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REVIEW ARTICLE

Moringa oleifera as a food fortificant: Recent trends and prospects

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Abstract *Moringa oleifera* tree is referred to as a miracle tree due to its rich source of certain macro and micro nutrients of great importance in human nutrition. The chemical composition of the different parts of the *Moringa* tree may vary depending on cultivar and source. *M. oleifera* leaf, seed and flower have found numerous applications in food. In this review we firstly summarized the present knowledge on the use of *M. oleifera* as a food fortificant in amala (stiff dough), ogi (maize gruel), bread, biscuits, yoghurt, cheese and in making soups. The knowledge gap in the reported research was provided and possible future applications of *M. oleifera* in foods as well as the need for a well-structured and planned experimental design were suggested.

Contents

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1. Introduction

Moringa Oleifera is universally referred to as the miracle plant or the tree of life. The *Moringa* plant derives this name based on its uses, particularly with regard to medicine and nutrition. It is a plant native to the sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan (Fahey, 2005). *M. Oleifera* is the most widely cultivated among the 13 species of the *Moringaceae* family and it is exceptionally nutritious with a variety of uses. Almost all the parts of this miracle tree have been found to be very useful. Leaves are used as forage, tree trunk for making gums, flower nectar in honey and powdered seeds for water purification Fuglie (1999). *M. Oleifera* leaf has been used as an alternative food source to combat malnutrition, especially among children and infants (Anwar et al., 2007). *M. Oleifera* leaves are reported to contain substantial amounts of vitamin A, C and E (Hekmat et al., 2015). The leaves of *M. Oleifera* have also been found to contain appreciable amounts of total phenols, proteins, calcium, potassium, magnesium, iron, manganese and copper (Hekmat et al., 2015). *M. Oleifera* leaves are also good sources of phytonutrients such as carotenoids, tocopherols and ascorbic acid (Saini et al., 2014b, 2014d). These nutrients are known to scavenge free radicals when combined with a balanced diet and may have immunosuppressive effects (DanMalam et al., 2001). Besides the leaves, the flowers and fruits of *M. Oleifera* have also been found to contain appreciable amounts of carotenoids (Saini et al., 2014e).

In many parts of the world including Africa, the use of *M. Oleifera* as a food fortificant is on the increase. For instance, both fresh and dried *Moringa* leaves are included in meals in African countries such as Ghana, Nigeria, Ethiopia, East Africa and Malawi (Agbogidi and Ilondu, 2012). Many studies have shown the potential use of different parts of *M. Oleifera* in food applications such as in making soups (Babayeju et al., 2014), weaning foods (Arise et al., 2014), amala, a stiff dough made from yam and plantain flour (Karim et al., 2015, 2013), herbal biscuits (Alam et al., 2014), bread (Chinma et al., 2014), cake (Kolawole et al., 2013) and yoghurt (Hekmat et al., 2015). The use of this nutrient rich plant in fortifying foods is getting much attention. This review firstly summarizes the present knowledge on the use of *M. Oleifera* as a food fortificant. It then provides knowledge gap with a view to provide suggestions for potential applications in foods.

1.1. Nutritional value of M. Oleifera

M. Oleifera tree is a plant rich in a number of nutrients such as proteins, fibre and minerals (Jongrungruangchok et al., 2010; Moyo et al., 2011) that play important role in human nutrition. Many of the reported studies have shown that *M. Oleifera* leaves are exceptionally high in protein compared to other leaves consumed as food. The nutritional value of *M. Oleifera* leaves may vary with cultivar and source. For instance, Jongrungruangchok et al. (2010) observed variations in the protein (approx. 19–29%) and fibre (16–24%) contents of *M. Oleifera* leaves grown in 11 different provinces in Thailand. The protein content of the leaves reported by these authors is similar to those reported in Brazil (28%) (Teixeira et al., 2014) and South Africa (approx. 30%) (Moyo et al., 2011). The calcium, iron and potassium contents of the leaves were also found to show substantial variations (Jongrungruangchok et al., 2010). Yang et al. (2006) working with four cultivars of *Moringa* reported that *M. oleifera* had the highest amount of β-carotene, ascorbic acid (Vitamin C), α-tocopherol (Vitamin E) and iron. Fresh leaves of *M. Oleifera* have been found to be good sources of carotenoids such as trans-lutein (approx. 37 mg/100 g), trans-β-carotene (approx. 18 mg/100 g) and trans-zeaxanthin (approx. 6 mg/100 g) (Saini et al., 2014d). These authors similarly reported relatively high amounts of ascorbic acid (271 mg/100 g) and tocopherols (36.9 mg/100 g) in the fresh *M. Oleifera* leaves (Saini et al., 2014d). *M. oleifera* leaves have also been found to contain significant amount of essential amino acid and are rich in alpha linoleic acid (Moyo et al., 2011). The leaves are known to be excellent source of a wide range of dietary antioxidants (Moyo et al., 2012; Qwele et al., 2013; Saini et al., 2014d, 2014e; Yang et al., 2006). According to Yang et al. (2006), *M. oleifera* leaves have significantly higher antioxidant contents when compared to fruits such as strawberries known for high antioxidant contents. Other authors have similarly reported the antioxidant potential of the leaves of *M. Oleifera* (Saini et al., 2014b, 2014d). Other studies showed that *M. Oleifera* plant may find application in livestock industry for improving meat quality in terms of chemical composition, colour and lipid stability (Nkukwana et al., 2014a, 2014b, 2014c; Qwele et al., 2013). A recent study showed that iron from *M. Oleifera* can overcome iron deficiency and modulate the expression of iron-responsive genes better than conventional iron supplements (Saini et al., 2014a). Similarly, Saini et al. (2016) found that the relative bioavailability of folate from *M. Oleifera* leaves using rat model was very high (approx. 82%) suggesting that the *M. Oleifera* leaves can be a potential source of dietary folate. It is also important to mention that the *M. Oleifera* leaves, flower and tender pods are potential sources of polyunsaturated fatty acids, which may have some beneficial effects in *M. Oleifera* based products (Saini et al., 2014c). Many of the aforementioned nutritional benefits of *M. Oleifera* suggest that these plants can serve as a functional ingredient in the food and allied industries.

1.2. Purpose of food fortification

Food fortification involves the addition of essential nutrients such as vitamins and minerals to staple foods to improve their nutritional value. In most cases, fortification can lead to rapid improvements in the micronutrient status of a population at a reasonable cost. Foods to be fortified must be consumed adequately by a large proportion of the target individuals in a population. The fortificant also should be readily available, accessible and well absorbed into the food without causing a significant change in the sensory attributes of the fortified food (Allen et al., 2006). According to these authors, food fortification can take several forms such as mass fortification, targeted fortification and market-driven fortification. Whatever the purpose of fortification, it is pertinent to note that the food to be fortified (food vehicle) and fortificant must be compatible. Further, the fortificant must be such that, it does not improve the nutritional value of the food at the expense of the sensory properties. This is very important since consumers are first attracted by what they see and this can play a large role in determining the continuous patronage for such food commodity.

The use of *M. Oleifera* to improve the nutritional value of staple foods in many parts of the world including Africa may not necessarily fall under fortification or enrichment. As previously defined, fortification which is sometimes used interchangeably with enrichment involves the addition of specific micronutrients to staple foods to improve the overall nutritional value of the targeted population. In this review, we will be using fortification to describe the improvement in the nutritional value of staple foods containing *M. Oleifera*.

1.3. Food fortification with M. Oleifera

1.3.1. Stiff dough 'Amala'

Amala is a staple in many parts of Africa including Ghana and Nigeria (Abiodun and Akinoso, 2014; Jimoh and Olatidoye, 2009). It is a starchy gel or stiff dough traditionally prepared from yam (*Dioscorea* spp.) flour (Abiodun and Akinoso, 2014; Awoyale et al., 2010). However, amala has also been reportedly prepared from fermented cassava flour or plantain flour (Abulude and Ojediran, 2006; Karim et al., 2015, 2013). The major difference between the stiff dough types is in appearance and viscoelastic properties. Stiff dough can be made either singly with plantain flour or in combination with yam flour Abulude and Ojediran (2006). The *amala* is prepared by reconstituting yam, cassava or plantain flour in boiling water until a smooth paste is formed (Karim et al., 2013).

The low nutritional value of *amala* has prompted many researchers to fortify this staple with different fortificants such as distillers spent grain (Awoyale et al., 2010), soybean flour (Jimoh and Olatidoye, 2009) and *M. Oleifera* leaf powder (Karim et al., 2015, 2013).

M. Oleifera leaf powder (MOLP) at varying concentrations of 2.5%, 5%, 7.5% and 10% was reportedly used in the fortification of *amala* prepared from yam flour Karim et al. (2013). The addition of 10% MOLP was found to increase the protein content of *amala* by approximately 48% (Karim et al., 2013). Similarly, calcium, magnesium, potassium, sodium and iron contents of the fortified amala increased following the addition of MOLP. However, the colour of the *amala* fortified with 10% MOLP was poorly rated. Fortification of amala with MOLP beyond 2.5% was reported to adversely affect its sensory attributes (Karim et al., 2013).

In a recent study by these authors, the protein content of amala prepared from plantain flour fortified with MOLP up to 2.5% was three times higher (Table 1) than the unfortified amala (Karim et al., 2015). The protein content (6.36%) of amala prepared from yam flour fortified with 2.5% MOLP reported by Karim et al. (2013) was lower (1.6 times) (Table 1) than those reported for amala prepared from plantain flour fortified with 2.5% MOLP (Karim et al., 2015). The variation in the reported data by these two studies may be attributed to differences in the protein content of the MOLP used in the respective studies and possibly the influence of the slightly higher protein content in plantain flour compared to yam flour. Although, Karim et al. (2015), reported the chemical composition of the MOLP and plantain flour used in their study, the data for the initial chemical composition for yam flour and MOLP were not reported in their previous study (Karim et al., 2013).

MOLP was found to influence the functional properties such as swelling and pasting of MOLP fortified plantain flour (Karim et al., 2015). Karim et al. (2015) reported a progressive and significant reduction in the pasting and setback viscosities of plantain flour following the addition of MOLP. The reduction in setback viscosity is of great importance in the storage characteristics of amala. For instance, if the stiff dough is not consumed immediately after preparation, after certain time which may vary with the stiff dough type, syneresis or retrogradation sets in. The stiff dough releases water and becomes extremely soft. Although, the above authors reported the reduction in setback viscosity of plantain flour fortified with MOLP, the study did not report if the prepared fortified stiff dough showed better keeping quality with regards to lower retrogradation tendencies compared to the unfortified stiff dough. Therefore, it may be difficult to conclude that the reduction in setback viscosity of plantain flour following the addition of MOLP will result in actual reduction in syneresis when the stiff dough is eventually prepared. In this regard, more studies should establish the influence of the MOLP on

Table 1 Protein and selected mineral contents of stiff dough fortified with 2.5% MOLP.

Stiff dough Type	MOLP (%)	Protein (%)	Calcium (mg/100 g)	Magnesium (mg/100 g)	Potassium (mg/100 g)
**Plantain flour	0	3.52	190.03	94.06	4612.10
**Plantain flour	2.5	10.36	254.42	132.04	4945.10
*Yam flour	0	5.73	198.72	140.23	435.36
*Yam flour	2.5	6.35	200.14	144.70	484.39

MOLP: *Moringa oleifera* leaf powder.
[*] Karim et al. (2013).
[**] Karim et al. (2015).

stiff dough retrogradation tendencies and keeping quality. Further, the in-vivo and in-vitro digestibility properties of the fortified stiff dough must also be ascertained. This is particularly important as previous studies indicated that approximately 70% of the protein in MOLP is insoluble (Teixeira et al., 2014). These authors reported low in-vitro protein digestibility (33%) for MOLP. The low digestibility of MOLP was attributed to intrinsic resistance against digestive enzymes and possibly the presence of thermoresistant compounds such as tannins (Teixeira et al., 2014).

1.3.2. Cereal gruel

Cereal gruel also called *ogi* is regarded as both a weaning or complementary food for infants and a breakfast cereal for adults. It is a fermented cereal porridge made from maize, sorghum or millet. Traditionally, *ogi* is prepared by soaking the cereal grains in water for about 3 days followed by wet milling and sieving to remove bran, hulls and germ (Abioye and Aka, 2015; Ladunni et al., 2013). The filtrate, which is usually white starchy sediment, is fermented for about 2–3 days. During the production *ogi,* nutrients including protein and minerals are reportedly lost from the grain during sieving. The resulting *ogi* has been shown to be of low nutritional quality (Abioye and Aka, 2015; Akinrele and Bassir, 1967).

The addition of MOLP or *M. Oleifera* flower powder (MOFP) to ogi was found to substantially improve the nutritional value of maize or millet gruel (Abioye and Aka, 2015; Arise et al., 2014; Olorode et al., 2013). The vitamin A content was found to increase by approximately 15 fold (Olorode et al., 2013). Other nutrients, such as protein, calcium, iron and phosphorus contents also showed significant increase after the addition of MOLP (Abioye and Aka, 2015; Olorode et al., 2013). The effect of MOLP on nutrient content and functional properties of *ogi* has been found to vary among authors (Abioye and Aka, 2015; Olorode et al., 2013). Abioye and Aka (2015) working with white maize variety reported approximately 94% increase in protein content of ogi fortified with 15% MOLP. However, approximately 44% increase in protein content of ogi was reported for yellow maize fortified with the same (15%) MOLP (Olorode et al., 2013). Similarly, at the same MOLP concentration of 15%, the reported reduction in swelling power of the fortified ogi varied substantially. Approximately 8% reduction in swelling power was reported by Olorode et al. (2013), while a higher reduction swelling power (approx. 23%) was reported for white maize ogi fortified with MOLP as 15% (Abioye and Aka, 2015). The differences in protein content and swelling power could possibly be attributed to the initial protein, starch and lipid content of the maize. This seems plausible since these components may interfere with hydration and swelling. The initial protein content of the MOLP and possibly the accuracy of the protein determination method may also have accounted for the differences. However, both authors did not report the initial chemical composition of the maize and MOLP used. It is therefore difficult to attribute the source of variation between these studies to the above mentioned plausible reasons. Further, Abioye and Aka (2015) and Olorode et al. (2013) reportedly mixed the MOLP into the dried ogi. However, none of these authors reported the details of the experiment such as mixing time and mixing speed. These variables may also have contributed to the variation in the reported data. It is also very important to comment on the acceptability of the MOLP fortified ogi samples. According to the studies described above, acceptable ogi can be prepared using about 10% MOLP (Abioye and Aka, 2015; Olorode et al., 2013). The acceptability of MOLP fortified ogi may require larger sensory panel members above what was reported by these authors. This is very crucial and will determine to a greater extent the reliability of reported data in the literature. For instance, the studies on stiff dough showed that about 2.5% MOLP was sufficient to produce acceptable stiff dough with improved nutritional value (Karim et al., 2015, 2013). This level of MOLP incorporations into stiff dough is much lower than what was recommend for ogi (Abioye and Aka, 2015; Olorode et al., 2013). MOLP has a deep green colour which may be attributed to its high chlorophyll content and may mask the colour of most foods when added in large quantities (Karim et al., 2013). The use of MOFP has also been reported for improving the nutritional value of weaning foods prepared from maize and millet blends (Arise et al., 2014). These authors reported that weaning food fortified with 20% MOFP had higher rating in all sensory attributes measured. MOFP flower powder has a cream colour which may be more acceptable and appealing than MOLP especially at high concentrations. Although the study on weaning food reported the initial chemical composition of MOFP, the chemical composition of millet and maize was not reported (Arise et al., 2014). Shiriki et al. (2015) recently studied the nutritional quality of complementary food formulated from maize, peanut and soya bean fortified with *M. Oleifera* leaf using albino rats. Diets containing *M. Oleifera* displayed superior protein contents than diet without *M. Oleifera* and with commercially sold complementary food (Shiriki et al., 2015). Further, these authors showed that the inclusion of up to 10% *M. Oleifera* improved protein efficiency ratio (PER), net protein ratio (NPR) and feed conversion efficiency (FCE) of the complementary food in the experimental rats. The improvement in these protein quality parameters was attributed to the utilization of the increased protein and micronutrients from *M. Oleifera* leaves (Shiriki et al., 2015). Similarly, there was improvement in apparent digestibility (AD) of the *M. Oleifera* fortified diets, which compared favourably with Nestle Cerelac, a popular complementary food (Shiriki et al., 2015). However, at higher concentrations (15%) of *M. Oleifera* leaves in the formulated diet, there was a significant reduction in the measured protein quality parameters i.e. PER, NPR, FCE and AD. According to the authors, the lower values recorded for these parameters could be attributed to the lower quantity of *M. Oleifera* leaves consumed by the experimental rats, resulting from the bitter taste imparted by *M. Oleifera* leaves (Shiriki et al., 2015).

Many of the studies described above showed that products formulated with MOLP at high concentrations ($>2\%$) may generally be unacceptable to most consumers. Hence, subsequent studies on the use of MOLP should therefore be properly designed and optimized to account for the possible sources of variations such as mixing time, mixing speed, initial chemical composition of the base material and the use of larger sensory panel possible from outside the institution where the research is being done. Further, as previously indicated, the in-vivo and in-vitro digestibility properties of the fortified *ogi* must be assessed.

1.3.3. Bread

Several attempts have been made by researchers to either reduce or completely replace the *amount* of wheat flour used in bread formulation. According to Gallagher et al. (2004), the replacement of wheat gluten functionality in gluten-free dough based formulation such as bread poses a major challenge to food scientists. The advocacy for using composite flour in bread production stemmed from the huge cost of importing wheat flour to most developing countries. Besides the associated cost, efforts are being geared towards increasing the utilization of many underutilized crops in composite bread. However, till date, most breads produced from other flours have not shown superior quality to that obtained from 100% wheat flour. A few studies have reported comparable viscoelastic property of modified zein to that of gluten (Falade et al., 2014; Lawton, 1992; Schober et al., 2008; Taylor et al., 2016). Zein (maize prolamin) was reported to display viscoelastic properties similar to that of gluten in aqueous dough systems, when heated above its glass transition temperature (Lawton, 1992; Schober et al., 2008). The superiority of wheat gluten is associated with its viscoelastic property that allows the retention of carbon dioxide produced during dough fermentation (Erickson et al., 2012).

Bread is a staple in many parts of the world, whose quality is determined by several factors including loaf volume, the colour and texture of the crust and crumb. Its nutritional value is dependent on the ingredient used in its formulation.

The inclusion of *M. Oleifera* flower, seed or leaf powder in bread dough prepared from wheat flour alone or in combination with other flours has been reported to improve nutritional the value of bread (Chinma et al., 2014; Ogunsina et al., 2010; Sengev et al., 2013). For example, the protein and crude fibre content of wheat flour bread fortified with 5% MOLP was found to increase by approximately 54% and 56% respectively (Sengev et al., 2013). Other reports on MOLP fortified bread reported approximately 17% and 88% increase in protein and crude fibre content respectively (Chinma et al., 2014). The variations in the reported increase in nutrient content by these authors may be attributed to the influence of the ingredients such as MOLP and the wheat flour used in the bread formulation. The study by Chinma et al. (2014) on the use of MOLP in bread fortification combined germinated tigernut in the dough formulation. With this formulation, it will be very difficult to access the influence of MOLP separately from that of germinated tigernut. Many of these shortcomings in formulation and experimental designs have been addressed in previous sections. It is pertinent to state that, although, authors have the right to design a workable experiment, the design must be such that it will prevent ambiguity in linking the influence of ingredients used on the formulated product as previously indicated. The improvement in nutrient composition of MOLP fortified bread was found to be accompanied by poor sensory properties including crust and crumb colour and reduction in loaf volume, weight and height (Fig. 1a) compared to the unfortified bread (Sengev et al., 2013). Studies by Karim et al. (2013) on MOLP fortified amala similarly reported poor rating for amala fortified with MOLP beyond 2.5%. White bread is known to have a brown crust and a cream to white appearance. MOLP was found to mask the colour of the bread as shown in Fig. 2a. Similarly, the MOLP fortified bread samples were reported to have herbal flavour (Sengev et al., 2013). These authors suggested the use of flavouring agent that will mask the herbal flavour of MOLP in order to improve its acceptability in this regard.

A promising alternative in bread fortification using *M. Oleifera* is the seed or flower. *M. Oleifera* seed is equally rich in protein with values ranging between 27% and 33% (Mbah et al., 2012; Ogunsina et al., 2010). The fortification of wheat flour with *M. Oleifera* seed flour (MOSF) in bread production up to 15% reportedly increased protein content by approximately 67% without significantly altering the sensory properties (Ogunsina et al., 2010). Bread fortified with MOSF (Fig. 1b) showed comparable appearance to the control and superior appearance to those fortified with MOLP (Fig 1a). The physical properties such as loaf volume and crust colour of bread fortified with 5% MOSF were similar to those of the control.

Sensory quality such as colour, taste and aroma is important parameter that determines to a great extent the acceptability of a product. Colour seems to be the most important of all as an attractive product will get the attention of the consumer before other properties may play a role. Future studies on the use of MOLP in bread fortification should take this into account. High technology may be deployed to selectively separate the active protein component in *M. Oleifera* leaf while removing the chlorophyll content. If this is successful, MOLP will be a valuable ingredient with wide application in bread and other related pastry products.

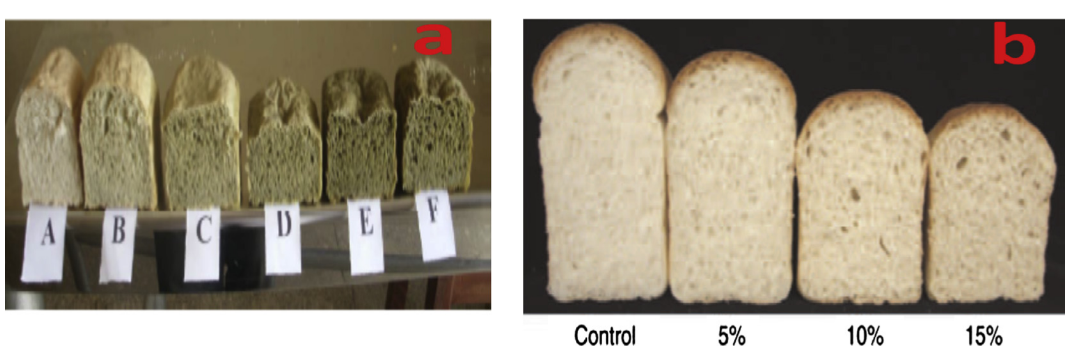

Figure 1 Appearance of bread fortified with MOLP (a) and MOSF (b). MOLP: *Moringa oleifera* leaf powder and MOSF: *Moringa oleifera* seed flour. A: 100% Wheat flour, B: 99% Wheat flour: 1% MOLP, C: 98% Wheat flour: 2% MOLP, D: 97% Wheat flour: 3% MOLP, E: 96% Wheat flour: 4% MOLP, and F: 95% Wheat flour: 5% MOLP. [a]Sengev et al. (2013) and [b]Ogunsina et al. (2010). Reproduced with permission from Publisher.

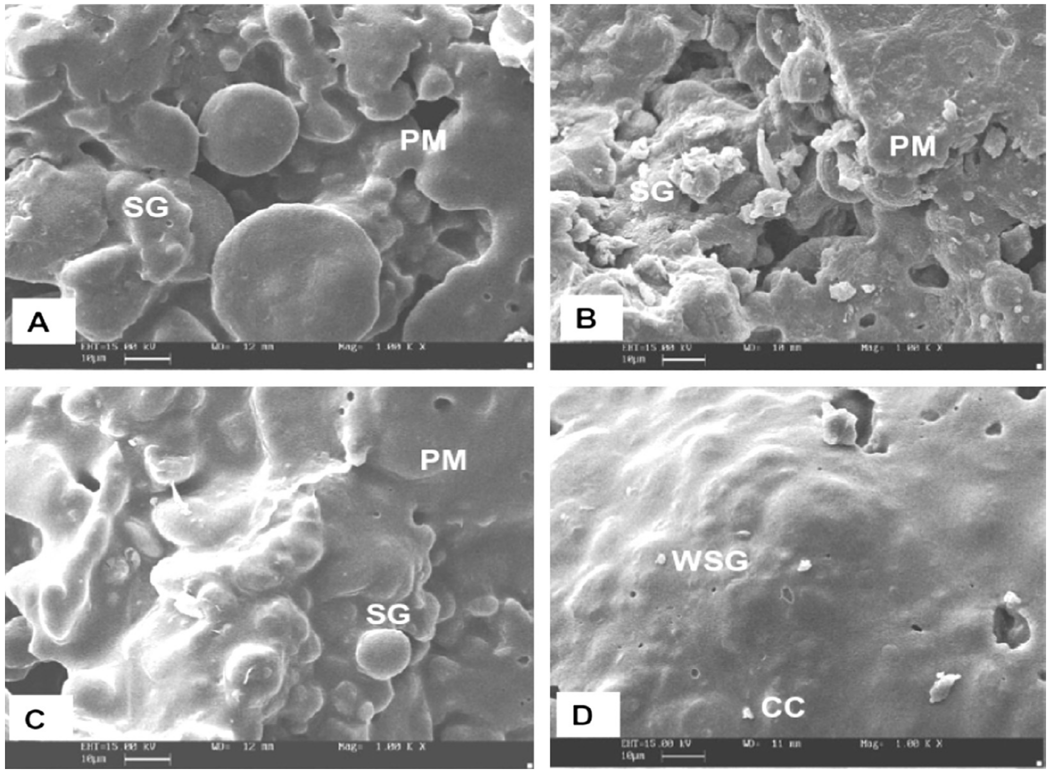

Figure 2 Micrographs of cookie surface fortified with MOLP (Dachana et al., 2010). A: Unfortified dough, B: 5% MOLP, C: 10% MOLP, D: 15% MOLP, SG: Starch granule, PM: Protein matrix, CC: Calcium oxalate crystals. WSG: Wrapped starch granules, and MOLP: *Moringa oleifera* leaf powder. Reproduced with permission from John Wiley and Sons with License Number: 3807761147821.

1.3.4. Biscuits

According to Claughton and Pearce (1989), baked snacks such as cookies are widely consumed in many part of the world. They are used for feeding and nutrition improvement programmes especially among low-income groups (Claughton and Pearce, 1989). Thus, biscuits can be regarded as food vehicle for carrying desired nutrients to the target individuals. The sensory properties of biscuits must not be altered beyond acceptable limits by the consumers. As previously indicated, whatever is to be added to any food as a fortificant, it must not improve the nutritional value of the food at the expense of the sensory properties.*M. Oleifera* seed (Ogunsina et al., 2010) or leaf (Alam et al., 2014; Dachana et al., 2010; Kar et al., 2013; Manaois et al., 2013) has also been employed in wheat biscuit or cookie fortification. Ogunsina et al. (2010) reported that 20% level of *M. Oleifera* seed flour (MOSF) produced wheat cookies with surface cracking pattern and colour similar to the control. Beyond this concentration, both colour and surface cracking pattern were adversely affected. Further, the protein contents of the fortified cookies were reportedly higher than those of the unfortified control. The protein content of cookies fortified with 10% and 20% MOSF increased by 45% and 90% respectively (Ogunsina et al., 2010). Wheat cookies fortified with 10% MOSF resulted in higher increase (45%) in protein content than those reported for wheat cookies fortified with 10% MOLP by different authors (approx. 1% increase) (Alam et al., 2014), (approx. 22% increase) (Dachana et al., 2010). Variation in the reported values may be due to differences in the chemical composition of the wheat flour used, the MOLP or MOSF. Also, quantities of other ingredients such as egg used in the various recipes may have accounted for these variations.

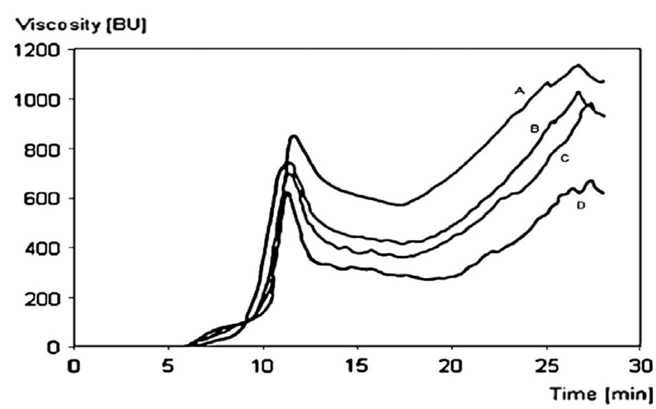

Figure 3 Amylograph of wheat flour fortified with MOLP (Dachana et al., 2010). MOLP: *Moringa oleifera* leaf powder. A: 0% MOLP, B: 5% MOLP C: 10% MOLP, and D: 15% MOLP. Reproduced with permission from John Wiley and Sons with License Number: 3807761147821.

Besides these factors, the nature of the *M. Oleifera* leaves, i.e. whether dried or fresh may also influence the nutrient content of the fortified cookies. Manaois et al. (2013), reported a higher increase (approx. 26%) in protein content of rice cookies fortified with freshly harvested 5% MOLP compared to dried MOLP at the same concentration which showed approximately 14% increase. However, only cookies fortified with 1% MOLP were acceptable by panellists and comparable to the unfortified control cookie (Manaois et al., 2013). Further studies may be required to establish the influence of dry or fresh *M. Oleifera* leaf and seeds on properties of wheat cookies. Although, there was improvement in nutritional content of the cookies for all the studies described above, the major challenge as observed for *M. Oleifera* fortified amala, ogi, bread and in this section is the poor acceptability of fortified products with increasing concentration of *M. Oleifera*.

The extent of interaction between *M. Oleifera* leaf and other ingredients used in cookie production at microstructural level has also been reported (Dachana et al., 2010). Starch granules were reportedly wrapped in cookies (Fig. 2) made with 10% and 15% MOLP (Dachana et al., 2010). The use of scanning electron micrograph (SEM) techniques to study interactions at micro level has been well documented. Other studies in which MOLP or MOSF has been used to fortify foods such as amala, ogi, bread as described above may further use SEM techniques to describe the relative positions of the added MOLP in the fortified food matrix. This may enhance the understanding of the interactions between the components and may also play a role in explaining the influence of MOLP or MOSF on digestibility of the fortified products. For instance the study by Dachana et al. (2010) on cookies fortified with MOLP as mentioned above showed that MOLP restricted starch granule swelling as evident in the reduction in peak viscosity (Fig. 3). This may have explained why the starch granules were wrapped in the wheat dough as shown in their SEM studies (figure not shown). Starch is known to contribute significantly to the swelling of flour matrix. The peak viscosity of the fortified wheat flour was found to decrease with increasing concentration of MOLP. Wheat flour fortified with 15% MOLP showed the highest reduction value of approximately 27% (Dachana et al., 2010).

1.3.5. Yoghurts and cheese

The use of MOLP in fortifying dairy products such as yoghurt and cheese at varying concentration up to about 3% has been reported in the literature (He et al., 2010; Hekmat et al., 2015; Kuikman and O'Connor, 2015; Salem et al., 2013). Probiotic yoghurt fortified with 0.5% MOLP and 5% sugar was reported to be acceptable to taste panel members (Hekmat et al., 2015). When MOLP was added at 1% concentration the yoghurt samples were found to have strong undesirable flavour. Studies by Kuikman and O'Connor (2015) however, reported an improvement in sensory attributes of yoghurt fortified with MOLP by adding banana, sweet potato and avocado. These authors used 17.09 g of MOLP per litre of yoghurt, which amounts to about 1.7% of MOLP. Among the studied fruits and vegetable yoghurt, MOLP fortified yoghurt with added banana was found to show comparable appearance, flavour, texture and overall acceptability with the yoghurt without MOLP (Table 2). The difference in the reports on the study of probiotic yoghurt fortified by MOLP with added fruits or vegetable and those reported by Hekmat et al. (2015) may be attributed to the influence of the respective fruits used. Banana, avocado and sweet potato may have contributed to the improved flavour, appearance and overall acceptability of the fortified yoghurts. According to Hekmat et al. (2015) the use of MOLP beyond 0.5% marred the appearance of probiotic yoghurt. However, up to approximately 2% MOLP with added fruits or vegetable was reported to produce acceptable yoghurt (Kuikman and O'Connor, 2015).

Table 2 Sensory scores of fruit yoghurt fortified with MOLP.*

Sample	Appearance	Flavour	Texture	Overall quality
Moringa	4.6 ± 2.8^{b}	5.4 ± 2.3^{b}	4.6 ± 2.4^{b}	4.5 ± 2.6^{bc}
Moringa-banana	6.9 ± 2.0^{a}	6.7 ± 2.1^{a}	6.2 ± 2.4^{a}	6.2 ± 2.8^{ac}
Moringa-sweet potato	5.4 ± 2.2^{b}	5.7 ± 2.5^{ab}	5.6 ± 2.1^{ab}	5.2 ± 2.7^{c}
Moringa-avocado	5.5 ± 2.6^{b}	5.1 ± 2.4^{b}	5.3 ± 2.4^{ab}	5.4 ± 2.6^{c}
Control	7.1 ± 1.8^{a}	6.9 ± 2.1^{a}	6.7 ± 2.0^{a}	7.2 ± 2.3^{a}

Mean ± SD. Mean with different superscript letters along a column are significantly different ($p < 0.05$).
* Kuikman and O'Connor (2015).

Other dairy application of MOLP is in cheese fortification. The nutrient content such as fat, ash protein and carbohydrate of cheese produced from buffalo milk fortified with MOLP was found to generally increase with increasing levels of added MOLP (Salem et al., 2013). The protein content of the cheese with 1%, 2% and 3% MOLP increased by 3%, 5% and 8% respectively. Similarly, the antioxidant properties of the fortified cheese substantially increased with increase in MOLP concentration. Cheese fortified with 3% MOLP reportedly showed higher (three times) antioxidant properties than the control cheese (Salem et al., 2013). Up to 1–2% MOLP was recommended for use in cheese fortification by these authors, since these levels (1–2%) of MOLP had comparable sensory properties with the control. Further, the MOLP fortified cheeses were reported to have good and comparable sensory quality with the control after three weeks of storage.

From the studies described above on dairy products (yoghurt and cheese), up to 2% of MOLP seem appropriate for use in both products depending on other food additives which may be added to suppress the herbal smell and intense green colour of MOLP, which usually mask MOLP fortified foods. Although the study on buffalo cheese reported that MOLP fortified cheeses showed comparable quality with the control cheese, the authors also pointed out that the acceptability of the fortified cheeses was influenced by the fact that the taste panel members were accustomed with MOLP and other herbal green leaves. Hence, it is imperative to emphasize that the use of MOLP in dairy products such as cheese and yoghurts may depend on the norms and cultural acceptance of herbal leaves. More awareness on the health benefits of MOLP should therefore be done. Further, the use of the seed and flower of *M. Oleifera*, which are also good sources of proteins and phytochemicals, could also be employed in dairy products since both the seed (Ogunsina et al., 2010) and the (Arise et al., 2014) flower have been found to cause minimal changes in colour of fortified products. Shelf stability studies on the fortified dairy products could also be assessed.

1.3.6. Cake

Studies on the fortification of cake using *M. Oleifera* seed, leaf or flower are very limited. Kolawole et al. (2013) reported the use of up to 20% MOLP in the fortification of wheat cake.

Their finding is similar to studies described above where there was improvement in the nutrient content of the fortified samples with increasing concentration of MOLP. However, the sensory property of the cake at MOLP level above 8% was reportedly rated low by the sensory panel. This further confirms the influence of the high chlorophyll content of the *M. Oleifera* plant which can strongly mask the colour of the fortified food (Karim et al., 2013). A more promising alternative for cake fortification may be the use of the seed and flower of *M. Oleifera* since their colour is not as strong as the leaf, yet they show relatively high nutrient content similar to that of the leaves.

1.3.7. Soup

The use of leafy vegetables in soup and dishes has been a practice that transcends human history. A recent survey on the utilization of *M. Oleifera* plant reported that its leaves have found applications in preparing soup, salad and for making tea (Stevens et al., 2013). Evidence of the use of *M. Oleifera* leaves, in making soup, exists in the literature (Babayeju et al., 2014; Chandramouli et al.). *M. Oleifera* was reportedly used in making soups alone or in combination with melon seed and spinach (Babayeju et al., 2014). In this study, six soup blends were produced, in varying proportion; spinach and melon (60:40), *M. Oleifera* leaf and melon (60:40), *M. Oleifera* leaf, spinach and melon (30:30:40), spinach (100), *M. Oleifera* leaf and spinach (50:50) and *M. Oleifera* leaf (100). The control soup made from spinach and melon in ratio 60:40 was reported to have the highest acceptability. According to these authors, up to 30% of *M. Oleifera* leaf can be used in making traditional dishes with added species and melon, since this level of inclusion had ratings next to the control among the studied samples (Babayeju et al., 2014). Although, the survey on the use of *M. Oleifera* showed that the leaves of this miracle plant are widely used for salads and in soup, very limited scientific studies exist to substantiate this claim. Consequently, it may be difficult to generalize this statement that *M. Oleifera* is widely used in dishes for making acceptable soup. Further, the survey was limited to a particular country suggesting that more studies need to be done on the knowledge and the actual use of *M. Oleifera* plant in soup application across other parts of the world. It is also necessary to state that the study described above on the use of *M. Oleifera* leaf by Babayeju et al. (2014), did not report the nutrient composition of the various formulation. Future studies may involve drying the soups and assessing the effect of processing on the nutrient profile as well as the shelf stability of the soups.

2. Conclusions and future research

M. Oleifera plant is indeed a miracle plant with enormous potentials yet to be fully explored in food application. The use of *M. Oleifera* leaf powder, *M. Oleifera* seed powder, *M. Oleifera* flower powder in various food applications such as in fortifying amala (stiff dough), ogi (*maize* gruel), bread, biscuits, yoghurt, cheese and in making soups was reviewed. Many of the studies summarized in this paper need further validation to substantiate their findings. For instance *M. Oleifera* leave powder was reported to reduce tendency for retrogradation in stiff dough prepared from plantain flour as shown by the low set back viscosity values. However, the study did not show retrogradation was actually affected when the stiff dough was prepared. Further, experimental designs should be such that variables such as mixing time and speed are well documented in research papers. In-vivo and in-vitro digestibility properties of fortified products must be determined. Nutrient bioavailability and phytochemical contents of *M. Oleifera* fortified products also need to be determined in future research. Although, many of the reviewed studies reported improvement in the nutritional value of foods fortified with *M. Oleifera*, none of the study showed the digestibility (in-vivo or in-vitro) and availability of these nutrients. Also very limited studies assessed the shelf stability of the fortified samples. Lastly, more sophisticated techniques such as the use of SEM, DSC, FTIR, XRD, RVA, and NMR techniques should be applied in future research.

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