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Review paper

Nutritional quality of pro-vitamin A, biofortified maize

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Vitamin A deficiency (VAD) which is caused by a chronic inadequate dietary intake of vitamin A is a major public health problem in many developing countries. In SSA countries, VAD continues to be a serious public health problem despite implemented strategies to alleviate VAD. Provitamin A bio fortified maize, which has been developed through plant breeding, has the potential to act as an additional strategy to eliminate VAD. The feasibility of using provitamin A biofortified maize to alleviate VAD is critically dependent on consumer acceptance of the provitamin A biofortified maize. Generally, biofortification is used to influence the nutritional composition of the provitamin A-biofortified maize grain varieties, including carotenoid composition. Thus, in terms of grain quality and nutritional composition, provitamin A-biofortified maize varieties would be, overall, a better food source than the normal white maize. Biofortification can be achieved through conventional selective breeding or through genetic engineering or molecular breeding. It could help to identify the traits that the breeders need to focus on, in order to make the biofortified maize more acceptable.

Key words: maize, provitamin A, biofortification, vitamin A deficiency

INTRODUCTION

Maize (Zea mays L.) is the world's most widely grown cereal crop. It is one of the most important food crops world-wide, serving as staple food, livestock feed, and industrial raw material (Troyer, 2006). It is one of the most important staple food crops in sub-Saharan Africa (SSA), predominantly produced and consumed directly by the smallholder farmers (Shiferaw et al., 2011). In Ethiopia, maize is one of the principal cereal crops ranking first in total production and productivity, and second to tef in area coverage. A total of 7.8 million tons of maize (31% of the total cereal) was produced on 2.1 million hectares (21% of the total area planted cereals) of land by nearly 11 million small households (31% of the total cereal) in 2016 (FAO, 2017). Worldwide, malnutrition is an underlying cause in the deaths of more than 3.5 million children under the age of 5 each year. Some 13 million infants are born each year with low birth weight (LBW). Fifty five million children are wasted, and of these 19 million are severely wasted. About 178 million children around the world are stunted. Of the estimated 178 million, 90 percent live in 36 countries, one of which is Ethiopia (Black et al., 2008). Ethiopia has witnessed encouraging progress in reducing malnutrition over the past decade. However, baseline levels of malnutrition remain so high that the country must continue to make significant investments in nutrition. Vitamin A deficiency (VAD) is a major public health problem in lower income countries, especially in Africa and South-East Asia (WHO, 2009). It occurs mainly in young children and women of childbearing age. Inadequate intake of vitamin A is the main cause of the deficiency. Globally, approximately 250 million pre-school children have VAD and an estimated 250 000 to 500 000 of these children become blind every year as a result of VAD (WHO, 2010). As mentioned earlier, the problem of VAD is particularly serious in Africa, where maize is a major part of the diet. Many attempts are being made to improve the nutritional quality of maize, since it represents a major staple in many developing countries; these efforts include genetic manipulation and fortification during processing. Biofortification is a genetic manipulation technique that seeks to improve the micronutrient content of staple foods consumed by people from poor socioeconomic backgrounds (Meenakshi et al., 2010). Biofortification targets poor people living in remote rural areas who are not reached by commercial fortification and supplementation programs (Li et al., 2007; Nestel et al., 2006). Micronutrient deficiencies not only affect physical health, but mental health as well the cognitive stunting of children, poor educational performance, lower work productivity and etc. Now a different strategy has emerged. Instead of trying to add something healthy to habitual diets, the logic is to start from the staple crops that people eat already, and then improve their nutritional quality. The strategy is 'biofortification' fortification in the field rather than in the factory. Biofortification of food crops makes sense as part of an integrated food-systems approach to reducing malnutrition. The promise it holds out is nutritional improvement without dietary change. However, processing the maize into food products may reduce its Provitamin A content. Provitamin A biofortified maize has been developed through plant breeding as a part of strategic intervention to alleviate or eliminate VAD in vulnerable communities. Biofortification involves breeding staple crops for increased vitamin and mineral content using the best traditional breeding practices and modern biotechnology (De Groote & Kimenju, 2008; Nestel et al., 2006). Efforts in this regard are being led by the Harvest Plus Challenge Program, a biofortification initiative within the Consultative Group on International Agricultural Research (CGIAR) that aims to reduce micronutrient malnutrition among less privileged populations in Africa, Asia and Latin America (Ortiz-Monasterio et al., 2007). Since maize is the preferred staple in Africa, including Ethiopia, provitamin A-biofortified maize has the greater potential to succeed as a new strategy to combat VAD in Africa, than the other crops (Tothova & Meyers, 2006; WHO, 2003). Generally, the knowledge of the nutritional quality of Provitamin A biofortified maize will be important in the utilization of Provitamin A maize to address vitamin A deficiency (VAD). Therefore, This study will provide important data on the nutritional composition and other quality attributes of Provitamin A biofortified maize varieties.

Vitamin A chemistry

Vitamin A is classified as a fat soluble vitamin. The term vitamin A includes Provitamin A carotenoids, which are dietary precursors of retinol and retinoid, including its active metabolites (Institute of Medicine, 2001). Retinaldehyde and retinoic acid are the main physiologically active forms of vitamin A and are both derived from retinol (Bender, 2003). Free retinol is not chemically stable and is present in food in small amounts as a variety of esters, mainly retinyl palmitate (Bender, 2003). Retinoic acid has a lower potency than retinol or retinyl esters and cannot be reduced to retinaldehyde or retinol (Bender, 2003). Of the 600 known carotenoids, approximately 50 have vitamin A activity, but food composition data are available for only three of these carotenoids (α-carotene, β-carotene and β-cryptoxanthin) (Institute of Medicine, 2001; Gregory, 1996). Alpha carotene, β-carotene and β-cryptoxanthin are also called Provitamin A carotenoids as they are precursors of vitamin A that can be converted into retinol by the body (Institute of Medicine, 2000a).

Food sources of vitamin A

Vitamin A from foods of animal origin is present in the form of preformed vitamin A, mainly in the form of retinyl esters. The main animal sources of vitamin A are liver, eggs, milk, and milk products. They contain 25 to 8,235 retinol equivalents (RE)/100 g of edible portion. In addition, the preformed vitamin A found in foods of animal origin is the most bioavailable dietary source of vitamin A (Faber & Wenhold, 2007). Even though these sources are rich in highly bioavailable vitamin A, their consumption among the population is still low. Plant foods rich in Provitamin A represent more than 80% of the total food intake of vitamin A because of their low cost, high availability, and diversity. Fruits, roots, tubers, and leafy vegetables are the main providers of Provitamin A carotenoids. Because of their availability and affordability, green leafy vegetables are consumed largely by the poor populations, but their Provitamin A activity has been proven to be less than previously assumed. Among fruits, mangoes constitute an important seasonal source of vitamin A. Yellow or orange sweet potatoes are rich in Provitamin A. Dark green leafy vegetables are regarded as the most common rich sources of provitamin A carotenoids among many developing countries while root crops such as carrot and yellow/orange sweet potato have the benefit of being available worldwide. Generally, Animal sourced foods though good sources of vitamin A are too expensive for poor communities to afford .This makes, foods of plant origin as an important source of pro-vitamin A in developing countries.

Role of vitamin A in health and human nutrition

Vitamin A is an essential component of human metabolism. This micronutrient is required for the normal functioning of the visual system, maintenance of cell function for growth, epithelial integrity, red blood cell production, immunity and reproduction. A deficiency of vitamin A can impact negatively on many body functions and overall health (WHO, 2009). Retinoic acid has an important role to play in regulating the expression of various genes that encode for structural proteins, enzymes, extracellular matrix proteins and retinol binding proteins and receptors. Retinoic acid is also essential for embryonic development and the maintenance of immune function (Institute of Medicine, 2001). The consumption of plant foods for their vitamin A activity has many advantages. They are accessible to low-income groups and are more adaptable to local food habits. Vitamin A is essential for the normal functioning of the visual system and is required for growth, development, immune function, and reproduction. It also intervenes on the wound healing process and protects the skin against the sun for instance. It protects cerebral cells from damages linked to the age and reduces heart attack risks and cerebro-vascular accidents. Education and counseling on the use of plant foods can improve provitamin A intake among populations at risk of vitamin A deficiency (Institute of Medicine, 2001).

Vitamin A deficiency (VAD)

Deficiencies in vitamins and minerals in our diets create major public health problems, mental as well as physical, especially in developing countries. Inadequate intake of essential amino acids, minerals and vitamins can occur from regular consumption of maize-based foods that usually have low levels of these nutrients, leading to nutritional deficiency disorders (Bouis et al., 2011). Vitamin A deficiency (VAD) is caused by a chronic inadequate dietary intake of vitamin A, which is insufficient to meet physiological needs, and leads to impaired tissue function (WHO, 2009). It is the world's commonest cause of childhood blindness. Vitamin A deficiency alone affects more than 43 million children younger than 5 years of age in SSA(Aguayo and Baker, 2005), which retards physical growth, depresses immune function, increases susceptibility to infectious diseases, and diminishes possibility of survival from serious illness (Wurtzel et al., 2012). It is estimated that 228 million children are affected sub-clinically and 500,000 children become partially or totally blind every year as a result of VAD (FAO, 2003). More than half of the cases occur in developing countries and this is attributed to the consumption of vitamin A deficient diets. Vitamin A deficiency also increases incidence of corneal blindness and contributes to poor growth and cognitive development in children as well as maternal death and poor pregnancy and lactation outcomes (Rice et al., 2004; Black et al., 2008). The risk of vitamin A deficiency disorders is greatly increased with low intake of vitamin A during periods such as infancy, childhood, pregnancy and lactation, when requirement for the vitamin increases (WHO, 2009).

Trends of vitamin A deficiency in Ethiopia

Micronutrient deficiencies, particularly iron, iodine and Vitamin A deficiencies are significant public health problems in Ethiopia. The 2011 EDHS estimated the national prevalence of stunting among children at 44.4 percent, the prevalence of underweight at 28.7 percent and wasting at 9.7 percent. The survey also revealed that the level of chronic malnutrition among women in Ethiopia is relatively high, with 27 percent of women either thin or undernourished that is, having a body mass index (BMI) of less than 18.5 kg/m2. Similarly, the prevalence of anemia among women in the reproductive age group (15–49) was found to be 17 percent (CSA, 2011). In this context, maize has been considered as an important target crop under the Harvest plus Challenge Program for increasing provitamin A levels in maize endosperm through conventional breeding to alleviate vitamin A deficiency in rural areas with limited access to supplements and fortified foods (Bouis et al., 2011)

Vulnerable groups to Vitamin A deficiency (VAD)

Children of preschool age are vulnerable to VAD because of the higher requirements for vitamin A needed for growth, low intake of vitamin A and increased exposure to infections. Children with measles, acute or prolonged diarrhea, acute lower respiratory infection, severe protein energy malnutrition (PEM), from poor communities and non-breastfed infants are also more vulnerable to VAD (Ahmed & Darnton-Hill, 2004). Pregnant and lactating women from poor socioeconomic backgrounds are also at risk for VAD as they may be unable to meet the increased requirements for vitamin A (Ahmed & Darnton-Hill, 2004).Generally, children between the ages of 6-59 months and from rural areas are the most at risk of VAD and experience more severe effects than any other age group (Labadarios & Van Middelkoop, 1995).

Strategies to dddress vitamin A deficiency

The elimination of micronutrient deficiencies is the key objective within the focus area of micronutrient malnutrition control. Many strategies have been set to increase the production, availability and access to foods rich in micro nutrients and to increase the consumption of foods rich in micronutrients and the bioavailability of micronutrients from the diet. The combination of strategies to address micronutrient deficiencies in the population include: supplementation, food fortification, promotion of dietary diversification as well as other related public health measures (Labadarios et al., 2005). These strategies are briefly discussed in the next section.

Biofortification

Fortification is the addition of essential vitamins and minerals to processed foods to improve their nutritional value (Sablah et al.,2013). It is a public health intervention that seeks to improve the micronutrient content of staple foods consumed by the majority of poor people (Meenakshi et al., 2010). Biofortification involves breeding staple crops for increased vitamin and mineral content, using the best traditional breeding practices and modern biotechnology (De Groote and Kimenju, 2008). According to Li et al., (2007), biofortification programme target the poor, vulnerable groups living in remote rural areas. One of the most important advantages of biofortification is that it is cost-effective (Nestel et al., 2006). The food fortification approach, to fortify food with essential nutrients, is a highly effective strategy to address micronutrient deficiency in developing countries.

Provitamin A biofortification of maize

Maize is one of the food vehicles used for fortification, as it was found to be one of the most commonly consumed food items. Biofortification takes advantage of the fact that staple crops are a predominant part of the diets of poor populations who have VAD or are at risk of VAD. There are also a large number of staple foods consumed by all family members in poor households at risk of VAD (Bouis, 2003). Biofortification can deliver naturally fortified foods to people who may not have access to commercially fortified foods that are more readily available in urban areas (Nestel et al., 2006). Biofortification and commercial fortification can therefore be regarded as complementary strategies to address micronutrient malnutrition (Bouis, 2003). Currently, breeding of crops with better nutrition is being led by the HarvestPlus Challenge Program. Harvest Plus is the biofortification initiative within the Consultative Group on International Agricultural Research (CGIAR). Harvest Plus aims to improve food security and enhance the quality of life by reducing micronutrient malnutrition among less privileged populations in Africa, Asia and Latin America (Harvest Plus Brief, 2006). Another advantage of biofortification is that there is less risk of vitamin A toxicity from biofortification, compared to excessive consumption of fortified foods and massive doses of vitamin A supplements, as the conversion of carotenoids into vitamin A in the body is controlled and regulated (Penniston and Tanumihardjo, 2006). Biofortification could succeed as a new and alternative way of dealing with the problem of VAD (De Groote & Kimenju, 2008; Mayer et al., 2008).

Dietary diversification/modification

Dietary diversification/modification refers to a variety of strategies that aim to increase the production, availability and access to foods rich in micronutrients. It also aims to increase the consumption of foods rich in micronutrients and/or the bioavailability of micronutrients from the diet. Dietary modification is a long-term strategy that can be achieved through improved methods of food preparation and preservation that minimizes the loss of micronutrients (Ruel,2001). Diversification of crops, introduction of new crops and the promotion of indigenous foods are also strategies that can be used to address micronutrient malnutrition (Faber & Wenhold, 2007). Although dietary diversification may be a desirable way of preventing micronutrient malnutrition, poverty and a lack of access to a variety of foods prevents it from being successful (Mayer et al., 2008).

Supplementation

The vitamin A supplementation programme is used as a primary prevention strategy which forms part of the routine immunization program, maternal health and the integrated management of childhood illnesses (Labadarios et al., 2005). The programme involves providing vitamin A supplementation to children aged 6-59 months and women in the post-partum period. Various studies have evaluated the vitamin A supplementation programme in SSA. Hendricks et al. (2007) reported many missed opportunities for supplementation, lack of awareness by mothers and a need for training of nurses. Another investigation concluded that the high dose vitamin A supplementation programme had not been successful as it had been unable to reach the most vulnerable target groups (Swart et al ., 2007). It was recommended that the programme should be optimized in order to achieve maximum impact and that the efficiency, effectiveness and safety of the programme be evaluated by the relevant stakeholders (Dhansay, 2007).

Nutritional composition of provitamin A, biofortified maize

Maize is composed of different minerals and vitamins that improve health in humans, however, it is devoid of nutrition (Gopalan et al., 2007). It is an ideal vehicle for provitamin-A enhancement and delivery in SSA because of its broad germplasm base, widespread use in preparation of different local foods, adaptation to diverse production environments, and the potential of the crop to generate and continually provide productive cultivars that are attractive to farmers. Maize kernels contain a carotene, b-cryptoxanthin and b-carotene that are converted into vitamin A in the human body (Pillay et al., 2014) as well as lutein and zeaxanthin, which collectively are essential for vision, immunity, reproduction, growth, development, maintenance of healthy respiratory and gastrointestinal systems, and for decreasing the risk of cancer, cataract, and macular degeneration (Fraser and Bramley, 2004). From all nutrients carotene is the most important quality attributes for provitamin A-biofortified maize.

Carotenoids

Maize is a logical crop for biofortification with provitamin A carotenoids as it exhibits considerable natural variation in carotenoid content and profiles. Some maize genotypes accumulate up to 66.0 ìg/g of total carotenoids (Harjes et al., 2008). Provitamin A carotenoids in maize grain includes α-carotene, β-carotene and β-cryptoxanthin. β-cryptoxanthin was the most abundant provitamin A carotenoid present in the provitamin A,biofortified maize grains (Pillay. K, 2011). The total provitamin A carotenoid concentration in the provitamin A-biofortified maize grain is high as compared to normal maize. Similar results were also reported by (Lozano-Alejo et al., 2007). However, the range of β-cryptoxanthin values reported in the present study is significantly higher, In contrast, a study by (Li et al., 2007) , showed considerably less β-cryptoxanthin concentration, when compared to that of β-carotene, in high β-carotene containing maize. Yet, it has to be emphasized that although β-cryptoxanthin is present in higher concentrations than β-carotene in many varieties or breeding lines of provitamin A-biofortified maize, it has only one-half of the provitamin A activity of β-carotene (Kimura et al. , 2007). In other hand the nutritional composition of vitamin A carotenoid is very low or absent in normal white maize. there is unbalanced nutritional composition, especially the lack of provitamin A carotenoids is one of the reason why malnutrition still exists in sub-Saharan Africa, where maize is a dietary staple (Nuss & Tanumihardjo, 2010).

Amino acids

The provitamin A-biofortified maize varieties had a higher concentration of most of the essential amino acids (threonine, valine, isoleucine, leucine and phenylalanine) compared to the white maize (Pillay. K, 2011). However, the levels of histidine and lysine were generally lower in the provitamin A-biofortified maize varieties compared to the white maize. With the non-essential amino acids, the levels of aspartic acid, glutamic acid, serine and alanine were generally higher in the provitamin A biofortified maize varieties, while the levels of glycine and arginine were higher in the white maize (Pillay. K, 2011). The normal white maize is known to be nutritionally deficient in lysine, while its leucine content is high (FAO, 1992). The concentrations of all the essential amino acids, except lysine, in all the provitamin A-biofortified maize varieties and the white variety was generally higher than the pattern of amino acid requirements for all age groups. The provitamin A-biofortified maize varieties were generally more nutritionally sufficient in the essential amino acids than the white maize variety. However, the lysine concentration in all maize varieties was consistently lower than the pattern of amino acid requirements in all age groups (Pillay. K, 2011).

Other nutrients

Provitamin A-biofortified maize has also high composition nutrients other than provitamin A carotenoids. Starch is the most abundant vital component present in the white maize variety, comprising nearly 71.3 % of starch. Starch and protein content of the provitamin A-biofortified varieties also high as compared to normal maize. But it varied across variety (Johnson, 2000). The fact that the provitamin A-biofortified maize varieties had higher protein and fat content than the white maize is encouraging. It indicates that in addition to provitamin A, the biofortified maize varieties could also contribute towards protein, fat and overall energy intake which could also potentially help to alleviate Protein Energy Malnutrition (PEM). PEM is also a major nutritional and health problem in sub-Saharan Africa (De Onis & Blössner, 2003). The higher protein, fat and energy content of the provitamin A-biofortified maize varieties may also help to improve the overall nutritional intake in sub-Saharan Africa, where low protein and energy staples (including cereal grains) form the basis of dietary intake. This shows that the provitamin A-biofortified maize varieties are superior sources of starch, fat and protein, compared to white maize. In order to account for the shortcomings in the nutritional composition of the provitamin A-biofortified maize varieties, food products made from this maize should be combined and complemented with foods that are good sources of the lacking nutrient (Pillay. K, 2011).

Maize grain quality

The provitamin A-biofortified varieties had higher hectolitre mass and milling index values compared to the white maize and the yellow/orange. This indicates that the provitamin A biofortified varieties have a better milling quality compared to the white maize variety. The biofortified maize varieties had higher grain fat content than the white variety. Generally, biofortification is used to influence the nutritional composition of the provitamin A-biofortified maize grain varieties, including carotenoid composition. Thus, in terms of grain quality and nutritional composition, provitamin A-biofortified maize varieties would be, overall, a better food source than the normal white maize.

Breeding strategy for provitamin A maize

The method of breeding has been one of the issues advanced for communities to reject certain provitamin A crops. Appropriate strategies are needed for improvement of provitamin A contents (Maqbool et el., 2018). Biofortification can be achieved through conventional selective breeding or through genetic engineering or molecular breeding. Different breeding strategies which could be used for provitamin A biofortification of maize are briefed in the below.

Classical methods

Classical plant breeding uses crossing of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. Plants are crossbred to introduce traits/genes from one variety or line into a new genetic background. In this approach the parent lines with high Provitamin A level are crossed over several generations to produce plants that have the desired provitamin A content along with desired agronomic traits (Pillay. K, 2011).

Molecular methods

Marker assisted selection (MAS) is an indirect selection process where a trait of interest is selected, not based on the trait itself, but on a marker linked to it (Ribaut and Hoisington, 1998). MAS is considered as a key approach for efficient breeding for high levels of provitamin A carotenoids in maize (Prasanna et al., 2010). The use of marker-assisted selection (MAS) in breeding for provitamin A concentration in maize became possible after Harjes et al. (2008) published results of association mapping research, and PCR-based markers were subsequently developed to enable selection for favorable alleles of LycE (lycopene epsilon cyclase), a crucial gene that governs partitioning of alpha and beta carotene branches in the carotenoid biosynthetic pathway. Generally the breeding strategy for developing provitamin A includes; Intra-population recurrent selection; it aims to compare the effectiveness of full sib vs. S1 recurrent selection for improving provitamin A. Conversion of white lines and yellow open pollinated varieties to enhanced provitamin A content. Pedigree breeding; it is a technique that plant-breeders employ during inbreeding of biofortification of maize with provitamin A carotenoids.

Challenges for development and adoption of provitamin A maize

Initially, most biofortified grains had comparatively lower yields (<4 metric tons per hectare) than their white counterparts. This had a serious implication as farmers were less willing to plant maize varieties that were low yielding (Smith et al., 2020). In addition, provitamin A carotenoids are sensitive to light and air. Sun drying or high temperature drying of maize grain decreases the amount of carotenoids. The cooking methods of food preparation also results in some loss of provitamin A carotenoids. Therefore, the retention of provitamin A in maize kernels is essential which is influenced by genotype and environmental factors such as temperature, exposure to sunlight in the field and during post-harvest handling. It is necessary to identify, introduce or develop new maize varieties rich in provitamin A that is adaptive to our agro-ecological niches and farmers condition. It should also be economically potential (Smith et al., 2020). The production of provitamin A crops will increase when communities accept to grow biofortified crops. Nutritional improvement at the cost of higher yields will potentially drag the adoption of provitamin A crops. Nutrition education is an important factor that affects the adoption and acceptability of biofortified crops (Tanumihardjo, 2008). If the mothers are educated about the importance of vitamin A, they will easily accept the biofortified crop (Chowdhury et al., 2011). It is important for communities to be educated and convinced that the consumption of vitamin A enriched crop variety may result in improved nutrition and health (Tanumihardjo, 2008). Limited research on biofortification, weak and inadequate physical infrastructure, laboratory for genetic engineering works along with poor extension mechanism also limit the research and dissemination of provitamin A enriched maize.

Acceptability of pro-vitamin A crops

During biofortification, there are changes that are introduced into the staple crops. Apart from enhanced nutrient content, there are usually changes in the colour and taste of the food crops. These changes play a part in whether the biofortified crops are accepted by the intended consumers or not (Tumuhimbise et al., 2013). The acceptability of biofortified crops is affected by several factors discussed below.

The method of breeding

The method of breeding has been one of the issues advanced for communities to reject certain provitamin A crops. Biofortification can be achieved through conventional selective breeding or through genetic engineering. However, genetic engineering as a technique for biofortification has been maligned and as such some people think that eating crops that are a result of genetic engineering "is like eating a gene". This may explain why golden rice that was developed through genetic engineering has not been fully accepted as a provitamin A crop (Tumuhimbise et al., 2013). Generally genetic engineered crops have tended to be a "political hot button" and the debate goes on and on. On the other hand, crops that are a result of conventional breeding have found favor within communities on this account. Crops such as orange fleshed sweet potatoes and biofortified cassava are highly appreciated. This may be partly explained by the involvement of farmers in the breeding process by the local research institutes. The adoption of biofortified crops are highly accepted only when the used technology was conventional breeding and stake holders, especially the farmers were involved in its development.

Visibility of the nutrients

The biofortification process changes the colour of the provitamin A crops. Biofortified crops where nutrients are visible as it is the case in provitamin A crops, the colour of the crops becomes a significant consideration. The colour challenge the acceptability and as well as the marketability of the crops. For example, the colour challenge has also been faced in marketing yellow maize. Biofortification of maize with provitamin A carotenoids changes the grain colour from white to yellow-orange, as well as the aroma and flavor of the maize (Pillay et al., 2011) Organoleptic studies of yellow maize conducted in eastern and southern Africa have shown that there is a cultural preference for white maize to yellow maize, which seems to be due to the unacceptable sensory properties of the yellow maize (De Groote and S. C. Kimenju., 2008). Fortunately, recent studies have indicated that yellow, provitamin A, biofortified maize has the potential to succeed as a new strategy of dealing with the serious problem of vitamin A deficiency, especially among children of pre-school age (Pillay et al., 2011).

Nutrition education

Nutrition education has also been cited as an important factor that affects acceptability of biofortified crops (S. A. Tanumihardjo, 2008). Nutrition education is an important tool in conveying the nutritional and health benefits of biofortified crops. Once the mothers had been educated on the importance of vitamin A, they easily adopted the biofortified crop (S. Chowdhury et al., 2011). It is important for communities to be educated and convinced that the change in colour of the crop consumed may result in improved nutrition and health (S. A. Tanumihardjo, 2008).

Economic potential

The success of biofortified pro-vitamin A crops will also depend on their economic potential. Farmers will adopt the new varieties as long as there is an assurance that economically they will benefit. In developing countries, the staple crops apart from being sources of food, they also sources of income. A crop that has limited yield does not get allocated substantial acreage in the farm. Besides, if the crop has nutritional potential and limited economic potential, men are likely to abandon such a crop to women (Pillay et al., 2011). In many developing countries, men do not involve themselves with crops that are not likely to earn them money and yet it is usually men who decide. How much land is allocated to which crop? Therefore, increased production of provitamin A crops will occur when communities have accepted to grow biofortified crops to ensure constant supply in the market. The cultivation of provitamin A crops must make economic sense to local farmers and be regarded as a commercial crop. Nutritional improvement at the cost of higher yields will potentially drag the adoption of provitamin A crops (Pillay et al., 2011).

CONCLUSION

Maize (Zea mays L.) is one of the most important cereal crops in world agricultural economy and ranks third next to wheat and rice in production. It is the world's most widely grown cereal crops and serving as staple food, livestock feed, and industrial raw material. Since it is genetically diverse crops, scientists have found varieties that have naturally high levels of provitamin A. Harvest plus is using these lines to breed high yielding varieties of biofortified maize with higher levels of provitamin A to combat vitamin A deficiency. Vitamin A deficiency (VAD) which is caused by a chronic inadequate dietary intake of vitamin A is a major public health problem in many developing countries. In SSA countries, VAD continues to be a serious public health problem despite implemented strategies to alleviate VAD. Provitamin A-biofortified maize, which has been developed through plant breeding, has the potential to act as an additional strategy to eliminate VAD. Although provitamin A-biofortified maize is known to have a higher provitamin A content compared to white maize, the nutritional composition of provitamin A-biofortified maize compared to that of white maize, with regards to nutrients other than provitamin A. The feasibility of using provitamin A-biofortified maize to alleviate VAD is critically dependent on consumer acceptance of the provitamin A-biofortified maize. The yellow/orange provitamin A-biofortified maize needs to be widely accepted by African consumers who are vulnerable to VAD, and are traditionally consumers of white maize. The limited studies on consumer acceptability of provitamin A-biofortified maize carried out in Africa indicate that, generally, yellow/orange maize is less acceptable and preferred relative to white maize. Generally, biofortification is used to influence the nutritional composition of the provitamin A-biofortified maize grain varieties, including carotenoid composition. Thus, in terms of grain quality and nutritional composition, provitamin A-biofortified maize varieties would be, overall, a better food source than the normal white maize. Biofortification can be achieved through conventional selective breeding or through genetic engineering or molecular breeding. It could help to identify the traits that the breeders need to focus on, in order to make the biofortified maize more acceptable.

AUTHOR CONTRIBUTIONS

Review all related documents and prepare manuscript draft.

COMPETING INTERESTS

The authors declare they have no conflict of interest. The manuscript has not been submitted for publication in other journal.

ETHICS APPROVAL

Not applicable.

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