

Chapter 11

Biofortification: Quality Improvement of Faba Bean



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11.1 Introduction

Faba bean (*Vicia faba* L.) is one of the major legume crops and belongs to genus *Vicia* L. in the family *Fabaceae*. Faba bean known as field bean, horse bean, and broad bean is regarded as one of the ancient accustomed legume among humans (Fig. 11.1) (Abebe et al., 2014). For over 8000 years it is a part of the diet in the Mediterranean, and it has spread throughout the world from here. China is the world largest producer of faba bean, they contribute 50% of worlds production and they are closely followed by Ethiopia, thus making Ethiopia the largest producer of faba bean in Africa (Chopra et al., 1989; FAOSTAT, 2007). There are various cultivars with large and small seeds (Bond et al., 1985). About 26,000 accessions are reportedly held in gene banks, collections could be found in ICARDA International Centre for Agricultural Research in the dry areas in Syria and the Vavilov Institute in Russia. Faba bean is one of the most important legume crops cultivated due to its high yielding potential, nutritional composition and the role as cover and forage crops (Maalouf et al., 2018a). Faba beans had been known to improve cereal based system and soil fertility through nitrogen fixation (Maalouf et al., 2018a; Jensen et al., 2010). Faba bean is low cost food rich in protein and adapts to all the ecological regions of the world, hence it is grown from the arctic circle to the equator and equally from the high altitudes to sea level. The majority of undernourished populations are in the developing countries of the world, they rely on faba bean as a crucial protein source for the low income group and rural populations. The high protein content of faba bean has made it a cardinal legume and a locum for meat among the

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Fig. 11.1 Faba bean seeds

teeming indigent groups (Crepon et al., 2010). In developed countries, faba beans are a composition of animal feeds of protein level between 20–41%. It stands as an avenue for economic sustainability for the farmers and equally a source of foreign currency for the under developed countries. Faba beans are generally utilized in crop rotation with cereals, basically to improve the soil health through fixation of atmospheric nitrogen (Sahile et al., 2008). In the Mediterranean, Middle East, Ethiopia and China, it is a common breakfast item, while the roasted seeds are cherished in India (Duke, 1981). Faba bean straw are highly valued, it is of premium importance in Sudan and Egypt, while the straw is employed for fuel and brick making in Ethiopia and Sudan. Faba bean is generally classified according to its seed size and colour (Etemadi et al., 2017). It varies from large seeds variety (>1.0 g/seed) to medium (0.5 – 1.0 g/seed) and small seeds (<0.5 g/seed) (Etemadi et al., 2017). It is commonly divided into four groups; *Vicia faba* var. *major* is the broad bean with large flat seeds, also known as broad beans; *Vicia faba* var. *equina* has medium sized seeds known as horsebean; *Vicia faba* var. *minor* is the tick bean with small round seeds; and *Vicia faba* var. *paucijuga* has small seeds. Duc et al. (1999), also reported that faba bean can be categorised with respect to the content of tannins

in the integuments and the content of vicine + convicine (VC) in the cotyledons. Micronutrient malnutrition has been the major problem in the developing countries because lots of people are suffering from micronutrient deficiency. Mineral and vitamin are essential in our daily diet but in developing countries, deficiencies in these parameters pose a public health problem to the consumers. The major mineral deficiency such as iron and zinc are common and widespread affecting more than half of the human population. This affliction could be alleviated through four major ways such as food supplementation, fortification, dietary diversification and biofortification. To alleviate malnutrition, Muluaem (2015) suggested that biofortification of crop is the best way of improving the quality of faba beans through breeding strategies. Biofortification is one of the cost effective and sustainable agricultural processes which can reduce vitamin and mineral deficiencies in the diet (Bouis et al., 2017). Therefore, food biofortification with micronutrients is very important for health, as it helps in alleviating the effect of “hidden hunger” or malnutrition at a relatively low cost (Horton et al., 2008). Through biofortification process, different genotypes of faba beans with drought tolerance, heat and frost tolerance, weed and disease tolerance, salinity tolerance etc. had been produced and released to increase productivity and yield of the crop. Likewise, the nutritional values (protein, zinc, iron, starch, fibre etc.) of the crop are improved while the antinutritional (tannin and phytate) compositions of the crop are reduced or eliminated in some species. Elimination of these antinutritional factors in some species and genotype of faba bean is useful for human health development and improvement since the essential trace elements from the dietary sources are available for absorption. It has been reported that phytate complexes bind divalent cations resulting in reduced bioavailability of the micronutrient while tannin complexes bind with protein resulting in reduced bioavailability of protein. This chapter presents quality improvement of faba bean through biofortification.

11.2 Production of Faba Beans (Broad Bean) Among the Continents

The area cultivated and yield of faba bean in 2015 to 2020 are shown in Table 11.1. Faba bean is rated as the third important grain legume in terms of the area cultivated, yield and production (Singh et al., 2013). In 2015, Africa countries cultivated larger areas (828,911 ha) than other continents but the yield was lower (15,191 hg/ha) than that of Asia, Europe and Oceania. But from year 2016 to 2020, Asia cultivated more areas with higher yield than other countries. There were increases in the yields in Africa and Asia countries while the yield decreased drastically in 2019 in Oceania countries. Increase in the yield may be as a result of replacement of the old variety (landraces) to improved varieties which are resistant to drought, heat, diseases etc. Reduction in the yield may be due to attack by insect, seed type, environmental conditions, soil condition/ nutrients, cultural practices adopted during cultivation

Table 11.1 Cultivated area and yield of faba bean

Year	Area harvested (ha) ^a					Yield (hg/ha) ^a				
	Africa	Americas	Asia	Europe	Oceania	Africa	Americas	Asia	Europe	Oceania
2015	828,911	178,007	797,720	437,978	163,900	15,191	12,008	20,043	29,665	17,315
2016	711,963	169,975	866,222	488,762	350,457	17,591	12,103	19,932	30,034	12,085
2017	749,323	171,245	893,725	502,472	232,732	19,352	12,304	21,218	32,543	20,778
2018	793,849	185,143	920,618	635,219	313,051	20,112	12,106	20,609	22,281	13,276
2019	756,158	182,373	887,804	553,613	233,967	19,709	12,086	20,677	28,773	9976
2020	762,542	187,394	867,721	638,950	214,892	19,554	12,230	20,833	28,613	14,565

Source: FAOSTAT database ([2022](#))

^aAggregate values

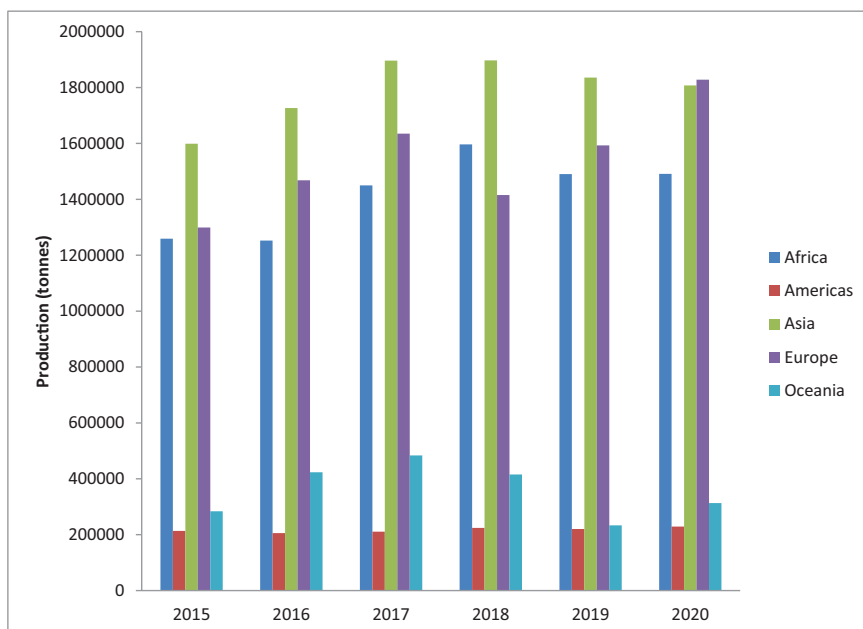


Fig. 11.2 Production of faba bean from 2015 to 2020. (Source: FAOSTAT database (2022))

etc. Asia countries are the leading producers of faba beans from 2015 to 2019 followed by the European countries as shown in Fig. 11.2. However in year 2020, production of faba beans was highest in the European countries. Oceania and Americas produced the least quantities of faba bean from 2015 to 2020. There were decline in the production of the faba bean from 2018 to 2020 and this may be due to susceptibility of landraces and cultivars to biotic and abiotic stresses with *Orobanche crenata*, which is the the major factor in North African countries such as Morocco (Maalouf et al., 2018a).

11.3 Factors Affecting Faba Beans Productivity

Researchers have identified numerous factors affecting the cultivation and production of faba beans. These factors caused biotic (parasitic weed, foliar diseases, and soil borne borne diseases) and abiotic (drought, heat, water logging, frost) stresses in the crops thereby affecting the yield and nutrients of the crops (Abdellatif et al., 2012; Maalouf, et al., 2018b). Among the factors are:

11.3.1 Drought

This is a major environmental factor affecting the physiological and biochemical properties of the crop by limiting faba bean growth, development and productivity (Li et al., 2018; Abid et al., 2020). Drought can be described as water deficit or change in water status leading to stress in the plant. Drought affects faba bean seed quality because it's among the factors regulating the seed protein content. Studies have shown that faba bean grown during drought conditions have impaired nitrogen fixation but increased the protein and sulphur contents of the faba bean (Rharrabti et al., 2001; Singh, 2007; Alghamdi, 2009). However, Smith (2018) reported that drought have no significant effect on the mineral contents and amino acids concentration in the crop. According to Amede and Schubert (2003), faba beans are more sensitive to drought than other legumes. Katerji et al. (2011) explained that drought caused reduction in grain and straw yield especially during flowering, early podding and grain stages. Drought stress caused increase in flowers number while the pods/seed numbers were greatly reduced due to high rate of abscission in faba bean (Sekara et al., 2001). De Costa et al. (1997) observed that different faba bean cultivars react to different water regimes and shortage of water lead to reduced leaf initiation, canopy size, expansion and biomass production. Reduction in faba bean yield and productivity was aided by increased soil salinity level during drought. Abid et al. (2020) suggested the use of 1 mM of β -aminobutyric acid (BABA) to improved the drought tolerance of faba bean. It was observed that the leaf relative water content, transpiration rate, stomatal conductance, photosynthesis rate were increased while the water use efficiency, malondialdehyde, electrolyte leakage levels and hydrogen peroxide (H_2O_2) were decreased. There was reduced cell membrane damage as a result of oxidative stress (Abid et al., 2020). Adaptation to drought depends on the species (within and between species) and genotypic differences as reported by Abdellatif et al. (2012).

11.3.2 Temperature

Faba bean is highly sensitive to heat stress especially during reproductive and seed filling stages. The optimum temperature required for flowering is 22–23 °C according to Patrick and Stoddard (2010). Extreme heat is detrimental to the production of faba bean in some countries such as Sudan, Ethiopia, Egypt etc. The effect of high temperature could lead to small and short stem crop with few pods and branches (Maalouf et al., 2018b). Extreme heat (42 °C) causes reduction in the yield, growth rate, photosynthetic pigments concentration and membrane stability (Hamada, 2001; Bishop et al., 2016). Bishop et al. (2016) explained further the effect of heat stress on faba bean during floral development. In the study, it was discovered that heat stress caused reductions in the yield of faba beans during reproductive development which may be due to gametophyte damage and failure of fertilization. Heat

stress caused variations in the cell wall components, starch, soluble sugars, lipid etc. while different patterns were observed in the oxidative stress enzymes of faba bean (Filek et al. 1997; Lavania et al., 2015). Frost is another temperature related factor that caused excessive yield loss in faba beans at early stage of flowering but two genotypes of faba bean (IX474/4-3 and 11NF010a-2) have been reported to have low sensitivity during reproductive and vegetative stages by Alharbi et al. (2021). Frost is categorized into radiation and advection frost based on the climatic and temperature conditions (Snyder & Abreu, 2005). The extent of damage caused by frost to faba bean is determined by the growth stage, duration, frost severity and frequency (Dalezios, 2017). Faba beans are reported to have moderate tolerance to frost because of the thick pod walls which protect the seeds during growth and development (GRDC, 2017). Severe frost affects the flower, yield and losses as a result of distorted growth which weakens the stem and subjects it to disease attack during early vegetation and flowering. Other studies on the effect of frost on faba bean varieties had been done in Australia, Central Alberta, and Europe and the best faba bean frost tolerant varieties had been recommended (Maqbool et al., 2010; Henriquez et al., 2018; Alharbi et al., 2021; Neugschwandtner et al., 2022).

11.3.3 Diseases

The yield of faba bean is affected by several biotic and abiotic factors. In Africa several pathogens are documented to be associated with faba beans (Nene et al., 1988). The production system and agroecological conditions set the importance of the pathogens (Najar et al., 2000). Faba bean is reported to be affected by over hundred types of viruses. However, of great economic importance in Africa and Asia are 16 viruses with varying symptoms such as yellowing, stunting and necrosis (Najar et al., 2000). The faba bean leaf roll virus is of extreme importance. It causes stunting and yellowing of the crop. Additionally, the beet western yellow virus, faba bean necrotic yellow virus, milk vetch dwarf virus, chick pea chlorotic dwarf virus and finally soy bean dwarf virus are all of significance and causes yellowing and stunting of the crop. The viruses are transmitted by aphids and they are limited to the stem. The chick pea chlorotic dwarf virus is spread by the leaf hopper. In some cases, complete crop failure has been attributed to these viruses (Najar et al., 2000). Another chief pest of faba beans is phytonemaode. All over the world, plant parasitic nematodes brings about significant reduction in yield of many crops (Fabiyyi & Olatunji, 2018; Fabiyyi et al., 2018a, b, 2019, 2020a, b). They have impacted largely in the production of pulse crops (Feyisa, 2021). The nematode genera that have been documented to parasitize the rhizosphere of faba bean are *Pratylenchus*, *Rotylenchulus*, *Tylenchorynchus*, *Xiphinema*, *Ditylenchus* and *Tylenchus* (Feyisa, 2021). Among the list, *Xiphinema* and *Ditylenchus* are reported to be predominant. This corroborates the report of Sikora and Greco (1990), they established that severe damage is caused by *Ditylenchus dipsaci* and *Pratylenchus*. Investigations by Cobbett (1969), revealed that *Pratylenchus pinguicaudatus* is one of the important

plant parasitic nematode that is associated with faba bean. The presence of *Pratylenchus* spp. on faba bean was affirmed by Di Vito et al. (1994) and Greco and Di Vito (1994) with the isolation and identification of *Pthorpei* in the root zone of faba bean. Hopper (1991) reported that faba beans are not resistant to nematode pests and *Ditylenchus dipsaci* is the most damaging. Among the faba bean diseases listed by Torres et al. (2006) are downy mildew (*Peronospora viciae*), rust (*Uromyces viciae-fabae*), Ascochyta blight (*Ascochyta fabae*), foot rots (*Fusarium* spp.) and chocolate spot (*Botrytis fabae*). Faba bean is affected by parasitic and non parasitic weeds. The common parasitic weeds that affect faba bean in North and East Africa is broomrape (*Orobancha* spp.) (Torres et al., 2006; Maalouf et al., 2018a, b).

11.3.4 Waterlogging

Other factors include waterlogging which affect faba bean during the growth, flowering and physiological trait (chlorophyll) thereby reducing the yield of the crops. It had been observed that faba bean is the most tolerant to water logging among the legumes (Solaiman et al., 2007). Malik et al. (2015) stated that waterlogging caused poor germination and affected photosynthesis in legumes which in turn lead to decrease in dry matter accumulation. However, Pampana et al. (2016) stated that waterlogging reduced soil oxygen thereby causing inhibition in root respiration, decreased root and shoot growth. Also, there are reductions in photosynthesis, yield, plant growth, biological nitrogen fixation, the formation, function and survival of nodules (Davies et al., 2000). This can later result in death of the plant during the end of waterlogging as duration of waterlogging had severe effect on the plant. Due to these factors, biofortification of the faba bean is necessary to improve the yield and nutrients of the crop through plant breeding processes.

11.4 Overview of Biofortification in Developing Countries

Dependable food production is hinged on dealing with sparseness of micronutrients. The invisible snag of hunger which loiters around half of the world's population is analogous to paucity of proteins, vitamins and micronutrients which are requisite in the human diet. (Graham et al., 1999; Bouis, 2003; Paine et al., 2005). A puissant panacea to nutritional shortfall is biofortification. Over half of the world population is hugely affected by dearth of zinc, iron and vitamin A in their diets, preschool children and women are the most vulnerable. About 42% of children whose age's ranges between 6 months to 4 years are anaemic, while women within reproductive age have low concentration of haemoglobin (WHO, 2017a). High percentage mortality, poor growth and perceptive impediment has been noted with nutrient deficiencies (UNDP, 2003; UNSCN, 2004; WHO, 2017a, b). Nutrient deficiencies could be managed through supplementation and enrichment of the staple

foods; it is a novel management practice to check multi nutrient deficiencies in third world countries under the United Nations Sustainable Development Goal projected for the year 2030 (Haas et al., 2005; Bailey et al., 2015; United Nations, 2016). High quality breeding methods coupled with novel biotechnology approaches are involved, the method ensures that rural areas which are considered as remote and who's populations are undernourished are touched most especially in sub-Saharan Africa and Asia (Arsenault et al., 2010). Furthermore, in developing countries, farm productivity could be increased with biofortification of crops without any environmental consequence. Farmers will look out for the mineral improved seeds because the trace elements are equally responsible for disease resistance in plants with reduced environmental stress. Through this approach, national growth is achieved by means of development of the health and wellbeing of the citizenry, while work capacity is accomplished with high level of educational attainment (Lockyer et al., 2018). The first step to biofortification is a collaboration between nutrition, health and agricultural research centres. This is essential for staple crops like cassava, wheat, sweet potato, rice and maize, so as to bring about the best nutritional and agronomic qualities in the new cultivars of the crops (Goto et al., 1999; Gregorio et al., 2000; Tomlins et al., 2004; Van Jaarsveld et al., 2005). Nutrient retention through cooking is evaluated, while cultivars that are promising are evaluated for bioavailability of micronutrients for the nutritional impact if any before the new cultivars are released. Inquest in to the social factors, economic state and dietary requirement of the rural populace is also a factor to be considered in the development of bio fortified crop lines. For example, in a country where rice is commonly eaten, it is suggested that rice should be supplemented with iron to upgrade the iron consumption status of the populace (WHO, 2018). Close to 20 million of the world population are currently consuming bio fortified crops, this has augmented the diets in areas where food choices are limited coupled with poor agrarian soils (Bouis & Saltzman, 2017). To realize a good biofortification regime of staple foods, for the general community and populace, plants within built natural micronutrients may be cross bred with a staple crop to bring about crops with the preference traits. Fertilizers with micronutrients may be used during the growing period of the crops so that the crops would take this up and a determined level of micronutrients is imbued in the crops. Finally, accumulation of micronutrients in staple crops could be executed through gene modification. Here, micronutrients that do not exist in the staple crop could be inserted by way of gene modification. For babies in third world countries, complementary feeding programs could be established such that micronutrient fortified baby formulas would be served (WHO, 2016; De-Regil et al., 2013). Although, targeting the national population for biofortification is usually a herculean task, it is thus easier to focus on food production and distribution logistics, with this in mind, suitable target population is identified and the required nutrient is set (Lividini et al., 2017). After this, high quality genes are picked out while important attributes such as weather tolerance and disease resistance are equally considered. The last stage is testing of the fortified crop, if farmers would be willing to produce them and the opinion of the public on the new fortified crop is also sought (Birol et al., 2015). Once all the stages are completed, the new crop will be

released in to the market. In some cases, the bio fortified crops are met with rejection by a fraction of the population because of colour difference from the traditional crop which they are familiar with. For example, a staple crop fortified with vitamin A, may come with orange or bright yellow colour as against the white native crop that the populace is accustomed to. This may bring about a little set back in to the adoption of the staple crop by the community. In this circumstance, there is the need for jingles and educational programmes until the crop is accepted.

11.5 Methods of Biofortification

Biofortification is a process of increasing the amount of minerals and vitamins in a crop through agronomic practices, transgenic and plant breeding (Bouis & Saltzman, 2017). This is done to some staple foods in order to combat global micronutrient malnutrition. Thavarajah et al. (2014) stated that biofortification of certain pulse crops such as lentils, field pea and chickpea have been limited to some North America regions. An approach which focuses on manoeuvring of plant genome while mineral fertilizers could be applied during the crop growth to enhance solubility of micronutrients in the soil, was reported to be effective by White and Broadley (2009). The techniques that could be employed in biofortification of crops include.

Agronomic biofortification is a temporary way of increasing micronutrient in plant through the use of chemical fertilizers or foliar sprays (Cakmak, 2014). This is done especially when the target is to increase micronutrients which are absorbed directly by the plant such as zinc, but is not effective and efficient for micronutrients synthesized in the plant which cannot be absorbed directly (Lyons & Cakmak, 2012). By way of this method, zinc and iron could be augmented in nutrient deficient soils. Yield and accumulation of iron and zinc in grains has been achieved through fertilization (Alloway, 2008). Usually, iron chelates and acidification of the soil are used in place of inorganic iron in fertilizers due to precipitation and oxidation which prevents the use of inorganic iron by plants. This has proven to be efficacious in improving iron uptake and accessibility by plants (Wakeel et al., 2018). Research has demonstrated that application of foliar zinc is significantly more effective than fertilization in grains such as wheat, maize and rice. Solubilisation of zinc by soil bacteria is equally a reliable method which has been effective in increasing zinc concentration in shoots and roots of crops such as soybean and wheat (Madhaiyan et al., 2010). The use of plants like vetch broad bean and clover for nitrogen fixing purposes coupled with urea covered with zinc has been documented to increase the concentration of zinc in desired crops (Madhaiyan et al., 2010). The quality and vegetative growth of basmati rice was improved through surface fertilization using urea coated zinc rather than fertilisation with $ZnSO_4$ (Pooniya & Shivay, 2015). A cost effective method is the biofortification of selenium in wheat. The selenium is added via foliar spray and equally during seed germination and soaking process of the plant. This method has been used to augment selenium deficiency in human population (Masarovičová & Král'ová, 2012). In recent times, iron

deficiency has been combated by the addition of iodate salts and soluble iodide to water used for irrigation purposes to upgrade iron concentration in edible plant parts (Lyons et al., 2004). Surface application of KIO_3 is equally known to improve iodine content of rice, corn and wheat (Budke et al., 2020). This has also been established to be effective other than application through the soil. This method has been used in the fortification of apples with iodine (Cakmak et al., 2017). Early development of milk stages in cereals has been aided via fortification with iodine, high percentage of iodine was detected in the grains at harvest (Cakmak et al., 2017). Selective breeding has additionally been used as a method of biofortification. Conventional plant breeding technique requires identification and development of parent lines with high mineral or vitamin levels and cross breeding them to produce plants with the desired nutrient and agronomic traits (Bouis et al., 2017). The high nutrient profile parental lines are screened and utilized for production of molecular markers for marker assisted selection in pulses. Recombinant inbred lines for conventional breeding are successful in pulses due to availability of wide gene pool (Kumar & Banerjee, 2022).

Varieties of crops that are rich in micronutrients are crossed with crops that are deficient in some essential nutrients and traits (Malik & Maqbool, 2020). This procedure actually has some difficulties like absence of heritability and of genetic diversity. Thus monitoring for a long time and support is needed. This bottle neck has brought about the use of bio fertilizers in to lime light. This is regarded to have a lot of advantages, primarily because, environmental pollution is eliminated. Micro-organisms in the soil are very efficient in biofortification of crops. They make nutrients available to crops in usable forms (Dotaniya et al., 2016). Arbuscular Mycorrhizal Fungi (AMF) is employed lately in breeding programs, it increases productivity of crops, crop root development is assisted and uptake of essential nutrient by the plants is supported largely (Gashgari et al., 2020). Micro-organisms like *Pseudomonas chlororaphis* is reported to promote nutrient uptake and substantial plant growth (Sharma et al., 2003). A broad gene pool of faba bean has therefore been developed over the years, including local landraces, mass selections from landraces, open-pollinated populations, inbred lines, and cultivars (Duc et al., 2010; Karaköy et al., 2014). The EU database of faba beans registered varieties consist of 256 faba bean cultivars which are currently registered for growing in Europe (European Commission, 2017). According to Fouad et al. (2013), registered varieties feature a range of highly differing characteristics with limited genetic variation. Major traits targeted in selecting faba bean varieties include yield potential, quality, consistent performance, standing ability, suitability for human consumption or the feed market, days to maturity, seed size, as well as resistance to disease and abiotic stress.

The major focus of legume breeding, including faba bean, is yield. However, in many regions, faba bean crops are subject to different conditions of biotic and abiotic stress and, as such, yield is ultimately dependent on cultivar resilience to multiple stress conditions. Hence, breeding new cultivars with increased resilience to abiotic stresses, such as heat and salinity, continues to challenge breeders (Siddique et al., 2013; Nebiyu et al., 2016). Furthermore, winter hardiness is an important trait

in screening for cultivars to be cultivated during the cold season (Link et al., 2010). The importance and wide variation of traits relating to morphology, agronomy, and quality have been previously investigated and demonstrated for local faba bean genetic resources of different origins (Karaköy et al., 2014; Terzopoulos & Bebeli, 2008; Nasto et al., 2016; Basheer-Salimia et al., 2014; Zong et al., 2009). Some researchers were of the opinion that breeding programs need to incorporate a more complex evaluation and traits use such as root architecture, shoot architecture, parameters relating to stomatal function and disease resistance (Duc et al., 2015; Zhao et al., 2018; Khan et al., 2010; Khazaei et al., 2013; Torres et al., 2006).

Transgenic plant breeding is required in crops where the target nutrient does not exist naturally at the required levels (Bouis et al., 2017). According to Kumar and Banerjee (2022) transgenic methods for folate, iron, zinc micronutrient biofortification in pulses are in progress. The use of gene editing technology blocks the production of antinutrient fractions and enables microorganisms to be incorporated through the pathways for exploitation of metabolic engineering. Micronutrient deficiency in crops could also be improved by identifying genes controlling nutrient concentration through genomic technique. In wheat biofortification, methods like marker assisted selection (MAS), identification of quantitative trait loci (QTL) and GS, which are marker-assisted selection, quantitative trait loci and genomic selection has been used respectively. In this regard, genomics advancement has promoted biofortification of many important crops. Molecular markers and map loci are used to moderate traits and qualities of interest (Ali & Borrill, 2020). The genomic regions concerned with areas of desired traits are controlled by MAS. Sequenced genome of pulse crops have been used for micronutrient enrichment, multigene transfer and removal of antinutrients from edible tissues and restructuring of metabolic pathways (Beebe, 2020). This method depends on wide genetic pool for the transfer of targeted genes from one plant species to another which is independent of their taxonomic and evolutionary status (Garg et al., 2018). The genomic method has been employed widely in the fortification of maize with vitamin A. Cultivars with abundance of beta carotene are usually selected. Understanding MAS has been used to improve vitamin A content in maize cultivars from 1.80 to 8.14 µg/g (Goredema-Matongera et al., 2021).

11.6 Benefit of Biofortification

An enhanced level of vitamin A, zinc and iron are presently being used in developing countries (Meji et al., 2017). The benefits of consuming biofortified foods cannot be over emphasised. Vitamin A is available in foods like meat, liver and eggs. These are not within the reach of people with indigent life style. However, with the fortification of orange sweet potatoes, yellow cassava and orange maize, beta carotene is now included in the diets of the impoverished (Johnson & Mohn, 2017). The intake of biofortified foods by breast feeding mothers goes a long way in supplying the infant with vitamin A. If the breast milk does not contain sufficient amount of

vitamin A, the infant will be deficient with other analogous reverberations (Black et al., 2008). Thus material intake of supplemented foods is of high necessity. The efficacy of biofortification in rural settings is often determined by the level of vitamin A in breast milk. With reference to reports from FAOSTAT (2018), over 105 million metric tonnes of orange sweet potato was produced and this was introduced to African countries and south Asia. The orange sweet potatoes are known to contain 30–100 mg/kg of beta carotene, relative to the traditional varieties which contains 2 mg/kg (De Moura et al., 2015). The requisite daily intake for children is 150 g, while adults especially women needs 300 g (Hotz et al., 2012a, b), biofortified staple foods have assisted in supplying these daily essentials to the rural populace. Reports by Jalal et al. (1998) indicted that serum levels of retinol increased with the consumption of orange sweet potato on a daily basis for 3–10 weeks, while liver vitamin A in children was further elevated (van Jaarsveld et al., 2005). Among Bangladeshi women, significant level of beta carotene was recorded in women consuming the orange fleshed sweet potato against what was recorded in their counterparts feeding on the white sweet potato (Jamil et al., 2012). Serum retinol was observed to increase significantly in children fed with orange sweet potato three times a week, tissue wasting and low weight relative to age was equally low significantly (Low et al., 2007). Comparably, incidence of diarrhoea was cut down at 39% in children fed with orange flesh sweet potato (Jones & de Brauw, 2015). In like manner, McNiven et al. (2016) reported that children had increased level of plasma retinol after the intake of orange sweet potato for 2 years. Cassava bio fortification intervention programmes also came up with positive outcomes. Although the traditional cassava contains no pro-vitamin A. Biofortified yellow cassava varieties were introduced into the democratic republic of Congo and Nigeria in 2011 (Harvest Plus, 2014). Intake of yellow cassava by children in Kenya also elevated serum beta carotene significantly to 88% (Talsma et al., 2015). In experiments conducted with older women fed with bio fortified cassava porridge, an increase in plasma beta carotene was also recorded (La Frano et al., 2014). In Zambia, vitamin A content in the liver was increased to 73% with the consumption of yellow maize over a 90-day period (Gannon et al., 2014). Zinc inadequacy has been up graded by zinc fortified rice (Arsenault et al., 2010; Qin et al., 2012). Correspondingly, zinc fortified wheat is available in Bolivia, Pakistan, China and India. Pearl millet which is a staple crop in Africa and India has also being fortified with iron and zinc. Outcome of investigation on the consumption of zinc and iron fortified pearl millet in infants revealed that there was increase in total body iron and serum ferritin. In the Philippines, significant increase in serum ferritin and body iron was recorded in women fed with iron fortified rice (Haas et al., 2005). Bean fortified with iron is known to increase haemoglobin, serum ferritin and total body iron. In parallel, there was evidence of cognitive response improvement with parameters such as memory search, memory retrieval and spatial selective attention (Murray-Kolb et al., 2017). All staple crops fortified with micronutrients are generally known to supply relevant amount of nutrients needed, research has supported that crops fortified with iron increased the iron levels in the experimental subjects and populations (Finkelstein et al., 2015). In view of all the above, fortified faba beans will go a long way in addressing the nutritional requirement of the populace while improving the quality of faba bean.

11.7 Improvement in the Quality of Faba Beans

The quality improvement of faba beans to meet human demand had been the major target of research and this had led the researcher to focus on different methods to achieve this purpose. Plant selection/breeding according to Robinson et al. (2019), had been the major reason for improvement in the olden days but now it is limited to disease resistant plant, colour, taste, traits of yield etc. Improvement of faba beans are done through biofortification process leading to improved nutritional quality of the crop. Faba bean had been reported to have antinutritional factors which bind with the minerals and make them unavailable to consumers. Such antinutrients according to Turco et al. (2016) and Robinson et al. (2019), include phytate, tannin, alkaloid, saponin etc. which bind with the minerals and protein in the beans and make them unavailable to the consumer thereby impairing their health status. Gutierrez et al. (2008) established the existence of zero-tannin cultivars made from *zt-1* and *zt-2* (two recessive mutations). Ivarsson and Neil (2018) differentiated the zero-tannin crop based on the colour of the flower produced and this determines the yield performance and susceptibility to diseases. Abdellatif et al. (2012) studied drought stress tolerance of faba bean using morphological traits and seed storage protein pattern. Variety ‘Giza 3’ showed higher susceptibility to drought stress while the variety ‘Giza 843’ was more tolerant to drought stress. Seven accessions of heat tolerant varieties with high rate of pollen viability under 35 °C, high pod number and seed number per plant were identified. These accessions were INRA1631, IG11743, IG11843, VF626, VF351, VF522 and VF420 (Maalouf et al., 2018a, b). Two higher plant nitrogen faba bean accessions, 45/018/F8/7307/06A and Sakhal were developed and compared to other genotypes (Maalouf et al., 2016). Faba beans with partial resistance to chocolate spot were also released. These were Obsie (ILB 4427 XCS20DK), ‘Moti’ (ILB 4432 X Kuse-2-27-33), ‘Walki’ (ILB 4615 X Bulga 70) and ‘Gebelcho’ (ILB 4726 X ‘Tesfa’) (Maalouf et al., 2018a, b). The improved heat resistant faba bean varieties (Hudeiba-93 and Basabeer) were developed in collaboration with International Center for Agricultural Research in the Dry Areas (ICARDA) in 1993 and 2000 and Eddamer in 2012 in Sudan. According to Maalouf et al. (2018a, b) faba bean lines with resistance to *Orobanche*, disease resistance and heat tolerance were released with joint effort of ICARDA breeding programme and NARS partners, and faba beans varieties such as Najah, Chourok, Hashbenge (ILB4358), Giza843 and Misr3 were released in Tunisia, Ethiopia and Egypt respectively. Adhikari (2021) reported the release of improved faba bean variety (FBA Ayla) which has superior seed quality, disease resistance and high yielding in Australia. Improvement was also achieved in the yield of faba beans by Youseif et al. (2017) using *Rhizobium*/Agrobacterium strains in green house and significant increase was reported. Other improved genotypes available are the salinity tolerance and frost tolerance type which are able to withstand salinity and frost respectively. Faba bean genotypes containing tannin and low tannin contents were analysed and discovered that Ca, Mn, Mg, Cd and protein contents were higher in low tannin genotypes than the tannin genotypes (Khazaei &

Vandenberg, 2020). Faba bean cultivars namely Nubaria 2, Sakha 1, Sakha 3, and Sakha 4 were subjected to foliar application of fulvic acid (FA), the vegetative characters and yields were greatly improved. According to Abdel-Baky et al. (2019), treatment with 9 gL⁻¹ FA improved the nutritional qualities of faba bean significantly. Numerous faba bean genotypes had been developed and studied by Khan et al. (2015) and Gasim et al. (2015), the nutritional profiles of selective varieties were comparable to other legumes in protein, mineral contents etc.

11.8 Nutritional and Antinutritional Composition of Faba Beans

Faba bean is a valuable multipurpose crop which is grown for its nutritional and medicinal value. As reported by Etemadi et al. (2019), its seeds, pods and leaves are rich in protein and almost all elements required in the human diet. Aside protein, faba bean is also rich in, complex carbohydrates, dietary fibre, choline, lecithin, minerals and phenolic compounds (Mohseni & Golshani, 2013; Etemadi et al., 2018). The protein and starch content in faba beans were recorded to range from 275–374 gkg⁻¹ and 411–475 gkg⁻¹ respectively (Hood-Niefer et al., 2012). Yang et al. (2018) and Gu et al. (2020) reported protein contents ranging from 20–41% in faba beans. Faba bean protein is composed of globulin, albumin, glutelins and prolamins (Rahate et al., 2020). Likewise, the protein contains essential and non essential amino acids are dependent on the variety of the faba beans (Nosworthy et al., 2018). USDA (2021) reported higher percentage of carbohydrate in faba beans with high starch contents. Faba bean is a good source of both soluble and insoluble dietary fiber (Singh et al., 2014). The major bioactive compounds in the beans are flavonoid, phenolic compounds, terpenoids and lignans (Dhull et al., 2021). It has also been reported by Adamu et al. (2015) that faba bean is low in fat, sodium and free of cholesterol. Moreover, the leaves are good sources of copper in the human diet (Etemadi et al., 2019). As a medicinal plant, faba bean contains large amount of L-Dopa (Etemadi et al., 2018), a precursor of dopamine used as an important ingredient in the treatment of parkinson's disease and hormonal imbalance (Surwase et al., 2012; Hu et al., 2015; Paul and Gupta 2021). Faba bean ranks after velvet bean in terms of L-Dopa content (Soares et al., 2014). In addition to the common antinutritional components of legumes, faba bean contains vicine and convicine which with glucose-6-phosphate dehydrogenase (G-6-PD) deficiency can lead to acute haemolysis, a disease known as favism (Arese & Flora, 1990; Labba et al., 2021). Active derivatives of Vicine and Convicine contained in the seed: divicine and isouramil are toxic to human carriers of a widespread genetic defect (G-6-PD). The levels of antinutrients however vary according to the specific faba bean cultivar, stage of maturation, climate of cultivation, soil properties etc. (Kumar et al., 2015).

11.9 Conclusion

Faba bean is an important pulse and vegetable crop. Both dry and fresh seeds are recommended for their benefits to human nutrition as a dietary source of fiber and protein. However, from an agronomical point of view, adding faba bean to crop rotation systems improves soil, since atmospheric N₂ is fixed above 200 kg N ha⁻¹, and increases soil organic matter. Its inclusion in rotation systems therefore contributes to significant improvements in the sustainability of agricultural systems. Production of this legume species is vulnerable to biotic and abiotic stresses, such as ascochyta blight, broomrape infestation, water logging, and drought. These constraints require the urgent development of new varieties that are resilient to stresses. The new varieties should combine many characteristics, with the main aim of achieving atmospheric N₂, high yield and high protein content. Production of improved faba bean varieties would provide beans with different features and for different purposes. This will confer special characteristic in the crop and improve the nutrition of the consumers. Improved faba bean will solve the problem of micronutrient malnutrition in the developing countries. Also, the improved varieties would combat the production constraints which reduced the productivity of the crop.

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