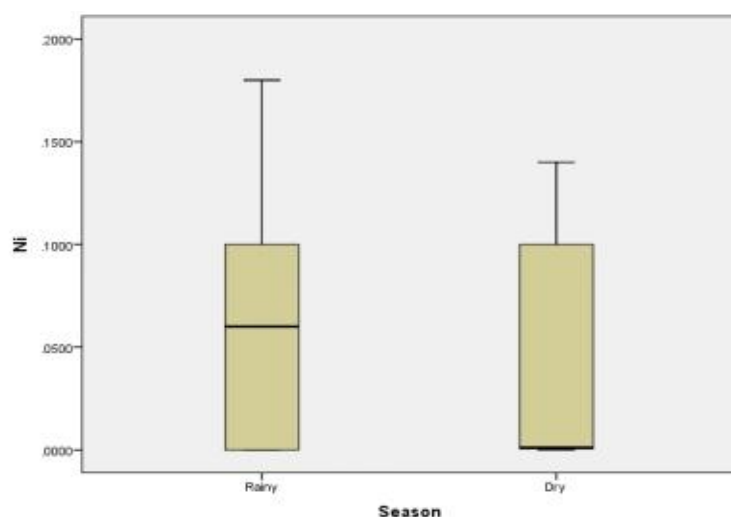


Figure 10: Box and Whisker plot for the annual spread of Ni concentrations in Ilorin

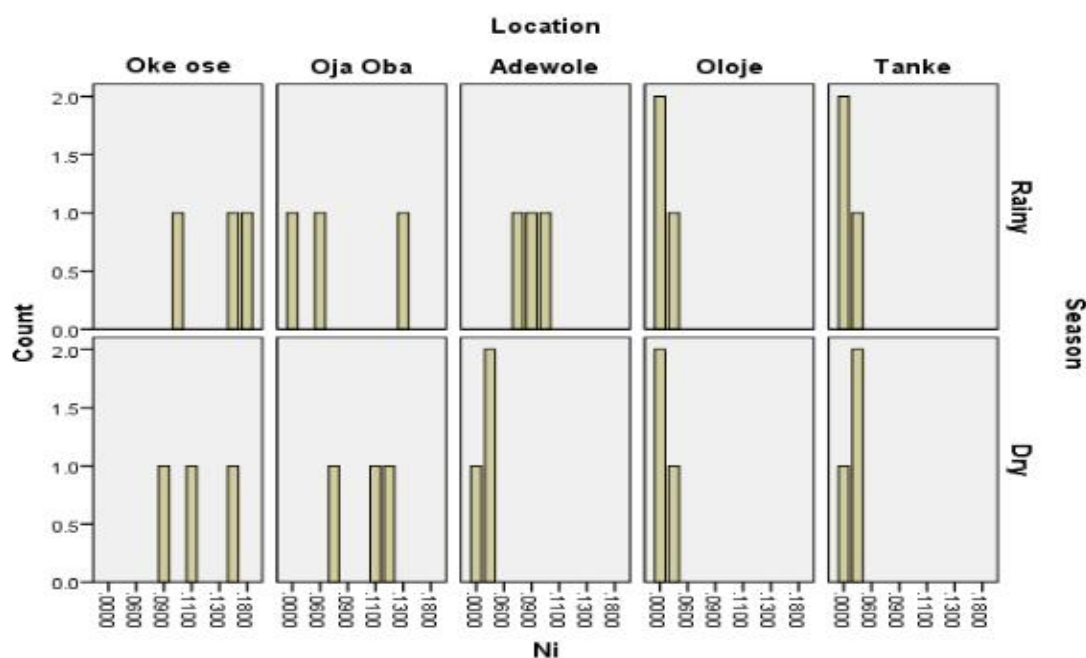
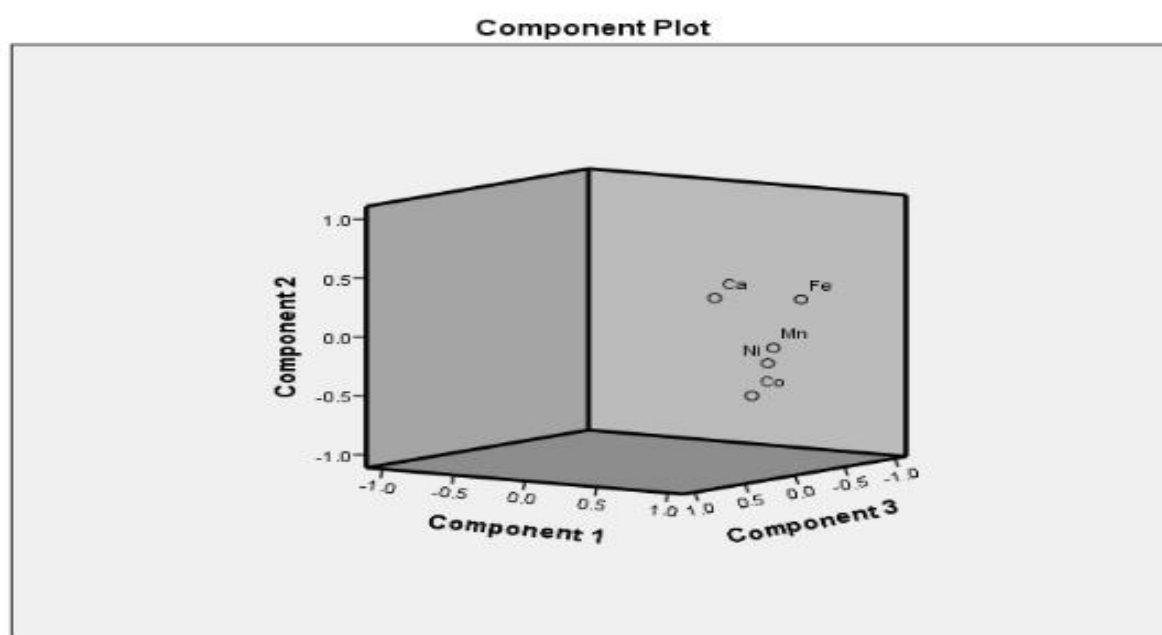
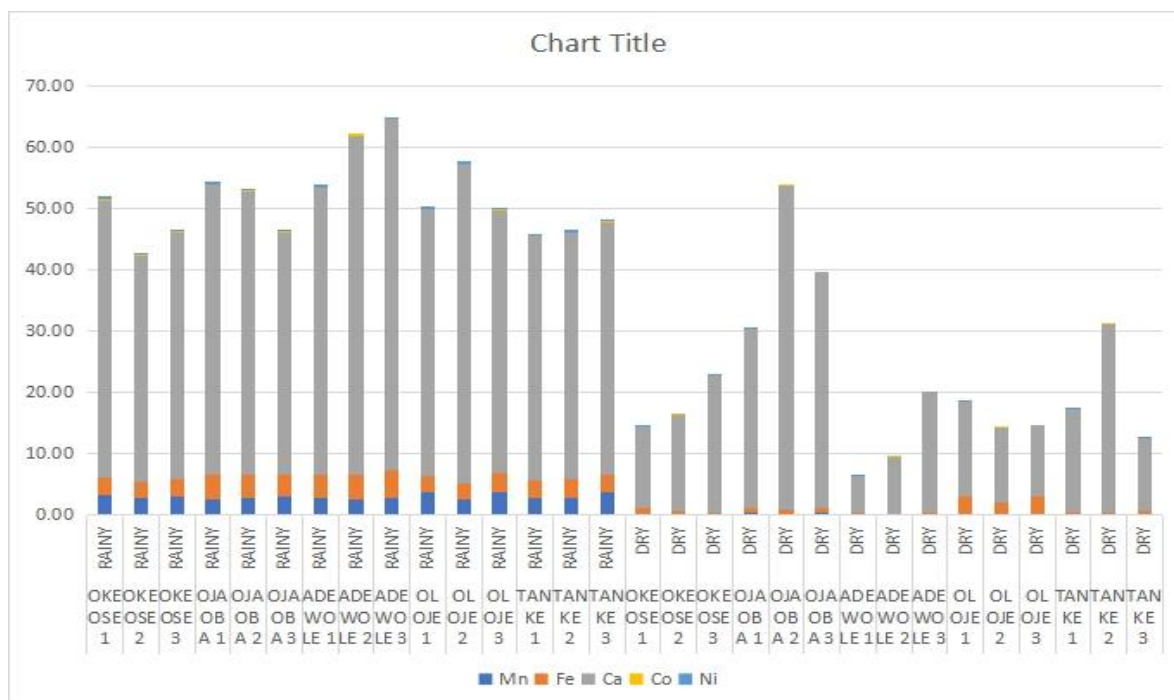


Figure 11: Bar chart for the seasonal spread of Ni concentrations in ground water samples collected from Ilorin

Standard two-dimensional PCA for five heavy metals (Mn, Fe, Ca, Co and Ni) measured at the 5 locations in Ilorin water (Fig. 12) is plotted. The distributions of Mn, Fe and Ca components are highly concentrated in Oke Ose, Oja Oba and Adewole. A similar study was also conducted in the automobile spare part and recycling market in Ilorin, and PCA values accounted for were 59.8% and 12.8% mainly from MN and Fe. (Orosun et al., 2020) which indicates that the potential pollution source of both locations is not only anthropogenic sources, but also from natural sources such as the weathering of the parent rock. PCA was also used to show seasonal variation in the concentration of heavy metals in all locations, as shown in Fig. 13. SPSS version 25 software was used to plot the cluster analysis graph and PCA (Figs. 13 and 14). The metals that are grouped together on the same axis indicate that these metals were of similar origin in the samples.



The annual mean of pH of sampled water ranged between 5.90 to 6.52. The results indicate that the water is alkaline. A very high significant variation was observed for rainy and dry. Highest values was recorded during dry season (Table 7, Fig. 15). The target water quality range (TWQR) for pH in seawater varies from 6–9. This study reveals that maximum and minimum pH values lie in the range 6-9, which indicates that water from Ilorin is of high quality. The pH of a water body is an important parameter since it can affect the toxicity of metals as well as their solubility. WHO (2010) recommends a pH value of 6.5 or higher for drinking water to prevent corrosion. Although a pH above 8.5 would be disadvantageous in the treatment and disinfection of drinking water with chlorine.

The order of increasing seasonal values is rainy < dry as summarized in Tables 6. More so, from the two-way analysis of variance computed, significant variations of $P (\leq 0.05)$ were found in Seasonal, Location and Interaction effect. The coefficient of variation (CV) is 99.7%

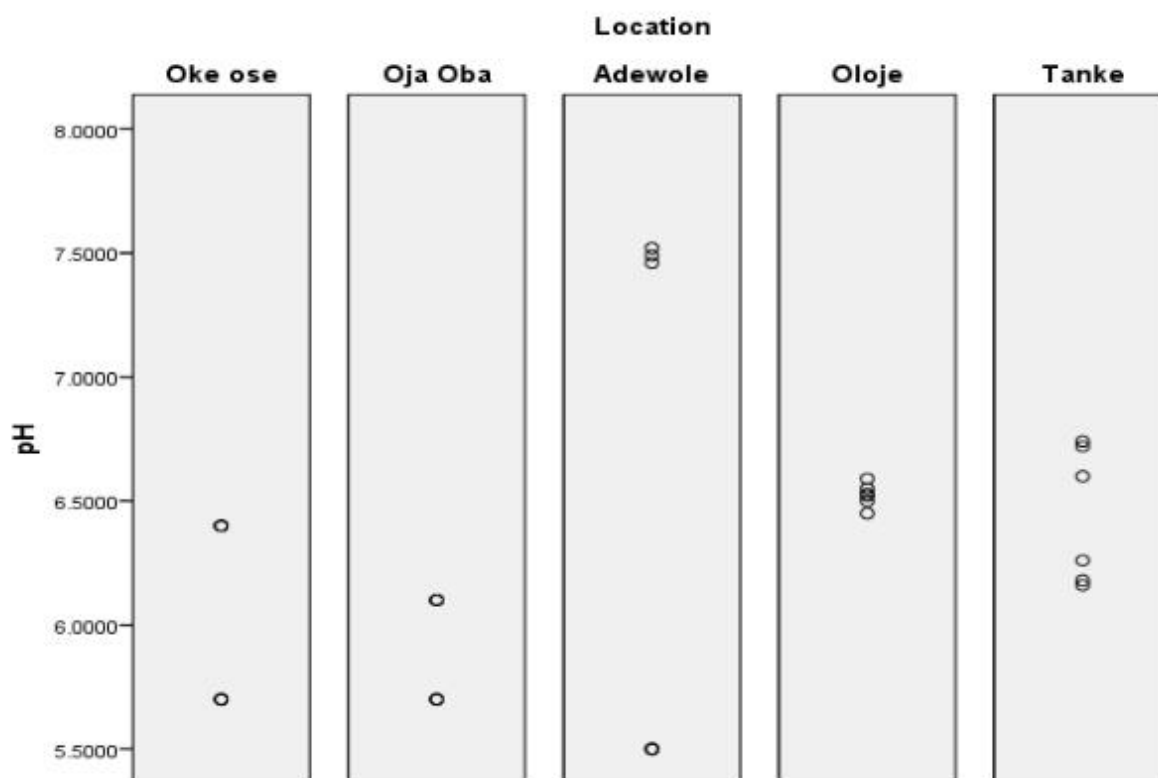


Figure 15: Seasonal variation of pH in water from different locations at Ilorin

Table 8: Seasonal and annual mean ($\pm$ SD) values of EC in different locations at Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
EC	Oke Ose	360 $\pm$ 0.00	570 $\pm$ 0.00	465 $\pm$ 115.02
	Oja Oba	180 $\pm$ 0.00	230 $\pm$ 0.00	205 $\pm$ 27.39
	Adewole	426.67 $\pm$ 5.77	582 $\pm$ 1.00	504.33 $\pm$ 85.16
	Oloje	1151 $\pm$ 7.00	287 $\pm$ 2.65	719 $\pm$ 473.26
	Tanke	185.67 $\pm$ 3.51	394 $\pm$ 1.00	289.83 $\pm$ 114.13
	Mean seasons	460.67 $\pm$ 400.70	412.6 $\pm$ 160.42	
	CV%		100.0%	
	p $\leq$ 0.05		***	***
	Interaction(p $\leq$ 0.05)		***	

EC is a measure of water's ability to conduct an electric current and is related to the amount of dissolved minerals in water, but it does not give an indication of which element is present but higher value of EC is a good indicator of the presence of contaminants such as sodium, potassium, chlorine and sulphate. The annual mean EC datas of sampled water ranged between 205 – 719 μ g/L. A very high significant variations was observed for rainy and dry seasons which are below the WHO recommended value of 900 μ g/L. Highest value was recorded during rainy season at location 4 (Oloje)

(Table 8, Fig. 16), when compared with (Mebratu and Zerabuk, 2011) in his work the EC values ranges from 44.1-2130 $\mu\text{S}/\text{cm}$, the higher value in the present study could be as a result of the depth of the borehole, in deeper depth rock water action process becomes more active, and thus EC increases with depth of water movement.

The order of increasing seasonal values is dry < rainy as summarized in Table 8. More so, from the two-way analysis of variance computed, significant variations of $P (\leq 0.05)$ were found in Seasonal, Location and Interaction effect. The coefficient of variation (CV) is 100%.

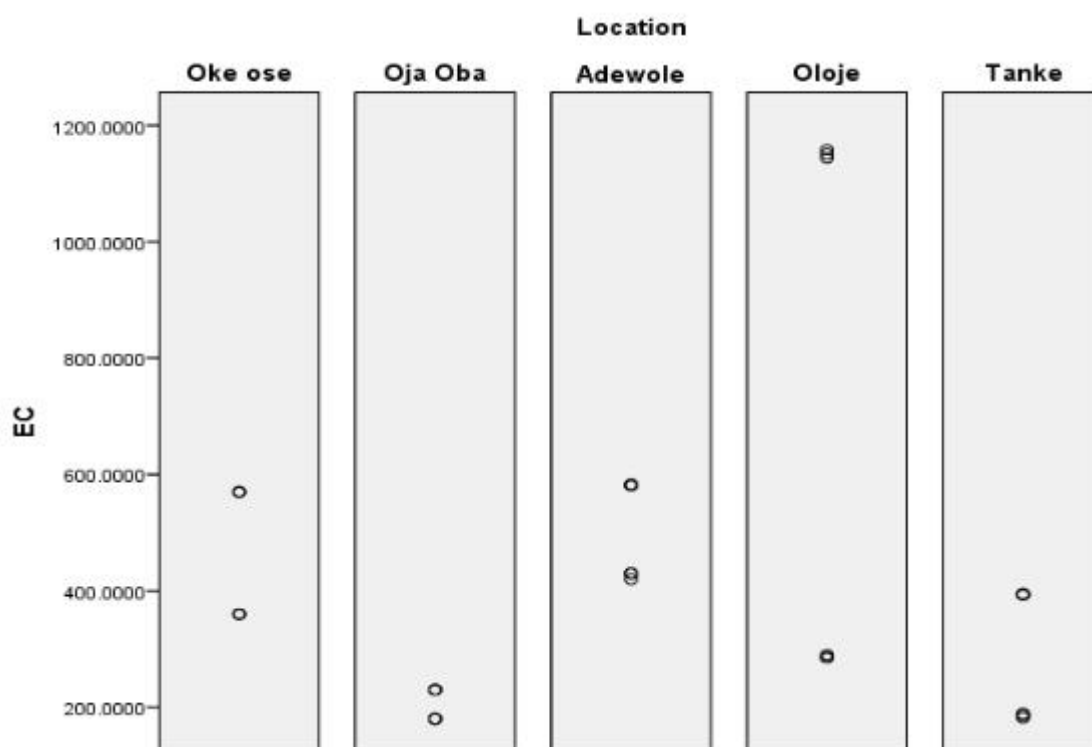


Figure 16: Seasonal variation of EC in water from different locations at Ilorin

Table 9: Seasonal and annual mean ($\pm$ SD) values of TDS in different locations at Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
TDS	Oke Ose	328.67 $\pm$ 0.58	538.33 $\pm$ 1.15	433.50 $\pm$ 114.84
	Oja Oba	161 $\pm$ 0.00	205.33 $\pm$ 1.15	183.17 $\pm$ 24.29
	Adewole	417.67 $\pm$ 2.31	292 $\pm$ 1.00	354.83 $\pm$ 68.85
	Oloje	576.33 $\pm$ 0.58	144 $\pm$ 0.00	360.17 $\pm$ 236.80
	Tanke	185.67 $\pm$ 3.51	394 $\pm$ 1.00	289.83 $\pm$ 114.13
	Mean seasons	333.87 $\pm$ 171.53	314.73 $\pm$ 156.46	
	CV%		100.0%	
	$p \leq 0.05$		***	***
	Interaction($p \leq 0.05$)		***	

Table 9 showed the annual mean of TDS for sampled water at all locations ranged from 183.17 $\pm$ 24.29 to 433.50 $\pm$ 114.84. Location 1 (Oke Ose) recorded the highest TDS value of 433.50 $\pm$ 114.84, while the lowest value, 183.17 $\pm$ 24.29, was recorded in location 2. The highest TDS value was recorded in the rainy season, with a mean value and SD of 576.33 $\pm$ 0.58; all the sample sites reported values below 1000mgL⁻¹. Low TDS is said to be a characteristic of hills and upland areas that represent areas of recharge. The order of increasing seasonal values is dry < rainy as summarized in Table 9 and Figure 17. When compared with (Mebratu and Zerabuk, 2011) in his work carried out on drinking water from urban areas of the Tigray Region, Northern Ethiopia the TDS ranges from 21-1593mg/L, it could be seen that Tigray region is highly polluted and poses more risk than the present study which could be as a result of sea deposit and sea water intrusion. Furthermore, from the two-way analysis of variance computed, significant variations of $P (\leq 0.05)$ were found in season, location and Interaction effects of

the two factors. The coefficient of variation (CV) is 100%, which means that the seasons were perfectly correlated.

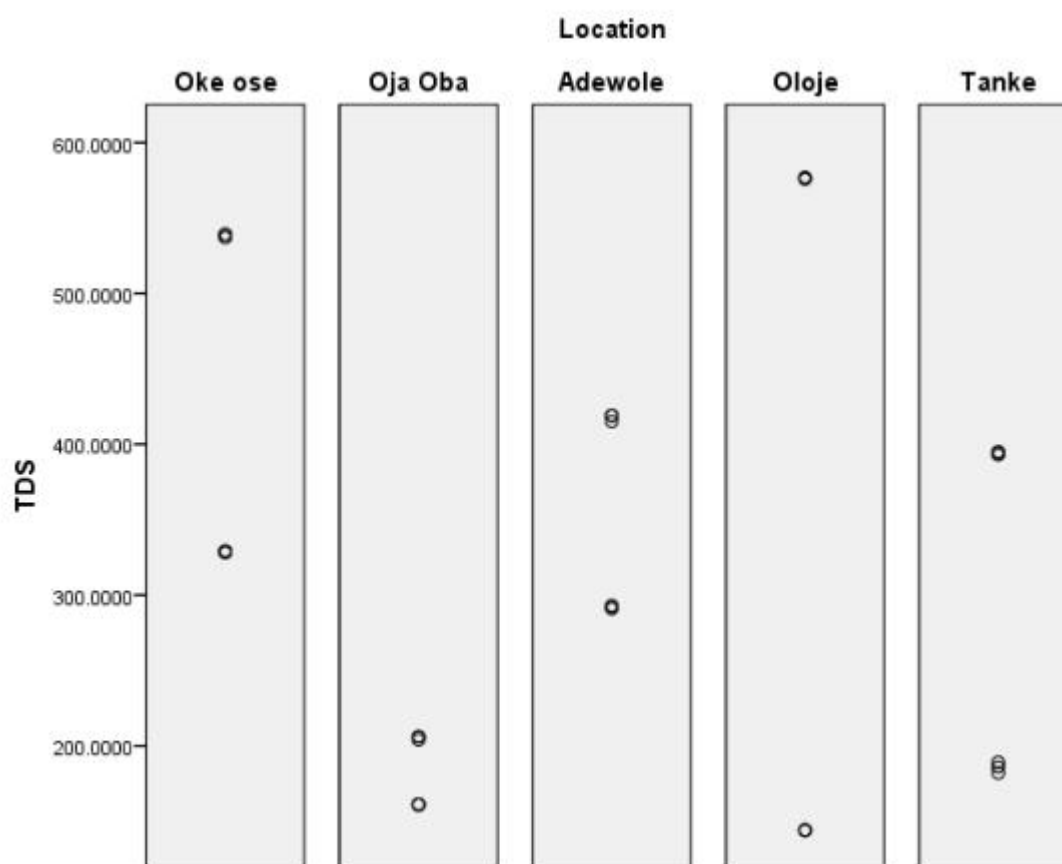


Figure 17: Seasonal variation of TDS in water from different locations at Ilorin

Table 10: Seasonal and annual mean ($\pm$ SD) values of TEMP in different locations at Ilorin

Physicochemical	Location	Rainy	Dry	Mean Location
TEMP	Oke Ose	30.43 $\pm$ 0.32	30.50 $\pm$ 0.26	30.47 $\pm$ 0.27
	Oja Oba	30.07 $\pm$ 0.32	29.7 $\pm$ 0.17	29.88 $\pm$ 0.31
	Adewole	27.30 $\pm$ 0.20	29.33 $\pm$ 0.12	28.32 $\pm$ 1.12
	Oloje	29.23 $\pm$ 0.12	29.13 $\pm$ 0.15	29.18 $\pm$ 0.13
	Tanke	29.10 $\pm$ 0.10	28.73 $\pm$ 0.12	28.92 $\pm$ 0.22
	Mean seasons	29.23 $\pm$ 1.21	29.48 $\pm$ 0.67	
	CV%		96.60%	
	p $\leq$ 0.05		***	***
	Interaction(p $\leq$ 0.05)		***	

The annual mean TEMP data of sampled water range between 28.32 – 30.47. A very highly significant variation was observed for rainy and dry. The highest value was recorded during the dry season at location 1 (Oke Ose), which is higher than the WHO permissible limit for water of 30 (Fig. 18).

The order of increasing seasonal values is dry < rainy as summarized in Table 10 when compared with (Mebrahtu and Zerabuk, 2011) in his work the temp range from 11.8 - 27.7, it can be seen that the present study has higher temp which could be as a result of solar radiation as the well water used has no lid cover. More so, from the two-way analysis of variance computed, significant variations of P ($\leq$ 0.05) were found in Seasonal, Location and Interaction effect. The coefficient of variation (CV) is 96.6%

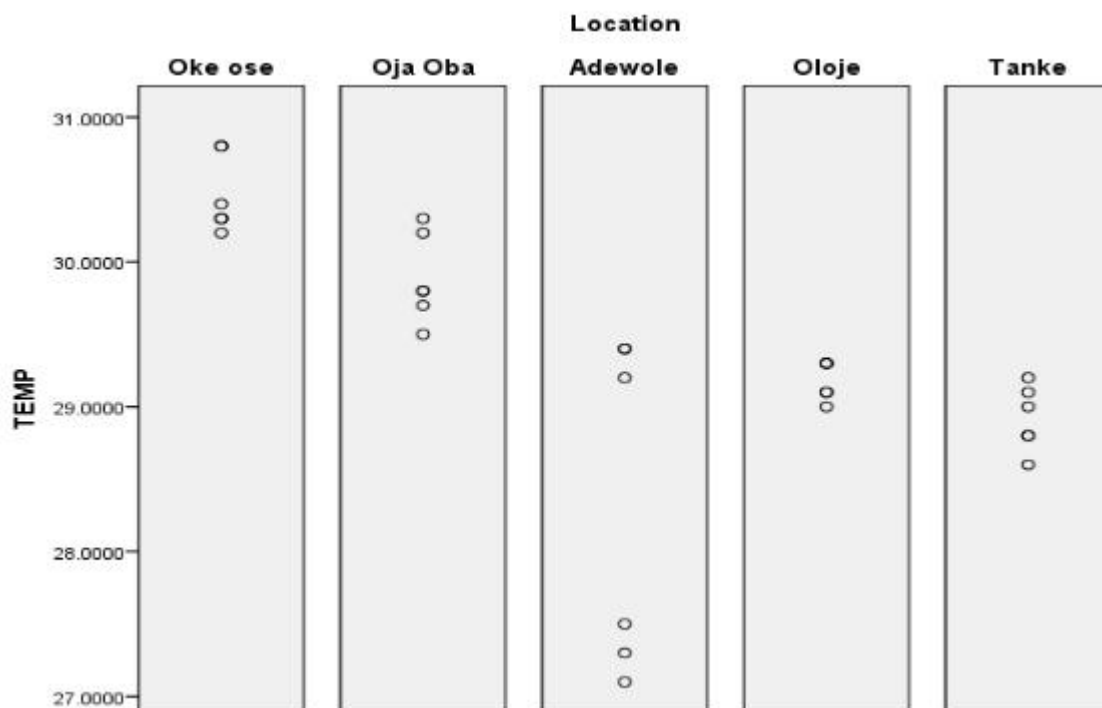


Figure 18: Seasonal variation of TEMP in water from different locations at Ilorin

Non-carcinogenic risk

Heavy metals such as cobalt and other heavy metals have been identified as potential health risks to the local and global populations. These heavy metals are primarily absorbed by drinking water, food consumption, and skin contact. Table 11 and Table 12 show the calculated average daily dosage (ADD) of these metals during the rainy and dry seasons at each of the sampling sites. During the rainy season, the overall heavy metal concentration in groundwater varies between 0.063 and 53.17 ppm, with Cobalt and Nickel having the lowest values of 0.063 ppm apiece and Calcium having the highest value of 53.17, in the order $Ca > Fe > Mn > Co > Ni$. During the dry season, concentrations range from 0.0003 to 40.28, with Cobalt and Nickel having the lowest values at 0.0003 and Calcium having the highest value at 2.73, in the pattern $Ca > Fe > Mn > Co > Ni$.

During the rainy season, the estimated average dosage intake (ADD) of Mn for both adults and children in Oke Ose is $5.48 \times 10^{-2} \text{mg/kg/day}$, and in Oja oba is $5.02 \times 10^{-2} \text{mg/kg/day}$, for Adewole is $5.04 \times 10^{-2} \text{mg/kg/day}$, in Oloje is $6.17 \times 10^{-2} \text{mg/kg/day}$, and in Tanke is estimated to be $5.62 \times 10^{-2} \text{m}$ (Table II). The estimated daily dosage for Mn in all of the locations was higher than the RFD limit set by the US EPA (1.4×10^{-2}) (Tay et al., 2019) and indicated that groundwater is not safe for Mn exposure. In Oke Ose, Oja Oba, Adewole, Oloje, and Tanke, the estimated ADD of Iron via ingestion and dermal contact for both adults and children was 5.07×10^{-2} , 6.91×10^{-2} , 7.33×10^{-2} , 4.88×10^{-2} , and 5.44×10^{-2} , respectively, which is safe for consumption because the ADD is lower than the RFD of Fe given by the US EPA (7×10^{-1}) (Tay et al., 2019). For Co in Oke Ose, Oja Oba, Adewole, Oloje, and Tanke, the ADD through ingestion and dermal contact for both adults and children was calculated to be 4.40×10^{-3} , $0.1.13 \times 10^{-3}$, 2.62×10^{-3} , respectively, which is safe to drink because the ADD is lower than the RFD. The estimated ADD for Ni ingestion and dermal contact in adults and children in Oke Ose, Oja Oba, Adewole, Oloje, and Tanke was 2.50×10^{-3} , $0.1.13 \times 10^{-3}$, 1.84×10^{-3} , and $1.60 \times 10^{-3} \text{mg/kg/day}$, respectively, which is safe for consumption because the ADD is lower than the RFD of Mn set by the US EPA (0.02mg/kg/day) (Kamunda et al., 2016). Although an excess of calcium per day without a medical necessity can induce kidney stones and sclerosis of the kidneys and blood vessels, calcium deficiency is one of the leading causes of osteoporosis (Cormick & Belizán, 2019). During the dry season, the estimated ADD (ingestion and dermal contact) levels for both adults and children is with the range $9.68 \times 10^{-4} \text{mg/kg/day}$ and $2.08 \times 10^{-2} \text{mg/kg/day}$ (Table 12), with Oloje recording the highest and Adewole recording the lowest.

For adults and children, the estimated ADD via (ingestion and dermal contact) for Fe through the locales ranges between (6.57×10^{-3} mg/kg/day and 1.22×10^{-1} mg/kg/day), with the greatest recorded in Oloje and the lowest in Adewole. For adults and children, the estimated ADD through (ingestion and dermal contact) for Co varies from (5.95×10^{-6} mg/kg/day and 1.19×10^{-5} mg/kg/day), with Adewole and Tanke having the highest. During the dry season, the estimated ADD (ingestion and dermal contact) levels for both adults and children range between 9.68×10^{-4} mg/kg/day and 2.08×10^{-2} mg/kg/day, with Oloje recording the highest and Adewole recording the lowest.

For adults and children, the estimated ADD via (ingestion and dermal contact) for Fe through the locales ranges between (6.57×10^{-3} mg/kg/day and 1.22×10^{-1} mg/kg/day), with the greatest recorded in Oloje and the lowest in Adewole. The estimated ADD through (ingestion and dermal contact) for adults and children for Co ranges from (5.95×10^{-6} mg/kg/day and 1.19×10^{-5} mg/kg/day) in which the highest is recorded in Adewole and Tanke. The estimated ADD for Ni via food and dermal contact ranges from (3.33×10^{-4} mg/kg/day and 6.67×10^{-4} mg/kg/day), with Oke Ose and Tanke having the greatest levels.

The estimated ADD for Mn in all areas was less than the RFD standard indicated by the US EPA (1.4×10^{-2} mg/kg/day), indicating that the groundwater is safe for Mn exposure. The calculated ADD for Fe was lower than the RFD value of Fe reported by the US EPA (0.7 mg/kg/day), indicating that it is safe to drink. The estimated ADD for Co and Ni was their RFD value in all sites, indicating that they were safe for eating. The THQing and THQderm for Adults and children for each metals and locations are represented in Table 13 and Table 14, The range of THQing and THQderm in all locations during raining season for adults is in the order Mn>Co>Ni>Fe see (Table 13).

Oke Ose has also for children, the THQing and THQderm ranges as Mn>Fe>Co>Ni (Table 14). During the dry season, the THQing and THQderm values for each metals in all the locations ranges as Mn>Fe>Co>Ni (Table 15) also for children the THQing and THQderm values ranges as Mn>Fe>Ni>Co (Table 16). The HI estimated for metals in each location for both adults and children during raining season are greater than 1 which is the recommended standard set by US EPA (2001) (Tables 13,14 and 15) which means the general populace should worry about the probably non-cancerous effect of these heavy metals during raining season, also in dry season, Oloje has HI value greater than 1 while others are within the recommended safe limit (<1) (Table 16) (Orosun et al., 2020).

Carcinogenic Risk

During the rainy season, the incremental lifetime cancer risk (ILCR) in Oke Ose, Oja Oba, Adewole, Oloje, and Tanke was calculated to be Ni (4.54×10^{-3}), Ni (3.67×10^{-3}), Ni (2.05×10^{-3}), Ni (3.35×10^{-3}) and Ni (2.92×10^{-3}), correspondingly. Cancer risks more than 10^{-4} are considered high because they pose a higher cancer risk, values between 10^{-4} and 10^{-6} are considered acceptable, and values less than 10^{-6} are considered extremely low cancer risks to humans (Orosun et al., 2020). The ILCR in Oke Ose, Oja Oba, Adewole, Oloje, and Tanke during the dry season was calculated to be Ni (2.16×10^{-5}), Ni (1.08×10^{-5}), Ni (6.47×10^{-6}) and Ni (2.16×10^{-5}) correspondingly. Because the readings are between 10^{-4} and 10^{-6} , they are thought to pose a modest cancer risk (Orosun et al., 2020).

Table 11: Average daily dose of heavy metals in groundwater samples collected within the study areas during raining season

Location s	Mn		Fe		Ca		Co		Ni	
	Concentration	ADD	Concentration	ADD	Concentration	ADD	Concentration	ADD	Concentration	ADD
Oke-Ose	3.1E+00	5.5E-02	2.8E+00	5.1E-02	4.1E+01	7.3E-01	2.5E-01	4.4E-03	1.4E-01	2.5E-03
Oja-Oba	2.8E+00	5.0E-02	3.9E+00	6.9E-02	4.4E+01	8.0E-01	1.2E-01	2.1E-03	1.1E-01	2.0E-03
Adewole	2.8E+00	5.0E-02	4.1E+00	7.3E-02	5.3E+01	9.5E-01	6.3E-02	1.1E-03	6.3E-02	1.1E-03
Oloje	3.4E+00	6.2E-02	2.7E+00	4.9E-02	4.6E+01	8.3E-01	1.5E-01	2.6E-03	1.0E-01	1.8E-03
Tanke	3.1E+00	5.6E-02	3.0E+00	5.4E-02	4.0E+01	7.2E-01	1.9E-01	3.4E-03	9.0E-02	1.6E-03

Table 12: Average daily dose of heavy metals in groundwater samples collected within the study areas during dry season

Locations	Mn		Fe		Ca		Co		Ni	
	Concentration	ADD	Concentration	ADD	Concentration	ADD	Concentration	ADD	Concentration	ADD
Oke-Ose	5.8E-02	1.0E-03	7.2E-01	1.3E-02	1.7E+01	3.1E-01	3.3E-04	6.0E-06	6.7E-04	1.2E-05
Oja-Oba	3.6E-01	6.5E-03	7.1E-01	1.3E-02	4.0E+01	7.2E-01	3.3E-04	6.0E-06	3.3E-04	5.9E-06
Adewole	5.4E-02	9.7E-04	3.7E-01	6.6E-03	1.2E+01	2.1E-01	6.7E-04	1.2E-05	3.3E-04	5.9E-06
Oloje	1.2E-01	2.1E-02	2.7E+00	1.2E-01	1.3E+01	1.4E-01	6.7E-04	9.5E-06	3.3E-04	3.6E-06
Tanke	8.9E-02	1.6E-03	4.9E-01	8.8E-03	2.0E+01	3.5E-01	6.7E-04	1.2E-05	6.7E-04	1.2E-05

Table 13: THQing, THQderm and HI of the heavy metals for adults during raining season

	Mn		Fe		Co		Ni		
Location	THQing	THQderm	THQing	THQderm	THQing	THQderm	THQing	THQderm	HI
Oke Ose	1.891	0.025	0.115	6×10^{-5}	0.438	9.38×10^{-5}	0.2	7.8×10^{-5}	2.669
Oja Oba	1.739	0.023	0.157	8.14×10^{-5}	0.214	4.5×10^{-5}	0.16	6.30×10^{-6}	2.292
Adewole	1.739	0.023	0.167	8.71×10^{-5}	0.113	2.38×10^{-5}	0.09	3.52×10^{-5}	2.132
Oloje	2.130	0.028	0.111	5.86×10^{-5}	0.263	5.44×10^{-5}	0.15	5.74×10^{-5}	2.682
Tanke	1.947	0.026	0.123	6.43×10^{-5}	0.338	6.88×10^{-5}	0.13	5×10^{-5}	2.564

Table 14: THQing, THQderm and HI of the heavy metals for children during raining season

	Mn		Fe		Co		Ni		
Location	THQing	THQderm	THQing	THQderm	THQing	THQderm	THQing	THQderm	HI
Oke ose	2.839	0.722	0.172	1.7×10^{-3}	0.656	2.69×10^{-3}	0.3	2.2×10^{-3}	7.36
Oja Oba	2.597	0.666	0.157	2.4×10^{-3}	0.319	1.32×10^{-3}	0.24	1.8×10^{-3}	6.42
Adewole	2.605	0.666	0.167	2.5×10^{-3}	0.169	6.88×10^{-4}	0.135	1.04×10^{-3}	6.18
Oloje	3.195	0.833	0.111	1.7×10^{-3}	0.394	1.63×10^{-3}	0.22	3.51×10^{-4}	7.84
Tanke	2.913	0.777	0.123	1.8×10^{-3}	0.506	2.06×10^{-3}	0.19	1.46×10^{-3}	7.30

Table 15: THQing, THQderm and HI of the heavy metals for adults during dry season

	Mn		Fe		Co		Ni		
Location	THQing	THQderm	THQing	THQderm	THQing	THQderm	THQing	THQderm	HI
Oke Ose	0.034	4.78×10^{-4}	2.96×10^{-2}	1.57×10^{-5}	5.94×10^{-4}	1.24×10^{-7}	9.5×10^{-4}	3.69×10^{-7}	6.56×10^{-2}
Oja Oba	0.217	3×10^{-3}	2.86×10^{-2}	1.57×10^{-5}	0	1.24×10^{-7}	0	1.83×10^{-8}	2.49×10^{-1}
Adewole	0	4.44×10^{-4}	1.43×10^{-2}	7.86×10^{-6}	0	2.49×10^{-7}	0	1.83×10^{-8}	1.47×10^{-2}
Oloje	1.695	1×10^{-3}	5.29×10^{-1}	5.86×10^{-5}	0	2.49×10^{-7}	0	1.83×10^{-8}	2.23
Tanke	0.065	7.22×10^{-4}	2×10^{-2}	1×10^{-5}	0	2.49×10^{-7}	0	3.69×10^{-7}	8.57×10^{-2}

Table 16: THQing, THQderm and HI of the heavy metals for children during dry season

Locations	Mn		Fe		Co		Ni		
	THQing	THQderm	THQing	THQderm	THQing	THQderm	THQing	THQderm	HI
Oke Ose	5.43×10^{-2}	1.39×10^{-2}	4.41×10^{-2}	4.57×10^{-4}	8.75×10^{-3}	3.69×10^{-6}	1.4×10^{-3}	1.09×10^{-5}	1.23×10^{-1}
Oja Oba	4.35×10^{-1}	8.89×10^{-3}	4.29×10^{-2}	4.43×10^{-4}	0	3.69×10^{-6}	0	5.37×10^{-6}	4.87×10^{-1}
Adewole	0	1.33×10^{-2}	2.86×10^{-2}	2.29×10^{-4}	0	7.5×10^{-6}	0	5.37×10^{-6}	4.2×10^{-2}
Oloje	1.09×10^{-1}	2.94×10^{-2}	1.66×10^{-1}	1.71×10^{-3}	0	7.5×10^{-6}	0	5.37×10^{-6}	3.06×10^{-1}
Tanke	8.7×10^{-2}	2.17×10^{-2}	3×10^{-2}	3.14×10^{-4}	0	7.5×10^{-6}	0	1.09×10^{-5}	1.39×10^{-1}

Table 17: Comparison of results concentration of heavy metals with international standard and pass work

Regulatory bodies/Research work	Mn	Fe	Ca	Co	Ni
WHO (2010)	0.1	0.3	75	Ns	0.07
US EPA (2009)	0.05	0.3	-	-	0.1
NSDWQ	0.2	0.3	75	Ns	0.02
(Aderinola et al., 2009)	0.09	1.41	-	-	0.14
(Okoro et al., 2019)	0.1-3.47	2.64-9.65	-	-	-
(Orosun et al., 2020)	0.02-0.06	0.03-0.07	-	-	-
(Odebunmi et al., 2014)	0.33-0.41	0.19-0.32	-	-	0.02-0.06
(Olatunji et al., 1970)	-	0-2.73	25.60-276.6	-	-
(Mebrahtu & Zerabruk, 2011)	0.031-0.038	0.097-0.919	-	0.011-0.030	0.033-0.041
Present study	0.05-3.44	0.37-4.09	11.60-44.40	0.0003-0.25	0.0003-0.14

Concentration of all the metals is within that of the pass work, but except for Ca, other metals (Mn, Fe, Co, Ni) range exceed the permissible limit set by international standards (WHO, US EPA, NSDWQ) (Table 17). For manganese, which ranges between (0.05-3.44) and has exceeded the international standard (0.1 (WHO 2008), 0.05 (US EPA 2009), 0.2(NSDWQ)) may be due to air erosion of dust or soil, mining and industrial discharges (ATSDR, 2000). For Fe, which ranges between (0.37-4.09) and has exceeded the permissible limit set by international standards (0.3 (WHO 2008), 0.3 (US EPA 2009), 0.3 (NSDWQ)), may be a result of industrial wastes, refining of Iron ores, and corrosion of iron-containing metals. Meanwhile, Ca is within each permissible limit. Nickel, on the other hand, ranges from 0.0003-0.14, which has exceeded the permissible limit set by international standards (0.07 WHO (2008), 0.02 (NSDWQ)). Maybe as a result of direct leaching from rocks and sediments, and also natural sources such as wind-blown dust derived from weathering of rocks and soils, forest fire and volcanic activities (Genchi et al., 2020).

CONCLUSION

The concentration of the heavy metals in the water samples collected in Oke Ose, Oja Oba, Adewole, Oloje and Tanke during the rainy season is much higher than during the dry season in each location. This follows those activities of the automobile spare part and recycling park (i.e Vehicular discharges and dusts, welding, poor disposal of spare parts, etc). This revelation was corroborated by the PCA analysis. While all the hazard indices estimated for both children and adults during the rainy season in all the locations are greater than 1 and less than 1 during the dry season, except in Oloje, the HI estimated is greater than 1 during the rainy season in all locations and also greater than 1 in Oloje during the dry season. The incremental life cancer risk levels range from level I to level II. It follows that the study areas should be concerned about the non-carcinogenic health risk during the rainy season and also during the dry season in Oloje.

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COMMUNITY-BASED CLIMATE ADAPTATION AMONG SMALLHOLDER FARMERS IN KWARA STATE, NIGERIA

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ABSTRACT

Climate change impacts negatively on people's livelihoods, particularly in developing countries, such as Nigeria, where agriculture employs a large proportion of the population and the farming systems are dominated by smallholder farmers. Smallholder farmers often adopt several ways to farming systems; in many instances, adaptation strategies have exacerbated poverty, food insecurity and left behind vulnerable agrarian communities. This study assessed the smallholder farmers' community-based adaptation measures to climate change impact in Kwara State. The study was carried out in the four agricultural zones of Kwara State. Sample size was determined after Krejcie and Morgan's (1970). Altogether, 1,470 farmer households were sampled, 4 Focus Group Discussions (FGD) sessions and 5 Key Informant Interviews (KII) were also conducted in the 4 zones. Descriptive statistics, including thematic analyses, were used in this study. Mixed farming (60.5%), planting of improved seedlings (46.2%) and changing planting dates (36.1%) were the most prominent community-based adaptation strategies in the study area. The study concluded that the community-based adaptation strategies of smallholder farmers were effective in checking the menace of climate change. It was recommended that aggressive climate education of local farmers, intervention of early warning, and provision of climate-suitable crops should be encouraged among the smallholder farmers.

Keywords: Adaptive, Agriculture, Ecological zones, Food security & Livelihoods

INTRODUCTION

Climate change adaptation capacity varies across and within societies. Adaptation is a critical strategy for farmers to cope with the negative effects of climate change and variability, which in turn helps poor farm households increase agricultural production (Yesuf et al., 2008). Similarly, smallholder farmers' knowledge of adaptation methods may help them better deal with the challenges of climate change (Deressa et al., 2009). This implies that understanding adaptation measures at the micro level of farm household is critical for developing accurate and appropriate policies. According to Maddison (2007), the propensity of farmers living in different locations to adapt varies. Farmers in different areas or agricultural zones are predisposed to and capable of adapting to climate change differently. Adaptation is generally geared toward agricultural production, primarily through irrigation and crop-resistant species planting. Most local farmers are aware that the stress on their local environment and livelihoods has increased, and a lack of adaptation capacity is a serious issue (Jones et al., 2011). Climate change poses a significant threat to smallholder farmers and threatens to undermine global progress toward poverty alleviation, food security, and sustainable development (Vermeulen et al 2012; Lipper et al 2014).

Globally, there are an estimated 475 million smallholder farmers cultivating less than 2 ha of land (Lowder et al 2016), many of whom are poor, experience food insecurity, and live in highly precarious conditions (Morton 2007; Cohn et al 2017). Smallholder farmers are highly vulnerable to climate change because most depend on rain-fed agriculture, cultivate marginal areas, and lack access to technical or financial support that could help them invest in more climate-resilient agriculture (Morton 2007; Holland et al 2017; Donatti et al 2018). While there is growing evidence of the vulnerability of smallholder farmers to climate change (Cohn et al 2017; Harvey et al 2014), and increased interest in ensuring food security under climate change (Vermeulen et al 2012; Lipper et al 2014), adaptation efforts are still hindered by the lack of information on how smallholder farmers are experiencing and responding to climate change. Policy makers, donors, and practitioners interested in developing policies, institutional responses, and strategies for smallholder farmer adaptation need detailed, context specific information on what climate change impacts smallholder farmers is experiencing and

whether (and how) they are adapting their management strategies to deal with these impacts (Castellanos et al 2013; Donatti et al 2017).

While the international community has increasingly emphasized the need for adaptation in recent years and more funding has been made available for adaptation, most efforts to help countries adapt have been centered on top-down approaches and policy solutions (Wilbanks and Kates 1999; Reid et al. 2009). However, given that climate change impacts, appropriate responses, and, to some extent, adaptive capacity, are location specific, adaptation at the community level is critical to the process of adaptation. Community organizing for adaptation to climate change also increases resilience to climate risks by strengthening and expanding social networks and links with supporting institutions (Adger 2003; Tompkins and Adger 2004). The recent emphasis on Community Based Adaptation (CBA) in both theory and practice reflects the significance of community-based development efforts (Hickey and Mohan 2004; Dodman and Mitlin 2011), as well as research on participatory disaster risk management (Allen 2006; Mercer et al. 2008; van Aalst, Cannon, and Burton 2008). Autonomous adaptation (that is, individuals adapting their behavior according to perceived climate change) is insufficient to address the challenge of climate change. For example, farmers acting individually may choose to expand agricultural production in response to climate change, leading to resource degradation and increasing the burden on other members of the community. To avoid this negative outcome, communities must work collectively to address the many challenges they face. Furthermore, effective autonomous adaptation seldom transpires without some degree of CBA. Collective adaptation influences individual adaptation decisions and resilience to climate change by facilitating information diffusion and risk sharing (Boahene, Snijders, and Folmer 1999; Isham 2002; Fafschamps and Lund 2003; Bandiera and Rasul 2006). Given that adaptation is often location specific, local forums frequently are the best site for co-production of forecasts and discussion of strategies to be taken up by individuals. Valdivia et al. (2010) found that community workshops helped individuals identify local climate trends and adaptation strategies.

While several studies limited their geographic scope, this study would benefit from a wider geographical scope across different ecological zones to deepen understanding of how different communities are adapting to climate change and their effectiveness on their livelihoods which is critical for developing fit-for-purpose climate change policies. This study is limited to the state's agricultural zones, which are divided into four: A-Derived Savannah Zone (Baruten, Kaiama). B-Flood Plain Zone (Patigi, Edu). C-Guinea Savannah Zone (Asa, Moro, Ilorin West, Ilorin South, Ilorin East). D-Rainforest region (Irepodun, Oyun, Offa, Isin, Ekiti, Ifelodun, Oke-Ero). This study evaluated the effectiveness of climate change adaptation strategies used by smallholder farmers in Kwara State's various agro-ecological zones. The study examined the community-based adaptation measures of smallholder farmers in the four agricultural zones of Kwara State, Nigeria. This study was conducted at the micro level, making it very interesting to be used as a guideline document for future research in Kwara State and to the same climatic, socioeconomic, and geographical areas, while also considering the specific adaptation strategies in the study area. The study aid in the comprehension of climate change perception, identify the most used adaptation strategies among specific set of options, and justify factors that significantly influence adaptation strategies. The study will make significant contributions to climate change discourse and will provide insights that possess the potential to shape climate change policies in Kwara, Nigeria, and all of Africa.

MATERIALS AND METHODS

The research design for this study was mixed methods research design. This design is appropriate and recommended by Neuman (2005) because it allows for the integration of both qualitative and quantitative data, providing a comprehensive understanding of the complex issue of climate change adaptation among smallholder farmers. Qualitative data was collected through Key informant interviews with stakeholders, focus group discussions with smallholder farmers, and content analysis of relevant documents. Quantitative data was collected through surveys of smallholder farmers and analysis of existing data on the adoption and implementation of climate change adaptation strategies. The sample size calculator used yielded a margin of error of (confidence interval) =5% (usually a common choice) and a confidence level of 95% (other common choices are 90% or 99%), while the population size was 6753, 13704, 12902, and 5385, respectively. This was a total projected farmers population of farmers in each LGAs from 2010 to 2021 from Department of Planning, Monitoring and Evaluation, Kwara State Agricultural development Project, Ilorin. For the study, 364 respondents from

zone A, 374 for zone B, 373 for zone C, and 359 for zone D were chosen for questionnaire administration. This makes a total of 1470. The questionnaire was android based using open data kit (ODK) also known as ODK Collect. A modular, extensible, and open-source suite of tools designed to empower users to build information services for developing regions. ODK currently consists of four tools: Collect, Aggregate, Voice, and Build (ODK 2010). The collected data was subjected to both quantitative and qualitative analysis. Discussions from participants on issues gained from semi-structured interviews were used to corroborate the interactions. Descriptive statistic including simple percentages, mean, standard deviation, charts, graphs. Thematic analysis which is a widely used method for analysing qualitative data that provides immersion in the dataset, familiarization with data, and the generation of provisional ideas. Thematic analysis of the transcriptions of interviews with major stakeholder in the study area was done. The interviews were recorded and transcribed verbatim and then listened to a second time to add non-verbal information such as changes in the interviewee's tones, moods, pauses, and silences during the interviews.

RESULTS AND DISCUSSIONS

Climate change adaptation strategies are essential responses to the ongoing and projected impacts of climate change. These strategies involve proactive measures aimed at minimizing vulnerabilities, enhancing resilience, and safeguarding ecosystems, infrastructure, and human well-being in the face of changing climatic conditions. They encompass a wide range of approaches, from infrastructure improvements to policy changes, to help communities and societies effectively cope with the challenges posed by a warming planet. However, responses that concerned those climate change impacts that needs coping strategies was revealed in table 1. Crop Failure which garnered 81.6% response, is considered as climate change impacts that require coping mechanisms the most in the studied regions and more prominent in the derived savanna, rainforest and guinea savanna zones, while drought is perceived as the second most prominent climate change impact in the regions garnering a perception rate of 69.2% which is prominent in the rainforest and guinea savanna zones. Other identified climate change impacts include erosion, death of livestock and flooding that garnered 46.4%, 36.4% and 14.1% respectively. The long-term effects (or general effect) of all the identified climate variables are considered as a challenge that is affecting or will possibly affect the study area.

Climate changes have brought about significant challenges for agricultural communities in Nigeria. To adapt to these changes and ensure livelihoods, various adaptive measures have been proposed and implemented. Community-based adaptation (CBA) is one growing proposal that argues for tailored support at the local level to enable vulnerable people to identify and implement appropriate community-based responses to climate change themselves. IPCC has also recognized the importance of community-based adaptation measures as it provides a wealth of knowledge, such that society across the globe can deal with the impacts of climate change to the extent possible through appropriate adaptation measures rooted in the capacity and strengths of local communities. In the face of shifting climate patterns and their impacts on agriculture, water resources, and public health, community-based adaptive measures emerge as a vital response in Nigeria. As climate change continues to challenge traditional norms, local communities are increasingly at the forefront of innovative solutions to protect their livelihoods and well-being. These community based adaptive measures empower local populations to address the challenges posed by climate changes in Nigeria. However, table 2 revealed the community-based adaptation strategies of smallholder farmers in the study area that were mostly used by the respondents. The table 3 also revealed the various reasons or factors that limited the adoption (or ineffective use) of the coping strategies. It shows in the study that 598 respondents accounting for 56.1% applied the identified strategies while 43.9% did not. From the coping strategies adopted to curb or mitigate the adverse effect of climate change in the studied regions, *Mixed Farming* (60.5%) was the most widely adopted method in the studied communities. This finding was followed by that of *Change Crop Varieties* which was adopted by 46.2% of the respondents. *Changing Planting Dates* and *Planting Early Maturing Crops* were adopted by 36.1% and 34.3% of the respondents respectively. *Irrigation*, *Planting Trees*, *Temporary Migration*, and *Soil and Water Management* was adopted by the respondents at 26.9%, 24.1%, 21.6%, and 12.4% respectively. The least adopted adaptation strategies in the study area are *Buying insurance* (0.2%), *Reducing Number of Livestock* (3.5%), *Seek Off-Farming Employment* (4.3%), and *Others* (2.5%).

Focus group discussion (FGD) and key informant interview was also conducted in the study area for a qualitative response from major stakeholder including smallholder farmer, community leaders, government extension worker, professionals and residents that has firsthand information of the study area. The FGDs carried out at the various communities revealed several adaptive measures based on the agricultural zones. This discussion delves into the key strategies that communities can employ to navigate the challenges posed by altered rainfall and temperature patterns, fostering resilience and sustainability in the vital sectors of agriculture, water resources, and public health within the Nigerian context. Respondents in the derived savanna and flood plain zone revealed that *'they have increased the use of chemicals'* and also *'have started making ridges'* as a coping strategy. Respondents from the derived savanna zone claimed *'they have introduced increased mixed farming, bush fallowing, shifting cultivation, planting of improved seedlings, increased use of fertilizer, frequent use of veterinary medicine for their livestock and the use of ice-blocked water to freeze their shear butter'*. The majority of the respondents in the study area claimed to have introduced *'afforestation'* but more prominent in the derived savanna zone. Respondents also revealed that they have all changed their planting period (rainforest, derived savanna and floodplain zones). FGD also revealed that *'Deforestation'* has been discouraged in the Guinea savanna zone, and planting of economic trees has been introduced. *'Traditional prayers'* have been introduced in all zones but more common in the guinea savanna zone, *'soil conversation'* has been introduced and *'planting of leguminous plants'* too has been encouraging in the guinea savanna zone. There has been the introduction of *'community intervention'* in both derived savanna and guinea savanna (we contribute for those that has problem of destructive wind in their homes).

Fadama farming, upland farming and irrigation was encouraged in the floodplain zone. Irrigation was also practiced at guinea savanna zone. Essentially, most of these adaptive measures introduced has its negative impact but the most significant of them all is the use of chemicals. Respondents from the derived savanna zone stated that *"spraying of chemical which reduce soil fertility and weaken the land and cause erosion"*. *"these are the use of chemicals, insecticides, and herbicides among others"* The flood plain zone also shared their opinion on the use of chemicals...*use of chemicals "... dangerous to our health as no safety precautions are not being taken."* *"...it also destroys farmland"*. FGD conducted at DS zone revealed that they Prohibit tree falling especially economic trees. Another respondent stated planting of economic trees. A respondent revealed they get financial assistant among villagers to rebuild houses through community intervention among themselves. Respondents from Gwaria stated that they use farm machinery, they plant improved seedlings especially maize. Though the improved seedling is not much as it is a very new adoption. Flood plain zone respondents revealed that they plant improved seedlings, mechanized farming, they also use manpower, a respondent indicates that they don't plant long term crops again. A respondent at kpada revealed that their major crop farming is rice but now we have introduced different crops plantation (sorghum, groundnut maize cowpea and beniseed). Another respondent states that they do irrigation and local water pump (we plead to govt to construct dam for us). Finally, a respondent revealed they "we do fadama land, upland farming, and late planting. FGD at GS revealed that they now plant leguminous crops, respondent stated they do soil conservation. A respondent's states that they do irrigation. Other respondents' states that they have discouraged indiscriminate cutting down of trees for charcoal and furniture. A respondent also said they now plant economic tree such as mango and cahew trees. Most of the effects of climate change in the guinea savanna zone are erosion (we put sand in sack to control erosion), Chimpanzee eat our crops such as maize. A respondent state that locust bean tree has reduced due to too much rain and wind affects the fruit.

Key informant interview (KII) was conducted among major stakeholder including the Emirs, village head and agricultural department officers of the local government representing the zones. Climate changes have brought about significant challenges for agricultural communities in Nigeria. To adapt to these changes and ensure livelihoods, various adaptive measures have been proposed and implemented. The specific adaptive measures adopted by the interviewed respondents in the studied regions will be critically assessed and discussed accordingly. The Emirs of the derived savanna zone and village heads in the guinea savanna zone claimed they have introduced *'Climate intervention programs'* in the communities to help reduced climate change effects. *'Crop propagation'* was encouraged in the derived savanna and flood plain zone. All respondents in the study area mentioned that in most cases to just *'rely on God'* for intervention. The KII revealed that in the derived savanna that "application of chemical like fertilizer "use of fertilizer..., use of chemicals (herbicides). The flood

plain also revealed “We develop the habit of using fertilizer...” “Use of chemicals...”. Key informant interview conducted at the Derived savanna (DS) zone revealed that due to climate change effects, *‘they have exploited all our virgin land for farming’*, *‘Yam tuber spoiling inside the ground due to pest invasion’*. Respondent at Kugiji (DS) stated that they now use chemical in his farm and another farmers respondents said he didn’t believe in the use of chemical, but they use chemicals during farming process to keep pest from our plantation such as spraying chemical. A respondent said they use herbicides (24D chemical) to clear weeds on farmland. It weakens the land and reduces soil fertility, another respondent said they use herbicides and chemicals on the farm. Respondents at Kugiji revealed “we pray to Gods, community intervention, mixed farming, use of fertilizer, temporary migration (fallowing), improved seedling (maize, rice sorghum. Kanikoko and venrah respondents for KII also confirmed the use of chemical (herbicides) and fertilizers for farming, which they don’t normally use before. Kugiji village head states that bush fallowings, improved seedlings, changing to variety of crops and planting of trees are adaptation measure of DS. Kikon Gwarua states that planting of variety of crop mostly yam that can survive the changing climate, improved seedlings (maize, soyabeans, millet), use of fertilizer, use of herbicides are the adaptive measure in their community. Emir of Kaiama states that We are planting short duration varieties of crops (maize, Guinea corn, beans, and cassava), he also revealed that early plantings, short duration of crops cultivation. Use of chemicals (herbicides). Respondents at Koro community of Flood plain zone revealed that they use chemicals during all stages of cultivation (before planting we use sulphonate, relisate, forceup. We use 24D chemicals during plantation and Atrazine powder for pest control). Kpada and koro stated that they also use chemicals for their farming. Kusogi also revealed that they use chemicals for farming at all stages. Respondent from Lade community also stated they use of insecticides to spray farmland. fadama farming (fertilizer and herbicide) and spraying can. Also soil and water conservation was practised. Emir of Patigi revealed that during the flood, station officers educate farmers who plant along the coast of the River Niger to move to the upland area for farming irrigation. Irrigation schemes during dry season (rice maize cassava and guinea corn plantation) are encouraged. We also advise farmers to plant according to the climate. They should avoid planting long duration crops (improved seedlings) ... irrigation, surface irrigation, improved seedling farming (backyard planting of yam whereby u plant inside polythene bags), soil and water conservation, fadama farming (fertilizer and herbicide) and spraying can. Lade respondent states improved seedlings. Respondent at Lade revealed that the use of chemicals, improved seedlings, use of tractors as before we use our hands, use of other farm machineries like planters’ sprayers and cans are adaptive measures used at the area. Kpada respondent states improved seedlings, irrigation with local pumping lowland farming to upland framings, we develop the habit of using fertilizer which has led to farmland expansion. Lade village head use of chemicals, improved seedlings, use of tractors as before we use our hands, use of other farm machineries like planters’ sprayers and can.

Kii respondent at GS stated that munching, fertilizers abuse, manure fertilizer (cow dung and chicken shit), systematic ridges across the farmland. Another village head states that early approach to farming season (maize, melon, soyabeans, cassava sweet potato yam guinea corn), practicing early plantings, doing irrigation, and planting improved seedlings. Koro farmers representative revealed that they plant same crop but use diff methods, use of chemicals. We now have big farms compare to the past. Plant improved crops (maize). fertilizers are being abuse so we encouraged manure fertilizer (cow dung and chicken shit). munching ... systematic ridges across the farmland. fertilizers abuse, manure fertilizer (cow dung and chicken shit). Afon representative of farmers states they only plant whenever rain start as there is nothing we can do. He also states that they plant cashew tress on the land that is not fertile anymore. He also revealed that they control deforestation (charcoal and furniture) but it’s not effective as it is also a means of getting money as farming is not productive again. Ira community respondent stated the use of fertiliser and irrigation as an adopted measure. Ijagbo respondents’ states that they practice late planting. Ipee respondent states that they practice early plantings, improved seedling plantings, use of fertilizer, necessary surveillance. The use of chemicals as an adaptive measure against the negative effect of climate and weather variables (such as rainfall and temperature as recognized as the most significant climate or weather variable by the interviewees) mainly in terms of low crop yields, pest invasion, depletion of soil nutrients due to erosion and leaching, or because of direct sunlight on soils, etc., cannot be overlooked. Although the use of chemicals was encouraged as a means of tackling the adverse effects of climate and weather variables, continual use of these chemicals have an adverse effect on soil in the long-run; chemicals like pesticides and herbicides can help control pests and diseases that thrive in changing climatic

conditions but can also impose great loss such as death and illness to livestock and communities thus causing financial loss to the farmers as it was stated at the guinea savanna zone of the study area. Elevated temperatures and altered rainfall patterns may create more favourable condition for certain pests and diseases. Proper use and application of other environmentally friendly options (such as planting improved seeds, soil conservation, mixed cropping, and farming, etc.) of tackling weather and climate variables should be encouraged.

With regards to the reasons or factors that hindered the adoption of the identified climate adaptation strategies, table 3 revealed that the *Lack of Knowledge* (74.6%) was recognized as the most prominent reasons limiting the adoption of the strategies. *Lack of Information* and *Lack of Capital* were considered as a limiting factor by approximately equal number of respondents 58.3% and 58.4% respectively) while the least recognized factors constituted *Not Observing the Climate Related Problems* (12.2%), *Shortage of Farmland* (3.4%), *Giving Less Emphasis to Climate Change Problems* (7.1%), and *Others* (1.9%). According to Kumar et al. (2020), smallholder farmers face series of challenges, to which climate change is risk multiplier. These include poor natural resource management (land and water especially). Limited land tenure security, small farmland sizes, low technological access, low market access and limited investment. Going by all these, the impact of climate change in the coming decades may be so eminent and raises concerns regarding adaptive ability and/or the likely responses of the agricultural sector.

Limited financial, human, and technological resources hinder the implementation of effective adaptation strategies. Developing regions often lack the necessary infrastructure and funding to adequately prepare for the adverse effects of climate change. These constraints were posited by the interviewees across the different regions and groups (i.e. FGD and KILs): FGD conducted in all zones of the study also revealed the challenges of adopting the community-based measures as identified at Kugiji, venrah and kanikoko community of Derived Savanna zone states that lack of financial assistance either from government, individual or an NGO makes it difficult for adoption of measures. Koro, kusogi and Lade revealed that financial aids, manpower, logistics support, mechanized farming support, bad roads for transportation. Kpada respondents' states that "*distance from modern market, food price and no stable electricity supply are the major constraints of adaptation strategies*" in the flood plain zone. They also advise people on deforestation to protect the soil (afforestation). Control deforestation. We also engaged stakeholders on the synergy. advocate for late and early crop planting. Afon of Guinea Savanna zone states that financial assistance, global market are major constraint. Aiyede of Guinea Savanna stated that lack of water, lack of electricity, bad roads, lack of security are the major constraint of adaption. Ojo and Baiyegunhi (2020) also stated that despite its significant role, the limited availability of capital has been identified as a setback to climate change adaptation in developing countries. This is even more worrisome in the coastal region of Nigeria where the locals are predominantly poor and often isolated due to difficult terrain as it is in the floodplain zone of the study area (Patigi). Atedhor et al., (2022) also identified access to credit facilities as one of the empowerment options for women especially in the household and community-based climate change adaptation and disaster risk reduction in the Niger Delta region. Fodeke and Odjugo (2012) also discussed the relevant of business opportunities that can help in climate change adaptation and environmental management in Nigeria, while the usefulness of agricultural cooperatives as a vital tool in adapting to climate change was x-rayed in Odjugo (2013).

Table 1: Climate change effects that needs coping strategy.

What is the climate change impacts that need coping mechanisms?	Guinea Savannah	Rainforest	Floodplain	Derived Savannah	Frequency	Percentage (%)
Flooding	29	7	51	77	164	14.1
Drought	247	283	131	143	804	69.2

Crop Failure	230	268	87	363	948	81.6
Erosion	83	86	16	354	539	46.4
Death of Livestock	107	102	22	191	423	36.4

Source: Author's Compilation (2024)

Table 2: Community-Based Adaptation strategies Yes = 598 (56.1%)

Strategies	Guinea Savannah	Rainforest	Floodplain	Derived Savannah	Frequency	Percentage (%)
Buying Insurance	0	0	1	0	1	0.2
change crop variety	69	52	62	93	276	46.2
mixed farming	101	112	30	119	362	60.5
temporary migration	16	16	40	57	129	21.6
planting early maturing crops.	62	84	14	45	205	34.3
soil and water management	23	20	11	20	74	12.4
planting trees	55	52	7	30	144	24.1
irrigation	36	28	85	12	161	26.9
changing planting dates	21	72	21	102	216	36.1
seek off-farming employment	5	2	2	17	26	4.3
reduce number of livestock	0	0	2	19	21	3.5
Others	14	0	1	0	15	2.5

Source: Author's Compilation (2024)

Table 3: Factors that hindered the adoption. NO = 468 (43.9%)

Reasons	Guinea Savannah	Rainforest	Floodplain	Derived Savannah	Frequency	Percentage
Lack of Information	40	86	4	143	273	58.3
Lack of Capital	39	84	5	146	274	58.4
Lack of Knowledge	35	64	16	234	349	74.6
Shortage of Farmland	4	10	2	0	16	3.4
Not Observing the Climate Related Problems	5	5	5	42	57	12.2

Giving Less Emphasis to Climate Change Problem	3	5	10	5	33	7.1
Others	3	2	2	2	9	1.9

Source: Author's Compilation (2024).

CONCLUSION

The study has used a mixed method to assess the efficiency of climate change adaptation strategies, especially the community-based adaptation strategies among smallholder farmers in the study area, and used their perception of historical climatic data over the past twenty years. The studied communities are dominated by smallholder farmers who live on or below the poverty line. Farming is majorly rainfed in the study area. Thus, the climate trend has had negative impacts on agriculture due to its link to agricultural productivity in the study area. It was concluded that Climate change often exacerbates ecosystem degradation, making it harder for the communities to adapt in the study area. Carrying out this study in four major agricultural zones of the region and further research in different ecological zones advocates for more knowledge and wider decision-making.

It was recommended that smallholder farmers should regulate the use of chemicals for farming to reduce the risks of crop failure and reduce soil infertility, especially in the floodplain zone of the study area. Farmers should also promote community-based adaptation through emphasis on farm-level adaptation. Cultural practices such as hand irrigation, making ridges, planting shading trees, among others, should be improved.

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Kwara Agricultural Development Plan

All the traditional institution of the study area.

Ethical Clearance

This research was approved for the Principal Investigator (Rafiu Fasilat Olajumoke) by the University of Ilorin, Ilorin, Nigeria Ethical Review Committee on the 14th of September 2023 with UERC Approval Number: UERC/ASN/2023/2607.

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INTEGRATING BIO EFFECTORS IN REGENERATIVE HORTICULTURE FOR SUSTAINABLE NUTRIENT SUPPLY IN CROP PRODUCTION AMIDST CLIMATE CHANGE

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ABSTRACT

Climate change is causing a need for innovative strategies to ensure sustainability and food security in crop production. This necessitates research in agriculture and horticulture to develop methods for increasing food production and improving access to nutritious food. With a comprehensive evaluation of farming practices, production, distribution, and food consumption, "regenerative agriculture" and "regenerative farming" have gained interest as potential solutions. This systematic review evaluates the effectiveness of integrating biofertilizer in regenerative horticulture for sustainable nutrient supply in crop production, focusing on field studies by African farmers and researchers. It also assesses their effectiveness under various environmental conditions, including drought, salinity, and temperature fluctuations. A thorough literature search identified relevant field-based studies involving African farmers using various biofertilizer. Criteria for inclusion were studies that examined the impact of biofertilizer on crop yield, soil health, and nutrient efficiency. Data extraction and quality assessment were performed on the selected studies, followed by a meta-analysis. The findings suggest that integrating biofertilizer into regenerative horticulture is a viable strategy for sustainable nutrient management in crop production amid climate change. Field studies by African farmers show the practical benefits and growth of these practices, supporting their broader adoption for enhanced agricultural sustainability and food security.

Keywords: Farming systems, Greenhouse gases, Horticultural crops, Micro-organisms, Soil fertility

INTRODUCTION

The agriculture industry is under a lot of pressure, as the growing population requires more nutritious food to be produced. This necessitates either more land to be farmed or the current land should be made more productive. It makes more sense to make the current land more productive than to farm more land because it is going to reduce carbon stock. The application of chemical agents in farm land has historically increased horticultural crop production significantly, their excessive use and negative effects pose substantial threats to soil ecosystems and contribute to environmental pollution (Zehra et al., 2021). There are several farming systems that are advocating for low use of synthetic fertilizers or no synthetic fertilizer at all such as organic farming, permaculture etc. In more recent times, the concern about GHG emission led to advocacy for conservation agriculture (CA) of which one of the three key principles is zero or no-tillage (NT). However, conservation agriculture continues to rely heavily on use of synthetic fertilizers and pesticides leading to a search for another "suite" of alternatives in the form of regenerative agriculture. The birth of regenerative agriculture and its history is well detailed by Giller et al. 2020.

Regenerative farming can be defined as a comprehensive, long-term approach designed to maximize food production with minimal resource use, aiming to restore rather than deplete the soil, and simultaneously providing a viable solution for carbon sequestration (Avasiloaiei et al., 2023; Rhodes, 2017). As reducing CO₂ emissions to mitigate regional and global climate change is one of the most challenging issues facing humanity (Fang et al., 2018). This shift towards regenerative agricultural practices includes the adoption of various organic and conservation farming techniques aimed at preserving and enhancing soil organic matter. These practices include minimum tillage, the cultivation

of cover crops and green manures, composting, mulching, and crop rotation (Avasiloaiei et al., 2023; Rhodes, 2017). Importantly, regenerative agriculture extends beyond sustainability characterized by maintaining the existing soil health by employing methods that actively renourish and regenerate the soil (LaCanne & Lundgren, 2018; Rhodes, 2017). Whilst there are minor differences that exist amongst proponents of this approach regarding the place of synthetic fertilizers, there is general agreement that bio-fertilizers will drive increased productivity in the future (Ngoroyemoto et al, 2021).

A bio-fertilizer is broadly defined as an organic material and/or microorganism that is utilized to enhance nutrient uptake, stimulate plant growth, and improve stress tolerance or crop quality (Van Oosten et al., 2017). In the specific context of the African smallholder farmer, if they work, and initial capital layout is affordable, bio-fertilizers may offer a better alternative to use instead of synthetic fertilizers. Available statistics on the use of inorganic fertilizers show that Africa lags far behind other continents in the use of fertilizers (Ariga et al., 2019; Summit, 2006) mainly because of costs that are driven by, among other factors, poor infrastructure and markets. Horticulture has garnered increasing recognition in many African countries as concern has moved from food security to food and nutrition security. Horticultural commodities, for example vegetables demand large amounts of nutrients for high levels of production and productivity required to feed an increasing African population expected to reach 1 billion by 2030 (Abel et al., 2016). Will it be possible to feed this increasing population by bio-fertilizers as suggested by those advocating regenerative agriculture? Are there any products ready for the market or already in use in the horticulture sector? Is there evidence of their effectiveness at a field scale and can we overcome the problem of heterogeneity posed by the African landscape in scaling up and out “green revolution” technologies? This review seeks answers to these questions and is aimed at contributing to a discussion of alternative approaches to fertilizing horticultural crops.

METHODOLOGY

Search strategy

To explore the use of bio effectors in regenerative horticulture for sustainable nutrient supply in crop production amidst climate change in Africa, we followed the PRISMA guidelines for a systematic review (Kadir Shahar et al., 2020). Peer-reviewed literature was obtained using Science direct, Scopus and, google scholar, looking for publications that researched bio-fertilizers / bio-stimulants in Africa, regenerative horticulture, nutrient supply, slow nutrient release fertilizer, crop production, and climate change. To source information, the following key words and phrases were used, "bioeffectors" OR "biostimulants" OR "slow release fertilizer" AND "organic material" AND "regenerative farming" AND "climate change" AND "Africa"

Inclusion and Exclusion Criteria

The selection of studies from the literature search was based on predefined criteria, which are outlined as follows:

Inclusion criteria	Exclusion criteria
Field experiment studies	Studies conducted in glasshouses only
Studies that involved testing the effect of biofertilizer in the field and were subsequently analyzed in the lab	Studies conducted in the Lab and Incubation studies
Studies that investigated the effect of biofertilizer on both fully grown plants and seedlings	Conference papers, editorials, letters, commentary, short surveys, and notes
Articles written in English	Articles not Written in English
Peer reviewed articles	Non-peer Reviewed articles
Studies from the lab and field	Studies from field to the lab only
Studies that investigate biofertilizers only	Studies include synthetic fertilizer and biofertilizer.

Hand search and data management

To improve sensitivity and find more comparable studies, we looked through the published paper reference lists. The Excel program was used to handle and manage the retrieved references found through database searches. Replications were eliminated and added to a duplicate collection.

Data extraction

Data from the selected articles was independently screened and extracted by a single author (A.M). The search result was done by reading the title and abstract of the retrieved papers to determine if the article was relevant to the study. Once determined the full text of the selected articles were further analysed to extract relevant information. The information that was collected and extracted after full text reading from each article included year, study area and country, type of biofertilizer studied, soil type that the biofertilizer was used in, type of crop used, main research findings, and conclusions. Collected articles were categorised by country and biofertilizer type.

Data analysis

The variables analysed included countries in Africa where the research was carried out, biofertilizer, organic material used to produce biofertilizer, type of crop, type of soil, and the existence of monitoring indicators. Indicators were classified into compositional indicators (species diversity, life form, and family) and structural indicators (plant height, stem diameter, yield, and quality). The articles assessed were grouped from January 1992 to June 2024. Journals with the largest number of articles on this subject were recorded and mapped, indicating the study areas on a global level.

Risk of bias assessment

The methodological quality of eligible studies was ranked and classified using the Jadad scale as part of the quality assessment process. Every study was assigned a value between 0 and 5, considering factors such as blinding and randomization. Research with a Jada score of more than 3 was regarded as of good quality. The Cochrane Collaboration risk of bias evaluation methods, which include the following six domains: sequence creation, allocation concealment, blinding, incomplete data, selective reporting, and additional bias, was used to evaluate the quality of the included studies. The risk of bias evaluation was carried out separately by the first two authors, who discussed any discrepancies with a third author. The author's classification of bias is low risk, high risk, or unclear risk.

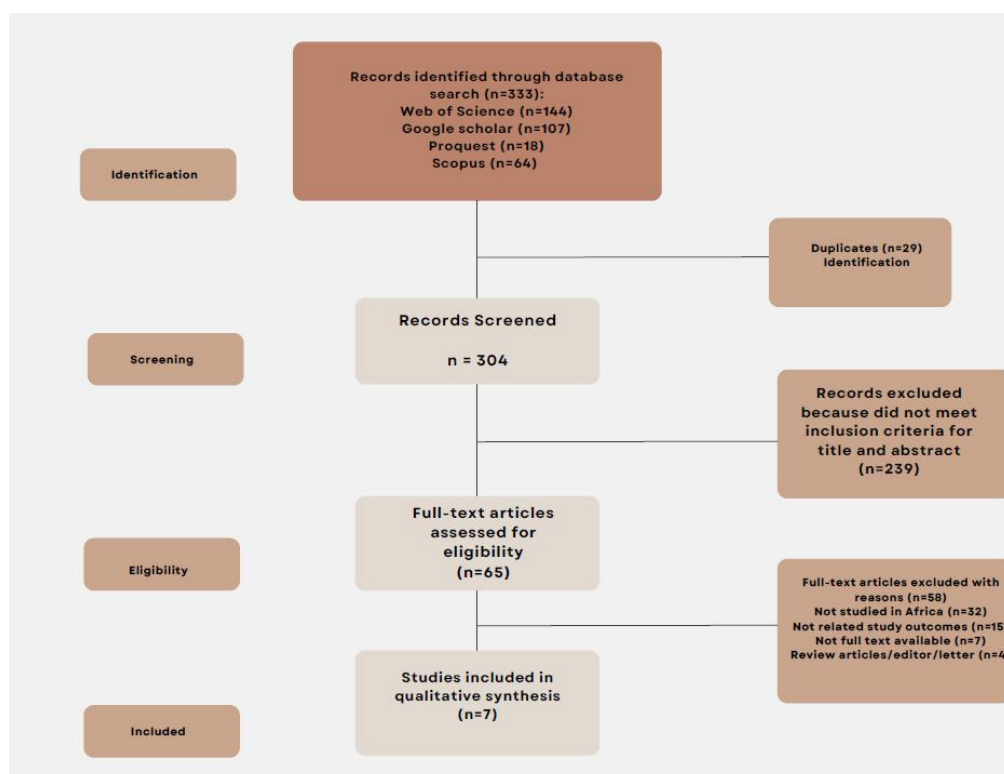


Figure 1: Flow diagram of the selection process used to identify studies for inclusion in this review based on PRISMA Statement (Kadir Shahar et al., 2020).

RESULTS

Study Selection

A total of 333 records were identified through four databases. A total of 304 records remained after duplicates were removed. Of those remaining, 239 records were deemed ineligible based on their titles and abstracts. Of the 65 papers that were qualified for a full-text review, 57 full-text articles were excluded because they did not meet the eligibility criteria for the review (Fig. 1).

General characteristics of the included studies

Seven peer-reviewed journal articles were included in the use for the analysis and interpretation of the data. All the selected studies included the investigation of biofertilizers and its associated factors as their main findings. General characteristics of the included studies and their study findings are summarised in Table 1.

Four of the included studies were of randomised complete block design (RCBD), two were split-plot-design and one was Complete randomised block design. The trials were conducted in the field in all the studies but with different climatic conditions. Three of the studies were conducted in one season only, another three were conducted in two seasons and one was conducted in three seasons. Two of the studies used amino acid based biofertilizers, whilst another two used arbuscular mycorrhizal fungi (AMF) and composts, two used *Azotobacter Chroococcum*, and one used BS14 *Acinetobacter* sp. and BS36 (*Rahnella aquatilis*).

Table 1: General characteristics and summary of the results of the included studies

Author/ year	Study design	Study location	Microorganisms	Objective	Main findings
Tahiri, et al., 2024	Randomised Complete Block Design with 30 replicates	Morocco	Amino acids	Studied Bio- fertilizer's effects on green bean growth and soil characteristics.	Biofertilizers increased leaf number by 52.95% and foliar weight by 83.45%. Pod weight improved by 50% at 75 days and 63.65% at 90 days. Pod length increased by 48% at 75 days and 78% at 90 days. Time affected growth parameters.
El-Beltagi, et al., 2023	Split-plot design with four replicates	Egypt	Amino acids	Examine impact of liquid yeast waste and amino acids on broccoli with varied watering.	Applying liquid yeast waste (CMS) and Cargo amino acids (AAS) to plants increased growth, yield, and quality compared to controls at different watering schedules. Ascorbic acids and phenol content also improved significantly. The highest broccoli productivity was with CMS every five days, while the lowest was without biostimulants every 15 days.
El-Ghany, et al., 2020	Randomized Complete Block Design (RCBD) factorial with	Egypt	<i>Azotobacter</i> <i>Chroococcum</i>	Studying exopolysaccharide- producing bacteria (<i>Azotobacter</i> <i>chroococcum</i>) & melatonin with	Salinity stress decreased faba bean growth in saline soil. Bacteria and melatonin improved growth and yield in both soils. Both

	two factors			varying concentrations (0, 25, 50, 100 µM) on faba bean growth in salinity.	increased nutrient concentrations and reduced harmful ions in salt-stressed beans.
Tahiri, et al., 2022	Completely Randomized Block design with four blocks	Morocco	BS14 (<i>Acinetobacter</i> sp.) and BS36 (<i>Rahnella aquatilis</i>)	To evaluate the effects of plant growth promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF) (AMF1: <i>Rhizophagus irregularis</i> , AMF2: consortium), Comp, and NPK on lettuce growth, yield, and soil properties.	The biofertilizers-biostimulants were applied alone or in combinations and significantly increased lettuce dry weight, number of leaves, and yield compared to the control. The highest plant dry weight was obtained by NPK, PGPR+AMF2+Comp, and PGPR treatments in the first experiment, and by NPK, Comp, and PGPR+AMF1+Comp treatments in the second experiment. The treatments also increased soil organic matter and available phosphorus, with the highest values observed for PGPR+AMF2+Comp and PGPR+AMF1+Comp treatments.
Boutasknit, et al., 2021	Split-plot design with 5 replicates	Morocco	Arbuscular mycorrhizal fungi (AMF) and <i>R. irregularis</i>	Study effect of compost and arbuscular mycorrhizal fungi (AMF) on garlic growth, physiology, biochemical traits, yield under environmental conditions.	The use of AMF or compost increased soil carbon and mineral contents. Total organic carbon in plants treated with compost or inoculated with AMF showed significant improvements compared to the control. Compost+AMF also increased phosphorus and nitrogen levels. AMF had higher mycorrhizal frequency than compost+AMF. <i>R. irregularis</i> , compost, and their combination enhanced plant growth, with compost+AMF yielding the best results. Stomatal conductance, sugars, proteins, chlorophyll, and carotenoids were also increased by these

					treatments compared to the control.
Lahbouki, et al., 2024	Randomized block design with 36 replicates	Morocco	Arbuscular mycorrhizal fungi (AMF)	Investigate the effect of horse manure-based organic amendments mixed with arbuscular mycorrhizal fungi on tomato quality and soil health.	Drought stress reduced tomato fruit growth and yield but increased osmoprotectant and antioxidant levels. Biofertilizer application, especially (C1+AMF), countered the effects of drought by significantly enhancing fruit yields (60%), ascorbic acid levels (59%), and free amino acids content (90%). It also improved bioactive compound activity and soil properties.
Abdel, et al., 2023	Randomized Complete Block design with 3 replicates	Egypt	Effective microorganisms (<i>Azotobacter chroococcum</i> and <i>Azospirillum brasilense</i>) and strains of <i>Bacillus</i> spp.	The study aimed to explore the impact of different mycorrhizae biofertilizer effective microorganisms (EMs) on growth and yield of Italian Red cv. onions and Cara cv. potatoes, while mitigating climate change effects.	Biofertilizers containing 75% NPK yielded the best results, improving soil properties, increasing beneficial microorganisms, enhancing onion and potato production, and reducing reliance on chemical pesticides and mineral fertilizers.

Quality assessment

Quality assessment for each study was conducted using Crowe Critical Analysis Tool; an established and validated tool used in assessing the quality of observational studies (Kadir Shahar et al., 2020). Two studies were rated to be of high quality, while the other three studies were of acceptable quality (Table 2).

Table 2: Quality assessment of studies using Crowe Critical Analysis Tool (CCAT) (Kadir Shahar et al., 2020).

Category	Tahiri, et al., 2024	El-Beltagi, et al., 2023	El-Ghany, et al., 2020	Tahiri, et al., 2022	Boutasknit, et al., 2021	Lahbouki, et al., 2024	Abdel, et al., 2023
1. Preliminaries (/5)	4	4	4	4	4	4	4
2. Introduction (/5)	4	4	4	4	4	4	4
3. Design (/5)	3	4	4	4	3	3	4
4. Sampling (/5)	3	4	4	4	3	3	4
5. Data collection (/5)	3	4	4	4	3	3	3
6. Ethical matters (/5)	3	4	4	4	3	3	4
7. Results (/5)	3	4	3	3	3	3	4

8. Discussion (/5)	3	4	3	4	3	3	4
9. Total score (/40)	26	32	30	31	26	26	31
10. Percentage (%)	65	80	75	77.1	65	65	77.1

Effect of biofertilizers on vegetable plant growth

Biostimulants increased leaf number by 52.95% and foliar weight by 83.45% in plants, according to the results obtained (Tahiri, et al., 2024). AAs and CMS foliar application enhances plant growth and yield with varied watering frequencies than controls (El-Beltagi, et al., 2023). Salinity stress reduced faba bean plant growth parameters in saline soil. Bacteria and/or melatonin improved growth under both soils. Enhanced nutrient concentrations and decreased Na⁺ and Cl⁻ levels (El-Ghany, et al., 2020). NPK, PGPR+AMF2+Comp, and PGPR treatments increased plant DW by 109%, 109%, and 95%, respectively, compared to control in first experiment. NPK treatment showed highest increase (77%) in second experiment (Tahiri, et al., 2022). Application of *R. irregularis* and compost, alone or combined, significantly increased shoot height and root length compared to the control. Biofertilizers also improved shoot and root dry weight, with the best results seen in compost+AMF treatment, enhancing bulb yield (Boutasknit, et al., 2021). On the DS (drought-stressed) condition, a marked reduction in yield and fruit growth was observed compared with WW conditions (Lahbouki, et al., 2024). EM treatment (T2) increased onion fresh weight to 225.3 g, surpassing mycorrhizae and NPK treatments (T1, T3, T4). Length of the plant was unaffected. Potato plant growth varied with different treatments, some traits increased while others decreased accordingly (Abdel, et al., 2023).

Effect of biofertilizer on vegetable yield

On DS conditions, the application of AMF, C1, C2, AMF+C1, and AMF+C2 improved yield (43, 63, 67, 60, and 50%, respectively) and DW (23, 44, 50, 48 and 49%, respectively), compared with control plants (Lahbouki, et al., 2024). Biofertilizers improved garlic bulb yield compared to the control. Compost+AMF showed the highest increase at 81%, followed by compost alone at 77%. Nutrient-rich compost and AMF's nutrient transfer ability likely contributed to the growth (Boutasknit, et al., 2021). Biofertilizers-biostimulants significantly increased lettuce yield with various treatments showing positive effects. The first experiment had highest yields with NPK, PGPR+AMF2, PGPR+AMF1+Comp, PGPR, AMF2+Comp, AMF1+Comp, and AMF2 treatments. In the second experiment, NPK based fertilizers had the highest yield increment (Tahiri, et al., 2022). Plants treated with different melatonin concentrations had greater seed weight, 100-seed weight, and seed yield compared to control plants in both locations. The most effective concentration was 100 µM, significantly increasing yield components. The application of 100 µM melatonin improved seed weight, 100-seed weight, and seed yield in saline and non-saline soils (El-Ghany, et al., 2020). The analysis showed that pod length varied based on treatment and sampling time. Managed plants had longer green bean pods compared to control plants, with lengths increasing over time (Tahiri, et al., 2024). Bio-stimulants and irrigation frequency impacted yield components and quality in broccoli. Spraying plants with CMS and AAs resulted in higher head weight, diameter, height, and Total soluble solids (TSS) content compared to untreated plants. Maximum values were seen in plants watered every 5 days, while lowest values were observed in plants watered every 15 days (El-Beltagi, et al., 2023). The effects of different treatments on onion and potato production were evaluated. Results showed that 100% NPK and EM treatments had minimal impact on onion yield. Mycorrhizae treatment had a yield of 36.8 t ha⁻¹, while the lowest yield was 29.5 t ha⁻¹. Potato production varied among treatments, with T2 having the highest yield of 767 g/plant, T4 as control having 725 g/plant, T3 having the lowest at 512.6 g/plant, and T1 at 623.6 g/plant. Total fresh potato tuber yield was 37.0 t ha⁻¹ for T2 and T4, with the lowest at 23.0 t ha⁻¹ for T3 (Abdel, et al., 2023).

Effect of biofertilizers on soil fertility

The effect of effective microorganisms (EMs) or mycorrhizae integrated with 75% of recommended NPK doses on soil properties was studied. Soil bulk density decreased with all treatments compared to control, except EMs + 75% NPK. Soil pH decreased significantly with mycorrhizae, while EMs had no effect. Electrical conductivity decreased for all treatments, with T2 being most effective. Organic carbon and available nutrients increased significantly with EMs or mycorrhizae treatments (Abdel, et al., 2023). Soil changed under drought stress (DS) vs. well-watered (WW). Biostimulants/fertilizers improved WW soil more than controls. DS soil amended with biostimulants enhanced TOC, AP, N

levels (Lahbouki, et al., 2024). Different treatments, including compost, mycorrhizae, and their combination, significantly improved soil physicochemical parameters compared to the control. The pH was initially greater than 7, with low organic matter and total carbon. Significant changes in nutrient levels were observed, with compost showing the greatest improvement (Boutasknit, et al., 2021). Treatments increased soil organic matter and available phosphorus, with PGPR+AMF treatments showing highest results (Tahiri et al., 2022). Measured parameters of soil showed significant values exceeding normal levels, with a pH of 8 indicating basic soil. Organic matter, phosphorus, calcium, magnesium, potassium, and manganese were high, while iron, limestone, and zinc were low (Tahiri, et al., 2024).

DISCUSSION

For centuries, farmers relied on natural methods like fallow periods or animal manure to enhance soil fertility. The introduction of synthetic fertilizers revolutionized agriculture and paired with advancements in irrigation and mechanization, led to the "green revolution" that addressed the global need for increased food production. However, the widespread use of chemical inputs had negative impacts on the environment, prompting a shift towards sustainable farming practices to reduce pollution and protect natural resources. Hence, there is a need for integrated experiments to evaluate the impacts of new products designed to enhance crop productivity (biofertilizers) while still protecting the environment.

Effect of biofertilizers on vegetable plant growth

The vigorous plant growth in green beans (Tahiri, et al., 2024) and broccoli (El-Beltagi, et al., 2024) maybe associated with the presence of amino acid in the biofertilizers, as they are known to facilitate the transport of elements (metal translocation through xylem) (Popko et al., 2018). The use of *Azotobacter chroococcum* in the biofertilizer in the study conducted by (El-Ghany, et al., 2020) enhanced the growth of faba bean plant and potatoes and onions (Abdel et al., 2023). Similar results were found in a study by (Romero-Perdomo et al., 2017) where growth of cotton plants was positively affected by *Azotobacter chroococcum*. This bacteria produces enzymes that synthesize growth hormones, and it also assists in the mineralization of nitrogen through nitrogen fixation (Hakeem et al., 2016). The use of BS14 (*Acinetobacter* sp.) and BS36 (*Rahnella aquatilis*) increased the growth of lettuce significantly (Tahiri et al., 2022), similar results were found in a study (Tahiri et al., 2022) in a tomato plant. *Acinetobacter* sp. and *Pseudomonas* sp. are both important for their abilities to solubilize phosphate, produce indole acetic acid (IAA), and exhibit ACC deaminase activity. *Acinetobacter* sp. also produces EPSs and siderophores, reduces plant antioxidant enzyme activity in stress, and increases gibberellic acid levels for plant growth (Tahiri et al., 2022). The results of a study by (Boutasknit et al., 2021) on Garlic and that of (Lahbouki et al., 2024) on tomatoes both the vegetative growth was positively affected by the application of Arbuscular mycorrhizal fungi (AMF). AMF increase the C allocation of the host plant below ground, which can form a microbial community composition (Sun & Shahrajabian, 2023), hence it positively affected the plant growth of the above mentioned plants.

Effect of biofertilizer on yield and soil fertility

The degradation, nutrient leaching, less of organic matter in African soil are resulting in low crop productivity that threatens food security in the region. In the included studies biofertilizer have a positive impact on both yield of different vegetable plants and health of different soil types. The positive results may be due to the different microorganisms in the biofertilizers used. Two of the studies included were investigating biofertilizers on beans. Beans play a vital role in nitrogen fixation, meaning the next crop to be planted after beans will have enough nitrogen for the life cycle. All the studies that were performed in two or three studies show that the yield of the first season was smaller than the second seasons yield and third seasons yield. These positive results in the yield over a period of time provide answers to the question "Will it be possible to feed this increasing population by bio-fertilizers as suggested by those advocating regenerative agriculture?", it shows that the use of biofertilizers in the regenerative agriculture can feed the increasing population. Also, the increment is shown in soil health as the biofertilizer is being used more. Figure 2 shows the impact of biofertilizer on plant growth, yield and soil fertility. The microorganisms serve as active agents for nutrient sequestration, recycling and supply to plants. The microenvironment of plant rhizosphere is a major hub for microbial diversity and functionalities that contribute enormously to the plant and soil health (Sahu et al., 2019). This gives back hope that the degraded soils in small scale farmers in Africa can

be restored using the biofertilizers, the increment on the soil organic matter and other soil fertility components shows that the long-term use of biofertilizers can restore soil health.

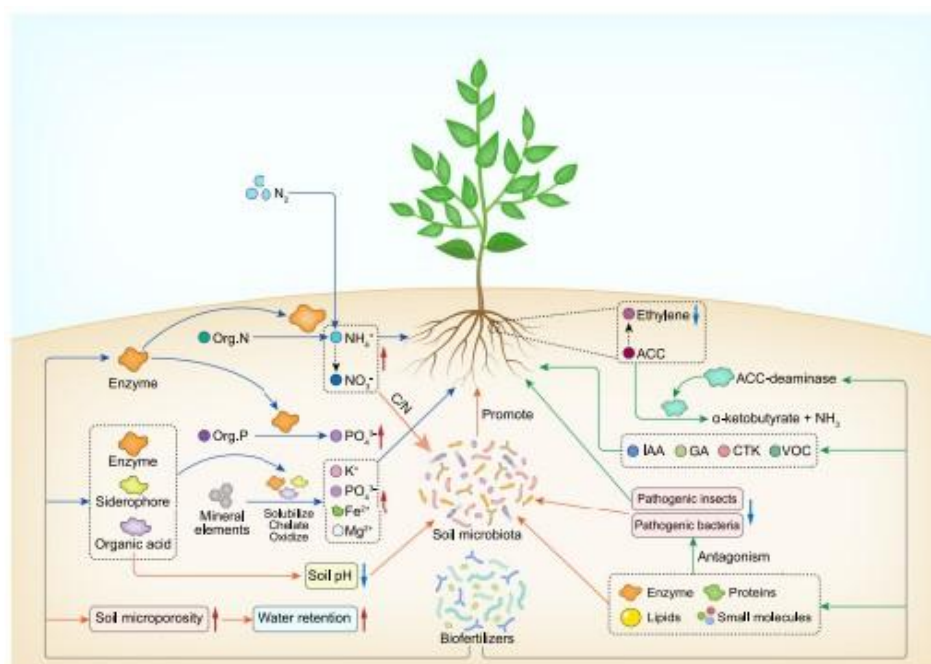


Figure 2: Mechanism of plant-growth promotion by biofertilizers. (1) Biofertilizers can improve the nutritional status of plants. Bacteria in the biofertilizer can convert N_2 into inorganic nitrogen (NH_4^+ , NO_3^-), and the organic phosphorus in the soil into inorganic phosphorus. The organic acids, siderophores, and enzymes secreted by bacteria can release PO_4^{3-} , K^+ , Fe^{2+} , and Mg^{2+} from mineral elements by dissolution, chelation, and oxidization. (2) Biofertilizers can regulate plant-growth. The plant hormones (IAA, GA, and CTK) secreted by bacteria in biofertilizers can promote the proliferation and growth of plant cells. ACC deaminase secreted by bacteria can reduce the content of ACC, the precursor of ethylene synthesis in plants, thereby reducing ethylene content. Biofertilizers can secrete VOC (2, 3-butanediol and 3-hydroxy-2-butanone) to promote plant growth and induce resistance or tolerance in plant systems. Enzymes, lipids, and small molecular weight substances secreted by bacteria can inhibit or kill harmful bacteria and pests, and reduce the damage of harmful bacteria and pests to plants. (3) Biofertilizers can improve soil environmental conditions. Bacteria in biofertilizers can change the soil structure, improve soil microporosity, and improve water retention. The organic acids secreted by beneficial bacteria can reduce soil pH, increase N content, and inhibit harmful bacteria, thereby affecting microbiota community in the soil (Zhao et al., 2024).

Effect of biofertilizers on GHG emission in comparison to synthetic fertilizers

Agriculture industry is the major contributor to the Greenhouse gas emission. Concerns were raised about pollution of water bodies with chemicals that had negative effects on human health, increased emission of greenhouses (GHG) such as carbon dioxide, methane and nitrous oxide among other concerns giving rise to a search for alternative approaches to farming that would allow more sustainable production and better protection of the environment. The type of fertilizer used is crucial as some of the material that made up those fertilizers are harmful and require a certain depth of tillage for them to be effective, leading to reduced carbon stock. Furthermore, by enhancing plant productivity and directly adding carbon to the soil, the utilization of biofertilizer can contribute to increasing soil organic carbon (SOC) levels while also reducing emissions linked to mineral fertilizer production and application (Rehberger et al., 2023). Research findings show that using both inorganic and organic fertilizers can raise soil carbon levels, but analysis indicates that organic fertilizers enhance carbon sequestration more effectively than inorganic fertilizers (0.82MgC/ha/yr compared to 0.54MgC/ha/yr) (Rehberger et al., 2023).

The use of Biofertilizer in different climatic conditions

All the included studies were conducted in different climatic regions and in different seasons. Four of the studies were conducted in semi-arid regions with cold winter and hot summer, the other three

were not mentioned the climatic conditions they were conducted in. The application biofertilizer made the plants to be resistant to biotic/abiotic stress, which has been observed with different plant species. It also made the tomato plants resistant to drought (Lahbouki et al., 2024). The plants were also resistant to pathogens that could kill them due to less water and other factors. It is clear that the use of biofertilizers can be used to reduce the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.

Impact of Biofertilizers on the economy of African continent

Approximations show that soil infertility in Africa results in the annual loss of around US\$4 billion and 6 billion hectares of land due to nutrient depletion and degradation (Aloo et al., 2021). The increment on the yield of the vegetables shows promise that the use of biofertilizers on regenerative agriculture can have a positive impact on the economy of the African continent. The most important advantages of biostimulants include improved profits, stimulated plant reactions, decreased operating costs, reduced application of fertilizers, improved root protection from soil pathogens, and enhanced drought tolerance; moreover, they repel pests, accelerate root establishment, boost fertilization, enhance stress tolerance, ameliorate fertilization, alleviate leaching, detoxify heavy metals and chemicals, and improve stomata opening and plant transpiration (Sun & Shahrabian, 2023). The recycling of biowaste to produce biofertilizer is another way of reducing costs in small scale holder farmers. The questions that we were seeking answers to: “Are there any products ready for the market or already in use in the horticulture sector? Is there evidence of their effectiveness at a field scale and can we overcome the problem of heterogeneity posed by the African landscape in scaling up and out “green revolution” technologies?” The literature shows that there are products already in use in the horticulture industry with very little evidence of their performance at a field scale. Examples of some of the products are shown in table 3. The microorganisms in these products vary and they also work differently when applied in the soil. The question of heterogeneity in soil found in the African region can be answered, if there is available knowledge and more understanding of the type of soils and the biofertilizer to be applied according to the state or type of the soil.

Table 3: Examples of commercialized biofertilizers in some African countries (Aloo et al., 2021).

Rhizobacteria	Product name	Company	Country
<i>B. subtilis</i>	B-RUS, Extrasol	Ag-Chem Africa Ltd	South Africa
<i>Bacillus</i> sp., <i>Enterobacter</i> spp., <i>Pseudomonas</i> , <i>Rhizobium</i>	Organo	Microbial solution Ltd	South Africa
<i>Bacillus</i> sp.	LifeForce, Biostart, Waterbac, FirstBase	Microbial solution Ltd	South Africa
<i>Azospirillum brasilense</i>	Mazospirflo, Azo-N	Soygro Ltd	South Africa
<i>Rhizobium</i>	SeedQuestR	Soygro Ltd	South Africa
<i>Bradyrhizobium elkanii</i>	Likuiq Semia	Microbial Solution Ltd	South Africa
<i>B. japonicum</i>	Histick	BASF South Africa Ltd	South Africa
<i>Azospirillum</i> spp.	Azo-N	BioControl Products	South Africa
<i>Bacillus</i> sp., <i>Pseudomonas</i> sp., <i>Rhizobium</i> , <i>Azotobacter</i>	Organico	Amka Products	South Africa
<i>Bradyrhizobium</i>	Nodumax	IITA ^b	Nigeria
<i>Bacillus subtilis</i>	Bac up	BioControl Product SA	South Africa
<i>Bradyrhizobium japonicum</i>	Soyflo, Vault N Soy	Soygro Ltd	South Africa
<i>Azotobacter</i> sp., <i>Lactobacillus</i> sp., <i>Pseudomonas fluorescens</i>	Soil Vital Q	BioControl	South

		Products SA	Africa
<i>Bravibacillus, Paenibacillus, Sporolactobacillus</i>	SoilFix	BioControl Products SA	South Africa
Not revealed	Biofix	MEA Fertilizer Ltd	Kenya

Limitations of the study

An area of concern in this research is the limited range of studies that were considered, as they specifically looked at field experiments testing the impact of biofertilizers and then conducted further analysis in a laboratory setting. The findings' generalizability could be restricted by not including studies done only in glasshouses, labs, or using incubation, and by excluding those that use both synthetic and biofertilizers. Moreover, the study's focus on peer-reviewed articles in English may have resulted in the exclusion of pertinent research from non-English languages and non-peer-reviewed sources. These specific criteria guarantee the quality and importance of the studies accepted, but it might also lead to publication bias and restrict the range of evidence evaluated.

CONCLUSION

In conclusion, the integration of biofertilizer in regenerative horticulture presents a promising strategy for sustainable nutrient supply in crop production, particularly in the context of climate change. The systematic review shows that biofertilizers application results in notable enhancements in vegetable growth and yield, along with improved soil fertility. Additionally, the decrease in greenhouse gas emissions reinforces the possibility of biofertilizers making a positive impact on climate change mitigation. Nevertheless, even though biofertilizer products are accessible in the market, there is still a significant lack of understanding about how to use them effectively in the various soil types present in Africa. It is essential to fill this knowledge gap in order to maximize the advantages of biofertilizers for supporting sustainable agriculture and guaranteeing food security in face of climate change.

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Data Availability Statement: The data supporting the findings of this study are available within the manuscript and its supplementary materials. Additional datasets generated and analyzed during the current study are stored in an Excel file. These datasets are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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MECHANICAL CHARACTERISATION OF A BANANA FIBRE/RECYCLED PET FIBRE HYBRID COMPOSITE FOR FURNITURE BOARDS APPLICATION

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ABSTRACT

There is a need to develop environmentally friendly and cost-effective alternative material for furniture boards. Utilization of natural composite materials lowers the rate of deforestation as these can be used as substitute material for boards. The composite also incorporates single use plastic material in recycled fibrous form. The study developed and characterised a banana fibre and recycled polyethylene terephthalate fibre hybrid and evaluate its suitability for furniture boards. Banana fibres are a natural renewable resource and were extracted using a combination of water retting and mechanical decortication. Extracted banana fibres were treated with 5% sodium hydroxide solution. The banana fibres had a moisture content of 10%, fibre diameter of 166 μm and an average tensile strength of 58 MPa. The mass fraction of the banana fibre used was between 0-10% and that of recycled polyethylene terephthalate was between 0-15%. The composite was fabricated using the hand layup method. The tensile strength of the fabricated hybrid composite ranged from 9.01 to 20 MPa, compression strength from 41.7 MPa to 152.8 MPa and the flexural strength from 5.6 MPa to 48 MPa. The composite mechanical properties showed feasibility for use of the in boards in furniture applications based on comparison with industry standards. Further research needs to be carried out on flammability and impact absorption of the composite.

Keywords: Banana fibres, Composites, Furniture boards, Polyethylene Terephthalate, Mechanical Properties

INTRODUCTION

The heightened environmental awareness worldwide led by the increased consequences of climate change have forced research into the use of sustainable materials from renewable materials (Oh, et al., 2024). One type of renewable material is natural fibres. These fibres can be extracted from numerous plants such as hemp, jute, banana and various by products of food crops (Elfaleh, et al., 2023). These natural fibres have attracted significant research as they are renewable, relatively inexpensive and available in abundance. The increased deforestation due to demand for wood has necessitated investigation into alternative materials for wood (Yang, et al., 2023). There are various composites made from natural fibres that can serve as substitutes for wood. Banana fibre-based composites are a type of viable material for use in fiberboards.

Banana plants produce natural bast fibres that can be used to manufacture fibre boards. The word banana is Arabic, and it means finger (Jagadeesh, 2015). There are about 300 species of banana and about 20 are fit for human's consumption (Jagadeesh, 2015). To obtain the best fibre, the plants are cut when they are almost at the flowering stage, before any fruit has formed (Pujari, 2014). Banana fibre is a product of agricultural waste from cultivation of banana plant and has over the years been under-utilized (Fan, 2022). The banana plant produces twice more waste than bananas (Laksham & Hitish, 2023). The banana outer layers are rich in fibre and, after harvesting are usually left to rot or in some cases, they are burnt to dispose of the waste (Jagadeesh, 2015). This brings about challenges of air pollution and land pollution within the areas. This disposal method contributes to the greenhouse effect, countering the efforts of trying to reduce emission of greenhouse gases. Banana fibre has great potential to be used in the paper industry, textile industry and in composite materials (Boopalan, 2014). However, natural fibres have several limitations if used exclusively as reinforcement. The limitations include low mechanical properties and non-homogeneity of the fibres have a bearing on the ultimate composite strength (Royan, Leong, Chan, Tan, & Shamsuddin, 2021). This necessitates the inclusion of synthetic fibres. However, synthetic fibre production is generally not environmentally friendly which has led researchers to focus on recycling existing polymeric material to

reduce the quantity making its way to landfills (Zuniga, Aranda, & Rivas, 2023). Hence this study seeks to utilize recycled polyethylene terephthalate fibres as reinforcement material in the composite and alleviate some of the shortcomings of banana fibres in the process.

PET (Polyethylene terephthalate) is a plastic that is widely used in packaging and in making packaging bottles because of various desirable properties (Singh, 2021). These include its lightweight, high strength, durability, high chemical resistance and good barrier properties (for both gas and moisture). However, after use in packaging the PET items find themselves in landfills. The PET does not easily degrade and takes around 300 to 450 years to decompose naturally (Awaja & Pavel, 2005). Hence, it remains as waste which leads to environmental issues. This necessitates research into effectively reuse or recycling of the PET waste material. The use of recycled PET (rPET) minimizes environmental issues such as greenhouse effects (Canto, 2012) and addresses the issue of excessive PET within landfills. Thus, their incorporation into composite materials helps find a way to use the rPET effectively and helps improve mechanical properties of the composite material produced (Singh, 2020). This study sought to develop a partially biodegradable composite from banana fibre and reinforced with PET fibres to enhance the mechanical properties of the composite for it to be suitable in various furniture board applications.

MATERIALS AND METHODS

Materials

The properties of the raw materials used in this research, which include the banana fibres, rPET fibres and polyester resin are outlined in the subsequent subsections.

Banana fibres

The banana fibres used had a tensile strength of 58.60 MPa and a moisture absorption of 10%. Figure 1 shows the SEM image of the surface of the banana fibres after going through alkali treatment. The chemical treatments on the banana fibre resulted in a change of the texture of the fibres making the fibres rougher.

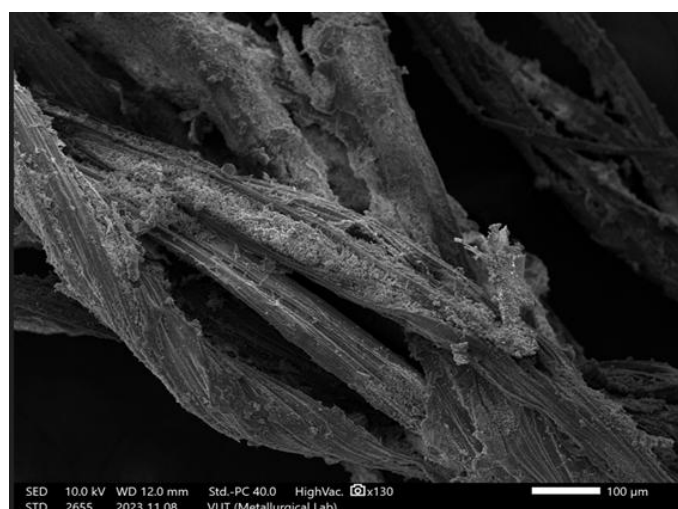


Figure 1 – SEM image of treated banana fibres

Mechanical properties of recycled PET fibres

Recycled PET fibres were used in the study. The PET fibres were produced by crushing and recycling waste PET bottles and extruding them into fibres. The fibres used in the study had the properties shown in Table 1.

Table 1 – The properties of rPET

Property	Value
Density (g/cm ³)	1.38
Length (mm)	3
Diameter range (µm)	20-30
Tensile strength (MPa)	11.20-25
Young modulus (GPa)	1.02- 3.10
Elongation at break (%)	5.00-7.05

Polyester resin

Table 2 shows the physical and mechanical properties of general polyester used.

Table 2 – The properties of general polyester resin

Property	Value
Density g/cm ³	1.2
Young modulus (GPa)	3.1
Tensile strength (MPa)	57.0
Compression strength (MPa)	100.0
Elongation at break (%)	4.0
Water absorption (%)	0.1
Izod impact strength	2.5

Composite experimental design

The hybrid composite was fabricated using hand layup method according to a three level and two factor experimental design shown in Table 3.

Table 3 – Full factorial composite experimental design

Sample	Banana fibre Volume fraction (%)	rPET fibres Volume fraction (%)
1	0.0	0.0
2	5.0	0.0
3	10.0	0.0
4	0.0	7.5
5	5.0	7.5
6	10.0	7.5
7	0.0	15.0
8	5.0	15.0
9	10.0	15.0

Characterization of composite

The composite was tested to determine the tensile strength, moisture absorption and flexural strength.

Tensile strength test

The tensile test was done according to ASTM D3039M/d3039 (D3039, 2014). The test was carried out on a Testometric Micro 500 model. The speed of the testing was set at 201 mm/min.

Flexural strength tests

The flexural strength tests were carried out according to ASTM D7264 (ASTM D., 2021). This was done on a three-point flexural fixture. The span to thickness ratio was kept at 32:1 and a 5kN load cell used. The crosshead speed applied was 0.20 kN/sec. The formula used to calculate the flexural strength in MPa as shown in equation 1

$$F_{cf} = \frac{3FL}{2bd^2} \quad (1)$$

Where, F_{cf} is flexural strength, F is Maximum strength, L is Maximum load, b is Width of specimen and d is thickness.

Compression strength test

The standard used for the compressive strength test was ASTM D695 (ASTM D.-2., 2023). The specimen used was cut into a rectangular shape with dimensions 250 mm × 40 mm × 10 mm measured to the nearest 0.1 mm. The specimens were compressively loaded at a loading rate of 180 kN/min.

Water absorption test

The water absorption test was carried out in accordance with ASTM D570 (ASTM, 2022). The samples were cut from each mass fraction, weighed then placed in an oven at 100 degrees Celsius for 2 hours then cooled for 2 hours. The percentage increase in weight during immersion was calculated using equation 2.

$$\text{Weight gain}(w) = \frac{m_1 - m_2}{m_1} \times 100\% \quad (2)$$

Where w , m_1 , m_2 are the moisture absorption content, weight of dried and wet composite material respectively.

Density

The density of the hybrid composites was measured according to ASTM D792 (ASTM D.-2., 2020). The weight of the specimen with varying composition was obtained using a balance with an accuracy of 0.1g.

RESULTS AND DISCUSSION

The fabricated composite was characterized by analyzing its mechanical and physical properties. The mechanical properties analyzed included flexural strength, water absorption, tensile strength, density, and compression strength. The effects of fibre content on the tensile, flexural and compression strengths of the hybrid composite were evaluated.

The effect of fibre content on Tensile properties

Figure 1 shows the effect of fibre content on the tensile properties of the banana fibre (BF) /recycled polyethylene terephthalate (rPET).

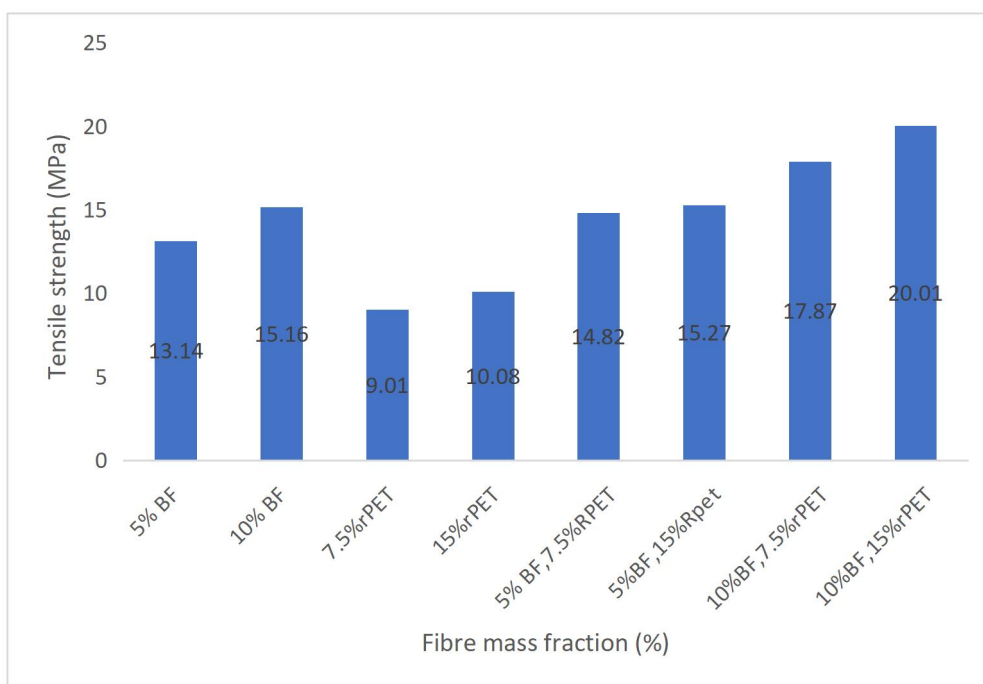


Figure 1 – The effect of fibre content on the tensile strength of banana-rPET reinforced polyester composite

The trend shows that the increase in banana fibre content from 5 to 10% caused an increase in the tensile strength from 13.14 MPa to 15.16 MPa. The tensile strength also increased when the volume of rPET increased from 7.5% to 15% from 9.01 MPa to 10.08 MPa. The incorporation of both the BF and the rPET saw a further increase in the tensile strength with the highest tensile strength of 20.1 MPa obtained when the hybrid composite consisted of 10% BF and 15% BF. Keeping the fibre fraction of the BF at 5% and varying the fibre fraction of the rPET between 7.5% to 15% shows an increase in the tensile strength by 3%. The use of both BF and rPET increase the tensile strength as the hybrid formulations have tensile strengths higher than the composites with only BF or rPET.

Several factors affect the strength of fibre reinforced composites. These include the fibre strength fibre volume fraction, fibre length fibre orientation and fibre matrix interfacial bond. The increase in the tensile strength of the from 9.01 MPa to 10.08MPa can be attributed to the fact that at low fibre content the number of fibres is too low to take part in stress transfer but as the fibre content is increased its load bearing capacity also increases. The results found align with the results reported by (Joseph, Sreekala, Oommen, Koshy, & Thomas, 2002) where it was found that hybridizing banana fibres and glass fibres caused an increase in the tensile properties of the hybrid composite.

The effect of fibre content on compression strength

Figure 2 shows the compression strength results for the different composite formulations

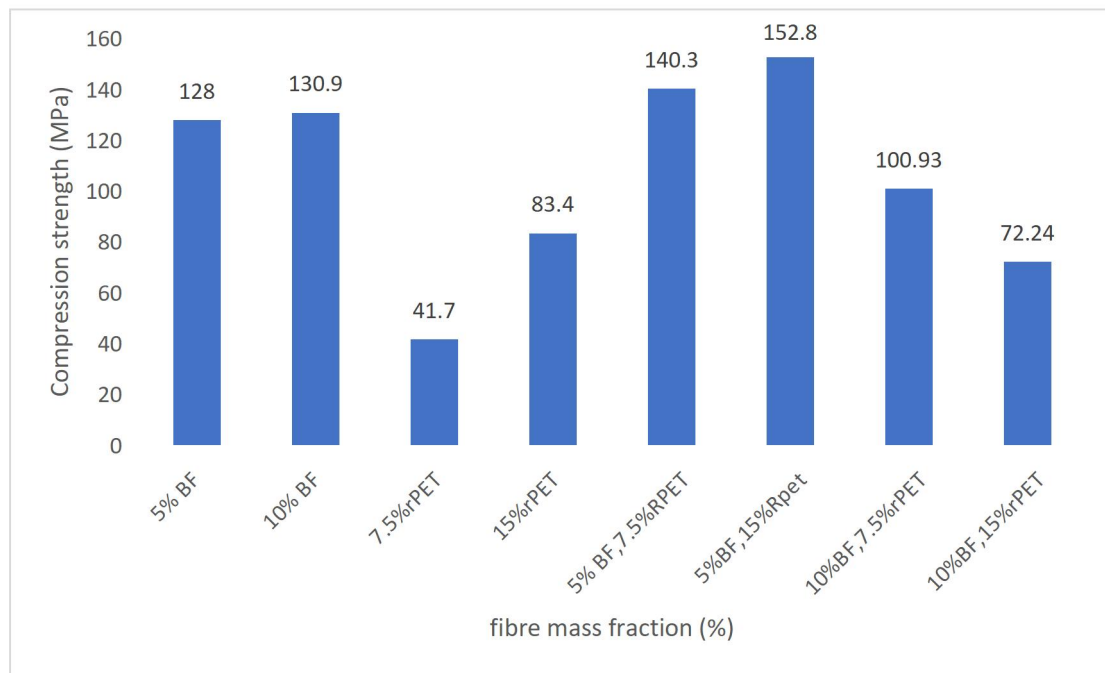


Figure 2 - The results for compression strength test

The results indicate that there is an increase in compression strength with an increase in fibre content. For 5% BF the compression strength is 128 MPa and this increased to 130.9 MPa. The compression strength of rPET also increased, almost doubling with the increase of the rPET from 7.5% to 15%. The highest compression strength was found when the BF fibres were kept constant at 5% and the rPET varied from 7.5% to 15%. The compression strength increased from 140.3 MPa to 152.8 MPa. However, in the case where the BF was kept at 10% and the rPET was varied it was observed that the compression strength decreased from 100.9 MPa to 72.2 MPa.

Compression test determines the behavior of a composite material. The ultimate compressive strength of the composite is mainly dependent on the strength of the matrix and fibre matrix adhesion. The high compressive strength of the hybrid composite can be attributed to strong interfacial bond between the fibres and the matrix. However, the drop in the compression strength where the banana fibre content is at elevated level of 10% and the rPET fibres are varied can be caused by reduction of the content of the matrix. As fibre loading increases the adhesion between the fibres and the matrix decreases and this poor bond can cause buckling or kinking of the composite under a compressive load. These results are comparable to the results presented by (Awulella, 2016; Gong, et al., 2024) which stated that fibre micro buckling or kinking are initiated mechanisms of compressive failure.

The effect of fibre content on flexural strength

Figure 3 is a presentation of the flexural strength of the banana/rPET fibre polyester composite

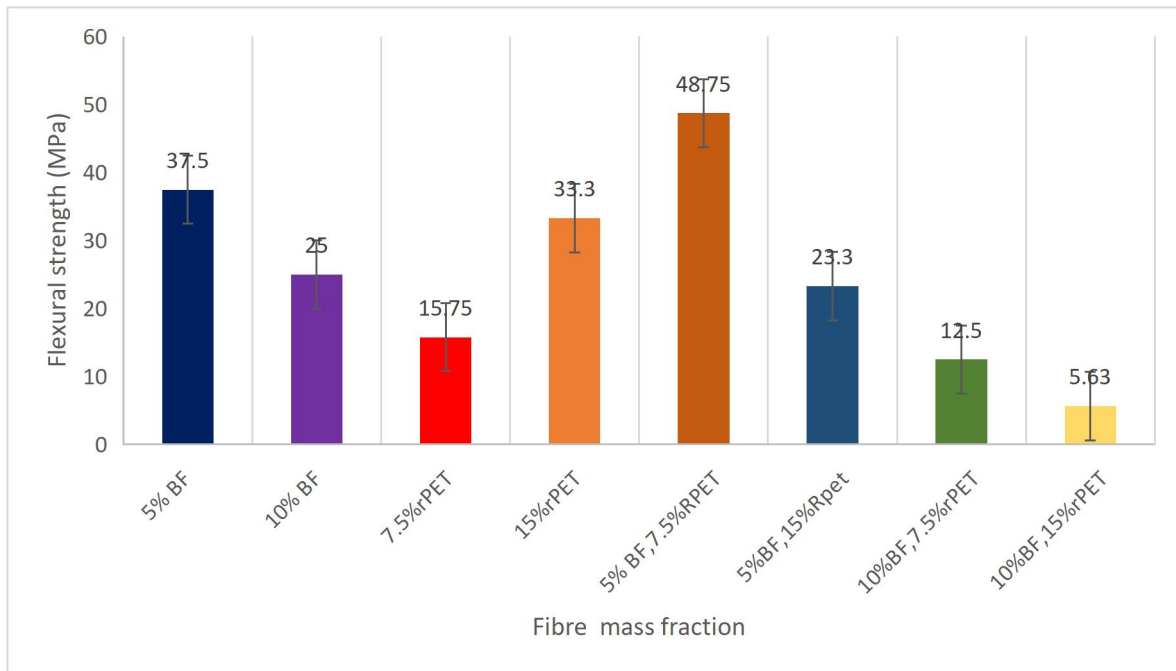


Figure 3 - The results of flexural strength test

The results show that an increase in the banana fibre content from 5% to 10% resulted in a decrease in flexural strength of the composite. The opposite happened with an increase of rPET fibres from 7.5% to 15 % which saw an increase in flexural strength from 15.75 MPa to 33.3 MPa. When the banana fibre was kept constant at 5% and the rPET varied between 7.5% to 15%, the hybrid composite had the highest flexural strength of 48.75 MPa which then decreased to 23 MPa at 15% rPET. The hybrid composite with 10% BF and the rPET varied between 7.5% and 15% was observed to have the lowest flexural strength which decreased with increase in the rPET from 12.5 MPa to 5.6 MPa.

Flexural strength properties of a composite depend mainly on the fibre orientation and location of the resin rich areas (Nassar & Nassar, 2020) . Flexural strength assesses the capability of composites to withstand bending before they rupture. The decrease in the flexural strength can be attributed to formation of binder less agglomerates at high fibre content which hinders stress transfer and causes the stiffness to decrease. Similar results were observed in other studies by (Sreekala, 2002) . Higher fibre content tends to cause air voids during manufacture and delamination of fibre matrix interference inside the composite plate. Hence flexural strength decreases as there is improper stress distribution inside the composite plate. In flexural load the top layer is subject to compressive stress and bottom layer is subject to tensile stress. Due to dual loading condition, the crack formulation takes place in both top layer and bottom layer of the composite.

The effect of fibre content on water absorption

Composites materials used in furniture applications are exposed to varying environmental conditions during use and hence it is important to analyze the durability of the natural fibre composite after exposure to water. Figure 4 shows the results of the water absorption test.

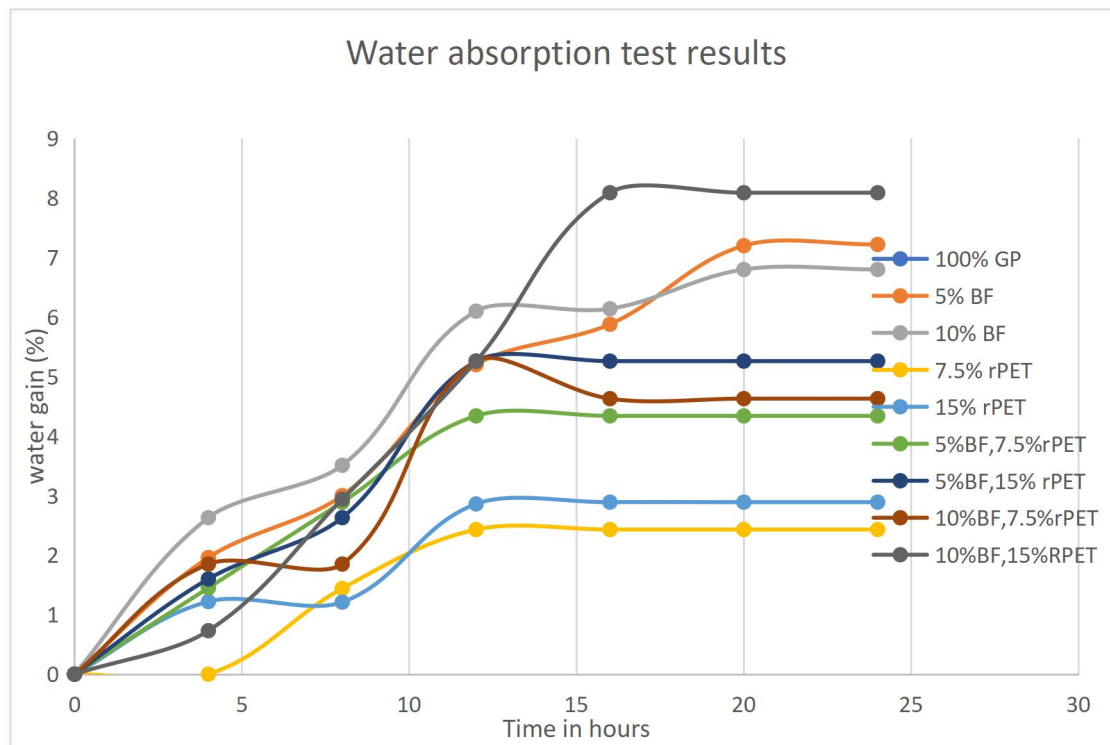


Figure 4 - The results of water absorption

The composite containing the 10% banana fibre and 15% rPET had the highest water absorption rate followed while the composite containing 15% rPET had the lowest water absorption. The water absorption rate of the composites consisting of a higher percentage of banana fibre have a higher absorption of water. This is due to the hydrophilic nature of the banana fibres which causes the fibres to absorb more water than the synthetic fibre containing composites. From the graph the 5% BF,7.5% rPET composite has the average water absorption. The low water uptake of the composites makes it suitable for furniture board applications.

CONCLUSION

The study investigated the effect of varying the PET and banana fibre content on the mechanical properties of the composite. The following conclusions were drawn from the experimental work.

- An increase in the tensile properties of the hybrid composite was recorded with an increase in the percentage of the banana fibres. For example, with the rPET fibre kept at 7.5 % there is an increase of tensile strength of almost 45% indicating that the banana fibres influence the tensile strength of the composite.
- The compression strength was found to range from 41.70 MPa to 152.80 MPa with the maximum compression strength being found when the combination of fibres is 5% BF and 15% rPET.
- The flexural strength increased with hybridization, but it declined with increase in the fibre mass fraction of banana fibres, as it moved from 23.31MPa to 5.63 MPa with the rPET kept constant at 15% and the BF varied from 5% to 10%.
- Density increased with an increase in the fibre fraction and the compression strength was found to decrease at the highest fibre volume fraction.
- The response of the composite to moisture was good with a maximum of 8.9% water gain recorded. This indicates that the composite can be used in environments where it will be exposed to moisture with minimum water absorption.

There is need for further research into prolonged water exposure of the composite material and its effect on its durability and mechanical properties. Furthermore, research into flammability and impact resistance of the composite material is necessary as these properties have a bearing on its durability.

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Data Availability Statement

All the data that supports this study is included within this paper.

Conflicts of Interest:

The authors declare that there is no conflict of interests in this publication.

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FAKE-CHECKING HUBS AND INFORMATION DISORDER IN NIGERIA: A STUDY OF FACTCHECKHUB, DUBAWA, AND AFRICACHECK

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ABSTRACT

As fake news, information and communication disorder continue to raise concerns in society, several counter measures are evolving to combat the communication scourge. This study examines the role of social media in the information disorder in Africa and assesses how well three popular fact-checking websites - FactCheckHub, Dubawa, and Africa Check - are addressing the communication malaise. It adopts the content analysis methodology to identify common misinformation kinds on Nigerian social media, examines the existing fact-checking techniques, and evaluates the role of the sampled fact-checking platforms in combating information disorder. The study investigates how social media promotes the propagation of false narratives and the societal repercussions that follow, drawing on academic frameworks related to information disorder, disinformation, and fact-checking. Purposive sampling of false material from well-known social media sites is used in the data collection process, along with a thorough sampling of fact-checks from the three selected fact-checking platforms over a one-year period (2022). There are both quantitative and qualitative analyses, covering case studies, frequency analysis, content classification, and thematic analysis. The study recognizes the potential limits and ethical issues, including sample biases and the dynamic nature of information disorder. However, it intends to contribute to broader conversations on media literacy, information integrity, and the promotion of an informed society in the digital age by offering insights into the dynamics of disinformation in Nigeria and the function of fact-checking activities in checking it.

Keyword: Fake News, Information Disorder, Fact-Checking, Africa

INTRODUCTION

In the contemporary digital era, the proliferation of social media platforms has fundamentally transformed the way in which information is disseminated and consumed. This development has consequently brought into being the phenomenon of information disorder, which encompasses the constructs of misinformation, disinformation, and mal-information (Wardle & Derakhshan, 2017). Nigeria, characterized by its heterogeneous populace and dynamic online communities, has not escaped the adversities associated with information disorder.

The prevalence of erroneous or deceptive information can yield extensive repercussions, including eroding public trust, inciting social turmoil, and even endangering public health and safety (Bradshaw & Howard, 2019). Within the Nigerian context, the ramifications of information disorder have manifested with particular intensity, aggravating pre-existing societal frictions and presenting formidable challenges to effective governance and democratic processes (Adamu & Rasheed, 2020). In response to the challenges posed by information disorder, fact-checking platforms have emerged as indispensable instruments in the quest for truth and accountability. These platforms employ meticulous research methodologies and expert analysis to authenticate claims, refute falsehoods, and give the public accurate information (Graves, 2016). In Nigeria, three notable fact-checking platforms - FactCheckHub, Dubawa, and Africa Check - have assumed leadership, meticulously examining claims disseminated through social and traditional media channels.

The significance of fact-checking platforms in countering misinformation cannot be over-emphasized. By equipping citizens with trustworthy information, these platforms fulfil a critical function in nurturing an informed public discourse, promoting transparency, and holding institutions and individuals accountable (Amazeen, 2020). Nonetheless, the efficacy of these platforms within the Nigerian milieu necessitates further scholarly inquiry.

The extensive proliferation of social media platforms and the simplicity of disseminating information online have engendered an environment conducive to the spread of misinformation in Nigeria. Social media platforms such as Facebook, X (formerly Twitter), and WhatsApp have evolved into fertile breeding grounds for rumours, conspiracy theories, and erroneous narratives, frequently amplified by orchestrated disinformation campaigns (Okoro & Okolie, 2021). These misleading narratives can exploit pre-existing societal divisions, exacerbating polarization and eroding trust in institutions and democratic processes.

The implications of information disorder in Nigeria are extensive and multifaceted. In the political arena, the circulation of false information can significantly impact electoral outcomes, shape public perception, and compromise the integrity of democratic processes (Nnanwube et al., 2020). Moreover, the dissemination of health-related misinformation poses considerable threats to public health initiatives, potentially obstructing efforts to combat diseases, advocate for vaccinations, and disseminate accurate medical information (Adamu & Rasheed, 2020).

Fact-checking platforms assume a pivotal role in mitigating information disorder through the verification of claims, the debunking of falsehoods, and the provision of accurate information to the public. FactCheckHub, Dubawa, and Africa Check have emerged as significant entities within the Nigerian fact-checking landscape, utilizing diverse methodologies and leveraging expertise from various disciplines (Chiluwa & Ifukor, 2015). However, the effectiveness of these platforms in engaging and influencing diverse audiences, as well as their capacity to combat entrenched misinformation narratives, remain an area ripe for further investigation.

The purpose of this study, therefore, is to look at how social media platforms contribute to information disorder in Nigeria, as well as to assess the efficiency of three prominent fact-checking services (FactCheckHub, Dubawa, and Africa Check) in tackling this menace. Using the content analysis approach, the study objectives are threefold, namely:

1. To identify the types of misinformation prevalent on social media platforms in Nigeria,
2. To analyze the fact-checking approaches employed by FactCheckHub, Dubawa, and Africa Check, and
3. To assess the impact and reach of these platforms in combating information disorder within the Nigerian context.

This study intends to contribute to the larger conversation on media literacy, information integrity, and the development of a well-informed society by throwing light on the dynamics of information disorder in Nigeria and the role of fact-checking platforms in checking it.

Literature Review & Theoretical Framework

Information Disorder, Misinformation, and Fact-Checking

The notion of information disorder comprises misinformation, disinformation, and mal-information, each signifying distinct aspects of problematic information distribution (Wardle & Derakhshan, 2017). Misinformation pertains to the inadvertent propagation of inaccurate information, whereas disinformation is defined by intentional deceitful practices (Fallis, 2015). Mal-information, though a less frequently addressed yet equally detrimental occurrence, entails the malicious employment of accurate information (Wardle & Derakhshan, 2017). These classifications are essential for comprehending the intricate landscape of information pollution prevalent in the digital epoch.

The escalation of misinformation and disinformation presents substantial societal dilemmas, undermining public confidence, intensifying social fractures, and obstructing informed decision-making processes (Bradshaw & Howard, 2019). The swift dissemination of erroneous information through digital platforms has exacerbated these challenges, thereby necessitating the implementation of robust countermeasures (Vosoughi et al., 2018). The capacity of misinformation to sway political dynamics, public health responses, and social unity highlights the pressing need to confront this global issue (Allcott & Gentzkow, 2017).

Fact-checking has emerged as an indispensable instrument in the struggle against information disorder. This methodical process entails the verification of claims against credible sources and expert knowledge to delineate truth from falsehood (Graves, 2016). Global initiatives in fact-checking have multiplied, with organizations committed to refuting false assertions and furnishing the public with accurate information (Amazeen, 2020). The efficacy of fact-checking in rectifying misperceptions and mitigating the proliferation of misinformation has been evidenced in numerous studies, although challenges persist in engaging audiences entrenched in their convictions (Walter et al., 2020).

Theoretical frameworks have been constructed to augment the effectiveness of fact-checking endeavours. The "truth sandwich" model proposes a tactic of presenting accurate information both prior to and subsequent to addressing misinformation, thereby effectively situating the correction within a truthful framework (Curry et al., 2020). This methodology seeks to diminish the likelihood of inadvertently reinforcing false beliefs through repetition. Furthermore, the "trust-through-transparency" strategy underscores the necessity for fact-checkers to be forthcoming regarding their methodologies, sources, and potential biases to cultivate trust and credibility among the public (Stencel & Perry, 2016). The digital milieu presents both opportunities and challenges for fact-checking initiatives. Social media platforms, while frequently serving as conduits for misinformation, also offer channels for the

swift dissemination of fact-checks (Pennycook & Rand, 2019). Nonetheless, the sheer volume and rapidity of information available online frequently outstrip fact-checking efforts, thereby necessitating innovative methodologies such as automated fact-checking systems and collaborative networks of fact-checkers (Hassan et al., 2019). The incorporation of artificial intelligence into fact-checking processes holds promise for enhancing efforts to counter misinformation, although ethical considerations and the imperative for human oversight remain critical (Graves, 2018).

In the African context, fact-checking confronts distinctive challenges and opportunities. Constraints related to resources, linguistic diversity, and disparate levels of digital literacy significantly influence the efficacy of fact-checking initiatives (Cheruiyot & Ferrer-Conill, 2018). Nonetheless, the increasing acknowledgement of the necessity to combat misinformation has precipitated the formation of local fact-checking organizations and partnerships with international networks (Cunliffe-Jones, 2022). These endeavours are vital for addressing region-specific misinformation and fostering trust in fact-checking processes among the diverse populations of Africa.

Because information disorder is ever-changing, fact-checking procedures must be constantly researched and adapted. Studies have investigated the psychological aspects that influence the belief in and spread of misinformation, informing more targeted approaches to fact-checking and correction (Lewandowsky et al. 2012). Furthermore, research into the long-term effects of fact-checking on public discourse and information ecosystems continues to influence industry best practices (Nyhan & Reifler, 2015). As information disorder remains a chronic concern, the role of fact-checking as a cornerstone of information integrity is expected to rise, supported by breakthroughs in technology, interdisciplinary research, and worldwide collaboration.

Social Media's Role in Information Disorder

Social media platforms have emerged as critical entities within the domain of information disorder, significantly influencing the processes by which information is generated, circulated, and consumed (Chiluwa & Ifukor, 2015). The intrinsic attributes of these platforms - including their accessibility, rapid information dissemination capabilities, and the absence of conventional editorial gatekeeping - have fostered an environment conducive to the swift propagation of both misinformation and disinformation. This global phenomenon carries particular ramifications for Africa, where the escalating penetration of the internet and the adoption of smartphones have resulted in a notable increase in the utilization of social media.

The simplicity with which content can be disseminated through social media platforms has facilitated the democratization of information distribution, enabling individuals and organizations to instantaneously reach extensive audiences (Vosoughi et al., 2018). Nevertheless, this democratization is accompanied by a significant drawback: the propensity for erroneous or deceptive narratives to rapidly gain traction. The network effects characteristic of social media exacerbate this concern, as content can be swiftly circulated across interconnected networks, frequently outpacing the efforts of fact-checkers (Vosoughi et al., 2018).

Empirical research has persistently underscored the role of social media in enabling information disorder across diverse contexts. Within the political arena, investigations have scrutinized how fabricated news and orchestrated disinformation campaigns can sway electoral outcomes and shape public sentiment (Bradshaw & Howard, 2019; Woolley & Howard, 2018). The capacity of social media to influence political results has engendered apprehensions regarding the integrity of democratic processes, particularly in areas characterized by emergent democratic institutions.

The health sector has similarly felt the repercussions of misinformation propagated via social media. During public health emergencies, such as the COVID-19 pandemic, social media platforms transformed into fertile grounds for health-related misinformation (Bridgman et al., 2020; Cinelli et al., 2020). The swift dissemination of inaccurate health information not only undermined public health initiatives but also posed direct threats to the well-being of individuals and communities.

In the African context, and specifically in Nigeria, numerous studies have investigated the role of social media in the spread of misinformation and its societal consequences. Okoro and Okolie (2021) examined the dissemination of misinformation on social media amid the COVID-19 pandemic in Nigeria. Their research identified critical factors contributing to this issue, including the low levels of media literacy among the populace and the existence of coordinated disinformation campaigns. These findings highlight the imperative for targeted interventions aimed at enhancing digital literacy and critical thinking capabilities among social media users.

The ramifications of misinformation driven by social media extend beyond health crises to affect fundamental democratic processes. Nnanwube et al. (2020) analyzed the impact of fake news on

electoral mechanisms in Nigeria, emphasizing how misinformation can compromise the integrity of democratic institutions. Their research underscores the urgent necessity for strategies designed to protect electoral processes from the destabilizing influences of misinformation propagated through social media. The distinctive characteristics of social media platforms amplify their effectiveness as conduits for misinformation. Algorithms engineered to optimize user engagement often favour sensational or emotionally charged content, which may encompass misinformation. This algorithmic amplification can foster echo chambers and filter bubbles, wherein users predominantly encounter information that reinforces their pre-existing beliefs, further entrenching false narratives (Spohr, 2017). Moreover, the commercial frameworks of numerous social media platforms, which predominantly depend on advertising income, promote the generation and dissemination of content that commands user attention, irrespective of its authenticity. This financial incentive paradigm can unintentionally endorse the production and proliferation of misinformation, thereby establishing a formidable environment for fact-checkers and truth-seekers (Bakir & McStay, 2018) to operate.

The function of social media in the context of information disorder is further complicated by the transnational characteristics of these platforms. Misinformation can seamlessly traverse national boundaries, rendering it difficult for domestic regulatory systems to effectively confront the issue. This global proliferation of misinformation propagated by social media necessitates international collaboration and synchronized efforts to combat the phenomenon of information disorder.

In reaction to these challenges, several stakeholders have instituted initiatives aimed at curbing the dissemination of misinformation on social media platforms. The platforms themselves have established partnerships for fact-checking, implemented content moderation policies, and developed user education initiatives. Nonetheless, the efficacy of these measures remains a topic of contention, with detractors contending that they are frequently reactive and inadequate in addressing the magnitude of the problem.

Fact-checking organizations have emerged as essential agents in the fight against misinformation perpetuated by social media. These entities engage in the verification of claims circulating within social media and strive to furnish the public with accurate information. However, the overwhelming volume of content present on social media platforms often surpasses the capacity of fact-checkers, thereby underscoring the necessity for more robust and scalable solutions.

Educational and media literacy initiatives have also been advocated as enduring strategies to combat information disorder. By equipping users with the competencies required to critically assess the information they encounter on social media, these programmes aspire to cultivate a more resilient populace that is less vulnerable to misinformation.

As social media continues to advance and new platforms emerge, the realm of information disorder is expected to remain in flux. Addressing this challenge will necessitate ongoing scholarly inquiry, innovative methodologies, and collaboration among platforms, policymakers, researchers, and civil society organizations. Only through such concerted efforts can we aspire to harness the beneficial potential of social media while alleviating its role in perpetuating information disorder.

Overview of Fact-Checking Platforms: FactCheckHub, Dubawa, and Africa Check

In light of the complexities introduced by information disorder, a variety of fact-checking initiatives have emerged within the Nigerian context. Three distinguished platforms – FactCheckHub, Dubawa, and Africa Check – have taken leading roles in the endeavour to mitigate misinformation and foster the dissemination of accurate information.

FactCheckHub, which was established in the year 2019, represents a collaborative initiative among several Nigerian media entities and civil society organizations (FactCheckHub, n.d.). This platform implements a stringent fact-checking protocol that encompasses comprehensive research, verification, and adherence to journalistic standards to evaluate the veracity of claims and narratives prevalent within the Nigerian information landscape.

Dubawa, which commenced operations in 2018, functions as a non-profit organization committed to the advancement of truth and accountability within the public domain (Dubawa, n.d.). The platform harnesses the expertise of a diverse team comprising researchers, journalists, and subject matter experts to conduct fact-checks across a multitude of sectors, including politics, health, and societal issues. The methodology employed by Dubawa includes exhaustive investigations, consultations with authoritative sources, and the provision of contextual analysis to effectively counteract misinformation.

Africa Check, which was established in 2012, stands as a significant fact-checking organization with operations spanning various African nations, including Nigeria (Africa Check, n.d.). This platform utilizes a meticulous verification framework, relying on a network of researchers, journalists, and

subject matter experts to scrutinize claims and furnish accurate information to the populace. The scope of Africa Check's endeavours encompasses an extensive array of subjects, ranging from political and governance issues to health and social matters.

These fact-checking platforms have assumed a pivotal role in the fight against misinformation in Nigeria, employing a variety of methodologies and specialized knowledge to authenticate claims and deliver accurate information to the citizenry. Nevertheless, their efficacy in engaging and influencing a wide array of audiences, along with their capacity to challenge deeply entrenched misinformation narratives, continues to be an area ripe for further inquiry and scholarly investigation.

Through the exploration of the theoretical underpinnings of information disorder, misinformation, and fact-checking, in conjunction with an examination of previous studies regarding the role of social media in the proliferation of misinformation and a comprehensive overview of the three fact-checking platforms under scrutiny, this literature review lays a solid groundwork for the study's aims and methodological approach.

METHODOLOGY

To investigate the role of social media platforms in contributing to information disorder in Nigeria and evaluate the effectiveness of three fact-checking platforms (FactCheckHub, Dubawa, and Africa Check) in addressing this issue, this study employs a content analysis methodology. Content analysis is a widely used research technique for the systematic and objective examination of various forms of communication, including text, images, and multimedia content (Neuendorf, 2017). Content analysis allows researchers to make inferences about the characteristics, meanings, and potential effects of the analyzed content (Krippendorff, 2018). In the context of this study, content analysis enables a thorough examination of the types of misinformation prevalent on social media platforms in Nigeria, as well as an assessment of the fact-checking approaches employed by the three platforms under investigation. The content analysis approach aligns with the research objectives, as it facilitates the identification of misinformation narratives, the analysis of fact-checking methodologies, and the evaluation of the platforms' impact and reach in combating information disorder. Both quantitative and qualitative analyses were conducted, providing a comprehensive understanding of the phenomenon under study.

Data Collection Process

The data collection process involved manual examination of checks on the website of selected fact-checking hub to know the frequency of information fact-checked for the period as well as other variables associated such as source, content type, subject and others (e.g., January 2022 to December 2022). For the fact-checking platforms, a comprehensive collection of fact-checks, reports, and analysis published by FactCheckHub, Dubawa, and Africa Check during the same time frame was conducted. This included both the platforms' public-facing content and any additional documentation or data provided by the organizations themselves. To ensure a comprehensive and diverse sample, the data collection process encompasses various topics and domains, including but not limited to politics, health, social issues, and governance. Additionally, the sampling considered the geographical distribution and demographic characteristics of the content to capture potential regional and cultural variations.

Data Analysis Procedures

The data analysis procedures involve a combination of quantitative and qualitative approaches to address the research objectives comprehensively.

Quantitative Analysis:

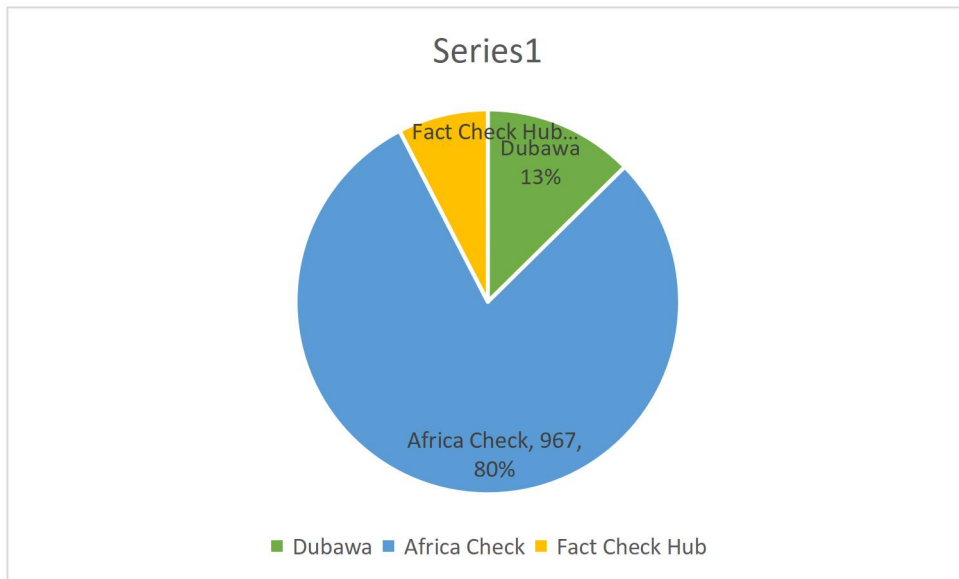
- Frequency analysis: Identifying the prevalence and distribution of various types of misinformation narratives on social media platforms.
- Content categorization: Classifying the misinformation narratives and fact-checking content based on predefined categories (e.g., topic, type of misinformation, source, etc.).
- Comparative analysis: Evaluating the volume and characteristics of fact-checking activities across the three platforms.

Qualitative Analysis:

- Thematic analysis: Identifying and analyzing recurring themes, patterns, and narratives within the misinformation content and fact-checking approaches.

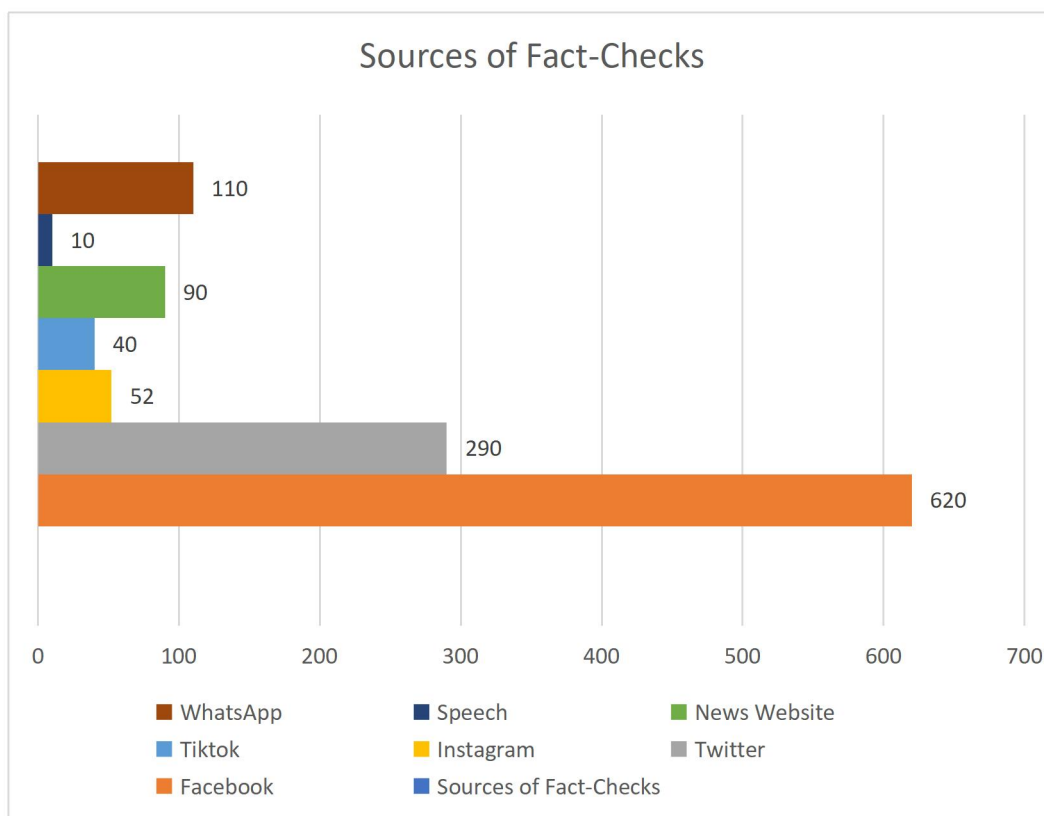
Data Presentation and Analysis

Chat 1: Frequency of Fact-checks by selected organizations



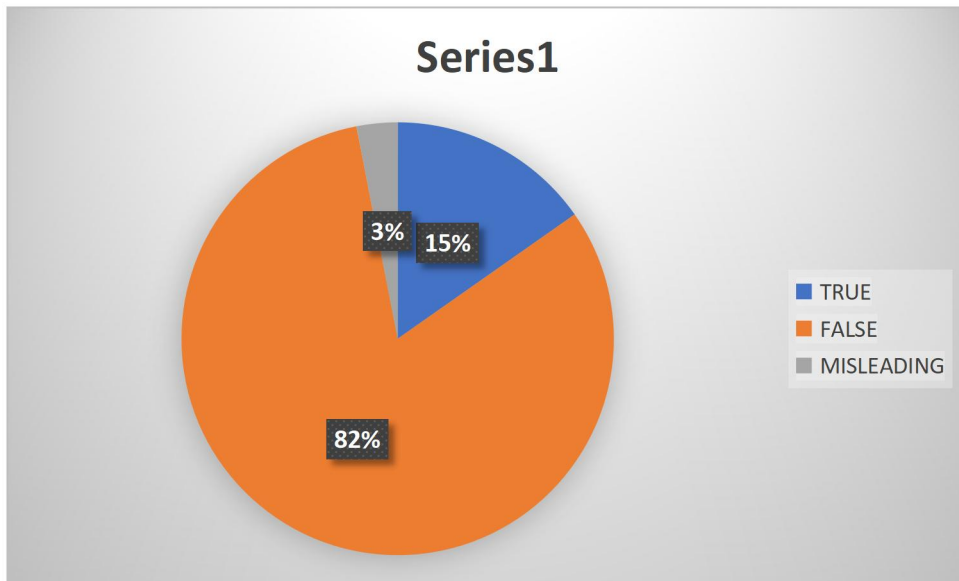
Africa Check emerged as the dominant fact-checking organization, handling 79.8% of the total fact-checks. This suggests that Africa Check has a more extensive reach, or resources compared to Dubawa and Fact Check Hub. The disparity in fact-checking volume among these organizations might influence the overall representation of information disorder in Africa.

Chart 2: Sources of Information Disorder for Fact-Checks



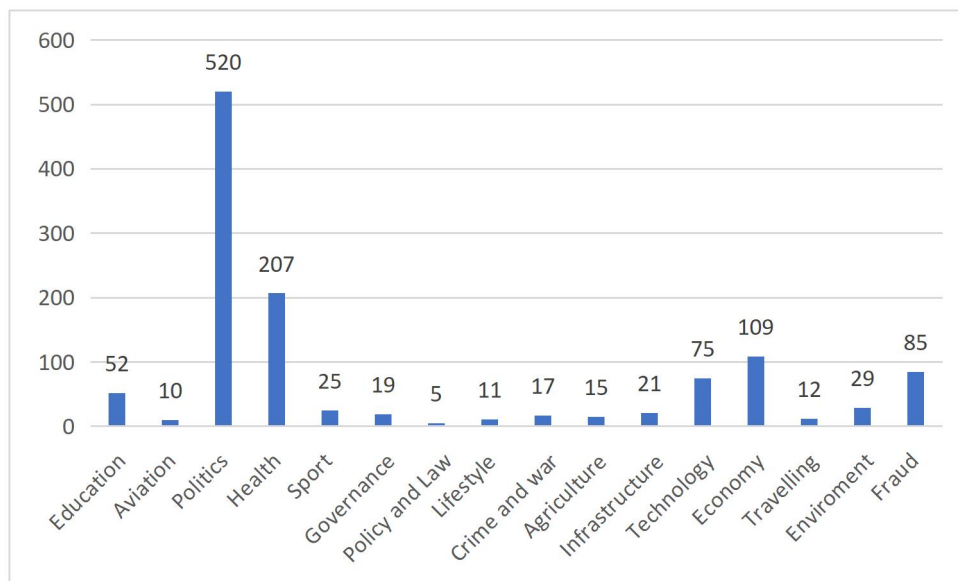
Social media platforms account for the majority of fact-checked claims. Facebook leads with 620 instances, followed by Twitter (290) and WhatsApp (110). This highlights the significant role that social media plays in the spread of information (and misinformation) in Africa. The presence of newer platforms like TikTok (40 instances) indicates an evolving nature of information dissemination.

Chart 3: Result of Claims Fact-Checked



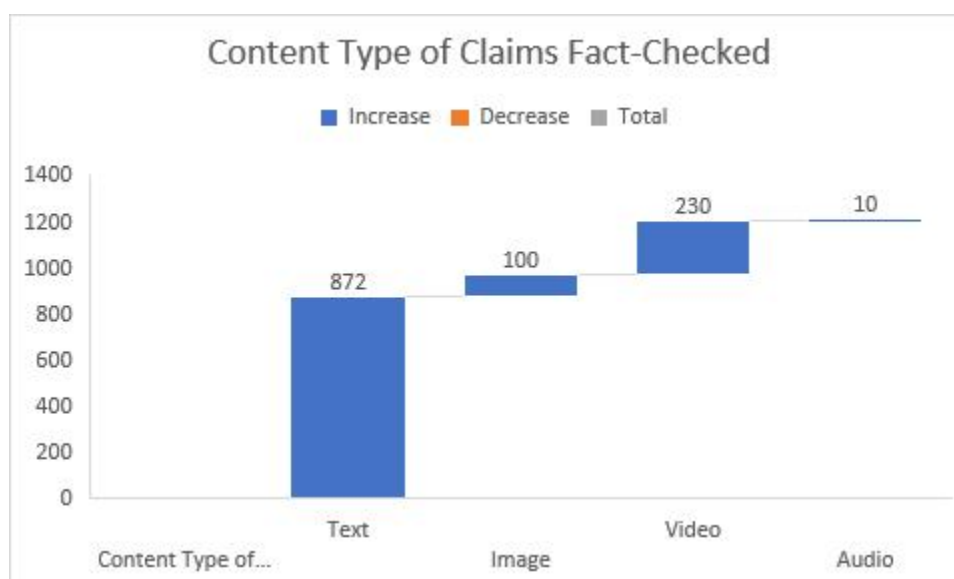
Out of the 1,212 fact-checked claims, 990 (81.7%) were found to be false, while only 185 (15.3%) were true, and 37 (3%) were misleading. This alarming ratio underscores the severity of information disorder in the region and the crucial role of fact-checking organizations in combating it.

Chart 4: Subjects of Claims Fact-Checked



Politics dominates the subjects of fact-checked claims with 520 instances, followed by health (207) and economy (109). This distribution reflects the areas most vulnerable to misinformation and might indicate public interest or concern in these topics. The significant presence of health-related claims could be attributed to the global health situations (e.g., COVID-19 pandemic).

Chart 5: Content Type of Claims Fact-Checked



Text-based content, 872(73%%) instances, is by far the most common format for claims requiring fact-checking, followed by video, 230(19%) and image, 100(8%). This distribution suggests that while text remains the primary vehicle for information, visual content (videos and images combined) accounts for a significant proportion (27.2%) of fact-checked claims.

DISCUSSION OF FINDING

The examination of fact-checking data derived from three African organizations elucidates numerous noteworthy trends within the domain of information disorder throughout the continent. Social media platforms, notably Facebook, Twitter, and WhatsApp, have emerged as the predominant sources of claims necessitating fact-checking, corroborating the findings of scholarly works such as Allcott and Gentzkow (2017) and Wasserman and Madrid-Morales (2019) regarding the role of social media in the propagation of misinformation. The substantial incidence of false information, with 81.7% of fact-checked claims identified as false, is in alignment with research conducted by Vosoughi et al. (2018) concerning the swift dissemination of false news across social media platforms. Misinformation relating to politics was found to be the most prevalent category among the fact-checked claims, succeeded by health and economic topics, which is consistent with the findings presented by Brennen et al. (2020) regarding the predominance of politically charged misinformation. While text-based content remained the most frequently encountered format for fact-checked claims, the notable presence of video and image content underscores the increasing significance of visual social media in the dissemination of information, as articulated by Highfield and Leaver (2016).

The advent of novel platforms such as TikTok within the fact-checking data emphasizes the dynamic nature of the social media environment, as underscored in investigations by Auxier and Anderson (2021). The substantial impact of private messaging applications like WhatsApp in the dissemination of claims is consistent with the research conducted by Resende et al. (2019) on misinformation within closed networks. The variation in the volume of fact-checking activities among organizations, wherein Africa Check undertakes a considerably higher number of fact-checks than its counterparts, is related to the findings by Graves and Cherubini (2016) on disparities in capacity among global fact-checking initiatives. The preeminence of health-related misinformation aligns with investigations such as those by Oyeyemi et al. (2014) concerning health misinformation in Africa, while the notable prevalence of economic and fraud-related claims resonates with the typology of fake news as identified by Tandoc et al. (2020). Notably, audio content was identified as the least prevalent format for fact-checked claims, which contrasts with concerns articulated by Vaccari and Chadwick (2020) regarding audio deepfakes and suggests a potential area for augmented scrutiny in fact-checking endeavours.

Collectively, these findings construct a detailed representation of the information disorder landscape in Africa, accentuating the pivotal role of social media, the prevalence of political and health misinformation, and the evolving characteristics of content types and platforms implicated in the dissemination of false information. This analysis not only informs strategic initiatives aimed at

combating misinformation and enhancing information integrity across the African continent but also contributes to the broader understanding of global patterns of information disorder and fact-checking methodologies. The concordance of these findings with international research accentuates the global nature of challenges associated with information disorder while simultaneously illuminating specific distinctive features of the African context.

CONCLUSION AND RECOMMENDATIONS

This study on information disorder in Africa, which uses fact-checking data from three organisations, finds a complicated ecosystem dominated by disinformation spread via social media. The findings show the prevalence of incorrect information, notably in the political, health, and economic realms, reflecting both worldwide trends and specific African concerns. The prevalence of disinformation on Facebook, Twitter, and WhatsApp highlights the vital role these platforms play in moulding public discourse, as well as the urgent need for specific actions.

The huge frequency of bogus claims (81.7%) highlights the critical need for increased digital literacy across the continent. The multiplicity of content kinds, from text to video, necessitates a multifaceted approach to fact-checking and public education. The emergence of new platforms like TikTok in the misinformation ecosystem signals the dynamic nature of the challenge, requiring constant adaptation from fact-checkers and policymakers alike.

To address these challenges, we recommend:

1. Strengthening collaboration between fact-checking organizations and social media platforms to develop more effective misinformation detection and removal systems.
2. Implementing comprehensive digital literacy programmes in educational curricula and public awareness campaigns, focusing on critical thinking and source verification skills.
3. Encouraging greater transparency from social media organizations regarding their algorithms and content moderation practices in African markets.
4. Developing region-specific fact-checking tools and strategies that account for linguistic diversity and local contexts.
5. Increasing support for local fact-checking initiatives to expand their capacity and reach, particularly in underserved areas.
6. Fostering cross-sector collaborations between fact-checkers, academia, media, and government to create a more robust information ecosystem.
7. Investing in research on the unique aspects of information disorder in Africa to inform evidence-based policies and interventions.

By implementing these recommendations, stakeholders can work towards mitigating the impact of misinformation and fostering a more informed and resilient digital society across Africa.

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NITROGEN CONTENT AND PROXIMATE COMPOSITION OF BURDOCK (*ARCTIUM LAPPA* L.) IN RESPONSE TO MINERAL FERTILIZER APPLICATION

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ABSTRACT

Nitrogen is a critical element in plant nutrition, playing a central role in amino acid and protein synthesis. However, the mineralization and uptake vary significantly across cultivation practices which remain silent like the case of burdock with multiutility values. In a pilot study of a factorial pot and field experiments of eight treatment combinations ($T_1=N_{423}P_{210}K_{315}$, $T_2=N_{423}P_{280}K_{315}$, $T_3=N_{635}P_{210}K_{315}$, $T_4=N_{635}P_{280}K_{315}$, $T_5=N_{846}P_{210}K_{315}$, $T_6=N_{846}P_{280}K_{315}$, $T_7=N_{1058}P_{210}K_{315}$ and $T_8=N_{1058}P_{280}K_{315}$ Kg/ha) laid out in a complete randomized design replicated five times. At harvest dry root and leaf samples were used to investigate the nitrogen content using the LECO nitrogen and protein analyser model 630-100-200 and proximate composition using the method of AOAC, (2005). Significant differences ($P<0.05$) were observed for nitrogen, protein, and carbohydrate content for root and leaf. However, no significant difference ($P>0.05$) was recorded for root lipid and leaf ash content. Furthermore, significant difference ($p<0.05$) was recorded among fertilizer treatments across cultivation practices. Leaf nitrogen and protein contents were higher than those of root. T_7 (20.9%) showed the most significant effect in protein content, resulting in a 9.4 % increase compared to the control for pot experiment. Overall, the root carbohydrate contents were higher than those of the leaf among treatments and cultivation practices, complementing the food value of burdock as a very good source of energy.

Keywords: Burdock, carbohydrate, nitrogen, proximate, cultivation practices

INTRODUCTION

Burdock (*Arctium lappa* L.) is a biennial herbaceous plant of the family Asteraceae that is used for various purposes such as food, medicine, manure, insect repellent and fungicides (Chen and Chen, 2010, Chan et al., 2011). Several studies have described the therapeutic and nutritional values of Burdock, which is associated with the high phytonutrient content present in the root, leaf and seed (Wang and Wu, 2013, Salama and Salama, 2016, Alhusaini et al., 2019, Bhatt et al., 2019, Wang et al., 2019, Yosri et al., 2023). Also, the root is highly consumed as salad, stew and as an ingredient for bread and muffins in the European and Asian continents (Kim et al., 2010, Tae et al., 2015, Zhang et al., 2021). The demand for Burdock keeps increasing with the increase in awareness as a multiutility plant in the different regions of the world, including South Africa, where most of the supply is mostly through importation from the region of its origin (Tanga, 2021). Despite the increase in demand, the cultivation practice of burdock remains silent in the different regions of the world, including South Africa, where, to the best of our knowledge, through a literature search, this is the first of its kind. Cultivation practices influences, nutrient uptake, growth, yield and nutrient composition in plants (Thakur et al., 2020, Saini et al., 2022). Farming practices can influence the quality and quantity of

phytonutrients in various plant parts (Sereme et al., 2016). Burdock (*Arctium lappa* L.) has minor cases of cultivation practices as a popular vegetable in the Asian continent (Imahori et al., 2010). Studies on the influence of organic and inorganic fertilizers on the morphological characteristics of burdock (Wu et al., 2017). Also, the effect of nitrogen fertilizer and harvesting date on growth and total phenolic content in leaves of burdock (Al-Zyadi, 2018). Furthermore, the influence of nitrogen fertilizer rates on nitrogen uptake, yield and free sugar content of burdock (Lee et al., 2016) has been investigated with little attention on the cultivation practices and nutrient uptake.

Macronutrients have a significant influence on plant growth and the accumulation of phytonutrients (Alhasan and Al-Ameri, 2021). Among the primary nutrients, nitrogen is the most important nutrient element to achieve maximum growth and yield in plants (Leghari et al., 2016). Most of the studies are on growth, yield and morphological characteristics of burdock. However, studies on the cultivation practices and uptake of nutrients in burdock and nutrient composition are limited. Therefore, this study was undertaken to investigate the influence of mineral fertilizer applications on the nitrogen uptake and proximate composition of plant materials obtained from a pot and field cultivated burdock in the Windland Region of the Western Cape region of South Africa.

MATERIALS AND METHODS

The root and leaf samples of burdock were obtained at harvest from a factorial pot and field experiments of burdock, with eight treatment combinations ($T_1=N_{423}P_{210}K_{315}$, $T_2=N_{423}P_{280}K_{315}$, $T_3=N_{635}P_{210}K_{315}$, $T_4=N_{635}P_{280}K_{315}$, $T_5=N_{846}P_{210}K_{315}$, $T_6=N_{846}P_{280}K_{315}$, $T_7=N_{1058}P_{210}K_{315}$ and $T_8=N_{1058}P_{280}K_{315}$ Kg/ha) replicated five times. The study was conducted at the research and teaching farm at the Department of Agriculture, Cape Peninsula University of Technology at coordinates (S33°37' E19° 37'). Fresh samples were washed and allowed to dry at room temperature for one week. Thereafter, dried samples were ground to powder using an electric grinding machine POLYMIX(PXMFC(90D)).

Nitrogen and proximate analysis of root and leaf samples.

Nitrogen and Protein content were analysed using the laboratory Equipment Corporation (LECO nitrogen and protein analyser model 630-100-200). Made in USA (St. Joseph, M.I 49085-2396 LECO cooperation 300 Lakeview Ave). The analysis was replicated five times, and the carbohydrate content was determined using estimation by difference [by subtracting the total ash content, crude lipid, crude protein and crude fibre from 100] (Aoac, 2005). This was done in the laboratory of the Food Technology Department at Bellville campus, Cape Peninsula University of Technology. Proximate analysis was done on dry ground leaf samples from the different treatments. Sulphuric acid and sodium hydroxide were used for crude fibre, Diethyl ether for crude lipid and incineration at 550 °C for ash content using the method of (Aoac, 2005), at the postgraduate Analytical Laboratory of the Department of Agriculture, Wellington Campus, Cape Peninsula University of Technology.

RESULTS

Influence of fertiliser treatment on proximate composition of burdock leaf and root samples

The different nutritional components for leaf samples of burdock for pot experiment were significantly ($P>0.05$) affected by fertilizer treatments (Table 1). Generally, the ash content for leaf samples was higher than those for root samples. T_7 had the highest influence for leaf ash content (18.1%) with a 7.7% increase compared to the control (T_1) and the least effect was recorded by T_4 (14.5%) with a 13.7% decrease compared to the control. For crude lipid content, T_2 (6.1%) had the highest influence with a 90.6% increase, while the least was recorded by T_3 (3.0%) with a 6.5% decrease compared to the control for leaf lipid content. Also, the leaf fibre content was significantly influenced by fertilizer treatment, with T_2 recording the highest effect with a 41.5% increase compared to the control. Furthermore, T_7 (20.9%) had the highest effect with a 9.42% increase compared to the control, while the least was recorded by T_2 (13.8%) with a 27.6% reduction compared to the control for leaf protein. Regarding carbohydrate content, T_4 (59.3%) had the highest yield with a 5.9% increase compared to the control for leaf (Table 1).

Table 1. Proximate analysis of leaf samples for the pot experiment at (P=0.05). Values are (Mean $\pm$ SD).

Treatments	% Ash Leaf	% Lipid leaf	% Fibre leaf	% Protein leaf	%Carbohydrate leaf
T ₁ (N ₁ P ₁ K ₁)	16.80 $\pm$ 0.57 ^{ab}	3.2 $\pm$ 0.84 ^{bc}	4.96 $\pm$ 1.46 ^{bc}	19.10 $\pm$ 0.32 ^b	55.94 $\pm$ 1.51 ^a
T ₂ (N ₁ P ₂ K ₁)	16.62 $\pm$ 0.85 ^{ab}	6.1 $\pm$ 2.90 ^a	8.48 $\pm$ 3.48 ^a	13.82 $\pm$ 0.39 ^f	54.98 $\pm$ 2.49 ^a
T ₃ (N ₂ P ₁ K ₁)	15.10 $\pm$ 1.88 ^{bc}	3.0 $\pm$ 1.06 ^c	7.12 $\pm$ 2.22 ^{ab}	15.92 $\pm$ 1.03 ^e	58.86 $\pm$ 4.05 ^a
T ₄ (N ₂ P ₂ K ₁)	14.50 $\pm$ 1.97 ^c	5.1 $\pm$ 1.08 ^{ab}	5.16 $\pm$ 2.51 ^{bc}	15.98 $\pm$ 0.49 ^e	59.26 $\pm$ 4.54 ^a
T ₅ (N ₃ P ₁ K ₁)	15.80 $\pm$ 1.15 ^{bc}	5.6 $\pm$ 2.22 ^{ab}	5.6 $\pm$ 2.21 ^{bc}	17.32 $\pm$ 0.42 ^d	55.68 $\pm$ 4.47 ^a
T ₆ (N ₃ P ₂ K ₁)	15.00 $\pm$ 1.32 ^{bc}	5.0 $\pm$ 0.35 ^{ab}	3.44 $\pm$ 0.83 ^c	18.10 $\pm$ 0.00 ^c	58.46 $\pm$ 1.57 ^a
T ₇ (N ₄ P ₁ K ₁)	18.10 $\pm$ 1.19 ^a	4.1 $\pm$ 2.10 ^{abc}	7.12 $\pm$ 1.11 ^{ab}	20.9 $\pm$ 0.00 ^a	49.78 $\pm$ 2.72 ^b
T ₈ (N ₄ P ₂ K ₁)	16.30 $\pm$ 1.68 ^{abc}	3.9 $\pm$ 1.47 ^{abc}	5.12 $\pm$ 1.11 ^{bc}	18.08 $\pm$ 0.04 ^c	56.60 $\pm$ 2.85 ^a
LSD	0.51	0.056	0.145	0.846	0.077

Means in the same column with the same superscript are not significantly difference (P $\geq$ 0.05). Values are means at (P =0.05). T₁=N350P213K213, T₂=N350P320K213, T₃=N525P213K213, T₄=N525P320K213, T₅=N700P213K213, T₆=N700P320K213, T₇=N800P213K213, T₈=N800P230K213 Kg/ha, LSD= Least Significant Different

Similarly, fertiliser treatment had a significant (P>0.5) effect on the nutritional composition of the root sample. However, for root lipid content, no significant effect(P<0.05) was recorded. (Table 2). T₇ (5.5%) recorded the highest effect with a 7.8% increase compared to the control, and the least effect was recorded by T₄ (3.8%) with a 25.5% decrease compared to the control. On the other hand, for root fibre content, T₂ (2.7%) recorded the highest effect with a 17.2% increase compared to the control and the least by T₄ (1.1%) with a 51.7 % reduction compared to the control. Equally, for root protein, the highest effect was demonstrated by T₇ (15.1%) with a 29.89% increase compared to the control, while the least was recorded by T₈ (10.7%) with a 7.9% reduction compared to the control. Overall, the root carbohydrate contents were higher than those of the leaf among the different fertilizer treatments (Table 2).

Table 2. Proximate analysis of root samples for the pot experiment at (P=0.05). Values are (Mean $\pm$ SD).

Treatments	% Ash Root	% Lipid Root	% Fibre Root	% Protein Root	%Carbohydrate Root
T ₁ (N ₁ P ₁ K ₁)	7.6 $\pm$ 1.92 ^{ab}	5.1 $\pm$ 0.96 ^a	2.32 $\pm$ 0.52 ^{ab}	11.64 $\pm$ 0.68 ^{bc}	73.34 $\pm$ 2.80 ^a
T ₂ (N ₁ P ₂ K ₁)	8.6 $\pm$ 3.72 ^a	4.6 $\pm$ 2.82 ^a	2.72 $\pm$ 1.73 ^a	11.48 $\pm$ 0.69 ^{bc}	72.60 $\pm$ 4.62 ^{ab}
T ₃ (N ₂ P ₁ K ₁)	6.1 $\pm$ 0.74 ^{ab}	4.4 $\pm$ 2.36 ^a	1.44 $\pm$ 0.67 ^{ab}	11.82 $\pm$ 0.18 ^{bc}	76.24 $\pm$ 1.53 ^a
T ₄ (N ₂ P ₂ K ₁)	5.9 $\pm$ 0.65 ^b	3.8 $\pm$ 1.35 ^a	1.12 $\pm$ 0.59 ^b	12.54 $\pm$ 0.84 ^b	76.64 $\pm$ 2.18 ^a
T ₅ (N ₃ P ₁ K ₁)	5.7 $\pm$ 1.04 ^b	4.3 $\pm$ 2.23 ^a	1.60 $\pm$ 0.89 ^{ab}	14.62 $\pm$ 1.39 ^a	73.78 $\pm$ 3.89 ^a
T ₆ (N ₃ P ₂ K ₁)	5.5 $\pm$ 1.27 ^b	4.1 $\pm$ 2.27 ^a	2.00 $\pm$ 1.23 ^{ab}	12.20 $\pm$ 0.00 ^b	76.20 $\pm$ 2.24 ^a
T ₇ (N ₄ P ₁ K ₁)	8.1 $\pm$ 1.71 ^{ab}	5.5 $\pm$ 2.72 ^a	2.40 $\pm$ 0.49 ^{ab}	15.12 $\pm$ 1.26 ^a	68.88 $\pm$ 4.63 ^b
T ₈ (N ₄ P ₂ K ₁)	7.5 $\pm$ 1.12 ^{ab}	5.4 $\pm$ 2.13 ^a	2.08 $\pm$ 0.52 ^{ab}	10.72 $\pm$ 0.45 ^c	74.30 $\pm$ 2.46 ^a
LSD	0.51	NS	0.065	0.061	0.079

Means in the same column with the same superscript are not significantly difference (P $\geq$ 0.05). Values are means at (P =0.05). T₁=N350P213K213, T₂=N350P320K213, T₃=N525P213K213, T₄=N525P320K213, T₅=N700P213K213, T₆=N700P320K213, T₇=N800P213K213, T₈=N800P230K213 Kg/ha, LSD= Least Significant Different

Interestingly, a similar scenario was recorded on fertilizer treatments on the leaf samples of field cultivated burdock, with an Ash content which was not significant (P>0.05) (Table 3). The nutritional components of burdock root and leaf samples for the field experiment also had a significant (P<0.05) influence on fertilizer treatments, except for leaf ash content, which was not significant (P>0.05). (Table 3). Overall, leaf ash contents were higher than those of roots among the different fertilizer treatments. T₂ (12.5%) had the highest leaf ash content with a 2.5 % increase compared to the control. (T₁). Furthermore, for leaf lipid content, T₆ (12.4%) recorded the highest yield with a 51.2% increase compared to the control. The least was recorded by T₈ (7.2%) with a 12.2% reduction compared to the control (Table 3).

Regarding the fibre and protein content, the leaf samples had higher yields than root samples among the fertilizer treatments. T₂ (6.6%) had the highest leaf fibre content with a 15.3% increase compared to the control, while T₆ (3.2%) had the highest root fibre content with a 185.7 % increase compared to the control. All the same for lipid protein content, T₇ (28.9%) recorded the highest with a 2.1 % increase compared to the control. While root protein T₅ (13.5%) recorded the highest with a 27.8 % increase compared to the control (Table 3).

Table 3. Proximate analysis of leaf samples for field experiment at (P=0.05). Values are (Mean ± SD).

Treatments	% Ash Leaf	% Lipid leaf	% Fibre leaf	% Protein leaf	%Carbohydrate leaf
T ₁ (N ₁ P ₁ K ₁)	12.2±0.57 ^a	8.2±0.91 ^{bc}	5.76±0.96 ^a	28.30±1.11 ^a	46.48±2.67 ^{ab}
T ₂ (N ₁ P ₂ K ₁)	12.5±1.36 ^a	9.2±1.15 ^{bc}	6.64±0.83 ^a	26.22±0.64 ^b	45.26±1.54 ^{ab}
T ₃ (N ₂ P ₁ K ₁)	11.5±0.50 ^a	10.2±0.91 ^{ab}	4.32±2.07 ^a	28.90±2.15 ^a	45.20±4.59 ^{ab}
T ₄ (N ₂ P ₂ K ₁)	12.0±1.17 ^a	10.0±1.26 ^{abc}	5.6±2.62 ^a	26.10±0.35 ^b	45.98±3.29 ^{ab}
T ₅ (N ₃ P ₁ K ₁)	11.4±0.89 ^a	8.2±0.84 ^{bc}	6.56±4.30 ^a	27.78±0.36 ^a	45.16±4.96 ^{ab}
T ₆ (N ₃ P ₂ K ₁)	11.6±0.65 ^a	12.2±4.87 ^a	6.08±2.46 ^a	28.60±0.42 ^a	41.84±3.01 ^b
T ₇ (N ₄ P ₁ K ₁)	11.7±0.84 ^a	7.9b±1.25 ^c	6.48±1.91 ^a	27.78±0.36 ^a	45.80±2.50 ^{ab}
T ₈ (N ₄ P ₂ K ₁)	11.9±1.08 ^a	7.2±0.76 ^c	6.64±0.36 ^a	28.20±0.55 ^a	51.80±13.07 ^a
LSD	NS	0.104	0.173	0.108	0.113

Means in the same column with the same superscript are not significantly difference (P≥0.05). Values are means at (P -0.05). T₁=N350P213K213, T₂=N350P320K213, T₃=N525P213K213, T₄=N525P320K213, T₅=N700P213K213, T₆=N700P320K213, T₇=N800P213K213, T₈=N800P230K213 Kg/ha, LSD= Least Significant Different

Similarly, for root ash content, T₅ (6.4%) had the highest yield with a 30.6 % increase compared to the control, while the least was recorded by T₈ (3.5%) with a 28.6% decrease compared to the control. (Table 4). Considering the carbohydrate content, root samples recorded higher yields than leaf samples. Nevertheless, T₈ (51.8%) recorded the highest yield with an 11.5% increase compared to the control. The least was recorded by T₆ (41.9%), with a 10% decrease compared to the control for leaf samples. Furthermore, T₂ (77.7 %) recorded the highest yield with a 2.6 % increase compared to the control, while the least was recorded by T₄ (46.7%) compared to the control for root samples. In the same way, for root lipid content, T₄ (38.3%) recorded the highest yield with a 403.9 % increase compared to the control, while the least was recorded by T₇ (5.8%) with a 23.7 % decrease compared to the control.(Table 4).

Table 4. Proximate analysis of root samples for field experiment at (P=0.05). Values are (Mean ± SD).

Treatments	% Ash Root	% Lipid Root	% Fibre Root	% Protein Root	%Carbohydrate Root
T ₁ (N ₁ P ₁ K ₁)	4.9±0.82 ^{ab}	7.6±3.42 ^d	1.12±0.34 ^c	10.56±0.39 ^c	75.80±3.50 ^a
T ₂ (N ₁ P ₂ K ₁)	5.8±0.91 ^{ab}	6.4±1.19 ^d	2.96±2.01 ^{ab}	7.10±0.35 ^e	77.74±2.77 ^a
T ₃ (N ₂ P ₁ K ₁)	5.3±1.45 ^{ab}	6.7±1.35 ^d	1.52±0.18 ^{bc}	10.48±0.25 ^c	75.80±0.99 ^a
T ₄ (N ₂ P ₂ K ₁)	5.3±1.35 ^{ab}	38.3±3.09 ^a	1.12±0.52 ^c	8.62±0.29 ^d	46.66±4.50 ^c
T ₅ (N ₃ P ₁ K ₁)	6.4±4.12 ^a	28.5±3.88 ^b	0.96±0.46 ^c	13.5±0.28 ^a	50.64±2.05 ^c
T ₆ (N ₃ P ₂ K ₁)	6.0±1.11 ^{ab}	29.5±6.44 ^b	3.20±1.49 ^a	11.9±0.54 ^b	49.40±7.05 ^c
T ₇ (N ₄ P ₁ K ₁)	5.3±0.76 ^{ab}	5.8±2.77 ^d	1.36±0.61 ^c	10.76±0.05 ^c	76.78±2.64 ^a
T ₈ (N ₄ P ₂ K ₁)	3.5±0.61 ^b	20.4±6.05 ^c	1.52±0.52 ^{bc}	10.7±0.27 ^c	63.88±6.15 ^b
LSD	0.57	0.519	0.053	0.234	0.165

Means in the same column with the same superscript are not significantly difference (P≥0.05). Values are means at (P -0.05). T₁=N350P213K213, T₂=N350P320K213, T₃=N525P213K213, T₄=N525P320K213, T₅=N700P213K213, T₆=N700P320K213, T₇=N800P213K213, T₈=N800P230K213 Kg/ha, LSD= Least Significant Different

Influence of fertilizer treatment on Nitrogen content burdock root and leaf samples

The nitrogen content for root samples of burdock was significantly (P>0.05) affected by fertilizer treatments across cultivation practices (Fig. 1). For the pot experiment, T₇ outperformed the other treatments with a 24.8 % increase compared to the control (T₁). However, for the field experiment T₆

recorded the highest significant effect ($p>0.05$) among fertilizer treatments. The least effect was recorded by T6, with a 92% reduction compared to the control. Overall, root tissue nitrogen for the pot experiment was higher than that for the field experiments (Fig. 1).

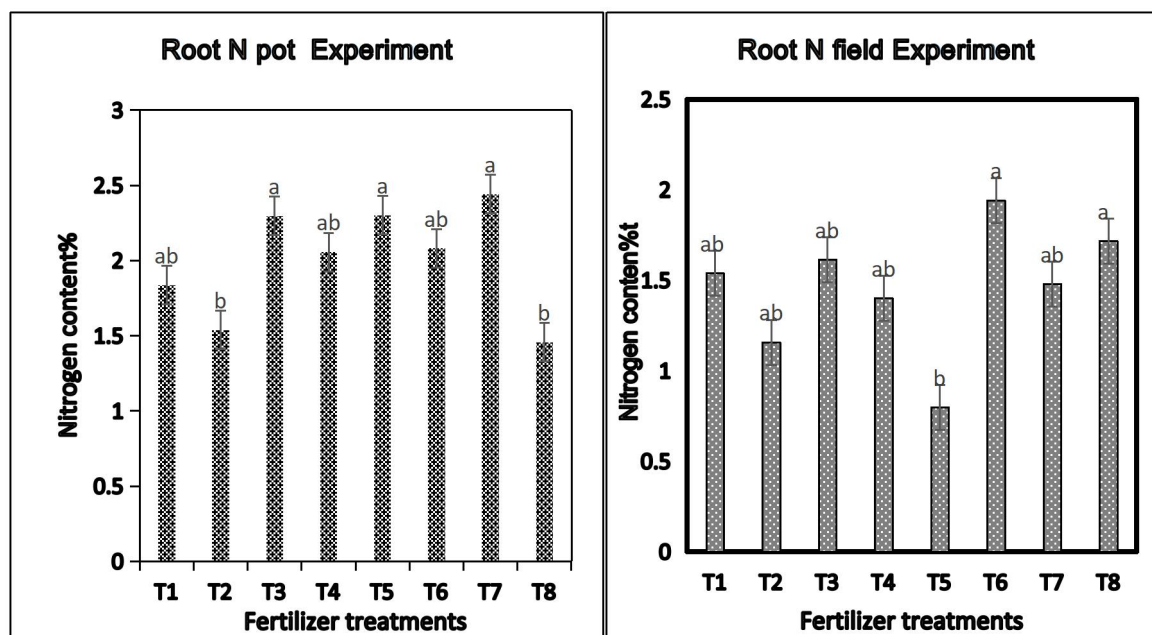


Fig 1. Influence of fertilizer treatment on root tissue nitrogen content for pot and field experiments. Similarly, the leaf nitrogen for pot experiment was significantly affected ($p>0.05$) by fertilizer treatments across cultivation practices, with the highest effected recorded by T₇ and the least by T₂. However, this was not the case for leaf tissue nitrogen for field experiment which was not significant ($P<0.05$) among fertilizer treatments (fig 2).

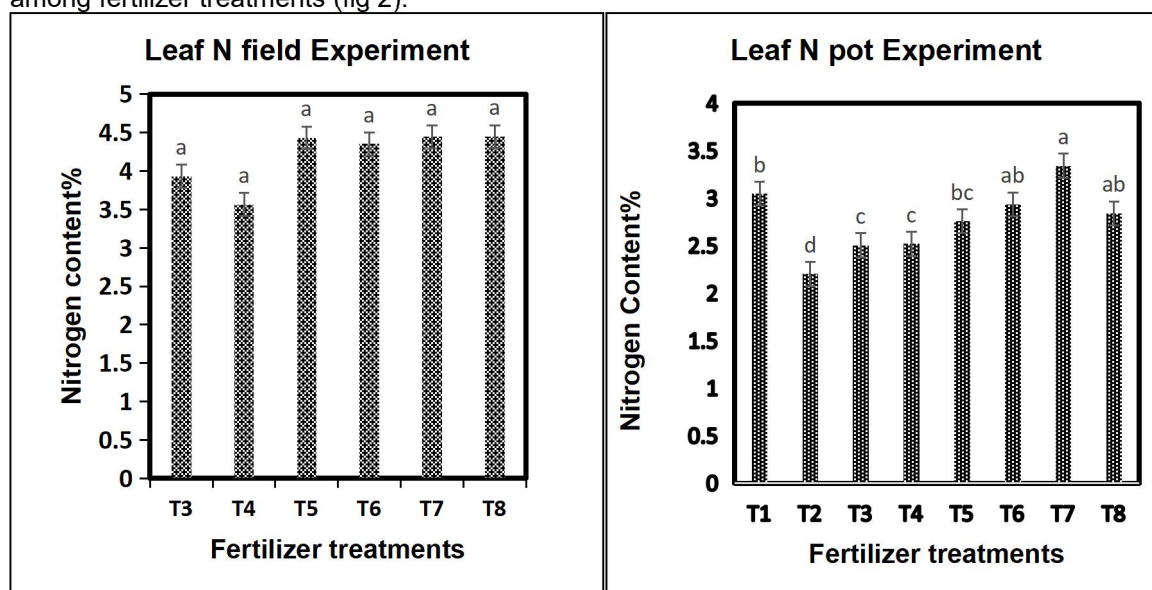


Fig 2. Influence of fertilizer treatment on leaf tissue nitrogen content for pot and field experiments.

DISCUSSION

Influence of fertilizer treatments on nutritional constituents of leaf and root samples of Burdock for pot and field experiments

The different nutritional components for leaf and root samples of burdock for the pot experiment were significantly ($P<0.05$) affected by fertilizer treatments except for root lipid content, which was not significant ($P>0.05$). This may be attributed to the differences in cultivation practices, which may have significantly impacted the assimilation of the nutritional components of the different parts of burdock,

since cultivation practices influence nutrient uptake, growth, yield and nutrient composition in plants (Thakur et al., 2020, Saini et al., 2022). Furthermore, the quality and quantity of phytonutrients in various plant parts can be influenced by farming practices (Sereme et al., 2016). Overall, the root carbohydrate contents were higher than those of the leaf among the different fertilizer treatments, complementing the food value of burdock as a very good source of energy. This is in agreement with Weckler (1887), who reported that Burdock roots may be an alternative to prebiotic oligosaccharides in bakery products for health benefits. Similarly, the high fibre content of this species also complements its medicinal potentials of anti-inflammatory and antitumor properties. Additionally, the essential components of the roots of burdock represented a valuable number of phytonutrients attributed to the medicinal and nutritional potentials of the species.

Influence of fertilizer treatments on Nitrogen content of burdock root and leaf samples for pot and field experiments.

The nitrogen content for root samples of burdock was significantly ($P>0.05$) affected by fertilizer treatments across cultivation practices. For the pot experiment, T₇ outperformed the other treatments with a 24.8% increase compared to the control. This may be attributed to the differences in fertiliser treatment combinations applied and management practices involved (Vanlauwe et al., 2011). Overall, the higher root tissue nitrogen for the pot experiment than for the field experiments may be attributed to nitrogen use efficiency in the pot experiment (Duncan et al., 2018). This may have been influenced by soil nutrient availability (Koorem et al., 2014), soil microorganisms, which might have influenced the nitrogen availability (Richardson and Simpson, 2011).

CONCLUSION

Fertilizer application enhances growth and development in plants under good production practices. This ultimately influences the degree of metabolism of phytonutrients in plant tissues, irrespective of the cultivation practices. Nutritionally, the leaf and root samples of Burdock had an ideal proportion of the different nutrients investigated. The significant differences observed among the different treatment combinations on the leaf and root samples and cultivation practices may be attributed to the fact that fertilizer treatments influence growth and accumulation of phytonutrients, which will influence the nutritional constituents. Overall, higher carbohydrate content identified Burdock to be an excellent source of energy. However, further study needs to be done using different cultivation practices to potentially validate these findings.

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Informed Consent Statement:

The study had no human subjects.

Data Availability Statement:

The data was captured in an Excel spreadsheet and was stored in eSango.

Ethical Clearance:

This was a field plot and a field agricultural experiment

Conflicts of Interest:

There is no conflict of interest

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