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Recent Progress and Challenges of Genetically Modified Crops

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ABSTRACT

There have been unending hot debates on the utilization of genetic engineering to create genetically modified (GM) crops since its first introduction about three decades ago. Numerous other developing countries face the existential challenge of feeding their rapidly increasing populations amidst unfriendly economic circumstances. These countries are gradually introducing and adopting GM crops as a strategy for improving food production and ensure food security. However, the introduction and adoption of GM crops currently raises numerous legal, economic, health, socio-economic, and ethical concerns. Despite these concerns, local farmers are continuously incited to adopt GM crops because of

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the well-known improved productivity associated with using such crops. A crucial issue facing developing countries, which has greatly hindered effective adoption of GM crops is the perspective of their citizens. This review therefore examines those perspectives, which is expected to guide future strategies for adopting GM crops in developing countries at large.

***Keywords*:** Agriculture, crop yield, food security, genetic modification, public perception, sustainable development

1. INTRODUCTION

There are unquestionable improvements in various developmental aspects around the world today. One of such improvements is evident in agriculture and it involves the application of biotechnology to improve productivity. In a bid to increase crop yield, biotechnology has been used to produce genetically modified (GM) crops. This is important because the world population is not stagnant but continuously increases, whereas it is very difficult for the size of arable land to increase. The need for corresponding increase in crop yield through the cultivation of GM crops is therefore necessary particularly in developing countries which are experiencing continuously increasing demand for food as a result of constant population growth. Such population increases can be viewed as outcomes of weak or non-existent population control laws or measures in developing countries, which are not also strictly enforced where they may be found to exist [1, 2]. Undoubtedly, such countries rely heavily on subsistence agriculture, thus facing challenges of feeding their ever-increasing populations amidst harsh economic circumstances but could obviate these challenges by cultivating GM crops [3].

GM crops refer to those plants whose DNA have been modified in an artificial manner by plant breeding [4]. Genetic modification of crops involves the transfer of specific individual genes within or across plant species or from organisms that are entirely unrelated to the recipient crop using genetic engineering, aimed at producing plants which show resistance to insects, viruses, and certain herbicides. The basic techniques for plant genetic engineering were introduced in the early 1980s and commercialized for the first time in the mid-1990s. Since then, the adoption of GM crops has continuously increased rapidly, which accounted for the recorded GM crops grown on 9% of global arable land in 2008 [4]. The traditional plant breeding techniques that have been employed to achieve the desired improvements in crops are laborious and mired with inaccuracies. Contrarily, advances in genetic engineering have heralded great possibilities of creating plants with desired qualities in very short time frames, coupled with high precision and accuracy [5].

In developing countries, pesticides are usually applied indiscriminately without guidance and regard to their negative effects on the environment and humans. It is believable that the use of pesticides has resulted in short-term improvements in crop production, but its consequent damages on biodiversity [6-8], food chain [9], human health [10], and economics of food production are evident [7, 10]. Thankfully, the genetic modification technique side-steps the need for pesticides application in controlling various plant pests. On the other hand, introducing herbicide-resistant traits in plants can significantly enhance the effectiveness of controlling weeds. The increasing rate of adopting GM crops by agricultural institutions of numerous countries around the globe notwithstanding, public concerns on its associated merits and risks

are unending [11, 12]. GM crops have been reported to pose negligible harm to human and environment, after evidences on its potential risks were evaluated by various regulatory bodies and independent science academies [13]. Moreover, numerous studies point to the gains of GM crops as regards improved crop yields and cost effectiveness in agriculture [14-16]. Benefits in the welfare of farm households that adopted GM crops have also been extensively reported [17, 18]. However, there are also contradicting arguments by some researchers, who opine that the evidences on the effects of GM crops are mixed, and studies conducted on its benefits might have problems regarding data collection and methods of evaluation [19, 20].

As developing countries are characterized by increasing population and declining crop yield, this paper is therefore designed to ascertain if developing countries should adopt the cultivation of GM crops as one of the measures to increase crop yield, which will of course, translate into improved food production (**Figure 1**). This paper examined the need for increase in crop yield by looking into the situation of food in developing countries and the reasons why the agriculture sector is declining thereby encouraging the heavy importation of various kinds of food. Furthermore, the benefits which are derivable from the cultivation of GM crops in developing countries are given. This paper also looked into the status of biotechnology bills in developing countries, which are yet to be passed into law in many developing countries. Consequently, some conclusions and future outlook are presented, which are expected to guide the decisions on GM crops in various developing countries, and provide useful information for further development of such crops.

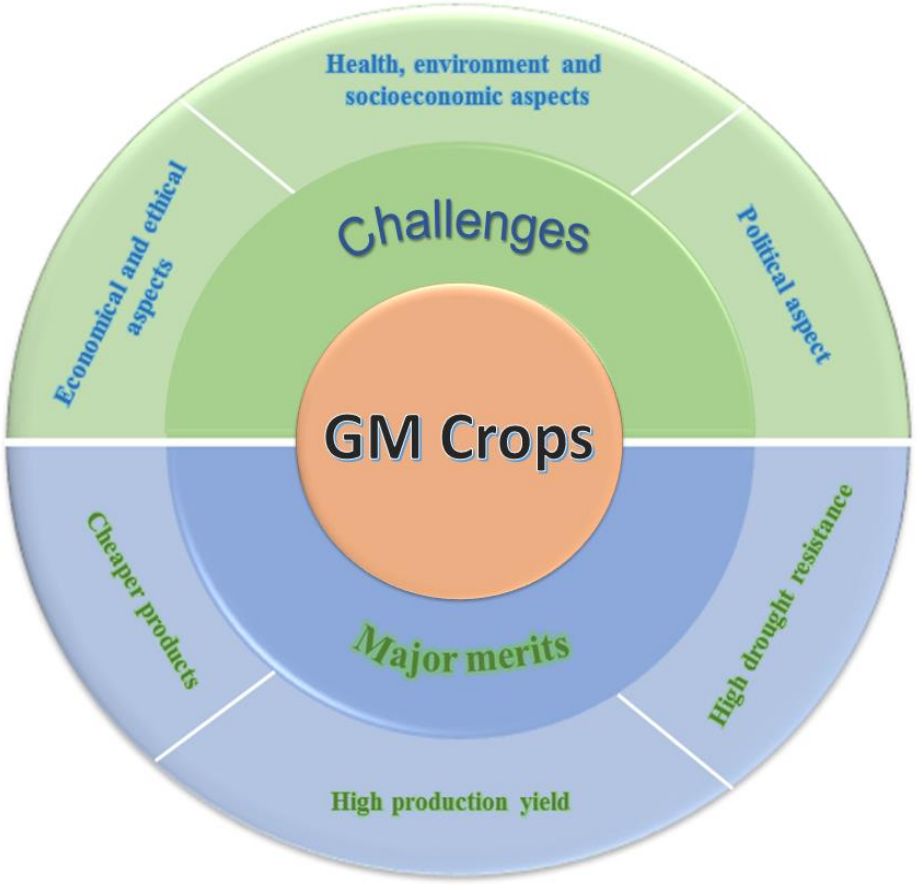

Figure 1. The major merits and challenges of GM crops

2. GENETIC MODIFICATION OF CROPS

In the world today, technological and scientific advancement has become a veritable tool in improving the life of humans. One of such advancements is biotechnology which is being applied in agriculture to produce improved crops and to increase crop yields. Biotechnology refers to utilizing scientific and engineering protocols in processing of substances through biological agents to ultimately provide goods for human use and various other applications [21].

Agricultural biotechnology therefore encompasses a wide range of technologies employed in agriculture to achieve improved food production [22]. In agricultural biotechnology, various technologies are applied to achieve beneficial outcomes including the genetic modification of plant species and animal populations for improved yield and/or efficacy, genetic characterization and the conservation of genetic resources, diagnosis of plant or animal diseases, development of vaccines against various diseases, and improvement of animal feeds. One of such technologies is genetic modification, which has been employed for the production of GM organisms [23].

The cultivation of GM crops is relatively a new development in the agricultural sector globally. In as much as the first commercial GM crops (tomatoes) were planted as early as 1994, significant number of crops with GM components were planted for the first time in 1996 (1.66 million hectares), and since then, there has been a substantial increase in GM-based cultivation and by 2012, the planted area rose to more than 160.4 million hectares [24]. In 2011, about 29 countries including 19 developing and 10 developed countries were planting GM crops, and various other countries had long joined the trend, with the three African countries (South Africa, Burkina Faso and Egypt) cumulatively planting over 2.5 million hectares [25]. Consequently, the African Union (AU) introduced a model biosafety law to aid its member in developing regiospecific biosafety laws and presently, South Africa, Burkina Faso, Kenya, Togo, Tanzania, Egypt, and Mali have enacted biosafety laws and GM crops are now widely grown and consumed in some of these countries such as Egypt, Burkina Faso, and South Africa [26].

Interestingly, significant advances have been generally made in genetic modification in the past four decades (**Table 1**) [27]. Like other innovations, the use of GM crops is under controversy with regard to its safety to humans and the environment. However, the World Health Organization (WHO), Royal Society, US National Research Council, and Organisation for Economic Co-operation and Development have continuously insisted that the risks that have been linked to the consumption of GM crops cannot be entirely attributed to such products [28]. It has been reported that GM foods have been certified as safe by the WHO, Food and Agriculture Organisation (FAO), AU and New Partnership for African Development (NEPAD) [29]. In other words, farmers and consumers need not to panic about the adverse impacts of consuming GM crops on their health. The aforementioned organizations argue that the methods of producing GM crops are quite precise, thus showing less likelihood to induce undetermined impacts [28]. However, despite the results of the risk assessments carried out on GM crops, some countries are yet willing to adopt the cultivation of GM crops. In 2002, some African countries that were battling the 2002 drought disaster received maize as food aid from the US. However, the maize kernels were first milled, to avoid being planted by farmers in Africa. Contrarily, food or environmental safety was not the major reason for the maize kernel milling, but commercial fear about the already existing negative perception of GM crops in Europe which will be the major destination of exported maize or meat obtained from animals that were fed with the maize by farmers in Africa [30].

The results of the risk assessments carried out on GM crops shows that they can be used especially by countries facing the challenges of feeding their increasing population.

Table 1. Critical advances in genetic modification in the past four decades

Year	Critical advance
1980	The first transgenic mice were made
1983	Polymerase chain reaction (PCR) was invented
1985	The first transgenic domestic animal (a pig) was made
1987	Discovery of the first human genetic map
1990	Launching of the human genome project
1991	The first trial of gene therapy on humans
1992	Development of the second-generation genetic map of human genome
1993	FDA approval of bovine somatotropin (bST) for enhancing milk production in dairy cows
1994	FDA approval of the first GM food sale (FLAVR SAVR tomato)
1996	The first cloned animal (Dolly the sheep) was made
1997	Sequencing of *E. coli* genome
1998	Sequencing of *M. tuberculosis* (bacterium) and *C. elegans* (roundworm)
1999	Decoding of the first human chromosome (chromosome 22)
2002	Assembly of mouse genome working draft
2003	Completion of the human genome sequencing

There is need for improvements in agriculture globally. Constant rise in population, climate change, and limited arable land and fresh water give rise to obvious challenges on the capacity of agriculture to meet the present-day global food, feed, fiber, and fuel demands and simultaneously reduce the associated environmental effects of producing such [31]. The WHO is estimating that the world human population will increase to about 9 billion by 2050 and to ensure food safety before then, global food production needs to be doubled or tripled on same available land expanse amidst water supply shortages dues to climate change [28]. Fortunately, a promising strategy to achieve this is by developing new varieties of crops by genetic engineering technology, which can incorporate desired genes into plants from distant plant relatives or entirely non-related plants [30].

Although the cultivation of GM crops is not a nostrum to end hunger in the world, it has the capacity of improving food production and consequent availability at present and many years to come with other attendant benefits. The methods of improving and using traditional and molecular genetic engineering techniques have formed the center of hot debates in recent years. Major discussions in this regard include strategies of making food crops to adapt to the gradual but continuous increase in global temperature, limited availability of water, and flooding due to climate change, as well as varying threats from pests and rising salinity [31]. For instance, China with a population of over 1.3 billion people is currently battling land degradation, persistent water shortages, but is making serious efforts in advancing transgenic green revolution to ensure food security for her citizens [32]. In about 29 countries that cultivated GM crops as at 2010, remarkable agronomic, health, environmental, economic as well as social gains were recorded [25]. In 2015, about 170 million hectares of land had been utilized for the cultivation of GM crops with major producers as US, China, Canada, India, Argentina, and Brazil [23].

3. PROCEDURE FOR GENERATING TRANSGENIC PLANTS

The procedure for generating transgenic plants is dependent on the method to be utilized, which majorly include:

(i) Recombinant DNA technology and
(ii) *Agrobacterium*-mediated transformation [33-35].

Using the *Agrobacterium*-mediated transformation method described by both Stanton [33] and utilized by Saker *et al*. [36] an improved variety of tomato, whose improved gene was obtained from a wild and non-edible tomato plant can be generated thus:

The process begins by cutting part of the stem from the wild-type tomato plant. The obtained piece of stem was ground in the presence of liquid nitrogen to harvest the inherent cell contents. The cell contents are then placed in a test tube containing reagents. The test tube and its contents were placed in an incubator. Thereafter, the contents were centrifuged to allow for the separation of the contents into different layers, among which is the DNA layer. The fluids in the test tubes can be coloured for ease of visualization. The DNA layer was collected and transferred to a different test tube. A restriction enzyme, ECO R1, was added to the DNA and thoroughly mixed. Also, the DNA sequence of the tomato was cut by the ECO R1, and sticky ends were thus created. Following the above-described protocol, the DNA of the wild tomato incorporated with a gene for enhancing sweetness could be prepared.

Purified bacterial plasmids are placed in a new test tube. Plasmids are small pieces of circular DNA that are extra-chromosomal. These plasmids come from the bacteria *Escherichia coli* and are a tool used by scientists to transfer DNA. ECO R1 is added to the test tube and the solution is mixed. ECO R1 recognizes and cuts plasmid DNA at the same place in the sequence as previously demonstrated in tomato DNA, creating complementary sticky ends - this completes the preparation of the plasmid DNA.

The next step entails creating recombinant tomato DNA. To achieve this, ligase was added to the plasmid DNA and the tomato to mediate sealing of the sticky ends generated in the previous process. The above mixture was incubated in the presence of a bacteria. It is possible that the bacteria could induce any of the following: reannealing of the tomato DNA to

itself, which does not necessarily produce recombinant DNA; facile reannealing of the bacterial plasmid DNA to itself, which also does not necessarily produce recombinant DNA; and annealing of the bacterial plasmid DNA with complementary tomato DNA sticky ends, thus producing recombinant DNA.

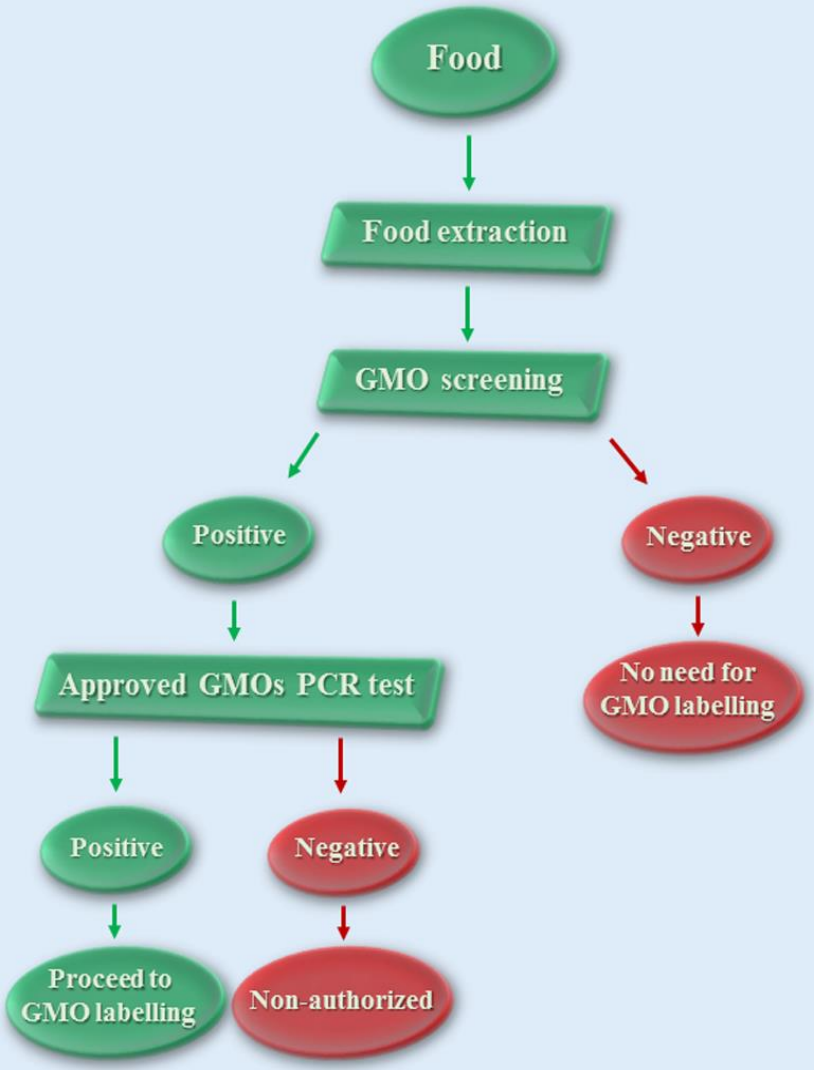

Figure 2. Procedure for testing GM foods

For the sole purpose of screening for the recombinant tomato-plasmid DNA, bacteria that contain selective nutrient media were cultured in petri dishes. Subsequently, it could be possible to identify the bacteria colony that possess the 'sweet' gene, which is of interest. Once identified, the colony of interest are transferred to various petri dishes and further incubated for maximized cells proliferation. Thereafter, the DNA of the 'sweet' gene was extracted and purified. The final step involves transferring the sweet taste created from the wild tomato to the edible ones. To achieve this, the DNA of the 'sweet' gene is coated with gold microparticles. Also, a leaf obtained from 'non-sweet' tomato plant was sterilely cultured in a petri dish.

The gold microparticles-coated recombinant DNA were accelerated by air pressure in a biolistic particle delivery system and directly shot into the 'non-sweet' tomato plant leaf. Due to particle size property, the gold microparticles-coated recombinant DNA can enter the cells of the tomato plant leaf. Inside the leaf, the recombinant 'sweet' gene DNA can be released from the gold microparticles, thus integrating with the tomato plant leaf-cell chromosomes. The transformed leaf cells could be transferred to an entirely new terrain to encourage their regeneration to transgenic tomato plants, ultimately fulfilling the production of tomatoes with enhanced taste. Additionally, for GM foods, the general testing procedure is summarized in **Figure 2**.

4. THE NEED FOR IMPROVEMENT IN CROP YIELDS

The continuous increase of Nigerian human population obviously creates more demand for food. From the United Nations (UN) world population prospectus report of 2017, the world's population now at 7.6 billion is estimated to reach 9.8 billion in 2050 [37]. This has necessitated the need to improve on agricultural productivity so as to ensure food security of the world's populace. The UN further predicted that Africa will experience huge population rise over the next century and that the population of Nigeria (currently the world's 7th largest) is expected to surpass that of the USA before the year 2050 [37]. It is extremely worrisome that in spite of the numerous natural resources of the country, the majority of Nigerians are still hungry, the nation is threatened by food insecurity, with population living on less than $1 per day, with lack of access to food, healthy living [38, 39]. The problem of ensuring food security is one of the major development challenges of Nigeria [40]. Food insecurity arises when the citizens of a country have limited access to adequate quantities of nutritious and appreciably safe food which is essential for proper growth and development, and healthy living. It may result from insufficient food purchasing power, uncontrolled domestic food wastage, unavailability of food, and improper food distribution [41]. The Food and Agricultural Organisation in 2002 included Nigeria in the list of countries facing adverse food needs [42]. This is indeed a worrisome situation considering the number of people that are entrenched in lack of food and calls for attention into the agriculture sector of Nigeria.

Over 70 % of Nigerians, reside in rural areas and are involved in agriculture thereby making Nigeria an agrarian country with an output highest among the Sub-Sahara African [38]. In Nigeria today, rice, yam, cassava, and corn dominate the landscape of available foods [43]. However, the agroecological condition of Nigeria is quite diversified, which can be leveraged to produce varieties of food [44]. In Nigeria today, about 74 million hectares of her land are arable which can be coupled with the irrigable portions of about 2.5 million hectares to maximize agricultural production [45-47]. The numerous agricultural resources of Nigeria notwithstanding, there has been a snaily growth in her agricultural sector over the last decades [44]. Unfortunately, it has been extremely difficult for Nigeria to meet the high food demand of her citizens, amidst constant growing population, thus resulting in a wide variation in food demand and national supply [40]. The food import bill of Nigeria was $5 billion as at 2014, and that of Africa was $35 billion in 2017 [48]. There is still a heavy dependence on imported food products in Nigeria, which are expectedly expensive for the local people to purchase. This has resulted in widespread malnutrition in the rural communities of Nigeria, with attendant increase in public health issues [49].

Additionally, several factors are responsible for the deficit in the production of food crops in Nigeria. It is rather unfortunate that small- and medium-scale famers contribute a whopping 90% of Nigeria's agricultural output [49]. As is typical of small-scale farmers in various developing countries around the world, lack of proper access to modern implements, markets, land and loans, as well as poor infrastructure are persistent [44]. Furthermore, constraints militating against agricultural production in Nigeria generally include unavailability of adequate amounts of fertilizers (because it is costly), climate change, insecurity of land tenure, low investment in agricultural-related research, poor resistance of staple crops to natural disasters such as drought, prevalent pests and animal diseases, inadequate storage facilities for agriculture products, and very poor policies on agriculture [43]. As the Nigerian agriculture is mainly dependent on rainfall, it is inherently vulnerable to weather variations [50-52]. One of the remarkable effects of climate change in Nigeria's agriculture is the increasing rates of annual rainfall in many coastal regions and corresponding decrease in rainfall in the continental areas [53]. Additionally, the worsening effects of desert encroachment in the northern region of Nigeria constitutes potential threat to the existence of millions of her citizens [54, 55]. Sand dunes are becoming rampant attributes of desertification and the migrating sand dunes have damaged huge expanse of arable land, thereby decreasing the availability of viable lands for agricultural production [53]. In addition to the aforementioned challenges, the exploration of natural resources is also a contributing factor to the low production of crops in Nigeria. For example, in Osun State communities where gold is largely deposited the top soil that is good for farming is being scrapped, farm lands are being destroyed by illegal miners [56, 57].

Nevertheless, it is pertinent to note that Nigeria's agriculture production can be improved thereby enhancing the availability of food in Nigeria. Nigeria was once notable for exporting agricultural products, and by the mid-1960s, she had above 1% share of the world's agricultural exports [58]. Before 1970, the major source of Nigeria's foreign exchange was agriculture, with her main exported agricultural products as cocoa, cotton, palm oil, palm kernel, groundnuts and rubber [59, 60]. Moreover, the agricultural sector contributed over 60% to GDP, also accounting for about 70% exports and satisfying more than 95% of food demands [61, 62]. However, the agricultural sector was grossly neglected during the heydays of Nigeria's oil boom which occurred in the 1970s [63]. Until now, the Nigerian government has totally focused on petroleum resource development [50-52]. Nigeria is at the top 10 in the list of world petroleum exporters, with its reserves suggesting that it could maintain the present exportation level of oil for not less than 25 years from now [58]. In 2000, the revenue from exportation of crude oil contributed above 98% of Nigeria's export earnings. However, the value decreased to 71% in 2011. Despite the huge revenue that the oil sector generates, Nigeria is still plagued with poverty [64]. It is rather unfortunate that Nigeria ranks top in the lists of countries exporting the largest amount of crude oil and those with the highest number of poor people [65, 66]. Furthermore, the situation is expected to worsen following the present shock in the oil sector. There has been more than a 50% decline in oil price since 2014 from about $115 per barrel to below $50, and this comes after five years of near-price stability [67, 68]. The falling oil prices has slashed the amount budgeted for capital expenditure in recent annual budgets by about 59% [68]. Consequently, 31 out of the 36 states in Nigeria have been finding it difficult to pay their wages and meet other expenses due to the shortfall in the federal allocation resulting from the fall in oil price [69].

The economic situation and highly increasing population in Nigeria call for attention in the non-oil sectors of the economy especially the agricultural sector which employs a huge

proportion of her population. It has been reported that apart from cocoa, none of the agricultural produce exported by Nigeria makes notable wave in the world market share at present [58].

There needs to be improvements in crop production in other to boost its contribution to Nigeria's economy as it was before oil exploration began in the country when Nigeria was among the major exporters of some crops as highlighted above. However, owing to the challenges facing crop production in Nigeria at present, it is therefore necessary for Nigerian farmers to embrace more efficient techniques to boost crop production and thereby increasing their income. One of such improved techniques is the cultivation of GM crops.

5. BIOTECHNOLOGY BILL IN DIFFERENT COUNTRIES

One of the challenges to the adoption and advancement of GM crops is the biotechnology bill of different countries. Whereas some countries have passed bills that allow for the importation and cultivation of GM crops, other countries have yet to do so. There are also some instances where some countries restrict the importation of GM crops of any kind. It is believed that as the society is advancing, the need to widespread acceptance of GM crops will increase with time. Considering that the population of many countries engaged in agriculture is constantly increasing, increase in crop yield is expected to have multiplier effects on the income of citizens, thereby reducing the percentage of the poor in such countries. However, it is in the hands of the governments of such countries to approve the cultivation of GM crops. For instance, in 2000 and 2002, the popular international biosafety protocol (Cartagena Protocol) was signed and ratified in Nigeria, respectively [70]. However, there have been numerous legislative challenges on the Nigerian biosafety bill which was first presented to the floor of her National Assembly in 2006 and eventually scaled through legislative processes in 2010 [5]. The legislative setbacks notwithstanding, stakeholders did not give up. On October 16 2014, a public hearing for an Act to establish the National Biosafety Management Agency was held at the National Assembly, in Abuja and stakeholders unanimously endorsed this biosafety bill, urging its speedy passage as the country has been missing out on huge economic and health opportunities. In 2019, the National Biosafety Management Agency Act was eventually signed into law by the President. The bill also incorporates prominent aspects of modern biosecurity and biotechnology in Nigeria. It also ensures that unapproved GM crops including seeds and grains that are intended for human consumption or components of animal feed are disallowed from going into Nigerian markets. Also, the agency is charged with the responsibility of policing and regulating genetic engineering technology in Nigeria as to ensure that the country is safe from becoming a dump site for unhealthy GM crops.

6. BENEFITS OF GM CROPS

So many countries are reaping the benefits of cultivating GM crops. One of the major benefits of GM crops is their contribution to crop productivity, which ultimately contributes to global food security, and high availability of feed and fibre [25, 71]. Burkina Faso became the leading cotton producer in West Africa as a result of agriculture biotechnology [72]. The increase in crop productivity is envisaged to yield spill-over impacts in local economies by generating direct and indirect employment opportunities, and ensure food security [73].

Between 1996 and 2016, the income generated globally from farming GM crops reached $186.1 billion and since 1996, with net economic benefit amounting to $18.2 billion [24].

Also, in 1997, South Africa gave its first approval for cultivating Bt yellow maize. As at 2002, about 20% of its maize crops had GM contents, which increased the net income of the country's GM maize farmers to about $27/hectare every year, without irrigation [30].

Another benefit of GM crops is the reduction of environmental impacts of agricultural practices. This is because, planting GM crops enhances the effective application of external impetus, thus ensuring environmental safety and sustainable agriculture [25, 71]. Specifically, cultivating GM crops reduces the need for applying conventional agrochemicals to combat viruses, fungi and other diseases [73]. According to Brookes and Barfoot, since 1996, the application of pesticides on areas cultivated with GM crop decreased by a whopping 503 million kg, accounting for nearly 8.8% decrease [24]. Additionally, some scientists argue that employing biotechnology in agriculture could offer solutions to major challenges that hinder food production including increased variation in climate conditions, dwindling rainfall rates and patterns, and the emergence of novel pests and diseases [28]. Hence, Nigeria has a lot to gain from the cultivation of GM crops. Since some of the biotech crops have been modified to thrive in areas with declining rainfall, they will be very beneficial to farmers in the northern parts of Nigeria that is experiencing desertification. Also, it will help to alleviate the challenges of high cost of farm inputs; a good example is fertilizers because the GM crops are high-yielding.

Furthermore, the carbohydrate metabolism involved in the industrial production of cyclodextrin, fructan, and enhanced starch quality were modified by genetic engineering to overcome some usage challenges. Transgenic potatoes solved the problems in potato production such as late blight, high-temperature responsiveness, and potato tuber moth. A typical benefit of genetic modification can also be seen in the annexin modification in plants. Annexins refer to the calcium- and membrane-binding proteins essential for the harsh environmental adaptability of plants. As a result, plants with modified annexin components maintained effectual photosynthesis in harsh environmental situations such as drought. The annexin modification ultimately increased crop yield from plants than their wild counterparts, even under limited available of water.

7. PERCEPTION OF DEVELOPING COUNTRIES ABOUT GM CROPS AND FOODS

The perception of developing countries about GM crops and foods is quite complex because: (1) various arguments so far are centred on dissents regarding the level of scientifically comprehending the potential adverse effects of genetic engineering processes; and (2) marked variations in the present food marketing and production systems, with probable huge economic effects, would necessitate mandatory labelling.

One of the major arguments on compulsory labelling is that GM foods consumers are entitled to knowing the constituents of their food. The above statement is specifically applicable to a variety of genetic engineering food products, whose health and potential environmental issues are yet to be satisfactorily resolved. Some individuals are against the adoption and consumption of GM crops and foods, respectively, due to religious or ethical reasons. Labelling appears to be the major way that consumers can make informed choices of what to buy, irrespective of their reasons. The main dissent against compulsory labelling bothers on the

practical issues about the cost and rigorous protocols which are necessary in ensuring that GM and regular foods are separated or testing both food categories for their GM compositions. On the contrary, some are of the view that such protocols amount to waste of resources and time, since there are yet no marked differences observed or recorded between currently available GM and conventional foods [74].

There are other issues that are germane to the implementation of mandatory labelling of GM foods. These include clearly defining the type of technologies used during production, deciding on tolerance levels for GM components before labelling, and choosing an appropriate method to verify that products are correctly labelled [75]. The major perspectives of developing countries about GM crops and foods can be classified as follows:

7. 1. Economical and ethical aspects

There are some companies in the food industry, that utilize GM components. In Nigeria for instance, these include Coca-Cola, Nestle, Arnotts, Golden Circle, Coles and Woolworths' house brands, and Cadburys [76, 77]. Presently, there is strong policy against importing GM foods in some African countries including Zambia, Lesotho, and Angola, where such importations are totally banned [5]. In other countries such as Nigeria where there are no such strong policies, this might be because many Nigerians do not see GM foods as the panacea in hunger alleviation for the common man. Others believe that the food companies that utilize GM crops in food production are more profit oriented and pay less to no attention on the potential associated risks of such food products. Also, the religious diversity of Nigeria has been responsible for serious ethical concerns about why there is need for the genetic modification of crops in the first instance. These sets of individuals opine that adequate management of conventional food production strategies could ensure food security. They strongly believe that the act of engineering varieties of plants and animals via genetically modifying their God-given (natural) genetic constitution is an act of playing God.

Undoubtedly, biotechnology holds strong promise to dramatically contribute to the role that developing countries could play in the agriculture sector; however, it is crucial to examine the factors that have slowed down the adoption of GM crops in such countries. Of course, there are merits and risks of adopting GM crops, but where the risks outweigh the merits, it becomes suicidal. At present, Western countries such as the USA has been supplying basic foods made from GM crops to developing countries, in a bid to ameliorate hunger and poverty in such countries. Notwithstanding, there are increasing anxieties on the health and genetic effects of consuming GM foods.

The strong desire and efforts of governments of developing countries at all stages to diversify their economy by drastically reducing the over-dependence on crude oil in a typical mono-economy may have been motivating the intention for adopting GM crops for improved food production. Additionally, her ever-increasing population and worrisome dependence on foreign food products continuously threaten food security in the country, which have been strained by inadequate water resources, poor soil quality, incidences of drought, alongside other economic and social problems. Based on the perspective of some Nigerians, the intention to adopt GM crops and foods is borne from agricultural advancement. However, others think that it is an implication of private sector-led research, development and livelihood options, and rights and ethical concerns [78].

The processes of developing and commercializing GM crops entail huge costs. For instance, the inventors of GM crops would ensure profitable returns on the funds they used for

such inventions. As a result, most developed biotech seeds and foods are patented, thereby making their infringements practically impossible. This implies that low-income agribusiness individuals have limited access to the seeds and foods, paving the way for big investors to control prize and exercise production monopoly. It is common knowledge that less competition leads to economic exploitation, thus limiting the accessibility of the final products by low-income (local) famers and the common man, ultimately extending the gap between the rich and poor. Some other Nigerians believe that the lack of skill and technology by most farmers in the country allows foreign capitalists to dominate the market, which might counter-productive effects on the economy of the country. Although there is limited access of biotech seeds and foods by local farmers, some developing countries have been making impressive efforts to adopt GM crops and foods in recent years, in furtherance to sustainable food production [79]. As the main aim of every investment is profit maximization, local farmers who are in a large proportion in Nigeria, will easily key into the use of GM crops. As a paradigm, farmer in China and India quickly adopted Bt. Cotton due to its well-known gains including high yield and reduced occupational hazard as farmers are exposed to less pesticides [16].

7. 2. Health, environment and socioeconomic aspects

Irrespective of the various problems confronting developing countries, some individuals believe that hastily adopting GM crops for food production might not be a good approach, as there still exist unanswered questions about its health and environmental safety, and socioeconomics. In terms of environmental safety, the concerns are mainly about the flow of genes by pollen flow between target GM crops and their wild counterparts, and the unforeseen negative off-target species impacts. For instance, a recent report has revealed how Bt. toxins indiscriminately kill numerous insect larvae species, even those that have beneficial agricultural importance [80]. As the production of food with GM crops requires routinely transferring proteins from organisms (including viruses) that are yet unconsumed in food into the food supply, there are growing health concerns about the development of novel allergies. As regards socioeconomics, there may be some form of corporate control of GM crops market and all of its analogous chemicals by entirely buying off seed-production companies, locking relevant farmers into exclusive agreements, and patenting seeds. These may give rise to sustainable agriculture and biodiversity [4, 81].

As is the case in some other countries, civil society groups and individuals that are entirely against GM crops and/or foods, and those that are reserved on the utilization of GM crops abound. In as much as there are conventional proclamations and scientific research information on the health safety of GM crops and foods, some anti-GM civil society groups and individuals still instigate fear about the potential health risks of such crops and foods produced with them.

This consequently mounts pressure on regulating agencies to repudiate activities on GM crops. Additionally, there are concerns among some individuals in Nigeria that the development of GM crops and foods will increase dependence on chemical pesticides as such crops encourage the use of chemicals with attendant negative effects on food, wildlife, and potable water. Moreover, a literature report has pointed to increase in plant toxins, and development of antibiotic resistance and “super weeds” as potential downsides of the development of GM crops [82]. Put together, it is imperative to properly investigate the chronic effects of GM crops and foods on human health and the environment, as to provide adequate strategies that can be utilized to prevent the risks that may arise from the consumption of such foods, thus mitigating the doubts of various individuals about their health and environment risks.

7. 3. Political aspect

Since the introduction of GM crops by the governments of various developing countries to their farmers, several anti GM crops and foods society groups have made serious efforts through the legislative arm of the government to create an Act of Parliament to stop the importation or growing of GM crops in the country [83]. However, there is yet no obvious impact of such efforts, as the legislature is yet to begging drafting such bill and the negative thoughts of individuals that are against GM crops and foods still persist. There have also been some workshops organized by various farmers association, research institutions, and scientists in Nigeria to lure prospective consumers and stakeholders, and publicly enlighten the entire populace about the safety of consuming GM foods. As a paradigm, the regulating agency, National Orientation Agency has continuously re-iterated the safety of biotech seeds and foods and encourage Nigerians to explore genetic engineering as a strategy to boost food production.

8. CONCLUSION AND OUTLOOK

One of the ways to increase crop yield is by the adoption of the cultivation of GM crops. GM crops are a product of biotechnology and new innovation in the global agriculture. Presently, GM crops are not cultivated widely in many developing countries, despite its benefits to individuals, national economies, and the environment. The benefits that are derivable from GM crops are numerous but a prominent one is that it increases crop productivity. Many developing countries are faced with the challenge of feeding her ever-increasing population. Their agriculture sector employs more than half of the entire populace but is yet to experience a boost due to the continued application of crude agricultural practices, coupled with the excessive use of fertilizers and pesticides. Hence, it is important for developing countries that are facing food insecurity to consider the cultivation of GM crops. Enactment of the biotechnology bill in such countries will pave the way for utilization of biotechnology to enhance agricultural production with salutary multiplier effects. Moreover, more efforts and research should be conducted on the long-term health and environmental risks of GM crops and foods, and outcomes of such research such be adequately communicated to the entire people. Additionally, public and private sector leaders are encouraged to consider the present level of awareness and acceptability of GM crops and foods by consumers to enable an enhanced strategic planning for improving the quantity and quality of GM products.

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