Journal of Pure and Applied Agriculture (2021) 6(1): 1-6
ISSN (Print) 2617-8672, ISSN (Online) 2617-8680
http://jpaa.aiou.edu.pk/
REVIEW PAPER

Plant breeding: A potential tool to sustain food security in Sub-Saharan Africa

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Received: 21 December 2020
Accepted: 12 March 2021

Abstract: The world human population has continued to increase over the years, this has affected availability and shorten supply of food. Food security challenge is bound to happen as the world human population is expected to reach 9 billion by the year 2050 if food production rate did not double its current production rate. The problem is compounded by the reduction in area of arable land available for farming and food production due to urbanization, salinity, land degradation, desertification, natural and man-made disasters, and climate change. The crop production and food security are under threat from these factors. To address challenges, a call for the development of improved new varieties of crop plants that can give more yield under abiotic and biotic stresses is inevitable; and can be achieved through improving various traits that are associated with yield in varieties of crops especially to more adaptive and resilient to inclement conditions. Adopting the knowledge of science particularly plant breeding and genetics is a way forward to meet future food demand in sub-Saharan Africa due to her relatively lagging pace in technology and inadequate research funding schemes. In this review work, we focus on the conventional plant breeding methods for food security sustainability in sub-Saharan Africa rather than technologies that the region's economy cannot sustain.

Keywords: Food demand, Food security, Human population, Plant breeding, Sub-Sahara Africa

To cite this article: Agbowuro, G. O., Salami, A. E., & Afolabi, M. S. (2021). Plant breeding: A potential tool to sustain food security in Sub-Saharan Africa. *Journal of Pure and Applied Agriculture*, *6*(1), 1-6.

Introduction

Food insecurity has become a global concern that needs urgent attention by all. Food is one of the most essential needs of the human race, including livestock globally. Feeding the growing human population with good and safe food is one of the greatest challenges fronting international organisations (Mueller et al., 2012). According to Food and Agriculture Organisation [FAO], (2002), food security is a state in which everybody has physical, social, cultural and economic access to safe, sufficient and nutritious food at all points in time to meet daily dietary requirements for health life. The level of food security is determined by its availability, accessibility, affordability, and utilization in any state, province, region or country as the case may be. United Nations Administrative Committee on Coordination-Subcommittee on Nutrition (UN ACC/SCN, 1991) describe food security at household level when every member of the family has access to quality, enough, and safe food, and the food is culturally acceptable and gotten at the right time needed. Moreover, food insecurity has been described also as the inability to access and/or afford sufficient, safe and quality food to satisfy human's daily dietary needs (Park et al., 2012). (FAO, 2019a) has estimated that over eight million people go hungry across the world and more than two billion people are deficient in basic micronutrients. In Africa, the number of undernourished people have increased significantly in Africa in the past 10 years (FAO, 2018), Malnutrition is one of the major factors responsible for physical malformations and weakness, poor growth and development and cause of diseases leading to premature deaths among children, (Development Initiatives, 2018).

Human population was projected to reach 9.7 billion by the year 2050 (Chawade et al., 2019), and to meet the food demand or this population, requires an increase in global food production rate (Royal Society, 2009). As the population grows, the demand for nutritious and safe food continues to increase, so is the increase in urbanization and standard of living (United Nations [UN], Department of Economic, and Social Affairs, Population Division, 2019 a&b). Since increasing human population outweighs food production increase, agricultural production needs to rise by 50% (Royal Society, 2009). Unfortunately, the arable land area available for cultivation is limited and also adversely impacted by urbanization, desertification, and environmental degradation. Moreover, numbers of people engaging in agricultural activities have decreased globally and especially across the African landscape due to rural-urban migration in search of quality life.

While the need to increase agricultural productivity on the limited arable land area cannot be overemphasized, climate change has adversely impacted agricultural production globally (Lenaerts et al., 2019). For example, as evident in high temperature, variation in rainfall and flooding in some parts of the world, sea surges, heat waves, glaciers melt and drought with dramatical effects in some areas (Schlenker & Roberts, 2009). There are also losses of agricultural produce on the field and in storage due to pests and diseases, a threat to global food security.

Reduction in agricultural yield losses due to biotic and abiotic stresses can enhance global good and safe food available, affordability and accessibility. The possible ways of ensuring food security in Sub-Saharan Africa are: food wastage reduction, bridging yield gap with improved agronomy, increase the size of arable land area and improved crop productivity through improved planting materials (Cassman et al., 2003; Godfray, et al., 2010; Laborte et al., 2012; Stuart et al., 2016; Kampman et al., 2020). Improving the yield and quality of underutilized crops like African yam bean, pigeon peas, Bambara groundnut, sword bean and lima bean by plant breeders to boost food security in sub-Saharan Africa. The causes of food insecurity cannot be resolved in isolation (Meemken & Qaim, 2018; Springmann et al., 2018). Plant breeding is one of the key strategies in combating these problems to ensure food security in sub-Saharan Africa as it is cost effective with a sound technical know-how in the region.

Plant breeding is an active area of science deliberate effort to change plants nature, and/or utilization of desired heritable variation that exist in the plant gene pool and its related wild species for the development of new improved varieties (Acquaah, 2012; Niazian & Niedbała, 2020). Landraces, wild relatives, initial breeding materials and advanced breeding materials serve as source of breeding materials that the plant breeders use to develop desired trait(s) by adopting efficient plant breeding strategy. Understanding, knowledge and information on the genetic base of the traits to improve, its mode of inheritance, the extent of gene actions, heterosis, the combined abilities and mode of action are the key pillars that plant breeders use to make improvement on plants. Plant breeding has the potential to resolve agricultural productivity problems to enhance food security. Nevertheless, it cannot fix all the problems related with agricultural production alone but has the capability to solve specific issues like increase crop productivity (higher yield), development of diseases and pests resistance, reduction in maturity time, enhancing nutritional value, elimination of toxic substance from crop, abiotic stresses adaptation, increase shelf-life, general improvement on plants agronomic traits with the aid of plant breeding techniques. The needs for genetic manipulation in plants may change based on the societal needs on what the plant provides such as food, pharmaceuticals, raw materials for agro-industries etc.

There is no gain saying that biotechnology is playing the roles of plant breeding in agricultural development more perfectly in developed nations but this has not been realistic in sub-Saharan African due to the poor economy situation, inadequate budgetary allocation to the few research stations available, poor technical know-how and poor agricultural policies in the region. The use of genetically modified crops developed through genetic engineering by farmers has been confirmed to lead to higher yields and improved nutrition compare to classical plant breeding (Qaim, 2016) but only few emerging economies like China, India, Pakistan, Bangladesh, and South Africa welcome the development (Zaidi et al., 2019). According to Nicolia et al. (2014), many Africa and Asia nations have refused to adopt the use of genetically modified crops due to fear of losing the export of their agricultural produce to European nations. However, many countries in sub-Saharan Africa have not developed technologies to commercialize plant biotechnology to improve agricultural production but plant breeding can serve this purpose. Massive use of agrochemicals such as fertilizers, fungicides, herbicides, and pesticides has led to different environmental problems. This review presents plant breeding as one of the ways forward for food security challenges in sub-Saharan Africa. low level technology and poor financial state that cannot put biotechnology that is already at work in developed nations in place to face the nearby future food security challenges ahead. Although, multi-disciplines like agronomy, extension, soil fertility, post-harvest approaches cannot be ruled. Nevertheless, plant breeding is an approach to start with.

Plant breeding addresses the need to increase crops yield

According to Ray et al. (2013), the world agricultural production will need to double the present production rate to meet the supply of the increasing human population to meet its food demand. About three billion people are projected to add to the present world human population in the next three decades thereby requiring increase in world food supplies to meet the projected world population increase (Acquaah, 2012). Though, crop production is increasing steadily to cater for the increasing world human population food demand but the rate at which human population increases is outgrowing the rate of food production increase, this is a great global challenge ahead (Bradshaw, 2017).

Ray et al. (2013) used an extensive crop production statistics to estimate global crop yield increases per unit land area for soybean, rice and corn. However, it was estimated by the authors that food production was far below the 2.4% increase required for a 100% projected increase in human population by 2050, and this will make feeding the world unrealistic by 2050. Also, available arable land for crop production is undergoing reduction from the associated effects of anthropogenic activities. Hence, more pressure on the lesser arable land area available for food production. To ensure food security in the nearest future, increasing crop yield per unit area is more visible and sustainable than expanding the farm size that its availability is not certain in sub-Saharan Africa where fame and hunger is a serious concern and the resource to feed the growing human population is decreasing day by day due to man-made and natural disasters, plant breeding as a strategies should be adopted to rescue the region by developing high-yielding varieties as technical and financial issues are great limitation in the region. Increase in crop yield such as grain, fodder, fibre, oil, seeds, fruits, sugar under biotic and abiotic stresses could be achieved by carefully selecting the crops with higher yield under optimal crop production conditions. The crops that perform optimally in a normal condition are likely to have higher yield in stressed conditions. Plant breeding as a tool has brought a lot of success stories in generating high yielding crop varieties in developed, developing and underdeveloped nations (Wolter et al., 2019). According to Acquaah (2012), plant breeding techniques have helped to increase maize yield from 2 tons/hectare in the 1940s to about 7 tons/hectare in the 1990s.

Plant breeding addresses the need to adapt plants to various abiotic stresses

Crops are endangered by various abiotic stresses like temperature increase, drought, heat and flood which are consequence of climatic changes and other factors such as soil salinity, heavy metal toxicity and oxidative stress. Climatic changes are one of the major threats to crop production. FAO (2005) reported that Africa is the most vulnerable to climate change. Prediction on climate change indicated that warming will be more than global annual mean with 3 to 4 ºC in few years ahead (Boko et al., 2007). The adverse effects of climate change happen through the rising levels of carbon-dioxide in the atmosphere and temperature (Nelson et al., 2009; Intergovernmental Panel on Climate Change [IPCC], 2014). Climate change increases the rate of extreme weather conditions like drought and floods (Hay et al., 2016). The fluctuation in rainfall pattern and increase in temperature was predicted to affect crop yield by almost 50% by 2080 (Nelson et al., 2009). Accumulation of heavy metals and salt in soils have also limited crop yield globally. Almost 831 million hectares of arable land is saline globally (Martinez-Beltran & Manzur, 2005). Wang et al. (2003) made a prediction that almost half of the arable land across the globe will be saline by 2050. Moreover, accumulation of heavy metals in soil is increasing globally (Vijayaragavan et al., 2011). Bio-accumulation of heavy metals in plant parts has a detrimental effect on plant growth and development (Breckle & Kahle, 1992) and are very hazardous to humans and livestock when consumed (Sanita di Toppi, & Gabbrielli, 1999). All these factors will impose negative implications on the key pillars of food security (food availability, accessibility, affordability and utilization) if not handled as a matter of urgency.

Smyth (2020) emphasized the importance of the need to speedily develop new crops varieties that are better adapted to new climatic conditions for better yield. Plant breeding as a tool can be used to adapt crops to the changes in climatic variabilities by making improvement on crop performance under various stress conditions using different breeding strategies (Trethowan et al., 2010). Crop varieties that are tolerant to salt salinity and toxic heavy metals can be also screened using plant breeding techniques and improvement will be made on the selected varieties. The release of heat, drought, salt and other abiotic factors resistant varieties through plant breeding (feasible and cost-effective technology) in sub-Saharan African will enhance food production and agricultural profitability in the region.

Plant breeding addresses the need to adapt crops to biotic stresses

Biotic stresses are one of the challenges to plant during its growth and developmental phases and a source of yield reduction. These biotic stresses are caused by living organisms like fungi, bacteria, virus, nematodes, oomycetes, pests, insects, herbivores, arachnids, weeds etc. and these are the major causes of different diseases, infections and damage to crops on the field which leads to yield reduction and also spoil the produce in the store or warehouse. These living agents causing biotic stresses compete with their host plant for nutrients which leads to plant poor performance or death. Insects, pests and herbivores feed and inflict injury to plant parts such as leaves, flowers and fruits, thereby initiating infection on the plants and even reduce the leaf area available for photosynthesis. Weeds compete with crops for space, light, water and nutrients. All these have a detrimental effect on plant growth and development. Severe stresses cause dysfunctions that prevent flowering, seed formation, fruit abortion and also induce senescence (Verma, et al., 2013). Reports of total yield losses had been recorded due to microorganism (Fritsche-Neto & Borém, 2012). Several reports had shown the levels of yield losses in crops due to abiotic factors. Prasad et al. (2006); Dean et al. (2012) reported that rice blast disease caused about 70-80 % grain yield losses in rice (Agbowuro et al., 2020a). Kumudini et al. (2008) reported 37-67% seed yield reduction in soybean due to soybean Asian rust in Brazil. It was reported by Vieira (1983) that over 45 micro-organisms which include virus, bacteria, fungi and nematodes reduce the yield of common beans in different regions and situations.

The huge amounts of fungicides and pesticides used by farmers have economic and negative environmental impact. The development and use of biotic stress-resistance varieties by plant breeders have reduced the cost of production and reduced yield losses over the years (Agbowuro et al., 2020b). The transfer of desired disease resistance alleles from some plant species to another using hybridization and repeated backcrossing have made crop production from to be stabilized one season to another. Crops with tolerance abilities from pests, insects and pathogens will exhibit most of its yield potential.

Plant breeding addresses the need to improve crop quality

Several anti-nutritional and toxic factors are found in some tropical plant parts and these factors are toxic to man and livestock if not properly processed (Makker & Becker, 1999). Cassava is at the top of the list of stable food consumed in Nigeria (Ilona et al., 2017). Cyanoglucosides linamarin and lotaustralin are present in cassava which makes them toxic and these compounds are hydrolyzed by endogenous enzyme linamarase to acetone cyanohydrin and cyanide (Nambisan, 2011). The problem of cyanogen presence in cassava is a great concern. Plant breeders have developed cassava varieties that are low in cyanogen (linamarin) content and cost-effective breeding research is still on-going to develop cassava varieties with less in cyanogen (linamarin) content. Anti-nutritional factors like non-protein amino acids, alkaloids, cyanogenic glycosides, tannins were present in some grain legumes and these anti-nutritional factors are either toxic, exhibit poor level of digestibility or unpalatable (Lal et al., 2017). Reduction of these anti-nutritional factors in some legumes can be achieved through plant breeding techniques.

According to Development Initiatives (2018), malnutrition is a problem that leads to poor growth and development, and premature death especially among children. Malnutrition reduces the immune system and mal-nourish individuals are prone to high risk of infections and infectious diseases. Malnutrition was estimated to contribute to about 33.3% of total child mortalities indirectly (World Food Programme, 2020). Kwashiorkor and marasmus are the two main protein energy malnutrition in sub-Saharan Africa. Quality protein maize has been developed by plant breeders with the aim of increasing the daily protein in-take to alleviate the problems associated with malnutrition in sub-Saharan Africa. A lot of research work is on-going to increase the quantity of amino acids in some stable food crops using various plant breeding methods. Vitamin A deficiency had become a public health problem for years. Introduction of vitamin A in the most consumed staple food (cassava) in Nigeria through plant breeding has helped to address the problem of vitamin A deficiency (Ilona et al., 2017).

Plant breeding addresses the need to improve general agronomic traits in crops

Pod shattering is a trait that causes a great yield loss in legumes on the field especially in highly susceptible cultivars. In common vetch (*Vici sativa* L.) cultivars, about 40-60% shattering rate was reported by Dong et al. (2016). Price et al. (1996) reported 11-25% yield loss in some Brassica species at the onset of maturity, while MacLeod (1981) claims that losses in Brassica species could be up to 50% in adverse seasons due to pod shattering. It was also reported by Hare and Lucas (1984) that seed losses as a result of pod shattering in big trefoil (*Lotus uliginosus* Schkuhr) is between 7-88%. Pod resistance to shattering in crops is highly heritable and is governed by more than one gene. Pod shattering resistance ability in crops can be improved by plant breeders to minimize losses by studying the inheritance pattern in particular crop species using a suitable plant breeding method such as generation mean analysis. This will greatly reduce yield loss on the field thereby boosting food sufficiency.

Climate change has tended to rainfall intensity, frequency and duration thereby making the crop plants with longer maturity period and high water requirement to give lower yield. Breeding for earliness in crops to produce optimally within a short period of time before the rain stops is important. Drought is regarded as a multidimensional stress limiting the growth and development of crop plants over time and space (Maazou et al., 2016). Visual symptoms of drought stress in crop plants are wilting; starting from the rolling of lower leaves followed by the upper leaves, changes from green colour to green-gray, stomata closure and reduction in photosynthesis rate (Maazou et al., 2016).

It was reported by FAOSTAT (2010) that 15%-20% of maize grain yield is lost on a yearly basis due to drought and the losses increase as the drought becomes more severe due to changes in climatic variables. Some farmers adopted irrigation to cushion the effects of drought but large numbers of farmers don't have access to irrigation in developing nations (World Bank, 2005). Selection and development of landrace accessions that are tolerant to drought by plant breeders is a way of overcoming the challenges of yield losses due to drought is of paramount importance.

Conclusion

Plant breeding offers a great potential in contributing to sustainable food security in sub-Saharan Africa. It requires little cost and technology to make improvement in plants though it takes time. Plant breeding is the best option in improving crops for higher yield or any desirable traits in any developing nation with poor economy and inadequate technology to commercialize the output of biotechnology and genetic engineering such as genetic modified crops. Adoption of improved cultivars played a vital role in alleviating hunger and poverty over years. Plant breeding as a tool in crop improvement has helped in increasing crop diversity, increased yield, offered good pests and diseases resistance, adaptation of crops to abiotic stresses, elimination of toxic substances in crops, improvement of crop yield quality, shorten the maturity period in crops, just to mention a few. More food are now being produced without necessarily increasing farm size with lesser cost of production. Thus, this will enhance food security sustainability.

Authors Contributions: G.O.A. initiated the review work, G.O.A. and M.S.A. wrote the manuscript and A.E.S. corrected the manuscript.

Acknowledgments: The authors are thankful to the library of Elizade University, Ilara-Mokin, Nigeria for using their resources.

Conflict of Interest: The authors declared that they have no conflict of interest.

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