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Imperativeness of Agricultural Technology for Sustainable Crop Production, Food Security and Public Health in Sub-Saharan Africa

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ABSTRACT

Crop production, food security, human health and economic activities in Sub-Saharan Africa are affected by many factors, including population dynamics, conflicts, crop diseases and recurrent climate change. Quantity and quality of crop yields are falling due to influences from these factors. The combined impacts of these factors invariably lead to poor access to nutrient-rich foods, severe hunger and massive increases in the prevalence and number of people living with protein-calorie malnutrition or vitamin-mineral deficiencies (VMD) in sub-Sahara Africa (SSA) and some parts of Asia. So far nearly 2 billion people in these regions are malnourished while 1 billion others suffer severe hunger. Classical strategies of crop improvement through conventional breeding programs for higher crop yields, nutrients enrichment, resistance to pests, diseases and other environmental stressors; or for improved water and fertilizer use efficiency are time consuming. Lack of useful genotypes (germplasms) also hampers the effective use of conventional approaches for crop improvement. Against this backdrop, availing growers with improved crop varieties requires a huge time lag. Overcoming these challenges will necessarily require a comprehensive approach involving combining classical breeding, with modern frontier agricultural technologies. Agricultural technologies such as immunization and biotechnology (genetic engineering) have strong potentials towards contributing to the development of healthier, higher yielding GM seeds, climate smart cultivars with capacity to endure salinity, soil reactions and disease, as well as transgenic varieties dense in essential nutrients and presenting improved appearances compliant with mechanization. Above all such GM varieties genetically equipped for early maturity are in all wise welcome especially in hunger prone, highly malnourished conflict ridden and extreme weather affected localities including sub-Saharan Africa. In the light of these therefore, this article reviewed the significance of biotechnology on crop improvement, human nutrition and health using available literature published between 1987-2018; and the outcomes of the review are hereby presented and discussed.

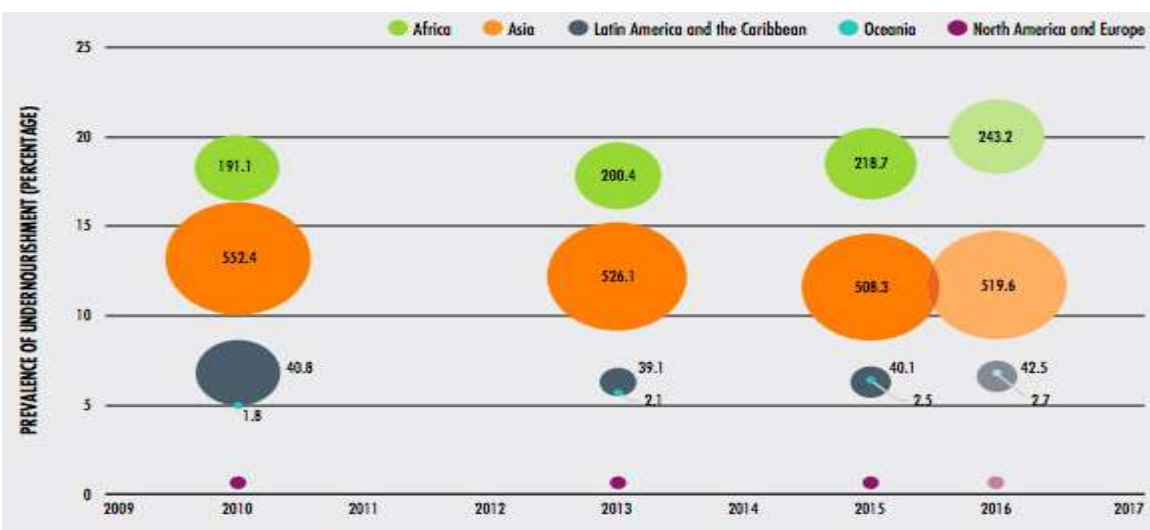
1.0 INTRODUCTION

1.1 Hunger and malnutrition: Some causes and implications

Literature suggests that 75 % of the people living in Asia and sub-Saharan Africa (SSA) derive their food and income from cultivating small farm-plots, inter-cropping a diversity of local crops and dealing with unique pests and plant diseases. Yields are usually low in such agricultural mixes (www.globalsciencebooks.info>images...). Many kinds of pests and diseases are involved in decimating agricultural crops, reducing their yield and produce quality in terms of chemical and biochemical compositions (Enyiukwu *et al*., 2014a; Amadioha and Enyiukwu, 2019). In addition to attacks by biotic agents, other factors reported to be associated with poor yields and restricting access to safe food or limiting food security include environmental stressors due to climate change and communal conflicts (World Hunger, 2018). In the overall, consumption of foods with reduced nutrient contents owing to attacks by pests and pathogens or contamination with mycotoxins will lead to serious health problems such as protein-calorie malnutrition (PCM) and vitamin-mineral deficiency (VMD) on the one hand (World Hunger, 2018) or an array of inflammation-associated medical issues such as cancer, allergies, birth defects etc. on the other (Enyiukwu *et al*., 2014b, c; 2018; Enyiukwu, 2019).

1.2 Malnourishment and malnutrition: A health bomb

Statistics shows that severe hunger and poverty affect 1 billion people worldwide while 2 billion others especially in the developing countries of Southern Asia and sub-Saharan Africa (SSA) are malnourished; thus constituting serious public health problems and contributing immensely to child mortality (BMF, 2011; World Hunger, 2018). Estimates from these sources showed that by 2050 the earth's population will reach 9 billion people; and with increasing scarce resources, pest and disease pressures, conflicts and changing climate, additional strains would be exerted on agricultural productivity. In SSA about 76 % disparities between actual and potential yield of crops has been documented due in large extent to these factors (World Hunger, 2018). Generally, an average of about 10.7 % of the population of the world majority of who are in Africa and Asia is undernourished, (Fig. 1). Studies conducted in different continents in 2016 revealed that amongst continents, the highest prevalence of malnourished people actually exist in SSA where 243.2 million people representing 23 % of the population and 519.6 million (<15 %) others in Asia are severely undernourished. Besides quantity of yields, quality of biological yields is also very important aspect for consideration in terms of food security and nourishment. Estimates suggest that undernourishment and malnutrition account for about 11 % of global burden of all diseases and is fingered as the number one risk factor to public health worldwide (World Hunger, 2018).



Year

*Number of undernourished people in Africa = 243.2 million; Asia = 519.6 million

Figure 1: Comparative prevalence and number of malnourished people in different continents of the world; **Source:** World hunger (2018)

Globally, out of the 250 million children reported with vitamin A deficiency, 0.5 million of them lapsed into blindness while 0.25 million others actually die from the deficiency. Up to 3.1 million people representing 45 % of children on a world scale actually die from malnutrition and so far it is considered the single underlying cause of 45-61 % deaths in measles, pneumonia, malaria and diarrhea-affected children. On the other hand, about 38 million children born in 54 countries suffer from iodine deficiency (ID). ID is known in medical circles for impairing cognitive development while 20 % of all maternal deaths have been liked to Fe deficiency anemia (World Hunger, 2018). Deficiency of Zn alone is reported to cause 4 % of all deaths of pre-school children around the world (GAIN, 2018). This source reported further that Fe, I, and Zn deficiencies culminate in not less than a loss of 2-3 % of national gross domestic products (GDP) of countries around the world.

VMD and iodine deficiency have been extensively fought through pharmaceutical and table salt fortification respectively. However, such methods are deemed expensive and not well utilized in rural areas probably due to poor sensitization and lack of public health professionals. Many workers believe that bio-fortification of crops presents a cheap, sustainable and far reaching solution to overcoming micronutrient deficiencies in sub-Sahara Africa. So far cassava, cauliflower, banana have been transgenically bio-fortified (Garg *et al*., 2018).

1.3 Conflicts: A contributor to under-nourishment and food-insecurity

Most localities in SSA are agrarian communities. Conflicts have been reported to underpin some of the interferences to sustained and sustainable agricultural production, food security and safety in sub-Saharan Africa. As at 2017, World Hunger (2018) reported that eruption of diverse forms of conflicts were responsible for starvation, acute food shortages and food insecurity in 18 countries and territories in the world. As a result more than 70 million people are in dire need of urgent food-related actions. Conflicts cause untold human displacement, disruption of agricultural land use, market infrastructure, limits access to foods and making malnutrition imminent or eminently prevalent in the region (Fig. 2) (World Hunger, 2018).

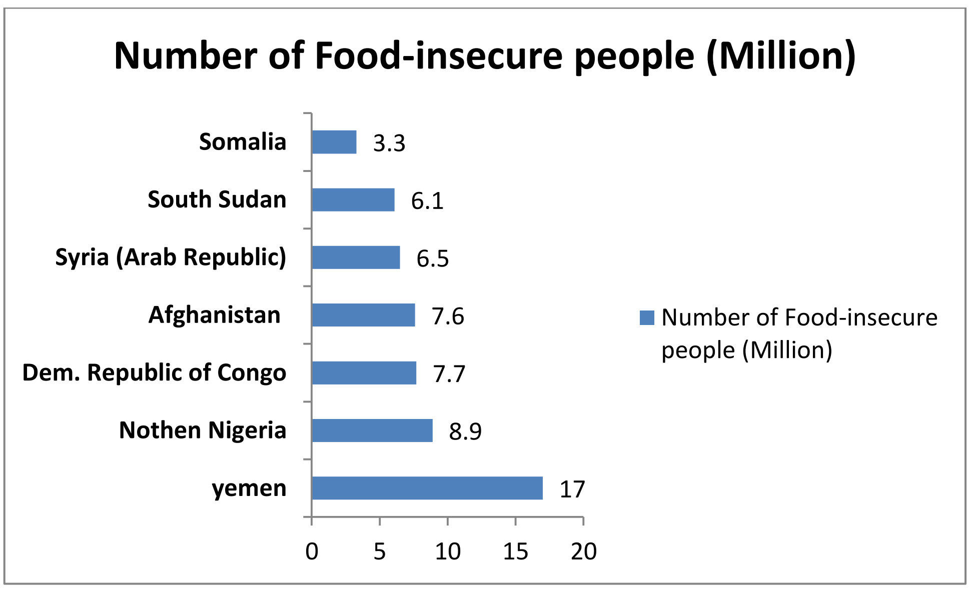


Figure 2: Conflict-induced food insecure people in sub-Sahara Africa and Yemen
Source: World Hunger (2018)

In Northern Nigeria for instance, nearly 9 million people (5 % of the country's population) are evidently malnourished due to "*Boko Haram*" insurgency while 6.1 million and 3.3 million others in South Sudan and Somalia respectively suffer the same fate (Fig. 2). Early maturing, climate smart GM agricultural cultivars would in no small measure contribute to bailing out these countries from vitamin-micronutrients deficiency and food insecurity (GAINS, 2018; Garg *et al.,* 2018).

1.4 Climate change: Another contributor to under-nourishment and food-insecurity

Climate change effects such as droughts and flooding were reportedly implicated for causing large scale food shortages and insecurity for 20 million people in SSA. In 2017 World Hunger (2018) reported that climate shocks were one of the main factors underpinning acute food shortages and food-insecurity experienced in 23 countries and territories around the world where not less than 39 million people are direly in urgent need for food-based action. In several agrarian communities especially in SSA where economic activities are driven by agriculture, droughts have been noted as a major cause of economic disruption or food crises in such settings. For instance, in Ethiopia alone 8.5 million people representing 27 % of the population of the country are food insecure; whereas 5.1 million (42 %) and 3.4 million (25 %) in Malawi and Kenya are not food secure (Fig. 3). Breeding to withstand or overcome extremes of climate effects have been suggested as a cheap and veritable way of ameliorating the impacts of climate change (Sadiku and Sadiku, 2011).

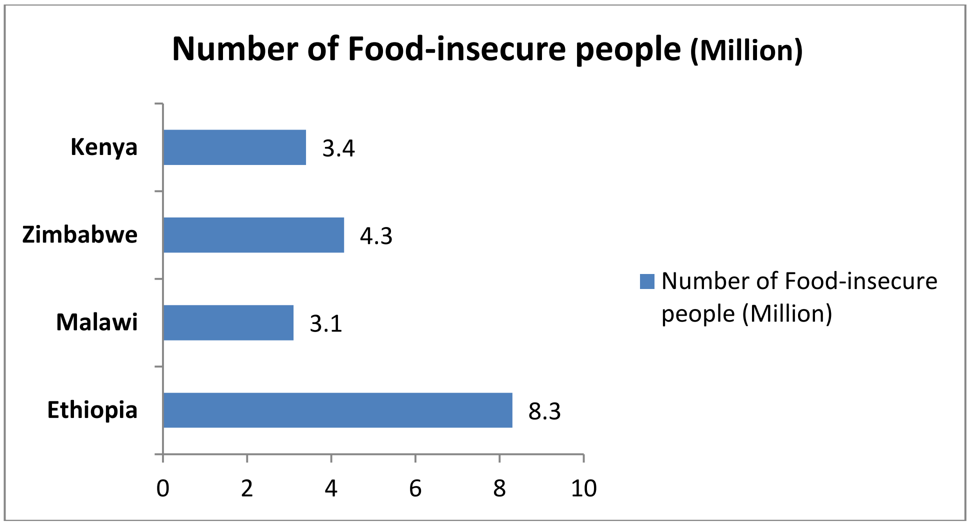


Figure 3: Number of people affected by climate change-induced food insecurity in SSA
Source: World Hunger (2018)

1.5 Food production and biotechnology

Lack of adoption of modern more productive agricultural technologies is seen as the single most important factor militating against food production (Enyiukwu *et al*., 2014a, c; 2016). There is no single solution to tackling the challenges encountered by farmers and growers of agricultural crops especially as it relates to losses occasioned by diseases and extremes of environmental influences on yield and crop quality, both in the field and storage. If we must attain food security therefore, a comprehensive approach to developing healthier seeds (or planting stocks), early maturing, more nutritious and stress-resistant varieties coupled with their agronomic management techniques aimed at improved yield and crop appearance are certainly welcome and urgently invited (BMF, 2011). This Foundation reported that such agricultural interventions will be 4 times more effective than any other approach including classical crop yield improvement strategies aimed at reducing hunger and poverty or approaches targeted at pharmaceutically improving secondary agricultural products for enhanced public health in the continent.

On these grounds TIFAC (2015) found that agricultural interventions in rsecent times will of certainty involve use of techniques of immunization and biotechnology for crop improvement. Crop biotechnology refers to any technique which utilizes biological organisms (or their products) to make, modify or improve a plant for the use of man or society. Biotechnology is a broad discipline drawing on the principles of molecular biology, bioinformatics, genetics and breeding, biochemistry, microbiology, plant physiology, pathology and entomology (Obi, 2000; Kumar and Gupta, 2012; Gupta and Kansha;l, 2018; Agarwal *et al*., 2018). It encompasses genetic engineering (recombinant DNA, gene transfers, embryo manipulation); tissue cultures (plant regeneration, monoclonal antibodies); biosensors and bioprocess engineering. These techniques and technologies hold tremendous potentials for improving crop production and protection through higher yielding crops, more nutritious cultivars, crops with better characteristic and appearance, low fertilizer requiring crops and those with improved ability to resist pests and diseases. It will also incorporate and encourage the sustainable propagation of plant varieties with useful and biologically active substances such as bio-pesticides, food additives or pharmaceutical attributes (Hellminch *et al*., 2008; TIFAC, 2015 Ghasemi *et al*., 2018).

The prevention of epidemics and reduction of crop yield losses and improving produce quality has been of great concern to stakeholders and growers of agricultural crops (Friday and Singh, 1991). These researchers are of the opinion that the use of resistant cultivars in crop production is one of the most attractive approaches for suppression of plant diseases since their use requires no particular action by the grower during the crop growth. According to them, resistant cultivars are generally compatible with other pests and disease management practices and often times sufficient enough to suppress diseases to tolerable levels. Plant disease resistance therefore is crucial to the reliable production of food and provides significant reduction in the agricultural use of other inputs leading to lower overhead costs on the farm economy (TIFAC, 2015). Across large regions and many crop species, it is estimated that on an annual basis in developed countries, pathogenic diseases typically reduce plants yield by about 10 %; but in developing economies of sub-Saharan Africa microbes-induced postharvest yield losses is often reported to exceed 30-50 % (Enyiukwu *et al*., 2014a; 2014c).

Plant disease resistance derives from both preformed and infection-induced responses mediated by immune systems. Plants generally do not have circulating immune cells, so most cell types in plants retain the capacity to express a broad suite of antimicrobial defenses. Preformed chemical compounds that contribute to resistance are secondary metabolites such as saponins, glycosides, antimicrobial proteins, enzyme inhibitors, and detoxifying enzymes that breakdown pathogen derived toxins (Enyiukwu *et al*., 2014d; Enyiukwu, 2019). On the other hand, inducible plant defenses which take place post-infection of the crop variety include chemicals such as hydrogen peroxide (H_2O_2), peroxynitrite and phytoalexins amongst which are camelexin and genistein as well as antimicrobial proteins made up of chitinases, β-glineanase and peroxidases. These secondary metabolites when produced by the host act as repellants or toxins agaist the growth or survival of pests or pathogens. The study of these secondary metabolites has provided sources of resistance genes to breeders which they incorporate in disease susceptible crops with desirable characteristics to shore up their resistance against pathogenic invasion (Frisvold and Reeves, 2010).

Plants may be out-rightly resistant to pathogens in which case they disallow entrance, penetration, and colonization of host plant tissue either through structural immunity or by use of an array of chemical inhibitors against the invading organisms. In some other cases they may be tolerant whereby they exhibit less disease damage despite similar levels of pathogen growth or attack (en.wikipedia.org/…). Usually, resistant varieties are bred through conventional breeding programmes involving selection, crossing and hybridization; or advanced gene marker-assisted technology (biotechnology) such as genetic engineering and crop tissue cultures. However, conventional breeding is seriously disadvantaged in being time consuming vis-a-viz gene transfers through biotechnology which greatly shortens the time frame required to produce new crop varieties. In contrast to genetic engineering, classical breeding in addition does not allow for trans-kingdom trait transfers and incorporation of desirable genes, traits or characteristics from across kingdoms into crops (TIFAC. 2015). Some researchers on these bases argue that the crop gene revolution era shall be driven by techniques of biotechnology and production of GM crops (Hellminch *et al*., 2008).

Biotechnology, hence through the instrumentality of genetically engineered crops or varieties portend great promise for food security in SSA. For example high yielding drought-tolerant maize and flood-tolerant rice which survives up to 2 weeks submersion under floods as well as orange flesh sweet potato cultivars very rich in pro-vitamin A to help fight vitamin A deficiency in humans have been developed for tropical African countries (Inyang, 2010; BMF, 2011). The adoption of these improved varieties genetically engineered for higher yield and nutrient contents, and/or resistance to pests, diseases, salinity and other climatic stressors by farmers facing difficult environmental growing conditions such as edaphic, disease and pest pressures could help in enhancing crop production. In the long run this could translate to overcoming hunger, guaranteeing food security, ensuring better incomes for farmers and overall public health of rural and urban dwellers (BMF, 2011).

Hence, in this paper the role of agricultural technology for sustainable production of high yielding crop varieties, food security and enhanced public health through nutrients enriched and mycotoxin contamination-free agro-produce in sub-Saharan Africa is presented and discussed.

2.0 MATERIALS AND METHODS

2.1 Data generation and consideration

Data presented in this work are apriori. They were generated from searches on the subject matter from current literature conducted in the databases of ResearchGate, Google and Google Scholar based on the methodology adopted by Mgbeahuruike *et al*. (2017; 2018) and Enyiukwu (2019). The search terms included uses of biotechnology in crop production, significance of biotechnology in plant protection and health, roles played by biotechnology in genetics and breeding in sub-Saharan Africa, future of biotechnology in integrated pest management, biotechnology and nutrition etc. Papers published both on *in vitro* and *in vivo* studies and other useful materials presented on some URLs from 1982 - 2019 were considered for inclusion for review in this work. However, papers and other materials not written in English or written in English prior to the above timeframe slated for consideration of materials for review for this work were excluded from consideration.

2.2 Genetics of crop resistance

Disease is one of the most important factors that can affect and lead to substantial loss in crop yield, produce quality and nutrient status (Amadioha, 2012; Amadioha and Enyiukwu, 2019). Pathogenic disease outcomes in crops are determined by the three-way interaction of virulent pathogen(s), susceptible host plant and favourable environmental condition(s) – an interaction termed disease triangle (Amadioha, 2012; Amadioha *et al*, 2012). The Cornell University (2013) noted that plants and pathogens interact at the molecular level; and plant resistance is based on the genetics of the host plant and the consequential molecular interaction between the two. Changes in the genetics of either may affect the interaction and depending on the complexity of the interaction, resistance may be short or long-lived. Therefore for resistance to ensue in plants Eickhoff *et al*. (2008) and Horas *et al*. (2018) pointed out that one of the following gene-based phenomena brought about by physiologically or biochemically induced mechanisms must take place:

- **Antibiosis:** This refers to adverse effects meted out on pathogens by the host crop due to the development of certain invasion impeding structures or synthesis and production in large amounts of noxious chemicals capable of annihilating or slowing down disease engendering metabolic activity of the pathogen.

- **Antixenosis:** This connotes repellant effects on pathogens by the host crop due to the development of certain structures, odours and colours which make the host unattractive and offensive or irritating chemicals whose taste or smells are capable of dispelling or warding-off the pathogens.

- **Tolerance**: In this case the host plant develops the ability to withstand, absorb and recover from onslaught of pathogenic disease attacks; and yet produce reasonable, profitable and economic yield of produce in both quantity and quality.

Resistance may be achieved by incorporating 1, 2 or many major or minor genes to a crop variety through breeding. Hence, resistance may be vertical (otherwise called specific, monogenic or oligogenic) being controlled by a single gene (R-gene). R-genes confer resistance to only one race of a particular pathogen and therefore can breakdown when challenged by different races, strains or biotypes of the same pathogen. In some cases, many varieties may contain multiple R-genes against the same pathogen, for example bell pepper variety have resistance genes (x3R) that confer resistance to three races of *Xanthomonas spp*. causing bacterial leaf spot disease of pepper. Specific resistance is aimed at a particular pathogen or pathogenic race and it is noted Cornell University (2013) to be most effective in annual crops or small grains. It is also effective against pathogens that do not spread easily such as soil-borne *Fusarium spp.* or pathogens that do not mutate frequently such as *Puccinia graminis*.

On the other hand, horizontal resistance (otherwise called non-specific, general, multi-gene resistance) is multiple gene-controlled crop resistance. It is important to note that this type of resistance does not completely prevent a plant from being damaged by a pathogen. However, it slows the infection process so much so that the pathogen does not grow well within its host or spread to other plants easily. Multi-gene resistance is reported to confer effective resistance against a broad suite of races of the same pathogen (Cornell University, 2013). General resistance in effect offers permanent protection to the crop and does not breakdown in the face of challenges from different races of the same pathogen. This type of resistance is of highest level in wild plants but lowest in highly improved crop varieties. Most plants we grow will tend to be selected almost solely because they are relatively trouble free and/or high yielding. So selecting a plant variety with resistance (tolerance) to disease makes it possible to avoid or lessen the use of chemical pesticides or other management tactics. In the overall, use of resistant crop varieties will decrease biological magnification of broken-down pesticide residues such as polychlorobiphenyls (PCBs) in the food chain and their attendant health burdens on ecological, biological and human systems (Enyiukwu and Awurum, 2013a, b; Enyiukwu *et al*., 2014b, 2018). As a result, plant resistance should be considered a cornerstone for disease and agro-ecological health management especially in integrated pest management programs or organic farming (Cornell University, 2011; Enyiukwu *et al.,* 2014c).

2.2.1 Trade-offs about development and use of resistant cultivars

In the view of some authorities, there is always some agronomic trade-offs to development of resistant varieties in crops. This is because those varieties which have increased immunity or resistance to a disease condition may be lacking in other desirable agronomic qualities such as yield, flavour or quality. For example in the temperate hemisphere, celery, resistant to wilts (*Fusarium oxysporum*) may be unacceptably ribby and low yielding. Again, a cultivar resistant to one disease may be susceptible to another equally important disease. As an instance lettuce resistant to mosaic virus may be sensitive to corky root disease, while another resistant to corky root may be vulnerable to downy mildews. In general, resistant varieties are not available for all crops and in some cases for most damaging diseases such as potato blight (*Phytophora infestans*) and white rot (*Sclerotium cepivorum*) of onion bulb no acceptable resistant cultivars are as yet available (en.wikipedia.org/resistant…). It is important to note also the fact that commercial seed companies and breeders have reluctance to and rarely develop resistant varieties for minor or specialty crops which are usually of greater interest and commonly grown by organic farmers. Besides, widespread cultivation of resistant variety provides excellent substrate (food source) for rapid development and spread of new race of pathogens which could be the single most important cause that could lead to epiphytotics. Therefore, the problem of unchecked variability of the pathogens, mutations and hybridization cause rapid evolution of new races, stains or biotypes of the pathogens; and prolonged cultivation of a single genotype in the area could contribute to massive failure of disease resistance. As a result, genetic uniformity though desirable in horticultural characteristics is very undesirable and often catastrophic when it occurs in the genes controlling resistance to diseases in crops (Friday and Singh, 1991).

2.3 Management of plant diseases for increased crop productivity

In terms of management of plant health, there are a number of crop protection strategies available for use against plant pathogenic disease invasions in the farm or organic garden; principal amongst them being the practice of good crop husbandry. This involves creating healthy soil and ensuring high standard of garden hygiene. But no matter how diverse and healthy the garden ecosystem may be, there will always be a degree of disease presence in the farm. As a result, the use of crop cultivars (or varieties) with inherent disease resistance is generally regarded as the first choice in plant disease management programmes and it is best used in concert with good agronomic practices (GAPs) such as appropriate tillage, accurate plant spacing and density, and clean equipment, crop and field sanitation techniques, crop or field rotation etc. to achieve reduction of plant disease presence in the farm. In any case, appropriate fungicides sprays should only be considered and used as a last resort in the management of pest or disease pressures in the farm – an agronomic technique termed integrated pest management (IPM) (Enyiukwu *et al*., 2014a, c).

3.0 Use of resistant crop varieties: Classical low-input approach to yield enhancement, pest reduction and control

Crop breeders aim amongst other goals to improve locally available and climatically adapted crop varieties for higher yields, enhanced and/or larger nutrient contents and resistance to pests and diseases. For example Vitamin A deficiency (VAD) is endemic and of great public health significance in Asia and sub-Saharan Africa where about 100 million children are reported to have low serum retinol (ajon.nutrition.org?content…). In Nigeria, Inyang (2010) noted that 9 million children (below 5 years of age) and 6 million pregnant or lactating mothers suffer from low serum retinol (<7µmol/L). The daily recommended intake (DRI) of retinol is 400 µg and 900 µg per day for under 6-year children and human adults respectively. Attempts at tackling VAD have largely and previously been based on use of expensive and often times inadequate pharmaceutical supplements. However, in recent times plant breeders at the International Center for Potatoes (CIP) have tried to solve this challenging public health problem by breeding orange flesh sweet potato (OFSP) cultivars incorporated with genetic ability to synthesize high levels of pro-vitamin A to help fight through appropriate nutrition the endemic challenge of Vitamin A deficiency (VAD) in developing countries especially in sub-Saharan Africa where the crop is a major staple (Inyang, 2010). OFSP is a very promising crop containing extremely high levels of Pro-Vitamin A (β-carotene), and as such it is believed to be the least expensive and an all time accessible source of dietary vitamin A to the poor; and thus could contribute immensely to retinol (Vitamin A) nutrition in humans (Inyang, 2010). In a modified relative dose-dependent evaluation conducted on primary school children, pupils fed OFSP meals have significantly increased serum retinol levels compared to children in the control group which had low serum retinol status (ajon,nutrition.org>content…).

Successful breeding for resistance has occurred in many different crop types – vegetables, fruits, field and ornamental crops. Tomato is one of the most consumed vegetable the world over, however its production is seriously constrained by wilt (*F. oxysporum f.sp. lycopersici*) especially in tropical acid soils. Darby (2016) reported that through breeding programmes tomato cultivars such as Big beef and Celebrity have been developed with inherent resistance to tomato mosaic virus, *Fusarium* and *Verticillium* wilts as well as N-deficiency disease. Similarly, this source noted that eggplant varieties such as Diamond, Nadia and Black Pride that can resist decimation from these fungal wilt organisms are also available in recent times. A list of some crop varieties bred for diverse reasons by universities, public or private researchers which have been registered and approved for dissemination to farmers by the Federal Government of Nigeria are presented in Table 1.

Relative to fruit and vegetable crops, generally field crops are considered inferior and low value crops; and hence costs of disease control programmes for economic production of field crops must be kept minimal. It is in these crops reasoned Cornell University (2013) that host plant resistance breeding has had the most impact. For instance, disease resistant varieties have become a standard agronomic method of controlling major bacterial, fungal and viral pathogens in corn, wheat, cereals and other field crops (Table 1). Bjomberg (2015) reported as an instance that several wheat varieties have been successfully bred for disease resistance through selection and breeding programmes Many of these breeding were done through classical crop improvements involving careful selection of closely related crop or race lines, hybridization and rigorous multi-year re-selection process of their progeny for those with desired characteristics or traits against those with undesirable traits.

Table 1: **Some improved crop varieties registered and approved for farmers in Nigeria**

Crop	Variety	Breeder	Cultivar traits	Source(s)
Rice	Faro 63	NCRI	Early maturing, high yielding	Abah (2014)
Sorgum	Pradhan	IAR/Sygenta	White, bold grains, high yielding	Abah (2014)
	MLSH 296 Gold	IAR/Sygenta	High grain yielding	Abah (2014)
	MLSH 151	IAR/Sygenta	Bold cream colour, high yielding	Abah (2014)
Potato	Marabel	NBCRI/Sygenta	Etra early maturing, high yielding, high dry matter content, high number of maketable tubers	Abah (2014)
Wheat	LACRI WHIT-5	IAR/IITA	High yielding, god baking quality	
	LACRI WHIT-6	IAR/IITA	Earjy maturing, high yielding	Abah (2014)
Maize	SAMMAZ 41	IAR/IITA	Early maturing, high grain yielding	Abah (2014)
	SAMMAZ 42	IAR/IITA	Long ear, low soil nitrogen tolerance	Abah (2014)
Soybean		NCRI/IITA	Extra early maturing, high yielding, promicous nodulation, resistance to rust,cercospora leaf spot and suitable for mechanization	Abah (2014)
Rice	Faro 64		Early maturing, high yielding, drought tolerant	
	Faro 65		Early maturing, high yielding, drought tolerant	Abah (2015)
Tomato	Kilele		Firm fruits, high yielding, tolerance to *Fusarium* wilth and late blight	The Guardian (2015)
	Chibli		Same as above	The Gurardian (2015)
	Tylka		Same as above	The Guardian (2015)
Maize	SAMMAZ 45	IAR/IITA	Alatoxin tolerant	The Guardian (2015)
	SAMMAZ 38	IITA	Intermedial level of β-carotene, high yielding, resistant to southern corn and *Curvularia* leaf spots	Babatunde (2013)
	SAMMAZ 39		Same as above but higher in pro-vitamin A.	Babatunde (2013)
	Ife Maize Hyb-5	IITA	Early maturing, *Strigga* resistant	Babatunde (2013)
	Ife Maize Hyb-5		Early maturing, *Strigga* resistant, Curvularia streak, leaf spot, bacterial blight and drought tolerant.	Babatunde (2013)
Sorghum	PD86W15	Dupont Ltd.	Resistant to Metsulfuran methyl which controls *Strigga spp*.	Babatunde (2013)
	PD86W16		Same as abve	Babatunde (2013)
Sweet potato	UMPO/3	NRCRI	High yield, high β-carotene content, tolerant to potato virus disease and weavils	Babatunde (2013)
Yam		NRCRI		Tony (2016)

However, such classical breeding programmes suffer two-fold disadvantage of being highly time consuming and from dearth of genotypes for crop improvements. In the view of some workers, this juncture in our quest for food security warrant or demand judicious blending of conventional, unconventional and frontier technologies to improve yield, yield attributes and produce quality. In the light of this cumbersome time consuming method, agricultural technology by way of immunization and biotechnology are not seen as alternatives but strongly advanced as viable complements that could effectively offset the demerits of classical and conventional breeding programmes for food security and better health in SSA (Bissankopp, 2015).

3.1 Host Plant Immunization: A crop improvement tool

Plants can be induced to become locally or systematically more resistant or at least tolerant to pests and disease pressures. Essentially, host plant immunization is the process of inducing or activating natural defense systems present in plants by using biotic organisms, their cell wall derivatives or certain abiotic factors. Although plants do not possess antibodies like humans or animals, they can however be systemically immunized against fungal, bacterial or viral diseases by prior inoculation, exposure or treatment with a mild strain or low doses of attenuated virulent strains of the pathogens or their elicitors (Arya and Sharma, 2016). The immunizing agents give signals which rouse the defense genes of the treated plant (or seed) and stimulate them to form systemic chemical or physical barriers that can ward-off invasion of pests or pathogens. This kind of immunity once acquired is stable even under field conditions (Othari and Patel, 2004).

Attenuated pathogens, hypo-virulent or non-virulent pathogens as well as certain root colonizing bacteria have been reported to induce resistance to a broad range of crop decimating pathogens through salicylic acid and certain induced proteins pathways (Oostendorp *et al*., 2001). Protection of some agricultural crops against several fungal and bacterial diseases by immunization has been achieved in field trials. For instance, Friday and Singh (1991) noted that water melons and musk melon plants immunized by restricted infection with *Colletotrichum lagenarium* prior to transplanting to the field recorded better survival (98 %) and smaller lesion following challenge with high inoculum density of the same pathogen in the field than untreated controls where survival rate of 32 % was recorded. Also, successful immunization of cucumber seeds against anthracnose fungus has been reported (TIFAC, 2015). Strains of *Cladosporium cucumerium, C. lagenarium* and hypo-virulent *Fusarium spp.*, or some strains of plant growth promoting *rhizobacterium* (PGPR) have been reported by several investigators to induce systemic resistance in cucumber remarked TIFAC (2015).

Similarly, Manchanahally *et al*. (1995) reported that seeds of different anthracnose-susceptible cucumber varieties treated with certain strains of *Phoma spp.* strongly conferred systemic immunity against *C. obiculare* the causal agent of the disease in the crop. These authors also recorded similar outcomes in trials when young seedlings of the same crop were immunized with non-pathogenic fungus obtained from rhizosphere of soysia grass (*Zoysia renufolia*). According to them such treatment afforded 90 % protection against anthracnose caused by *C. lagenarium* on the crop. In like manner Ajan and Potter (1991) found that restricted infection of the lower leaf of young cucumber seedlings with *C. lagenarium* induced systemic resistance against the attacks of the fungus as well as 12 other pathogens of the crop in the field. Thus suggesting that crop resistance achieved through immunization is broad and non-specific.

Systemic resistance in plants can also be induced using culture filtrates of certain microorganisms or in some other cases extracts of plant origin (Oostendorp *et al.,* 2001). In common bean, several workers have demonstrated that development of anthracnose symptoms due to *C. lindemuthianium* on leaves of the crop was greatly restricted when 10 primary leaves of the crop was injected 1 week earlier with low doses of conidia from culture filtrates of the same fungus (Kuc, 1982; Mandal *et al*., 2013; Arya and Sharma, 2016). Histological examination of the treated bean tissues showed that penetration of fungal infection pegs from appressoria of the organism as well as its hyphal growth in the epidermal cells was retarded in the immunized plants. The researchers further observed that cell walls of treated plants thickened while frequent distortion of the nuclei of the invading pathogenic fungi was also noted; all to oppose the penetration of the fungus at the attempted portals of entry in the inoculated bean plants.

On the other hand, Friday and Singh (1991) reported that the elicitor lipoglycoprotein (LGP) isolated from the fungus (*Phytophtora infestans*) when applied as a potato tuber treatment (at the rate of 0.0005%) was as effective as pre-sowing fungicide treatment against late blight and early leaf mould as well as brown patch and scab of the crop. Since 1972, mild mutant of the tomato mosaic virus (TMV) (M116) obtained by nitrous acid mutagenesis has been used commercially to inoculate and treat high value tomato plants against TMV in the glasshouse. Some workers have also reported the stimulation of natural defenses and development of resistance against TMV in common bean (*P. vulgaris*) when the plant is pre-injected 4-6 days before exposure to the virus (Kuc, 1982; Mandal *et al*., 2013; Arya and Sharma, 2016). In some trials in Southeast Nigeria on onion naturally infected by anthracnose and leaf blight in the field, Awurum *et al*. (2016) demonstrated that spraytreatment of the crop with aqueous extracts of *Azadirachta indica* 1-2 weeks before the arrival of the pathogenic propagules led to protection of the crop from decimation from the invading fungal pathogens. These researchers attributed the protection of the crop by the extracts to production of certain phenolic compounds which had been reported not only to inhibit pathogenic fungal spore germination and mycelia growth of the pathogens but also to strengthen the host's cell wall (Okwu and Njoku, 2009; Enyiukwu and Awurum, 2013b; Amadioha and Enyiukwu, 2019)

On the other hand, some synthetic or semi-synthetic chemicals have also been repotted to induce resistance in plants. Commercially available acibenzolar-5-methyl (BIO) is a systemically translocated agent in the SAR pathway which is commonly used for crop immunization, being applied at low doses to activate resistance in many crops against viral, bacterial and fungal diseases (Oostendorp *et al*., 2001). These researchers also noted that probendazole (Oryzemate) is being increasing recognized as an immunizing agent used mainly on commercial rice paddies to induce its resistance against bacterial leaf blight. According to TIFAC (2015) hairy root culture of callus infected by *Agrrobacterium rhizogenes* has been found to stimulate resistance against pathogenic infections and confer natural defense on treated crops. The mechanism of host plant immunization is suggested to be multiple and thought amongst others to involve stimulation and accumulation of some chemical agents (including phytoalexins) at sites of crop infection in order to inhibit development of the pathogen and/or signals that cause cells recovered from the site of infection of an inducing inoculation to respond rapidly when challenged by a pathogen (Kuc, 1982; Mandal *et al*., 2013; Arya and Sharma, 2016).

Plant immunization programmes have the advantages of being effective, against bacteria, fungi and viruses; it is systemic and persistent, significant in grafted crops, irreversible and can be achieved even from chemicals extracted from immunized plants – making it possible as a seed treatment strategy. Hence broad-spectrum crop disease immunizing agents hold significant potentials in agriculture to offer an additional option for the farmer to complement genetic disease resistance and/or use of synthetic fungicides to reduce the impacts of crop attacking pathogens (Oostendorp *et al*., 2001). However, though it appears as effective as systemic pesticides, it does not offset attacks by arthropod pests on treated crops and more-so it is not economically competitive with present day technology in chemical control against pathogenic organisms and has so far not received enough field-testing even though it has promise (Friday and Singh, 1991; Ajan and Potter, 1991).

3.2 Biotechnology a state-of-the-art approach to crop improvement

Several workers suggest that our quest for food sufficiency and security demand and warrant judicious blending of conventional, unconventional and frontier technologies to improve crop yield, yield attributes and produce quality (Eickhoff *et al*., 2008; Saeto *et al.,* 2011; Horas *et al*., 2018). Biotechnology has been advanced by many of these workers as holding ample potentials for sustainably improving crop production, bio-processing and animal farming at lower costs. Techniques such as genetic engineering, bio-process and fermentation engineering, tissue cultures and biosensors for biological monitoring are all components of biotechnology (Hellminch *et al*., 2008; Shiri *et al*., 2014; TIFAC, 2015). The impacts of biotechnology in food production and healthcare could be felt many ways:

1. African agriculture is characterized by prevalence of poor soils, and predominance of rain-fed farming systems with its time consuming farm practices. Our farming systems are strongly burdened by soils low in contents of nitrogen (N) and phosphorus (P); but high in content of toxic alumina (Thomson, 2008; Craig, 2016; 2017). Biotechnology is reasoned to hold strong capacity to play roles in the development of tropical crop genotypes that could withstand Al, Mn, Na and Fe toxicities in tropical soils (Obonyo *et al.*, 2014; TIFAC, 2015; Seyran and Craig, 2018). In terms of resilience to environmental stressors, the gene $HAHB_4$ in safflower has been identified to make the plant endue acute water shortages while the compound glycerubetaine in some plants enables them to tolerate saline environments. Incorporation of the former and the gene coding for glycerubetaine in rice has been made possible by frontier biotechnology techniques (Sanullah *et al*., 2017). And adoption of such crop varieties will help de-emphasize and possibly offset the defects of our predominantly rain-fed farming systems. Also, use of N-fixing and mechanization compliant crops made possible by biotechnology would contribute significantly to safer environment (Saeto, 2011).

2. Besides resilience to environmental stressors, biotechnology holds tremendous potentials in the area of development of non-chemical, low-cost alternative pest and pathogen management technologies such as development of fungal, bacterial, viral, nematode and insect resistant varieties (Kumar, 2010; Craig, 2016; 2017). Bearing in mind that classical breeding is only possible between closely related crop species; and that the resulting progeny has both desirable and undesirable characteristics, selection for the desired trait could be

cumbersome and an extremely time consuming process. Biotechnology is reasoned to be capable of playing a positive role in improving agronomic traits in tropical crops through the instrumentality of marker associated selection to increase both the yield and disease resistance potentials of crops within a short time interval. Biotechnology-assisted gene transfers are generally and comparatively regarded as cheaper than conventional breeding techniques and have been immensely utilized in Finland for the improvement of malting quality of barleys. In Califonia, USA transgenic gene transfers, have also helped to develop insect resistant seeds as well as to develop genetically improved banana in St. Paulo (TIFAC, 2015). This author reported further that maize, rice, tomato, potato and tobacco incorporated with Bt toxins hazardous to sucking and chewing insects which decimate field crops have been developed courtesy of biotechnology. Fagwalawa *et al.* (2013) holds the view that tissue culture technique of protoplasm fusion has been used to develop potato (*Solanium tuberosum*) resistant to Erwinia soft rot (*Pectobacterium carotovora*). Also, *In vitro* toxin tolerance has been employed to select for potato resistant to blight caused by *Phytophtora infestans*; and tobacco and *Arabdopsis brassica* to *Pseudomonas tablii*. Some of these GM crops synthesize chitinases which antagonize fungal pathogens like the soil dwelling *Rhizoctonia solani*, breaking down their cell wall and killing them. Knowledge from frontier biosciences such as molecular biology and techniques of biotechnology have helped plant pathologist understand crop resistance genes and virulence factors in pathogens.

3. Biotechnology processes could play active roles towards large scale production of a variety of microbes-derived pesticides and myco-herbicides. Antimicrobial proteins and plantibodies could serve to improve genetic resilience of crops against microbial invasion, and reduce synthetic pesticides input in agriculture (Shamin *et al*., 2013; TIFAC, 2015). Toxic natural proteins derived from soil-borne *Bacillus thuriengiensis* (Bt) have been incorporated into crop breeding for parasitic plant control in the agriculture of *Stigga* prone locations. It immunizes the entire plant as in *Strigga*-resistant cotton (Thomson, 2008; Sanullah *et al*.,). Hence, through biotechnology farmers in the overall could enjoy the luxury of crops that withstand adverse weather and edaphic conditions or damaging pressure of pests and diseases. Pesticides and herbicides residues in agro-produce pose serious public health concerns being reported as incitants or exacerbating factors for many forms of cancers in livestock and human systems (Enyiukwu *et al*., 2014b; 2018). Therefore toxic chemical residues and their associated effects in the food chain will undoubtedly be reduced when biotech-crops are adopted and consumed by humans (Kumar, 2010).

4. Development of higher nutrients containing crops such as cereals, tubers and corms rich in Fe, vitamin A, Beta-carotene, lycopene, and legumes richer in essential amino acids has been made possible with biotechnology (TIFAC, 2015). Biotechnology could make possible crop improvements which otherwise would be impossible with conventional or traditional crop improvement programmes. Transgenic soybeans with higher protein content, potatoes with more nutritional starch, beans with more essential acids and rice strengthened with the capacity to produce amino acids have all been made possible through biotechnological breeding (Sanulla *et al*., 2017). Development of fruits and vegetables with capacity for delayed over-ripening so as to prolong shelf life of produce and reduce postharvest losses has been made possible in modern agriculture by biotechnology (TIFAC, 2015).

5. Generation of disease-free planting stock in cassava, taro, sweet potato and bananas has been made possible especially in the third worlds where they form major staples using the technique of tissue culture and micro-propagation (TIFAC, 2015). Tissue culture of sugar cane in northern Nigeria has resulted in production of large numbers of disease-free and true to type sugarcane plantlets within a shorter period of time compared to conventional breeding (Usman, 2015). In several regards embryo rescue transgenic interventions has been used to facilitate wide crossing of organisms that would not normally produce offsprings or express certain desirable traits (Sanullah *et al*., 2017).

6. Biotechnology has been employed in the bio-remediation of arable lands where GMOs are used as bio-sanitizers to clean up and/or prevent build up of pesticides residues (Saeto, 2015; Keener and Balasubramanian, 2018). Restoration and bio-remediation of arable or marginal lands such as those around the Niger Delta area of Nigeria; involving clean up of agricultural lands polluted with spillages from industrially generated hydrocarbon companies with genetically modified organisms has been reported.

7. Development of bio-fertilizers. One of the ways in which biotechnology will impact global agriculture is by encouraging no-tillage and reducing the use of synthetic pesticides (Shiri *et al*., 2014). Certain microorganisms and minute plants such as *Rhizobium spp., Azotobacter spp., Azolla spp., Aspirillium spp.* and bluegreen algae have the capacity to absorb N and P from the atmosphere. Biotechnology has been used to multiply and introduce (inoculate) these organisms into the root zones (rhizosphere) of high value crops as bio-fertilizers to improve yield and yield attributes of crops (TIFAC, 2015).

8. Given that developing counties are faced with the challenge of rapidly increasing agricultural productivity to measure up with the food demands of their growing population; conventional agricultural practices increase the demand for land, space and available resources leading to deforestation, desertification, and environmental pollution; and with resultant negative effects on the climate, ecosystem, biogeochemical cycles and ultimately human health. However, innovative effects of biotechnology could provide practices to complement and offset the shortcomings of primitive unsustainable agriculture for increased food production. Biotechnology could contribute to increasing food production within existing land area (Saeto, 2011). This source is of the opinion that Marker-assisted breeding technique is time-saving and cost effective. It has helped agronomists in breeding of rape seeds with presence of little or no anti-nutrient factors such as erucic acid or glucosinolate and to develop crop varieties with uniform characteristics such as height, width, fruit size and shape as well as appearance that made for easier mechanization etc.

9. Biotechnology besides holding strong promise to bring prosperity by mitigating current and future problems to modern agriculture (Raman, 2017); it can contribute immensely to safe vaccines and public health. It reported that biotechnology holds very strong potentials in developing low cost and highly safe vaccines against animal and human infectious diseases. Such vaccines are biotechnologically conferred with both ability to enforce or strengthen both mucosal (lgA) and systemic (lgG) immunity on their host (Cheng and Daniel, 2015). According to this source over the last 5 years significant progress has been made in expressing vaccine antigens in edible leaves of lettuce. Such advances are achieved through using plant cells as bio-factories of immune-protective antigens which can also be purified and administered in humans orally or parenterally (Govea-Alonso *et al*., 2014; Takeyama *et al*., 2015).

10. Others such as early detection and diagnosis of phyto-diseases through use of DNA probes such as ELISA and other techniques could contribute to lowering postharvest losses and improving food sufficiency (Saeto *et al*., 2011). In terms of mitigating climate change effects, it has been reported that CO_2 use efficiency of biotech/Gm crops have resulted to removing CO_2 emissions estimated to equal removal of 16.8 million cars from the roads (ISAAA, 2017)

3.3 Constraints to biotechnology application: A third world perspective

Though amongst many researchers in the agro-scientific circles, it is overwhelmingly agreed that advance techniques of biotechnology are no substitutes to conventional breeding; rather they represent necessary complements which if appropriately utilized could prolong the lives of resistance genes and pesticides in use at present in agriculture (Oostendorp *et al*., 2001). However, adoption and utilization of biotechnology is not without constraints especially in low-income countries. Bissankopp (2015) is of the opinion that majority of third world countries have limited practical access to the state-of-the-art tools and the requisite germplasms (genotypes) to conduct and apply sophisticated biosciences research to meet their national crop and food production needs. Against the backdrop that third world countries are classified by the World Bank as low-income economies; generally speaking therefore, they lack the financial resources, infrastructural muscles and scientific human capital for such capital and wares intensive endeavours. Though the gene revolution have guaranteed increases in yield of crops and thus food supply, it is however broadly seen to have favoured the developed than the developing nation where hunger is widespread (Estrada *et al*., 2017).

Despite substantial advances in classical crop breeding and production as well as advances in plant health management strategies; global food supply is still lagging behind population statistics; being threatened by a plethora of pests and pathogens. Also, limited availability of the necessary genetic resources (germplasm) for most tropical crops strongly limits gene-based improvement efforts through classical breeding programs for most crops (Fagwalawa *et al,.* 2013). Again, though classical breeding techniques have been utilized to develop resistant species or varieties, the techniques more often than not involve time consuming processes which constitute a serious drawback *vis-a-viz* biotechnology

Another major impediment already being experienced by farmers in the USA which could cancel out the sustainability of the biotech approach especially in the area of weeds and arthropod pests management some researchers maintained is the resurgence of these pests due to cross resistance emanating from the over-reliance on use of these GM crops in non-integrated pest management (IPM) modules (Silva, 2017)

Even though majority of researches in the developed western economies hold the view that nothing is inherently and scientifically wrong with biotechnology and have largely adjudged biotech-foods as safe as conventionally produced foods; however its applications may have moral or environmental concerns especially in the third world countries where they are seen as culturo-moral aberrations. Hence GM crops may not be well received by all strata of society; because there are still some hesitations and uncertainties about the possible human health implications of consumption of biotech crops in some quarters (Estrada *et al*., 2017).

Besides environmental impact concerns and public reaction, tight and stiff regulations at national and international levels argued Herdt (2008) are seen as other major impediments against adoption and utilization of biotech crops. This is especially true of GE plant-based vaccines. In the case of genetically engineered plant-based vaccines, it is reported that much efforts and time is required to overcome the huddles of legislation and strict regulations between development of candidate vaccines, their clinical trials and progress into commercialization (Takeyama *et al*., 2015).

3.4 Roles and contributions of biotechnology in crop production, protection and public health: A broader perspective

3.4.1 Genetically engineered or transgenic crops

Growing scientific evidences presented by a diverse array of scientists suggest that biosciences and biotechnology if appropriately utilized could meaningfully enhance food production through breeding crops resistant to pathogenic (fungal, viral bacterial etc) invasion and environmental diseases such as heat, drought, salinity, chills and floods. Others are efficient nutrient and water use by crops; more nutritious and healthier foods aiding to reduce total land area used for agricultural production or optimizing agro-productivity of marginal soils (Bjomberg (2015). One such way this could be achieved is genetically modified (GM) or transgenic (TM) crops.

Genetically modified crops (GM) became commercially available in 1996; and they have become adopted rapidly by growers in not less than 28 countries around the world where they are approved for use in agriculture. Thus far, herbicide resistance, insect and/or disease resistance have been the dominant reasons advanced for their adoption. Others are altered nutrient composition, flower or fruit colour (en.wikipedia.org/gm-crops…). So far worldwide, the 10 most adopted GM crops are soybean, cotton, canola, maize, alfalfa, sugar beet, papaya, eggplant, potato and squash (Silva, 2017); four crops out of these however, commonly dominate GM crop productions (Fig. 4).

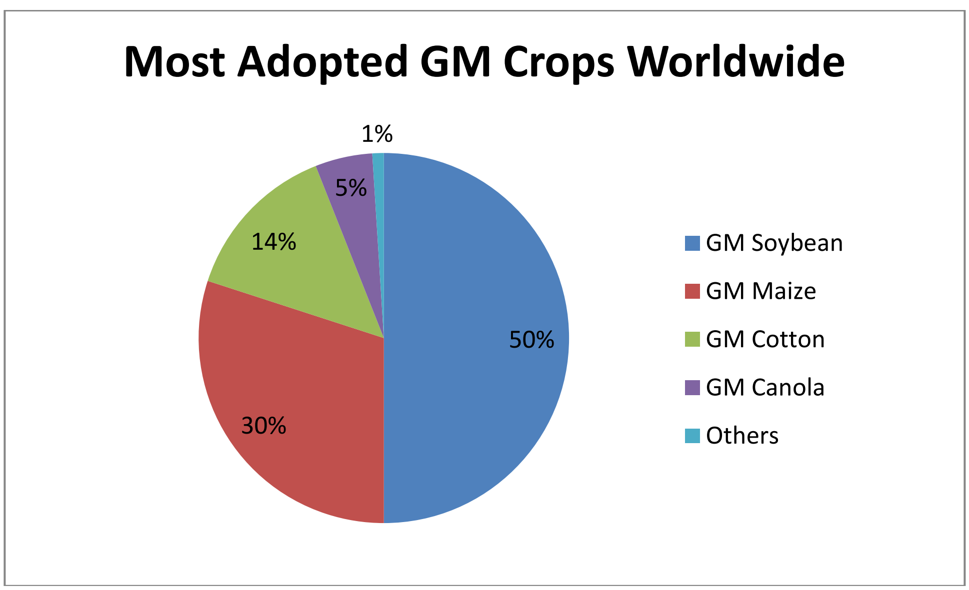


Figure 4: Total land area around the world planted to different genetically modified (GM) crops in 2004
Source: en.wikipedia.org (2017)

In terms of hectares of farmlands grown to biotech/GM crops, Frisvold and Reeves (2010) reported that as of 2008, genetically modified crops accounted for 90 % of all the lands grown to soybean, 78 % cotton, 72 % canola, as well as 60 % of all lands grown to maize worldwide. In 2014, 181.50 million hectares of arable land worldwide were reported to be planted with biotech/GM crops. Adoption and utilization of biotech/GM crops continues to increase worldwide as more and more countries either increase the total land area allocated to growing GM crops or have Okayed importation of same from the growing countries. Around the world, 67 countries actually used biotech crops as at 2017; these consisted of a total of 24 GM growing countries made up of 19 developing and 5 developed economies on the one hand and 43 non-growing nation that formally regulate importation and use of different kinds of biotech crops for food, feed, fuel and processing (ISAAA, 2017). Globally, in 2016, the total farmland area planted to biotech-crops hit an all time high of 185.1 million hectares (457.4 million acres) (Fig. 5); and increasing all the more by about 3.0 % to 189. 80 million hectares in the year 2017 ISAAA (2017) and Silva (2017) reported.

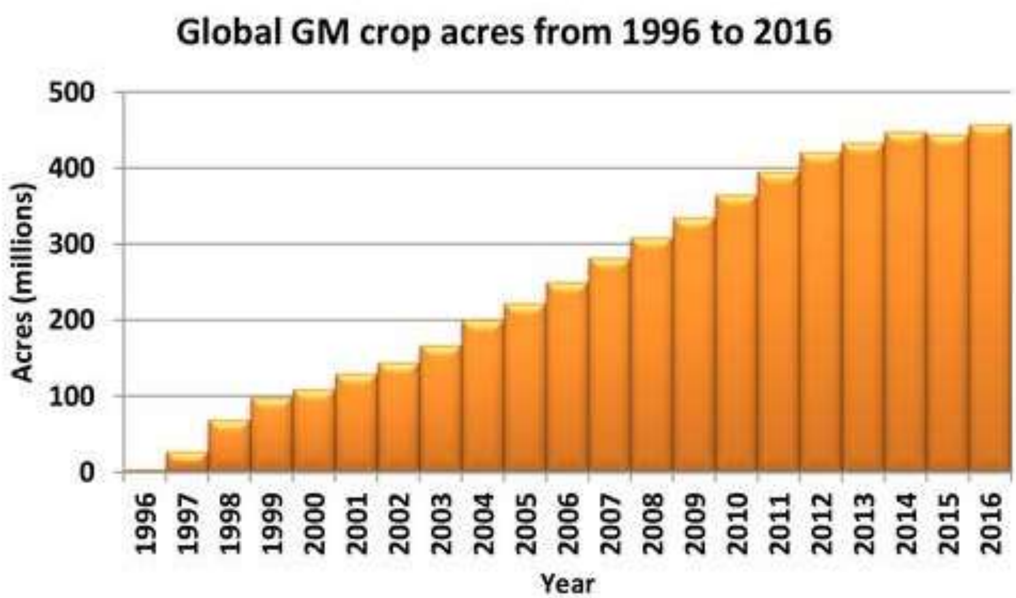


Figure 5: Total farmland area across the world planted to biotech/GM crop in 2017
Source: Silva (2017)

Approximately half of all the biotech/GM crops being adopted and grown in the world from 1996 to 2014 was grown in the USA, followed by Argentina until 2009 when it was overtaken by Brazil, then Canada, India and China (Fig. 6). However, with the adoption of biotech/Gm crops by third world countries like Mexico, Honduras, Bolivia, Columbia, Bangladesh, Vietnam, Pakistan and Sudan ISAAA (2017) reported that developing economies now accounts for 53 % of the global biotech areas planted. In all, this source argued that from inception up to 2016, that about 186.1 billion USD had been reaped largely as economic gains by 17 million small holder farmers around the world. ISAAA (2017) revealed further that not less than 15.80-18.2 USD accrued to farmers as direct global farm income in the same year, amounting to an average farm income of $102 per ha of GM cultivated land area (Silva, 2017; ISAAA, 2017).

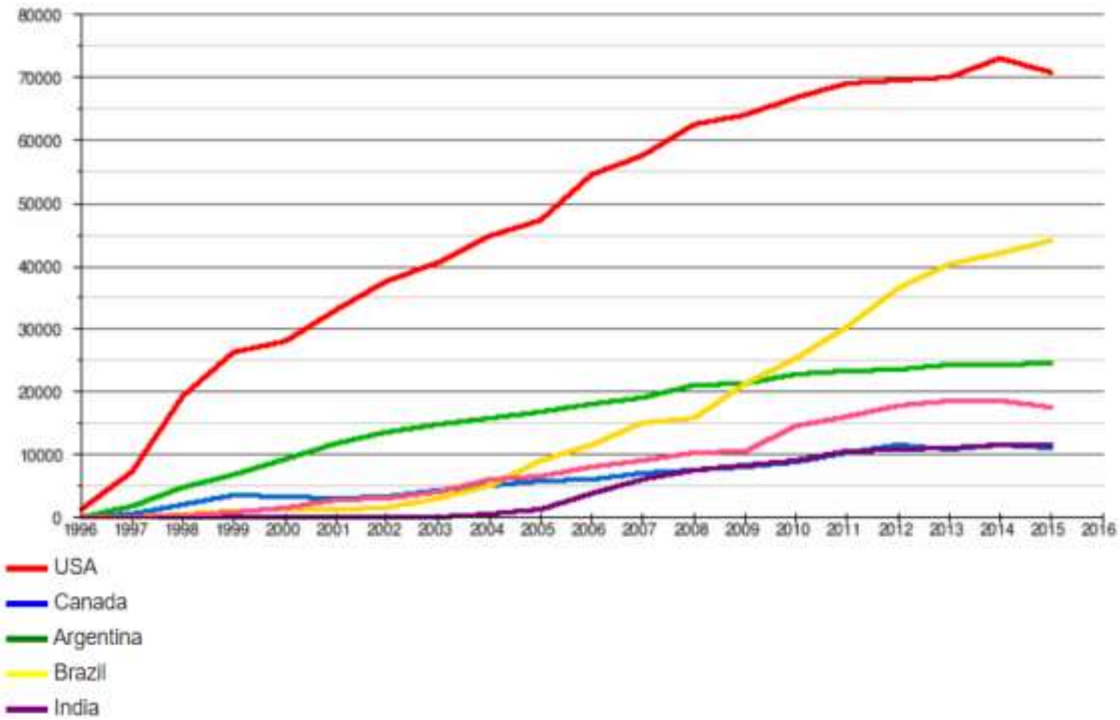


Figure 6: Total farmland area across the world planted to biotech/GM crop in 2017
Source: en.wikipedia.org (2017)

Adoption of insect resistant (IR) Bt cotton has led to shifts to insecticides of narrower spectrum, lower toxicity and less harmful environmental effects. Similarly, Bt maize resistant to European corn borer has led to increased yield and productivity of the crop. Nigeria is the world's largest consumer of cowpeas (beans). High pests and disease pressures have been identified as some of the major constraints militating against its economic and sufficient production in the country. As of now up to 3.6 million metric tonnes of this valuable grains are imported into the country to compensate for deficits in its local production which costs Nigeria about 20 billion Naira annually (Enyiukwu *et al*., 2014d; IAR, 2017). Biotechnologically Bt-fortified cowpea cultivars are being developed by the Institute of Agricultural Research (IAR) Samaru, as viable options to addressing these inadequacies (IAR, 2017).

In China, adoption of transgenic crops has provided not only short but medium term irreversible
benefits through reduced pesticide poisoning, reduced accumulation of chemical sediments in water bodies, and reduced production of mycotoxins in Bt maize. Herbicide resistant (HR) crops made weed control less management intensive and contributed to cleaner and environmentally safer society. On the other hand BMF (2011) remarked that drought tolerant maize and stress-tolerant rice varieties have been made available to Asian and African farmers in the Sub-Saharan Africa to compensate for effects of climate change.

Modern DNA technology has made it possible therefore, to engineer transgenic plants transformed with genes for tolerance to adverse environmental factors, resistance against specific diseases or genes coding for enzymes such as chitinases and glucanases directed against certain groups of pathogens (Oomycetes, fungi, viruses) or nucleic acid sequencing that lead to gene silencing of pathogens. For example, egg-plants transformed with bacterial gene coding for mannitol phosphodehydrogenase are tolerant against drought, low chilling and salt-induced osmotic stresses. Similarly gluthatione-S-transferase (GST) from rice engineered into maize plants enabled them to tolerate lower temperatures and germinate better under submergence in water. Furthermore, hybrid rice variety has been transformed with the rice gene $X_9$21 coding for resistance to bacterial blight caused by *Xanthomonas oryzae pv oryzae* resulting in broad spectrum resistance to races of the pathogen while retaining good agronomic characteristics. In tobacco transformation of the plant with animal anti-apoptotic genes, have been reported to make them to assume resistance to necrophilic pathogens as well as abiotic stress from extremes of cold, heat or salinity (Anon., 1998). Table 2 shows some crops undergoing genetic modifications and trials in some parts of the world..

Table 2: Examples of transgenic disease resistance projects in some agricultural crops

Year	Crop	Disease resistance	Mechanism	Development status
2012	Tomato	Bacterial spot	R gene from pepper	8 years of field trials
2012	Rice	Bacterial blight and bacterial streak	Engineered E gene	Laboratory
2012	Wheat	Powdery mildew	Over expressed R gene from wheat	2 years of field trials at time of publication
2011	Apple	Apple scab fungus	Thionin gene from barley	4 years of field trials at time of publication
2011	Potato	Potato virus Y	Pathogen-derived resistance	1 year of field trial at time of publication
2010	Apple	Fire blight	Antibacterial protein from moth	12 years of field trials at time of publication
2010	Tomato	Multibacterial resistance	PRR from *Arabidopsis*	Laboratory scale
2010	Banana	Xanthomonas wilt	Novel gene from pepper	Now in field trial
2009	Potato	Late blight	R genes from wild relatives	3 years of field trials
2009	Potato	Late blight	R gene from wild relative	2 years of field trials at time of publication
2008	Potato	Late blight	R gene from wild relative	2 yearss of field trials at time of publication
2008	Plum	Plum pox virus	Pathogen-derived resistance	Regulatory approvals, no commercial sales
2005	Rice	Bacterial streak	R gene from maize	Laboratory
2002	Barley	Stem rust	Resting lymphocyte kinase (RLK) gene from resistant barley cultivar	Laboratory
1997	Papaya	Ring spot virus	Pathogen-derived resistance	Approved and commercially sold since 1998, sold into Japan since 2012
1995	Squash	Three mosaic viruses	Pathogen-derived resistance	Approved and commercially sold since 1994
1993	Potato	Potato virus X	Mammalian interferon-induced enzyme	3 years of field trials at time of publication

Source: en.wikipedia.org

Anon. (1998) further noted that genes coding for several pathogenesis–related (PR) proteins (chitinases, glucanases) have been isolated, cloned and expressed in plants; thereby interfering with the development of certain groups of pathogens and providing resistance against certain crop decimating pathogens. For instance, these workers submitted that peanut plant transformed with antifungal genes coding for anti-pathogenic compounds was found to be 36 % superior in the reduction of the incidence of *Sclerotium* blight caused by *Sclerotium minor* compared to plants in the non-transgenic control group.

Similar technologies in various parts of the world have resulted in the development of many pests and pathogens resistant varieties. Tomato cultivars Big beef and Celebrity have been biotechnologically conferred with genetic properties to resist and overcome attacks from races of *Fusarium, Verticillium*, N., and tomato mosaic virus. Also, Nadia, Diamond and Black pride eggplant cultivars resistant to decimation by wilt-inducing fungi have also been developed (Darby, 2016). This source also confirmed that in peppers, cultivars including Italian sweet, Hungarian wax, Sweet chocolate bell and

Amahein Chile hot varieties capable of warding-off attacks from aphids-transmitted cucumber mosaic virus and powdery mildew resistant Zucchim squash cultivar are now commercially available. Apples are important fruit crop around the world. Scab, fire blight, cedar apple rust, and powdery mildews are some of the diseases affecting the efficient and profitable production of the crop. Waldeneffect (2013) reported that some apple cultivars such as liberty, Pima and Priscilla have been developed to be immune to apple scab disease, and strongly immune to apple rust. Similarly, Liberty – a biotechnologically modified apple variety has been reported to posses genetic resistance to powdery mildew and fire blight both of which are damaging fungal diseases of the crop (Waldeneffect, 2013).

Inserting segments of viral or other nucleic acids into plant genetic make-up (genome) often leads to silencing of genes of the virus or subsequent pathogens that have similar homologous sequences, thereby making the plant resistant. For example Anon (1998) noted further that insertion of a non-translatable coat protein coding sequence of the tobacco etch virus (TEV) produces transgenic plants that have symptoms on the leaves, but the rest of the plant remain free of symptoms. In like manner, insertion of a gene for double–stranded RNase from yeast into the genome of pea plant made the transgenic pea plant resistant to multiple viruses. Combining a host gene for resistance with pathogen–derived defense genes with genes coding for antimicrobial compounds provided for a broad and effective resistance in many host-pathogen combinations. This has been shown with the combination of a tobacco host gene with tobacco vein mottling virus coat protein gene, which showed broad and effective resistance to potyviruses in tobacco and combination with sweet 5 tomato gene for resistance resulted to immunity of the plant against tomato spotted wilt virus (TSWV).

Plants lack antibodies making machinery, but DNA technology has made it possible to transfer plants with additional genes that make possible the production of functional recombinant antibodies (plantibodies). They accumulate in intercellular spaces and chloroplasts and in the lumen of endoplasmic reticulum (ER) etc. affording the modified plant protection against several viruses such as tobacco mosaic virus (TMV), potato virus X (PVX), potato virus Y (PVY) and clover-yellow vein virus (CYVV). Recombinant techniques in biotechnology have allowed introduction of genes from the bacterium *Baccillus thurigoensis* (Bt) into plants which codes the host plant with proteins which kills lepidopeterous insect pests when ingested. The gene coding for this highly toxic protein confers resistance on the host plant genome (Bjomberg *et al*., 2015).

In Nigeria, to stem the impact of economic recession and food insecurity, diversification of her revenue base using green industry has been strongly advocated. We all know that SSA agriculture is characterized by marginal and highly leached, nutrient poor soils especially deficient in nitrogen (N); which consequently leads to very low yields (Abah, 2015). This has warranted the use of inorganic fertilizers to beef up and enhance crop output. Besides their negative agro-ecological disturbances and impacts, synthetic fertilizers put a large toll on the overhead expense of small-holder farms and thus prompting the need for other user-friendly alternatives such as bio-fertilizers and bio-pesticides (Enyiukwu *et al*., 2014a, d; 2016). In this light, Nigeria has partnered with some biotechnology organizations to rid its expansive water ways of notorious water hyacinth and convert same to bio-fertilizers (Abah, 2016). This source further reported that this mandate also extended to production of climate smart bio-fuels from the country's abundant flora which could aid in powering farm and industrial machinery not only at lower costs; but also such machineries will run with low greenhouse gas emissions (GHGs).

In this part of the world, rice is one of the most important cereal staples. With the exception of biotic pressures, low soil nitrogen status, salinity, and droughts have been identified as constraints to its profitable production. To this end it is estimated that over 40 % of rice consumed in Nigeria is imported from Asia. Recently, the National Cereal Research Institute (NCRI), Badeggi, Niger State, Nigeria through genetic engineering stacked the local NERICA rice variety with genes to make it nitrogen and water use efficient as well as salinity tolerant; resulting in the development and dissemination of a new rice variety called NEWEST. This cutting edge climate smart rice cultivar is expected upon release to command widespread adoption by farmers and tremendously boost local rice production in the country and stem importations of the commodity from abroad (Abah, 2015).

In Africa generally, maize is one of the cherished staples especially in the savanna and sahellian agro-ecologies (Chukwu and Enyiukwu, 2016). The association of some strains of fungi with the crop has led to its contamination with noxious mycotoxins such as aflatoxins, sterigmatocystin, fumonisins, ochtatoxins, trichothecenes and beauvericins (Enyiukwu *et al*., 2018). These fungi-derived toxins are known in medical circles to cause, induce or exacerbate different types of cancers, tumours, birth defects, allergies, immunological diseases, premature puberty in girls and even death (BMC, 1992; Enyiukwu *et al*., 2018). Biotechnology involving the use of genetic engineering has tremendously contributed to the biological control of mycotoxins in agricultural crops. The maize varieties

SAMMAZ-45 with a mean yield of 6.2 t/ha irrespective of agro-ecology developed at IAR, Samaru as well as AflaSafe® developed at the IITA, Ibadan Nigeria for example have been reported to be incorporated with the genetic mandate to resist association with certain mycotoxin-producing organisms and thus conferring them with freedom from contamination with their noxious aflatoxins (Bandypadiyay *et al*., 2007; FFN, 2016).

We understandi that protein-calorie malnutrition and micronutrient deficiency (MND) otherwise called hidden hunger are endemic public health challenges in most parts of the third world; with the later affecting nearly 2 billion people around the world ((GAIN, 2018; World Hunger, 2018). Though pharmaceutically enriching agro-based products have been attempted by many organizations for their management; however, bio-fortification of agricultural field crops through many pathways by transgenic insertion of genes from other organisms have been documented as a veritable complement to classical breeding of nutrients enriched crops which is de-merited in most cases by limited availability of diverse genetic resources for target components, poor heritability index, and low linkage drag in target crops (Garg *et al*., 2018). Many countries including Mexico, Brazil, India etc. are now integrating bio-enriched crops varieties in their farming systems. Hence, bio-fortification of crops via genetic manipulations could provide cheap and sustainable techniques of delivering high value amino acids, vitamins and micronutrients to rural populations with limited access to a broad array of nutrient-rich diets on one hand or poor access to medicare on the other in forms compatible with their stables and food forms. Rice varieties such as Golden rice has been transformed to produce 23 % more β-caotene and another capable of producing 150 folds of more folic acid has been developed (Garg *et al*., 2018). These authors argued that 100 g of the later could meet the folate needs of an average human adult per day. Some agricultural crops from diverse plant families genetically stacked with proximate or micro-nutrients are presented in Table 3.

Table 3: Some agricultural crops genetically engineered with amino acids and micronutrients

S/N	Crop(s)	Engineered to synthesize	Mechanism and Pathway
1	Cassava *Manihot esculenta*	Pro-vitamin A, and zinc (Zn)	Overexpressing PSY bacterial genes
2	Carrot (*Daucus carota ssp sativus*)	Calicium (Ca)	Expressing Arabidopsis H^+/Ca^{2+} transporter genes
3	Lettuce (*Lactuca sativa*)	Iron (Fe)	Expressing soybean feritin gene
4	Cauliflower (*Brassica oleacea*)	Pro-vitamin A (β-carotene)	Expressing/inserting LTR retro transferases
5	Banana (*Musa acuminata*)	Lycopene, lutein and β-carotene	Over expressing many genes
6	Wheat (*Triticum aestivum*)	β-carotene, iron (Fe) and amino acids	Ex[pressing bacterial PSY,
7	Maize (*Zea mays*)	β-carotene, vitamin E lysine and tryptophan	Ex[pressing multiple carotenogenic genes;
8	Barley (*Hordeum vulgare*)	Zinc (Zn) and iron (Fe)	Over expressing zinc transporters, expressing phytase gene HvPAPhy_A
9	Sorghum (*Soghum bicolor*)	Pro-vitamin A, lysine and …digestibillty	Over expressing HOMO188-A gene HT12 gene introduction; RNA silencing of of γ-kafirinproteins
10	Soybean (*Glycine max*)	Pro-vitamin A, cyteine and methionine	Overexpessing PSY and carotene desaturase, overexpressing maize zeinprotein and O-acetylserine sulphudrylase
11	Common bean (*Phaseolus vulgaris*)	Methionine enrichment	Increased expression of albumin from Brazilian nut
12	Potato (*Solanum tuberosum*)	Pro-vitamin A	Stacking PSYphytoene desaturase and lycopene β-cyclase, or gene ch
13	Sweet potato (*Ipomea batatas)*	β-carotene, lutein and anthocyanin synthesis	Overexpressing IbOr-hs gene and IbMyBI in white fleshed potato
14	Cassava (*Manihot esculenta)*	β-carotene, Zn and Fe for yellow fleshed tubers	Overexpressing bacterial PSY and soybean feritin genes

Source: Garg *et al*. (2018)

Though genetically modified crops have reportedly led to substantial reduction in sprays of synthetic fungicides and reduction in sprays for all pesticides put together, as well as reduced crop yield losses and quality variability; however, they have a broader advantage of being able to be deployed extensively over large hecterages for several years without evolution of resistance. Nevertheless, there are fears amongst some groups of scientists about biotech/GM crops not being sustainable because of likely evolution of insect or weed resistance by IR and HR crops respectively in the future (Friday and Singh, 1991). This fear has recently been sustained in the USA where Silva (2017) reported that glyphosate-tolerant and insect resistant weeds are alarmingly developing in areas where biotech/GM crops are predominantly grown in the country; making scientists to focus on other frontier approaches to stemming these tides. One of these frontier approaches towards ameliorating the attacks of and attendant losses from pests and diseases in farms are integrated disease management (IDM) which holds the health of the environment in high consideration in addition to reducing pest populations or pressures. For these reasons, chemical interventions are considered as last resort to checking plant diseases and when necessarily used, only chemicals with different modes of action (MOA) are utilized sequentially or in combination (Enyiukwu *et al*., 2014d; 2016).

Biotech/GM crops such as Bt maize, Bt cotton etc. can be highly compatible with integrated disease management (IDM) programmes. This will involve applying knowledge of biological systems and chemical modes of action in a sustainable manner and hence avoiding over-reliance on a single approach or toxin to achieve disease control (Enyiukwu *et al*., 2014d). Hence, other frontier approaches being employed by biotech scientists and genetic engineers to delay resistance development against genetically modified insect resistant (IR Bt) and/or herbicide resistant (HR) crops, are pyramiding (i.e. combining multiple genes that confer the same trait to a crop) in individual varieties. In other cases, these engineers stack (i.e. use different genes to confer multiple traits to a modified crop) varieties. For instance Frisvold and Reeves (2010) noted that stacked varieties for example might have pathogen and herbicide resistance or might be resistant to herbicide with different modes of action. They remarked that stacked or pyramided crop varieties will be critical part of crop management techniques against pests and diseases in the foreseeable future.

Climate change is one of the most serious threats that adversely affect in particular African agriculture. Its impacts are felt through prolonged droughts, flooding, extremes of cold and heat waves, emergence of difficult pest populations and recalcitrant weed and disease dynamics (Sadiku and Sadiku, 2011). In Tanzania, for example decreases in crop production as well as increases in pests and disease pressures attendant from changing weather patterns have led farmers to abandoning certain cereal crops especially maize and opting for millet and sorghum with a higher capacity for drought tolerance; and growing amongst legumes, pigeon peas in the stead of cowpeas which are comparatively less drought–friendly. These workers projected that African agriculture, being predominantly rain-fed, will likely experience a fall in terms of crop yield by up to 50 % owing to changing weather patterns in the foreseeable future. FAO predicts that come 2080, global crop production will fall by 15-20 % due to climate change effects; making climate smart crops a welcome development (FAO, 2018). These workers believed that breeding climate smart crops through the instrumentality of marker assisted biotech techniques to a diversity of genes will be one of the largest focus for accurate and speedy development of location or need-specific improved varieties in this century. Therefore in a world challenged by exploding human population, climate change and dwindling food production, smart crop varieties will without doubt contribute to reduced pests and disease attacks on crops without recourse to synthetic pesticides and in turn increase food production without dislodging food safety (Nagagarde *et al.,* 2017).

Studies by ISAAA (2017) revealed that climate change could and would seriously or at least considerably reduce the protein, zinc and iron contents of staple foods such as rice, potatoes, banana wheat, mustard, chickpea and pigeon peas. This in effect is estimated to put some 1.4 billion children at risk of iron deficiency diseases such as anaemia amongst others by the year 2050 these researchers projected.

The question now is -- how do we maintain, sustain or improve food and fibre production given the enormous challenge posed by climate change in sub Saharan Africa so as to attain food security? The answer lies in the use of pest resistant and eco-resilient varieties generated through agricultural biotechnology. In line with this therefore, the National Agricultural Seed Council of Nigeria has begun the trial of Bt cotton resistant to bollworm and Bt cowpea resistant to *Callosobrunchus maculatus* in 10 states of the country. Such varieties should be dense in nutrient, weather tolerant, grower-friendly and adaptable to such climate change features as:

- Extremes of cold conditions; and extremes of heat conditions; hence they must be
- Flood insensitive; or drought insensitive
- Herbicide resistant (HR); or insect pest resistant (IR)

- Parasitic weeds (*Striga* and *Electra spp.*) resistant
- Disease (pathogenic) resistant as well as have
- High germination profile and high yielding capacity

Though it may be difficult for a single variety to present all the foregoing characteristics, nevertheless, the variety should be able to have major attributes that are location–specific and location-demanded. Conventional breeding through selection and hybridization for desired traits may not totally be able to properly address the foregoing. Immunization techniques will have to be employed, however enough field trials have as yet not be carried out in this regard especially in SSA. Above all, advanced marker assisted breeding and/or crop genetic modification and engineering invariably will become imperative in African agriculture to meet its food and health mandates for its peoples. A view strongly shared by scientists at the Institute of Agricultural Research, Samaru, Nigeria (IAR, 2017).

Cultivars with disease and/or adverse weather resistances are adjudged the first and single most important choice in crop production and pest management programmes (Wikipedia, 2013a). Such cultivars come handy through marker assisted and/or genetic engineering platforms of GM or transgenic (TM) plants transformed with:

- Specific plant genes for resistance; specific plant coding for anti-pathogen compounds
- Specific nucleic genes that silence pathogen genes; combination of resistance genes
- Antibodies against the pathogens; and specific genes that code for enhanced vitamin A, iron, protein production

These transformations can be achieved through pyramiding and gene stacking (Garg *et al*., 2018). BMF (2011) availed Sub-Saharan African women farmers with biotechnologically improved rice and cowpea varieties that are drought tolerant and flood insensitive – "a leaf we must borrow in SSA and especially in Nigeria".

4.0 CONCLUSION AND POLICY RECOMMENDATION

In conclusion, factors of communal conflicts, climate change, pest and disease pressures amongst others have been reported to serious affect crop production, food security and public health. Classical crop breeding has been used over time to breed high yielding pest resistanr and more nutritious food crops. However, this approach is seriously constrained by lack of germplasms and huge time lags before new varieties could be developed. Warranting the need therefore, to engage other forms of crop improvement strategies to complement and offset the short-comings of classical breeding programs. Agricultural technology (immunization and biotechnology) for crop improvement in sub-Saharan Africa lies in the area of development of high-yielding climate smart varieties which so far remain the pivot of good and sustainable crop management strategies against biotic and abiotic stressors for increased agricultural productivity, food security and public health. Such varieties as a matter of necessity must be stacked with more nutrients, have the ability to resist pathogenic diseases and tolerant to such adverse weather conditions as flooding, drought and metals-induced (Al, Na, Mn, Cu, etc.) toxicities in soils etc Achieving these in shorter timelines will in no wise be outside the realms of modern agricultural technology. Against this backdrop, all tiers of governments of sub-Saharan African nations and other stakeholders in the agricultural, food and public health sub-sectors of their economies will do well to borrow leaves from such examples of nations like south Africa, China, USA, Canada Argentina, Mexico, Honduras etc. which have adopted and imbibed modern agricultural technologies of immunization and biotechnology to produce GM crops to improve the food, health of their citizenry and financial wellbeing of the concerned stakeholders.

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