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Genetically Modified Crops and Food Security in Nigeria; Facts and Myths

B. O. Ehirim[1,2,3*], M. Bashir[1], M. N. Ishaq[1], A. S. Gana[2], B. Z. Salihu[1], T. Gbadeyan[1], O. F. Nwankwo[3], E. Kouko[3], K. D. Tolorunse[2], J. Amedu[4], S. U. Echefu[5] and N. Danbaba[1]

[1]National Cereals Research Institute, P.M.B. 8, Badeggi, Niger State, Nigeria.
[2]Department of Crop Production, Federal University of Technology, Minna, Niger State, Nigeria.
[3]African Agricultural Technology Foundation, P.O. BOX 30709-00100, Nairobi, Kenya.
[4]National Biosafety Management Agency, P.M.B 2058, Abuja, Nigeria.
[5]National Biotechnology Development Agency, P.M.B 5118, Abuja, Nigeria.

Authors' contributions

This review was carried out in collaboration with all authors. Author BOE conceived and wrote the first draft. Authors MB, MNI, ASG and BZS helped in rearranging the second and third draft. Authors OFN and EK provided useful literatures to support some critical components of the writeup while authors TG, KDT, JA, SUE and ND at some point edited the draft before sending it out. All authors read and approved the final manuscript.

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ABSTRACT

Biotechnology *per se* is not a panacea for the world's problems of hunger and poverty. However, genetic engineering in particular offers outstanding potentials to increase the efficiency of crop improvement. Thus, biotechnology could enhance global food production and availability in a sustainable way. Studies have shown that transgenic crops are very appropriate for agricultural producers and consumers in developing countries as the entire technology can be packaged into the seed. It can easily be integrated into traditional smallholder farming systems through proper stewardship. Except for a few innovative transfer projects, the application of biotechnology until now remains concentrated in the industrialized world. However due to insufficient owned scientific and regulatory capacities, the increase in privatized international agricultural research and the

**Corresponding author: E-mail: bernard.ehirim@gmail.com;*

strengthening of intellectual property rights of these organizations complicate the access of developing countries to biotechnology. Therefore, profound government and Institutional adjustments that cuts across new technologies and regulations are essential to ensuring that biotechnology does not bypass the resource poor, smallholder farmers in Africa and Nigeria in particular.

Keywords: Biotechnology; biosafety; genetically modified organism; PCR.

1. INTRODUCTION

Today, around 800 million people suffer from hunger globally [1]. The United Nations estimate that the world's population will grow to reach 8.1 billion by 2030 [1]. Meeting global food requirements at that point will necessitate an increase in production by 50% [1]. If natural resources continue to be used the way they are today, they will not suffice to fuel this increase by then [2]. Along with a quantitative increase in food, its qualitative enhancement is likewise very important to effectively reduce famine and malnutrition thus illness and poverty [3,4]. Can biotechnology, particularly genetically modified (GM) plants make an appropriate contribution to improving the global food situation? Answers to this question have been seen to be controversial [5,6].

While Biotechnology should not be seen as a substitute for traditional tools of crop improvement, integrating biotechnological tools and techniques into conventional breeding programs could however, substantially enhance the efficiency of crop improvement in Agricultural Research and Development (R&D). Also, breeding could be accelerated for targeted genes and even for precise transfer of desired genes into crop species for genetic gain with the aid of newer biotechnologies that has proven and reported to cut time of breeding [7]. Biotechnology brings forth new crop traits that are not amenable to the conventional approach because while traditional cross-breeding is confined to the exchange of genetic material within a certain crop species, recombinant DNA techniques enable the transfer of valuable genes across species and even across kingdoms [8].

A case in point is *Bt* maize, where a gene of the soil bacterium *Bacillus thuringiensis* (*Bt*) has been incorporated into the plant genome to confer resistance to particular insects [9] and the NEWEST rice where *Agrobacterium tumefaciens* another soil born bacterium was used to stack Nitrogen-use efficient, Water-use efficient and Salt tolerant gene into rice [10,11].

Recent advances in molecular mapping and functional genomics, however, demonstrate that related biotechnology products will in the near to medium-term future be in the lead quite realistically in crop improvement programmes [12]. Thus, improved crop varieties could also be tailored to areas within our agroecological regions, which have been largely neglected by the green revolution. This approach if considered could increase productivity because the view by breeders to have one-in-all variety has limited productivity in the recent past.

Genetically modified (GM) crops have been commercially cultivated since 1996 [13]. Over the past years, the western world's production has continually increased due to increased adoption of GM product. At the end of 2005, GM crops were grown in 21 countries (USA accounting for 55% of global biotech cultivated area, Argentina, Brazil, Canada, China, Paraguay, India, Uruguay, Australia, Mexico, Romania, the Philippines and Spain. Countries with an area of less than 0.05 million ha include Colombia, Iran, Honduras, Portugal, Germany, France, Czech Republic.). In Africa, genetically modified (GM) crops have been commercially cultivated in four countries which include South Africa, Burkina Faso, Egypt and Sudan [14]. Since 1998, South Africa has been a major grower of GM crops, while Burkina Faso and Egypt followed in 2008 [15]. Sudan grew GM cotton in 2012. In the recent past, countries like Ghana, Nigeria, Cameroon, Malawi, Cote d"Ivoire, Mauritius, Namibia and Zambia have followed suit with their biosafety laws at different stages of completion and implementation [16]. Other countries, with the aid of international governments and foundation, are conducting confined trials and research on crops important to Africa. Crops under biotechnology research for use in Africa include cotton, maize, rice, cassava, cowpea, sorghum, potato, banana, sweet potato, sugar cane, coconut, squash and grape. More so, biotic and abiotic stress resistance are areas of research projects in Africa like drought, biofortification of crops etc. Official Global hectarage of GM crops in 2016 increased to 185.1 million hectares from 179.7 million hectares in 2015, an equivalent of 3% or 5.4 million increase in hectarage [17].

More than one third of the global area of GM crops is located in 11 developing countries [13]. Currently, the most widespread GM crops in the market are genetically modified varieties of soy, maize, cotton, and canola. These GM crops are herbicide-tolerant and/or resistant to certain pests [15]. An analogous GM rice variety was planted for the first time in 2005, in Iran [17]. Until now, GM crops have been developed predominantly by private multinational corporations whose products are mostly used to produce animal fodder and textiles. A smaller share is processed into food [18].

In as much as GM crops are still surrounded by controversial debates with several factors hindering their adoption, there is an urgent need for the advancement of agricultural biotechnology (e.g. crop bio-technology or genetic modification technology), particularly, to address food and nutrition security problems fighting against hunger, poverty crisis and to also ensure sustainable agricultural production in developing countries [13]. This paper therefore, highlights the promises and limitations of crop biotechnology from a food security perspective.

2. THE SCIENCE OF GENETICALLY MODIFIED ORGANISM (GMO)

The term "genetically modified organism" means an organism has undergone a process in which its genetic material is altered in a way that does not occur naturally by mating and/or natural recombination (Directive 2001/18/EC). GM crops are modified using recombinant DNA technology in three different ways, that is, transgenic, cisgenic, or intragenic modifications. 'Transgenic' modification involves the insertion of foreign DNA from an unrelated genus or species. 'Cisgenic' involves the insertion of one or more gene of related species or from a crossable donor. However, the introduction of specific alleles/genes present in the gene pool, without changes in DNA sequence is termed 'cisgenesis' [19], and such processes accelerate the breeding of species with long reproduction cycles with no linkage drag. Cisgenesis involves genetic modification using a complete copy of natural genes with their regulatory elements that belong exclusively to sexually compatible plants while Intragenesis refers to the transference of new combinations of genes and regulatory sequences belonging to that particular species but their coding regions of genes are combined with promoters and terminators of different genes from the same sexually compatible gene pool.

GM crops generally contain novel genes (transgenes) with improved quality traits, such as herbicide tolerance, and allow the developmental process to be dramatically accelerated [20]. GMO (genetically modified organisms) technology breaks the barrier of sexual incompatibility between plant species and subsequently, increase enormously the size of the available gene pool [20]. GM crops have revolutionized agricultural commodities by allowing breeders to introduce specific alleles from a wide variety of source to produce more useful and productive crops [8]. This has enormously helped in scientific breakthroughs within the agrarian research community. The rapid adoption of GM crops within the agricultural sector has increased agricultural productivity, contributed to economic growth, and allowed food demand to be met [21]. Genetically modified Bt corn carrying a gene variants of Cry proteins from the soil bacterium *B. thuringiensis* is a typical example. These proteins, also known as Bt toxins, specifically kill important plant pests like insects of the orders Lepidoptera, Coleoptera, Diptera, and others if ingested [22].

Bacillus thuringiensis is a Gram-positive spore-forming bacterium with entomopathogenic properties and has a long history of safety upon ingestion by humans. It also has been used as a sprayable biopesticide in organic farming [22]. During sporulation, *B. thuringiensis* accumulates a large number of parasporal crystals consisting of insecticidal crystal proteins (ICPs). Parasporally formed crystals are predominantly composed of one or more proteins (Cry and Cyt toxins) also called d-endotoxin, which lyse epithelial cells of the insect midgut by inserting pores into the plasma membrane. Cry toxins are innocuous to humans, vertebrates, and plants and are completely biodegradable [23]. This technology was also deployed in the Bt cowpeas pod borer resistance to Maruca currently commercialized in Nigeria by Institute for Agricultural Research (IAR) Zaria.

3. GM CROP VALIDATION METHODS

Methods for the detection, identification, and quantification of transgenic DNA in food and feed must be validated before application to routine regulation. Specificity, sensitivity, linearity, limit of detection and limit of quantification of GM organism (GMO) detection methods are tested with intra and interlaboratory analysis of certified reference material. An additional spike test may be needed to validate analysis method for food.

The preliminary screening of transgenic elements (element specific) is an efficient approach to both authorized and unauthorized GM crop detection. Although several polymerase chain reaction (PCR) free detection methods such as direct detection by DNA microarray [24] and magnetic capture with fluorescence cross correlation spectroscopy [25] have been described, PCR based methods are still the method of choice due to their versatility, sensitivity, and high-throughput potential. Preliminary screening by PCR is usually arranged in a multiplex or other equivalent form, to increase its screening efficiency.

Event-specific PCR, especially event-specific qPCR, is the gold standard of GM crop detection methods. Event-specific detection is necessary for authorized GM crop screening and identification in the European Union (European Commission [26]. Event-specific PCR methods are rarely used to screen GM crops because the number of GM crop traits far exceeds the capabilities of single multiplex PCR/ qPCR. However, analytical methods for detection of transgenic DNA in food and feed with particular attention on identifying multiple GM events in a single reaction were suggested by Marmiroli et al. [27].

The emergence of automated nucleic acid extraction and handling systems in conjunction with the development of high-throughput analysis technologies has significantly improved the capabilities of modern nucleic acid analysis. As the vast number of GM crop traits has become a major burden on GM crop detection, automated high-throughput technologies are necessary for future GM crop detection.

Various high-throughput nucleic acid analysis methods such as DNA microarrays [28], optical thin-film biosensor chips [29], capillary electrophoresis [30,31], microdroplet PCR [31], multiwall carbon nanotube-doped polypyrrole DNA biosensors [32], and loop-mediated isothermal amplification (LAMP) [33] have been successfully applied to GM crop detection.

The European Commission Directive (2001/18/ EC) addresses GMO Regulation 1829/2003 on genetically modified food and feed, whereas, regulation 1830/2003 addresses concerns on the traceability and labeling of GMOs. The first generation of GM crops contained a single Bt gene (Cry1Ac, Cry1ab, etc.) and enhanced economic benefits to farmers by increasing yields and cost-effectiveness [34].

Since the first GM crop approval in 1994, the increase in the number of approved GM crops has been relatively constant over the course of the past two decades. Today, 357 GM traits in various crops such as potato, canola, maize, rice, cotton, and soybean have been approved worldwide [35]. Besides the vast number of GM traits, the approval status (food, feed, and environment) of many GM crops varies from country to country. However, information regarding a GM plant's comprehensive approval and production status vary from country to country depending on their peculiarities, which is necessary for the comprehensive regulation of GM crops in world trade. In Nigeria, the National Biosafety Management Agency (NBMA) is charged with the responsibility of making sure that GM materials follow regulatory compliance processes to its approval before commercialization.

4. THE GLOBAL PERSPECTIVE TO GM CROP PLANTS

Within the globe, there have been a series of reports on protests against genetically modified organisms (GMO) especially crops. Records show that in July 2011, a group of protesters from Greenpeace, a non-governmental, environmental organization, broke into an experimental farm of the Commonwealth Scientific and Industrial Research Organization (CSIRO), an Australian federal government agency for scientific research, and destroyed the entire crop of genetically modified wheat. In August 2013, a research field of Golden Rice managed by the Philippine Government’s International Rice Research Institute (IRRI), and other public sector partners was attacked by anti-GMO activists. “Golden Rice” expresses high levels of beta-carotene (a precursor of vitamin A) thanks to its modified genetic properties [36]. Although different in many ways from the 2011 CSIRO break-in, the 2013 incident triggered strong condemnation by the scientific community, though that reaction failed to achieve consensus among public voices. The fundamental reason for the failure of that public consciousness towards GM was a continued lack of comprehensive understanding of current agricultural problems and the nature of GMO.

Table 1. Genetically modified crops that are tested or cultivated in Africa

Crop	Trait	Country
Cotton	Insect resistance	Egypt, Kenya, Malawi, Tanzania, Uganda, Zimbabwe
Maize	Drought resistance, insect resistance	Kenya, South Africa, Tanzania, Uganda, Zimbabwe
Cassava	Nutrient density, disease resistance, virus resistance	Ghana, Kenya, Nigeria, South Africa, Uganda
Cowpeas	Insect resistance	Burkina Faso, Ghana, Nigeria
Sorghum	Nutrient density	Kenya, South Africa
Potato	Virus resistance, insect resistance, fungal resistance	Egypt, South Africa
Banana	Nutrient density, disease resistance, fungal resistance	Uganda
Sweet potato	Virus resistance	Kenya, South Africa
Sugarcane	Growth, sugar content, virus resistance	Egypt, Mauritius, South Africa
Coconut	Virus resistance	Ivory Coast, Ghana
Squash	Virus resistance	Egypt
Grapes	Fungal resistance	South Africa
Rice	Nitrogen efficient water efficient and salt tolerant	Nigeria, Ghana Uganda

Although GM crops offer the possibility of expanding the accessible gene pool for plant breeding, however, there has been a lot of concern on its adoption [37].

Furthermore, there is a certain reluctance to accept GM foods created by transgenesis rather than cisgenics, as the later process appears to be more natural. Introduction of the R1 gene, which provides resistance to late blight of potato, from wild-type potato (*Solanum demissum*) to cultivated potato (*S. tuberosum*) is a cisgenic process. However, the transfer of the Bt gene from the bacterium *Bacillus thuringiensis* to the cotton genome to produces pest-resistant cotton is an example of transgenesis [38].

The most widely accepted genetically modified traits in GM crops are herbicide tolerance and insect resistance. GM soybean, maize, canola, and cotton which are either herbicide tolerant and/or insect resistant, are the most common GM crops in the market [35]. However, the rapid adoption of GM crops within the agricultural sector has increased agricultural productivity, contributed to economic growth, and allowed food demand to be met [21]. The adoption of GM within Africa is becoming encouraging with several confined trials and some commercialized GM crops across the continent.

According to a recent survey, the agronomic and economic benefits of GM crops are significant, as these benefits are dependent on the modified trait and geographical area [39]. High-yielding insect-resistant (IR) and herbicide-tolerant (HT) crops are greatly adopted by developing countries. Recently, genetically modified potato (InnateTM) generation I with multi-trait resistance to black-spot bruising and browning was developed using RNA interference technology (Simplot Company) and successfully commercialized in 160 ha in the USA [21]. InnateTM II with a disease resistance trait for late blight of potato was subsequently approved. In Nigeria the approval for the commercialization of Bt cowpea in 2017 also lays credence to GM crop acceptance.

5. THE NIGERIAN FOOD SECURITY CHALLENGES

Experts have convergent thoughts that Nigeria needs to rethink on her current modes of agricultural practices which limit food production and engage technology to boast food production and ensure food security for the populace. The current stereotype mode of farming is no longer sufficient for Nigeria’s food security and development goals and this system cuts across most of African countries. Isu [40] opined that “Nigeria cannot achieve food security as expected by procurement and annual distribution of fertilizers to peasant farmers”. This makes a call to engage technological innovations in combating food insecurity.

Despite the abundant agricultural resource and technical endowments as well as several interventions by successive past governments, Nigerian agricultural sector has been operating far below its potentials, consequently primary indices of food security at the national and the household levels are still unsatisfactory [41]. Access to adequate and well-balanced nutrition is limited, as nutritious food is at all time expensive. Food supply is very unstable, as post-harvest losses is put at between 15-40% within the food supply chain, giving rise to loss of seventy percent (70%) of perishable food that are scarce off season and thirty percent (30%) of durable foods [42]. Due to the low economic status of most of the citizens with 70.8% living below poverty line, the food intake and the general nutritional wellbeing of the populace is of low quality. Consequently, 65% of Nigerians are reported to be malnourished [43,44].

6. THE NIGERIAN GOVERNMENT AND GMO

Nigeria as a country is endowed with a variety of plant and animal species, which consist of about 7,895 plant species, identified in 338 families; 2,215 genera; 22,000 vertebrates and invertebrates' species [45]. All of these plant and animal species that form Nigeria's biodiversity are in abundance within the country, highly cherished and therefore, need conservation and sustainable utilization [45]. Today, 90 million Nigerians are in the state of vulnerability for lack of access to different kinds of food and are faced with a kind of food insecurity known as household food insecurity. The implication is that Nigeria should not take the issue of food security for granted. The increase in population and other overarching forces militate against food security in Nigeria when positioned against the back drop of rising number of consumers and shrinking per capital acreage of land for crop production brings the issue of food security in the country to the vanguard for national discourse [46].

The increasing application of biotechnology in agriculture has transformed the agricultural sector of national and global economics in very profound ways. Through the application of biotechnology in agriculture, millions have been fed in many poor countries on the Indian sub-continent where human population is fairly large [46].

The Nigerian government may not be said to have done badly in terms of accepting new technologies and, in this case biotechnology. The step government took on the 20th of April 2015 to sign the Biosafety Act into law which birthed and established the National Biosafety Management Agency (NBMA) to oversee, regulate and monitor the activities of companies, agencies and scientists linked with biotechnology and environmental activities was a step in the right direction. Since the inception of the agency, biotechnology activities in the country has scaled up and has been properly monitored. The deployment and usage of one of the most recognized biosafety protocol, the Cartagena Protocol on Biosafety by NBMA in the pursuit of their affairs is also commendable. The Cartagena Protocol on Biosafety is the most important international instrument in the field of biosafety. Among other things, it regulates transboundary movement of genetically modified organisms. The United Nations Environment Programme (UNEP) and the Global Environment Facility (GEF) provide support in building up national safety regulations. The UN *Codex Alimentarius* contains standards of food safety, and the World Trade Organisation (WTO) influences trade in GM crops [47]. Once a country has ratified international regulations and agreements, they define the framework for that country's national policies. This is the usual procedure in the countries of the South. However, there are also countries who define their national policy independently, without joining international agreements. One of such countries is the USA, which has not signed the Cartagena Protocol.

7. RISKS OF BIOTECHNOLOGY (GMO)

Besides the great potentials of biotechnology for increased food production and agricultural productivity, the risks must not be neglected. Often, the myth has always been dimensions for the environment and for human health which could occur due to the direct manipulation in the genetic makeup of organisms and because human knowledge is limited, the existence of unknown risks cannot be ruled out with absolute certainty, neither for transgenic crops, conventionally bred crops nor for any other technology.

According to current scientific knowledge, there are no indications that genetically modified crops are *per se* more dangerous than traditionally-bred varieties [48]. This does not mean that there are no risks at all. However, the predictable risks are not related to the biotechnological process but could be related to the products produced from the biotechnology which could also be implied to technologies from conventionally bred plant products. Thus, risk assessment studies have to be carried out on a case-by-case basis for each individual technology product. Environmental risks that need to be considered include the possible loss of biodiversity, detrimental effects on natural food chains and the emergence of more aggressive pathogen populations. Health risks include the possible occurrence of undesirable toxic by-products in the crop, the transmission of antibiotic resistances (used as marker genes) to microorganisms of human digestion and unknown allergic reactions by food consumers. It is however, important to note that if proper regulations accompany the biotech process and products, most of these concerns may not arise. Generally, the individual risk aspects apply to developed and developing countries alike [49].

8. THE WAY TO GO FOR NIGERIA

Nigeria as well as most African countries are among the list of developing countries in the world and as such are underequipped in terms of technical capacity to conduct modern biotechnology activities [50]. Human and physical infrastructural resources in Nigeria are grossly inadequate, forcing the country to be dependent of external funding in order to carry out most of its biotechnology activities. Government and stakeholders in the agricultural sector are however, persuaded to aggressively deploy necessary funds and machinery to speed up and bridge the gap of infrastructure deficit, modern equipment purchase and funding within the agriculture and agricultural biotechnology [51,52].

The Government is also advised to support and promote the activities of research institutes and the National Biosafety Management Agency by engaging them regularly to know their needs. Also, the National Biosafety Technical sub-committees established by the NBMA should always be comprised of experts on Agriculture, Environment, Health and Industry to make the numerous reviews of applications thorough.

NBMA therefore, should with the Act and all its legal frame work, utilize and enforce compliance without biases as this would have a direct link to creation of more employment, and boost food production by farmers and thereby alleviate hunger. The Act is crucial in the management of modern biotechnology activity in the country as it pursues food sufficiency/security, industrial growth, health improvement and environmental sustainability.

Promotion of public awareness and involvement of the public in decision making processes regarding genetically modified crops and its biosafety is highly important. The Cartagena Protocol takes account of this in Article 23. At the same time, in the form of the so-called “Biosafety Clearing-House”, the Protocol provides a forum for information exchange between countries.

Development cooperation can help to improve this situation by promoting public debates on GM crops. This can be done to support decision-making processes.

9. CONCLUSION

In the course of assessing biotechnology and its potential contribution to food security, it is important to make sure it is demand led where questions like: What are the interests behind its application? Who are the beneficiaries and who are the losers? The majority of commercialized GM crops so far have been developed by profit-oriented corporations for large-scale industrial agriculture. Until now, these crops have hardly contributed to food security for small-scale farmers in developing countries. Biotechnological applications must be adapted to each specific context. Environmental conditions, eating habits, and socio-cultural factors have a fundamental influence on whether the introduction of a crop makes sense.

Research geared towards improving the situation of resource poor small-scale farmers in a specific context could very well lead to positive results. It requires pragmatic approaches that respect the sovereignty of developing countries. The final decision on the development and cultivation of GM crops must be made by the countries concerned. However, these decisions should be made in a formal and transparent manner. When a country decides to adopt biotechnology, safety should be in the vanguard of such decision, moreover, the concept of trying to force a GM product on a country or introduce it through the backdoor must be strongly rejected especially in developing countries.

Biotechnology is leading agriculture into new dimensions. Its use is a call that most, probably cannot reverse. The question of whether genetically modified and conventional crops can exist side by side remains controversial. Moreover, biotechnology may further promote the expansion of largescale industrial production systems. The control and safety in the use of GM crops poses great challenges, particularly in developing countries.

Developmental cooperation is therefore, faced with the question of how future food security can be achieved in view of population growth and limited natural resources. Conventional technologies of varietal improvement and new cultivation practices continually produce advances. Improvements in the access of small-scale farmers to fertile land, water, credits and markets would considerably reduce hunger. In combination with other technologies, and in a form adapted to the needs of small-scale farmers, biotechnology could accelerate the process of achieving global food security. However, its use should be based on the precautionary principle. There can be no full guarantee of its harmlessness, careful weighing of risks and benefits with the help of regulatory agencies will always be necessary.

Finally, If the link between Government, Universities, Research Institutes, Regulators, Policy makers and Consumers are strengthened vis a vis the benefits from GM plants, sooner, the hunger in the land would be a thing not to worry much about in Africa as well Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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