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POTENTIAL FOR QUALITY PROTEIN MAIZE FOR REDUCING PROTEIN-ENERGY UNDERNUTRITION IN MAIZE DEPENDENT SUB-SAHARAN AFRICAN COUNTRIES: A REVIEW

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ABSTRACT

Most cereal crops, including maize (*Zea mays* L.), are deficient in essential amino acids, such as lysine and tryptophan; hence they are poor in protein quality. A mutant maize with elevated levels of lysine and tryptophan was developed by the International Maize and Wheat Improvement Centre (CIMMYT) and was called quality protein maize (QPM). Nonetheless, people in sub-Saharan Africa (SSA) continue to use normal endosperm maize (non-QPM) instead of QPM. The objective of this article was to examine the existing information on institutional arrangements, infrastructure and social systems hampering adoption of QPM and to identify opportunities for promoting the campaign for its utilisation in SSA, through innovative research for development initiatives. It is clear that QPM has superior nutritional value, both to humans and to monogastric animals compared to non-QPM. Lack of sound policies and awareness among farmers about the existence and advantages of QPM are some of major drawbacks to QPM adoption and realisation of its benefits. Most farmers hardly believe information regarding nutritional composition of varieties, without convincing visual evidence such as grain yield from demonstration plots. Many African governments have mounted campaigns geared to promote adoption of QPM varieties. Varying levels of QPM adoption have been recorded in South Africa, Burkina Faso, Uganda and Ghana with high QPM production under areas ranging from 12 500 to 71 250 ha. In order to reduce protein-energy undernutrition (PEU), SSA countries should implement policies that promote QPM adoption such as providing farmers with a premium price for the QPM grain. Results from meta-analysis community based studies revealed that QPM based diets resulted in a 12% improvement on weight and 9% increase in height in infant and young children compared to non-QPM based diets. Therefore, quality protein maize bears great potential for reducing PEU and its adoption could be high given that most SSA countries depend on maize as the major source of calories and protein.

Key Words: Bio-fortification, lysine, malnutrition, tryptophan, *Zea mays* L.

RÉSUMÉ

La plupart des cultures céréalières, y compris le maïs (*Zea mays* L.), sont déficients en acides aminés essentiels, tels que la lysine et le tryptophane, donc elles sont pauvres en protéines de qualité. Un maïs mutant avec des niveaux élevés de lysine et tryptophane était développé par le Centre International d'Amélioration du Maïs et du Blé (CIMMYT) appelé maïs à protéine de qualité (QPM). Néanmoins, les peuples de l'Afrique Sub-Saharienne (SSA) continuent d'utiliser le maïs à endosperme normal (non-QPM) à la place du QPM. L'objectif de cet article était d'examiner l'information existant sur les dispositions institutionnelles, les infrastructures et les systèmes sociaux empêchant l'adoption du QPM et pour identifier les opportunités pour une campagne de promotion pour son utilisation dans les SSA, à travers la recherche innovante pour les initiatives de développement. C'est clair que QPM a une valeur nutritionnelle supérieure au non-QPM, à la fois pour les hommes et les animaux monogastriques. L'absence d'une politique solide et de sensibilisation entre les producteurs concernant l'existence et les avantages du QPM sont les quelques facteurs limitant l'adoption de l'QPM et la réalisation de ses bénéfices. La plupart des producteurs croient difficilement les informations relatives à la composition nutritionnelle des variétés, sans l'existence d'une évidence visuelle comme le rendement en grain des parcelles de démonstration. Plusieurs gouvernements africains ont monté des campagnes pour promouvoir l'adoption des variétés QPM. Des niveaux d'adoption de l'QPM ont été enregistrés en Afrique du Sud, au Burkina Faso, en Ouganda et au Ghana avec une forte production de QPM sur des superficies variant de 12500 à 71250 ha. Dans le but de réduire le dénutrition protéino-énergétique (PEU), les pays du SSA devraient mettre en application les politiques qui favorisent l'adoption des QPM telles que fournir aux producteurs des prix réduits sur les graines de QPM. Les résultats des méta-analyses sur la base des études communautaires ont montré que les régimes alimentaires basés sur le QPM résultent en une augmentation de 12% du poids et 9% en taille des enfants et des petits enfants comparés aux régimes alimentaires basés sur les non-QPM. Donc, les maïs à protéine de qualité ont un grand potentiel de réduire le PEU et son adoption pourrait être forte étant donné que beaucoup de pays du SSA dépendent du maïs comme source principale d'énergie et de protéine.

Mots Clés: Bio-fortification, lysine, malnutrition, tryptophan, *Zea mays* L.

INTRODUCTION

Proper nutrition is important for the social, physical and mental well-being of humans throughout the world. However, proper nutrition remains a challenge, especially in most sub-Saharan African (SSA) countries, whose communities are largely cereal dependent. This has led to two main types of malnutrition; namely protein-energy undernutrition (PEU) (formerly known as protein-energy malnutrition, PEM); and micronutrient deficiency (Bouis and Welch, 2010; Morley, 2016). Pregnant women, the elderly and children under the age of five are the most vulnerable groups to PEU (Müller and Krawinkel, 2005; Mpofu *et al.*, 2014). Hoseini *et al.* (2015) reported that about 146 million children under the age of five lack adequate protein. Bain *et al.* (2013) asserted that one third of all children's deaths in SSA was due to PEU manifestation.

The diets of most resource limited people are mainly composed of cereals, with inadequate protein sources such as meat and eggs (Gupta *et al.*, 2009; Maseta *et al.*, 2017). To avoid PEU, all essential amino acids must be present in the human diet. The normal endosperm maize commonly found in diets naturally has all essential amino acids, except lysine and tryptophan thus making it impossible to combat PEU without supplementation with other rich protein sources (Bharti *et al.*, 2017). Despite the maize endosperm having other essential amino acids, lysine and tryptophan are equally essential in protein synthesis for tissue growth and also the conversion of tryptophan to niacin in the body reduces the incidence of pellagra (Babu and Prasanna, 2014; Motuma *et al.*, 2015; Sharma *et al.*, 2017).

The International Maize and Wheat Improvement Centre (CIMMYT) discovered a mutant maize with an *opaque-2* gene, which codes for a double increase in levels of the two most limiting essential amino acids for growth and development of humans and animals; lysine and tryptophan (Luong *et al.*, 2017). This mutant maize had other pleiotropic negative agronomic traits, which were eventually overcome through CIMMYT's conventional breeding methods, leading to the development of a variety with desirable agronomic traits that was termed quality protein maize (QPM) (Pandey *et al.*, 2016; Messing and Rutgers, 2017). Several researchers have reported the nutritional benefits of QPM in humans and monogastric animals (Galili and Amir, 2013; Vaswani *et al.*, 2015; Dei *et al.*, 2017). However, communities solely dependent on maize in their diets still record high PEU prevalent rates. This is mainly attributable to paucity of information among concerned communities about the existence and the nutritional benefits of QPM, in complementing protein needs of humans (De Groote *et al*., 2010; Kadafur *et al*., 2017). Furthermore, many other factors have obscured the promotion of QPM, particularly in SSA, due to lack of awareness campaigns on the benefits of QPM (Gregory and Sewando, 2013; De Groote *et al*., 2016). It was, therefore, prudent for this 2017 review to examine the existing information on institutional arrangements, infrastructure and social systems hampering QPM promotion and adoption and to identify opportunities for promoting the campaign for adoption and utilization of QPM varieties in SSA, to greater heights, through innovative research for development initiatives.

Protein-energy undernutrition and related challenges. Protein-energy undernutrition is an energy shortfall owing to the deficit of macronutrients such as proteins (Jensen *et al*., 2009; Morley, 2016). It can be acute (for example starvation) or chronic. Severity ranges from subclinical shortages to noticeable wasting (hair discoloration and loss, edema, and skin peeling), to starvation causing numerous malfunctioning of organ systems (Sivaramakrishnan and Patel, 2017).

Protein-energy undernutrition is usually diagnosed using laboratory testing, including serum albumin (Morley, 2016). Alleviation of PEU includes rectifying fluid and electrolyte anomalies and gradual nutrient replenishing, which can be done orally (Hofer *et al*., 2014). As a nutrient, protein is critically important to the body as it has many functions, including provision of essential amino acids for growth and tissue repair (Henley *et al*., 2010). The detrimental effects caused by PEU directly affects growth and development. Protein-energy undernutrition primarily manifest as kwashiorkor and marasmus (Bain *et al*., 2013; Morley, 2016). Kwashiorkor (nutritional edema) involves a fair to normal calories intake, with insufficient protein intake; whereas Marasmus (absence of edema) involves inadequate protein and calorie consumption (Bain *et al*., 2013). According to van der Pols-Vijlbrief *et al.* (2014), PEU leads to a plethora of health problems, which may include high mortality rates, increased health care costs, poor intellectual development and disorderly physical functioning in older adults.

Prevalence of PEU in SSA. The sub-Saharan region has the highest prevalence of undernourishment in the word, with more than one person in four people stunted due to lack of nutritious food (UNICEF, 2013; Ghosh *et al*., 2012; Maseta *et al*., 2017). Steyn and Mchiza (2014) reported that African countries such as Zambia, Rwanda and Zimbabwe recorded a low protein intake since 1980, signifying the need to promote initiatives geared to enhancing access and utilisation of readily available protein rich dietary resources in SSA.

Research has shown that one in every two children is wasted or stunted in Ethiopia, Madagascar and Burundi (UNICEF, 2013). It has also been long noted that undernutrition is prevalent among older African males and females with estimated prevalence of 9.5-36.1% and 13.1- 27%, respectively (Charlton and Rose, 2001). Nuss and Tanumihardjo (2011) and Steyn and Mchiza (2014) noted that dietary protein per *capita* in Malawi, Madagascar, Lesotho, Zambia and Zimbabwe had decreased to less than 50 g per day, per *capita*, since 1980, thereby worsening the problem of PEU in the region. These statistics are alarming, given that protein provides the body with much needed essential amino acids, such as lysine and tryptophan; hence high risk for malnutrition associated diseases due to weakened immune system (Prasanna *et al.*, 2001). Rich protein foods such as meat and eggs are rarely consumed by resource limited communities due to prohibitive costs (Nuss and Tanumihardjo, 2011).

Factors such as poverty, inadequate education, lack of sound policies and climate change vulnerability contribute heavily to the prevalence of PEU in SSA (De Onis *et al.*, 1993; Bain *et al.*, 2013; Goudet *et al.*, 2017).

Poverty factor. Poverty is regarded as the major contributory factor to communities' failure to procure food in SSA (Bain *et al.*, 2013; Ubesie and Ibeziakor, 2013). Without the necessary resources to secure food, many households are deprived from good nutrition due to lack of dietary diversity (Mkonda and He, 2017; Owach *et al.*, 2017). For example, Akombi *et al.* (2017) reported that at least one third of undernourished children in the world reside in Africa, which is mostly comprised of third world countries; thus cementing the fact that poverty leads to PEU. Similarly, it is estimated that one person out of seven suffers PEU in countries like Zambia due to high levels of poverty (Mubanga and Ferguson, 2017; Puskur *et al.*, 2017). However, effective partnerships among governments, the private sector and the civil society geared to alleviating poverty, such as intensifying food production and nutrition security will be necessary to achieve country and regional food security targets. Poverty reduction will see communities being able to afford not only alternative rich sources of protein but also able to purchase QPM seed leading to PEU reduction.

Education level. Education plays a significant role in deciding the nutritional status of communities in a given environment (Alaofè *et al.*, 2017; Akombi *et al.*, 2017). Sub-Saharan Africa reportedly has the lowest education levels globally (Asiedu, 2014); thus precipitating the PEU predicament. It has been reported that at least 40% of the world's out-of-school children, are found in SSA (Asiedu, 2014).

Uneducated women present high chances of disadvantaging children in terms of good healthy practices, such as exclusive breast-feeding and child access to healthy nutritious food, thereby contributing to increased PEU (Mehrotra, 2006; Akombi *et al.*, 2017). Akombi *et al.* (2017) concurred that households with parents of low education levels tend to have low disposable income and, hence, are likely to spend less on proper nutrition, resulting in PEU. However, it has been shown that new technology awareness such as QPM, is not related to education level, but its adoption is related to the education level of the target people (Taipale, 2013, Ghimire and Huang, 2015). Therefore, as a counter measure, there is need to tap in the existing education in countries such as Tanzania, Malawi, Kenya and Zambia to use it as a vehicle for QPM campaigns on the benefits of QPM (Langsten, 2014; Orodho, 2014; Zinkina and Korotayev, 2014). Education promotion, which has been widely implemented in SSA region, through government initiatives such as free primary education for all, should be used as the right platforms to spread information on the existence and nutritional qualities of QPM, in order to reduce the burdens of PEU (Atuhurra, 2016). In 2006, Ghana was one of the African countries that implemented a primary child school feeding programme in line with the agenda of the New Partnership for Africa's Development (NEPAD) (Asiedu, 2014). As a credit to the programme, enrolment doubled and many are literate and now the right target for the QPM campaigns leading to the successful adoption of QPM in Ghana (Asiedu, 2014; Awunyo-Vitor *et al.*, 2016). According to Steyn and Mchiza (2014) and Mabhaudhi *et al.* (2016) education enables the acquirement of skills that would empower households to have better access and understanding to human nutritional education information.

Sound policies. Similarly, the lack of sound policies, such as making it compulsory for each and every seed company to produce at least one QPM seed variety, may also be contributing to the prevalence of PEU in SSA.

As an example, Kinabo (2014) reported that available policies in Tanzania are more inclined on enhancing food availability rather than nutrition in particular hence not addressing the issue of PEU. According to Frelat *et al*. (2016) national policies and local interventions have intense bearings on the opportunities and constraints that affect the nation. Kinabo (2014) further reported that approximately 43% of policy documents from different ministries in Tanzania do not include any explicit mention of nutrition, hence the need to have sound policies which put more emphasis on PEU alleviation.

However, Frelat *et al*. (2016) interjected that policy frameworks should prioritize the nutrition agenda in all other policies since nutrition is a paramount and cross-cutting issue in order to improve the PEU status in SSA. Moreover, governments in countries such as Zambia, Zimbabwe and Malawi should propose and implement policies such as those advocating for half of the maize produced on the market to be QPM varieties. Also, policies that advocate for compulsory production of at least one QPM seed variety from each present seed company will also help to promote QPM production by making the QPM seed easily available and accessible, thereby aiding in alleviating PEU. Furthermore, there should be recommendations to inject open pollinated QPM varieties into communities, which will be non-formal seed sources. On a positive note, countries such as Rwanda implemented the National Food and Nutrition Policy, which forms the basis for the National Food and Nutrition Strategic Plan of 2013-2018 (NFNSP) in which the Rwandan government with the help of the World Health Organisation (WHO) seeks to fight PEU (WHO, 2014). The NFNSP attempts to prevent the prevalence of PEU by bringing together many interventions that protect women of child bearing age and children under the age of five from malnutrition starting from the first one thousand days (the period from conception through two years of life when stunting in children occurs). The plan also advocates for communication campaigns promoting adoption of nutritious bio-fortified crops such as QPM to meet the protein-energy requirement of the Rwandan citizens (WHO, 2014).

Population growth. Sub-Saharan Africa has been reported to have the highest world population growth rate of 2.5% per *annum* (Bongaarts *et al*., 2013; Naidoo *et al*., 2014). This increase in population has increased the stress on the limited resources available in most SSA countries in the fight against PEU (Shiferaw *et al*., 2014). This is mainly because some countries have failed to implement sustainable population regulation policies. For example, in 2009, Mali initiated the Family Code amendment, a policy which raised the legal marriage age to 18 in order to reduce population growth in the fight against PEU (May, 2017). However, this policy was eventually altered after the Muslim society in Mali demonstrated against it. This was clearly a setback due to the problem of policy space (a matrix of outcomes of anticipated scenarios resulting from policy changes), which aggravates the PEU menace (May, 2017). Moreover, countries such as Uganda are reported to have policies opposed to population reduction programmes, which in return strains available resources to combat PEU resulting in the 52% of the children suffering from PEU (Kakooza Mwesige *et al*., 2015; May, 2017). This clearly show that some African policy makers prioritise other developmental matters without endorsing the need to reduce population growth, which gives pressure on the available limited resources to reduce PEU (May, 2017).

According to Frelat *et al*. (2016), multi-sectoral policy coordination, recognising and understanding diverse households in SSA is key for the designing of policies that aim to improve food and nutrition security. Sunguya *et al*. (2014) earlier added that resilient nutrition governance aids in bringing down the magnitude of PEU in SSA. Moreover, education programs geared towards sustainable family growth can be used as good approaches to regulate family size and population growth thereby contributing to improving nutritional standards, which is a positive step to alleviation of PEU.

Climate change and variability. Climate change is another factor which needs to be considered when discussing about PEU management (Marx *et al.*, 2014; Connolly-Boutin and Smit, 2016; Phalkey *et al.*, 2016). The impact of climate change presents threat to Africa because of its climate sensitive economies (mainly agriculture based), than any other continent; and only through agricultural production can PEU be significantly reduced. Climate change effects are already being felt world over; especially in SSA, due to limited capacity to adapt (Nhemachena *et al.*, 2014). Agricultural production is largely being affected by climate change, which in turn vehemently affect human nutrition in a negative way leading to PEU prevalence (Bain *et al.*, 2013; Chivenge *et al.*, 2015; Connolly-Boutin and Smit, 2016). Sustainable solutions to climate change and variability come in the form of what have become to known as climate smart agriculture (Mbow *et al.*, 2014; Notenbaert *et al.*, 2017). Climate smart agriculture strives to reduce further emissions of greenhouse gases through reduction of usage of in-organic chemicals and promotion of sustainable farming systems such as conservation agriculture, which can boost agricultural productivity leading to PEU reduction (Altieri and Nicholls, 2017, Brandt *et al.*, 2017; Thierfelder *et al.*, 2017). Moreover, there is intensification of breeding maize (QPM) varieties adapted to harsh environmental conditions such as drought by international organisations such as CIMMYT in order to curb PEU in SSA (Setimela *et al.*, 2017).

Protein-energy management strategies. Nutrient supplementation and crop bio-fortification are the major strategies being used to reduce PEU in sub-Saharan Africa (Low *et al.*, 2015; Talsma *et al.*, 2016; De Valença *et al.*, 2017). Nutrient supplementation involves the addition of nutrients to diets in order to help some people meet their nutrient requirements (Marra and Boyar, 2009). For example, country wide vitamin A supplementation to infants, young children and women of bearing age has been implemented in African countries such as Kenya, Uganda, Tanzania, Zambia and Zimbabwe through their respective Ministries of Health (Low *et al.*, 2015; Wirth *et al.*, 2017). Additionally, in South Africa, progress has been made to control micronutrient deficiency through food fortification and supplementation, especially for the rural poor communities (Joint, 2012).

Biological fortification, also commonly known as bio-fortification allows for increased content of certain nutrients of crops and animals to be available for human consumption (Gunaratna *et al.*, 2010). Bio-fortification is relatively a new technology, which is being promoted worldwide to combat hidden hunger (undernutrition), which is as a result of most communities relying on staple foods, which lack some nutrients resulting in increased incidence of malnutrition (Machida *et al.*, 2014). It has been scientifically reported that bio-fortification is feasible without compromising agronomic productivity for crops such as maize; with high protein quality and vitamin A, that is QPM and pro-vitamin A maize, respectively (Andersson *et al.*, 2017; Covic *et al.*, 2017; Potrykus, 2017); hence bio-fortification is the way to go. Bio-fortified crops such as QPM have been developed to fight the problem of PEU in maize dependent communities such as the SSA. In Ghana, QPM production is high and QPM-based diets among children have been reported to promote good health (Abiose *et al.*, 2015).

People in the rural communities in SSA region try to compensate protein shortage with legumes in their diets (Table 1). However, legumes lack sulphur-containing amino acids

TABLE 1. Comparison of protein quantity and quality (lysine and tryptophan levels) of non- QPM and legume grains which make common diets in sub- Saharan Africa with QPM

Source	Protein	Lysine	Tryptophan
Glycine max L.	40.1- 44.5[a*]	6.3[h‡]	1.3[h‡]
Arachis hypogea L.	23.5- 26.6[a*]	0.93[d*]	0.31[d*]
Vigna unguiculata L.	15.5- 15.7[a*]	5.7[g*]	3.2[g*]
Phaseolus vulgaris L.	15.1- 15.4[a*]	7- 7.4[f#]	0.31- 0.32[e*]
QPM	10[c†]	2.7- 4.5[b†]	0.5- 1.1[b†]
Non-QPM	10[c†]	1.6- 2.6[b†]	0.2- 0.5[b†]

[a](Kwiri *et al.*, 2015); [b](Krivanek *et al.*, 2007); [c](Ignjatoviæ-Miciæ *et al.*, 2008; Wahab *et al.*, 2012); [d](Ingale and Shrivastava, 2011); [e](Comai *et al.*, 2007); [f](Baudoin and Maquet, 1999); [g](Otemuyiwa and Adewusi, 2014); [h](Hulshof *et al.*, 2017). *, †, # and ‡ represents g 100^{-1} g; total protein%; % of total amino acids and g kg^{-1} dry matter

such as methionine, which are also essential in protein synthesis, and are not consumed often compared to cereals such as maize and hence a drawback in fighting PEU (Ingale and Shrivastava, 2011; López Barrios *et al.*, 2014; Owuamanam *et al.*, 2014). Suggesting that QPM can be singled out as one of the most suitable and promising gate away to alleviating PEU especially in SSA since maize constitute a greater part of the daily diets in this region.

Quality protein maize an alternative way to combat protein-energy undernutrition. According to Sofi *et al.* (2009) and Nuss and Tanumihardjo (2010), almost one third of the global population, including SSA countries, rely mostly on cereals, especially rice and maize for their major supply of protein and energy. Available information shows that maize has a global protein contribution of 15%, which is not enough to meet the demands for world protein requirements (Sofi *et al.*, 2009). Hence, bio-fortified cereal crops such as the QPM, which can easily fit into the farming and food systems in SSA, have the potential to reduce the protein and essential amino acid inadequacy gaps in most developing cereal dependent countries (Nuss and Tanumihardjo, 2011).

QPM has an *opaque-2* gene, which codes for high levels of the two essential amino acids; lysine and tryptophan, and as a result it is highly superior to normal endosperm maize (non-QPM) in terms of nutrition (Sofi *et al.*, 2009; Singh *et al.*, 2012; Bisen *et al.*, 2017). Non-QPM varieties have an average of about 2% lysine and 0.4% tryptophan; whereas lysine and tryptophan levels in QPM average about 4 and 0.8% of the total protein content, respectively (Prasanna *et al.*, 2001; Krivanek *et al.*, 2007; Ignjatoviæ-Miciæ *et al.*, 2008; Kiria *et al.*, 2010). QPM constitutes 80% of the biological value of cow milk, compared to 45% of non-QPM (Machida *et al.*, 2014; Rajendran *et al.*, 2014). Mbuya *et al.* (2010) reported that QPM contains 70 to 100% more of lysine and tryptophan than non-QPM. These amino acids are used to make complete proteins in the body, and tryptophan reduces the incidence of PEU (pellagra and kwashiorkor) in children (Graham *et al.*, 1990).

It has been reported that QPM varieties have yielded positive benefits in Mexico, Central America and China for yield and reduction of PEU (Mbuya *et al.*, 2010). QPM has been shown to be of nutritive value both as a human food, especially for children and women of reproductive age and as an animal feed particularly the non-ruminants (Bello *et al.*, 2014). In China, QPM hybrids were recorded to attain yields which are 10% higher than those of non-QPM varieties (Mbuya *et al.*, 2010). Information from different studies shows that the crop has the potential to boost pig and poultry production, thereby increasing disposable income, food and nutrition security (Nuss and Tanumihardjo, 2011).

Researches carried out in countries including Ghana and Ethiopia revealed that children with kwashiorkor responded positively to diets with *opaque-2* proteins (Krivanek *et al.*, 2007; Nuss and Tanumihardjo, 2011). Studies confirmed that rats fed with 90% QPM for 28 days gained an average of 97 g, while those fed on non-QPM varieties attained an average of 27 g (Kiria *et al.*, 2010; Boateng *et al.*, 2012). These findings clearly demonstrate that QPM would be superior to non-QPM varieties, if used in the diet of humans and monogastric animals and can significantly contribute to PEU alleviation (Kiria *et al.*, 2010). Furthermore, researchers have revealed that approximately 100 g QPM is adequate for children to maintain the required levels of lysine and about 500 g is adequate for adults, thereby reducing maize intake required to meet sufficient body protein by 40% as compared to non-QPM varieties (Nuss and Tanumihardjo, 2011).

Current efforts in the promotion of QPM production. According to Bello *et al.* (2014) QPM and non-QPM varieties can only be differentiated through laboratory tests because based on phenotypic appearance they look the same. Research has shown that QPM varieties exhibit the same agronomic performance as non-QPM varieties (Bello *et al.*, 2014). Researches which demonstrate the yield and agronomic performance of QPM are important so as to convince farmers to undertake the adoption process of the QPM varieties. This is primarily because most farmers from the SSA region are more interested in the yield and agronomic performance of a variety than the nutritional composition which they cannot measure. Moreover, similarities of QPM to non-QPM varieties in terms of yield and agronomic performance, phenotypic appearance and palatability represent the strengths of QPM varieties, which needs to be exploited when promoting its adoption. Furthermore, QPM has the greatest opportunity to reduce PEU in SSA, since most communities in this region mostly cultivate and consume maize, hence QPM can easily fit in the food and farming systems of these communities due to its physical similarities to non-QPM.

Twumasi-Afriyie *et al.* (2016) reported that an estimated area of one million ha of land in SSA was under QPM production in 2015. Initially, QPM promotion began in Ghana and several other African countries, but its research has spread throughout the world. As reported by Krivanek *et al.*, (2007), Sofi *et al.* (2009) and Machida *et al.* (2014), 30 million ha is under maize production in the sub-Saharan region, but only less than 1% is approximated to be under QPM production; yet they share the same agronomic practices (Table 2). The low adoption of QPM varieties in many SSA countries can be attributed to the fact that the technology is still new and as a result a lot of maize farmers do not even know that maize with such benefits exists (Machida *et al.* (2014). It, therefore, calls for an increase in awareness campaigns involving mostly resource poor communities' in order to improve the adoption of QPM varieties in the fight against PEU.

In Africa, Ghana (Table 2) was the pioneer of QPM development and adoption, with its initial release of the much popular Obatanpa variety in 1992; and subsequent release of the other three varieties in 1997 covering an estimated area of 70 000 ha (Boateng *et al.*, 2012; Andam *et al.*, 2017). Countries such as Uganda, Burkina Faso and South Africa (Table 2) produce significant amounts of QPM (Twumasi-Afriye *et al.*, 2016). In Zimbabwe, several seed companies have availed QPM varieties such as MQ623 known as "Mama" from Mukushi Seeds, SC643 from Seed Co and ZS261Q from ARDA Seeds (Derera, Prof,

TABLE 2. African countries QPM production arranged according to area under QPM production

Country	Area under QPM production (ha)	Production description
Ghana	71 250	High
Uganda	46 717	High
Burkina Faso	20 600	High
South Africa	12 500	High
Mozambique	11 250	High
Mali	9000	Medium
Ethiopia	7283	Medium
Nigeria	4500	Low
Benin	4325	Low
Tanzania	4300	Low
Guinea	3875	Low
Malawi	1125	Low
Togo	750	Very low
Cote d'Ivoire	565	Very low
Senegal	500	Very low
Cameroon	305	Very low
Kenya	12	Very low
Zimbabwe	-	New adopters

Modified from Krivanek *et al.* (2007)

Seed Co Pvt Ltd, 2016; MacRoberts, Dr, Mukushi Seeds Pvt Ltd, 2016; Mhike, Dr, Pioneer Hi-bred International, 2016). Currently, the University of Zimbabwe in partnership with a non-governmental organisation; Welthungerhilfe under the Sustainable Intensification of Market Based Agriculture project are carrying out a research to promote the adoption of quality protein maize and orange fleshed sweet potato in Gokwe south district in order to curb PEU.

National nutrition policies. In SSA, several governments support the issue of nutrition, for instance Burkina Faso and Mali developed specific policies such as the National Plan of Action for Nutrition and the National Programme Plan for Food Fortification, respectively (Birner *et al.*, 2007). These policies are meant to help the nations to fight against PEU. In Zimbabwe, the government adopted a policy document; "the Zimbabwe Agenda For Sustainable Socio-Economic Transformation (ZIMASSET)" which spells out the need to create a self-sufficient and food surplus economy (Bonga, 2014). The ZIMASSET has clusters which include the one for Food Security and Nutrition. The government is also supporting private sector and donor supported non-governmental organisations, which are working in collaboration with the Ministry of Agriculture, Mechanisation and Irrigation Development for the promotion and production of bio-fortified crops such as QPM to lessen the problem of PEU. Furthermore, under the Command Agriculture policy, inputs are provided and farm management monitored resulting in bumper harvest (The Herald, 26 August 2017), thus increasing availability of quality food such as QPM. These are some of the countries implementing nutrition policies by trying to emulate Ghana. In Ghana, the success of QPM adoption and production is largely attributed to the promotional activities which involved state policy makers, Sasakawa Global 2000 and other private sectors (Machida *et al.*, 2014).

However, as asserted earlier some governments in SSA are not subsidizing QPM production and initiating awareness campaigns to drive adoption; and traders are not willing to pay a premium price for QPM grain (Kiria *et al*., 2010). All these factors have contributed to the slow adoption rates of QPM in SSA. Sub-Saharan African countries need to implement sound policies such as making it compulsory for every seed company in the region to produce at least one QPM seed variety in order to increase seed availability and accessibility to communities in trying to combat PEU.

CONCLUSIONS

QPM has the potential to combat PEU in many developing countries in SSA, which solely depend on maize for the bulk of their daily diets. QPM has been proven to exhibit the same agronomic performance as non-QPM varieties, hence, does not require any special agronomic practices and can be easily incorporated in smallholder farming and food systems in order to curb PEU. Nonetheless, QPM adoption has been slowed by the fact that the QPM distinctiveness is unnoticeable; hence farmers cannot hastily adopted QPM varieties as based on the purported nutritional value. Rather they would want high yielding varieties, since it is one of the major criteria used to select varieties to grow. Therefore, there is need to do many demonstration plots such that farmers can visually appreciate the similarity of yield and related agronomic performance between QPM and non-QPM varieties. With sound policies, infrastructure and campaigns for QPM, the protein nutrition of children, women of reproductive age and the elderly will improve significantly.

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