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Advances in Plant Breeding, Polemics of Genetically Modified Crops and Biosafety Frameworks in Ethiopia

Tadessa Daba[1], Tesfaye Disasa[1] & Melaku Alemu[2]

[1] National Agricultural Biotechnology Research Center, Ethiopian Institute of Agricultural Research, Holetta, Ethiopia

[2] Ethiopian Agricultural Research Council, Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia

Correspondence: Tadessa Daba, National Agricultural Biotechnology Research Center (NABRC), Ethiopian Institute of Agricultural Research, P.O. Box 249, Holetta, Ethiopia. Tel: 251-968-547-333. Fax: 251-112-362-325. E-mail: tadessadaba@yahoo.com

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Abstract

Ethiopia is one of the top African countries with fast population growth that requires technological interventions for improving agricultural production. Agriculture is entirely the source of food or nutrition security, raw material for agro-industries and export commodities for the country. The abrupt population increase augmented with challenges derived by climate change and newly emerging problems necessitate the use of modern plant breeding techniques. This paper provides insights of advancements in new crop improvement research, discourses associated with genetically engineered crops and biosafety frameworks in the country. Ethiopia has begun evaluation and use of genetically modified (GM) crops. The classical agricultural researches are being undertaken for more than five decades but require embracing modern tools to better address agricultural challenges. As compared to conventionally developed elite varieties, GM crops are found to be more advantageous based on their traits of interest in various ways. In handling GM research, there was no compromise on the biosafety procedures and regulations of the country. Bollworm resistant cotton, insect resistant and drought tolerant maize have already been evaluated incompliance with the country's biosafety framework and released for general use while few GM crops are still under confined or contained evaluations. Opponents are emerging in the country with the adoption of the technology and misinformation is undergoing using various media outlets. Public research and regulatory institutes have been providing evidence based information using all possible means. Continuous public awareness enhancement is equally important with the adaptation and use of new technologies.

Keywords: agriculture, biotechnology, biosafety, genetic modification, molecular genetics, public awareness

1. Introduction

Agriculture is one of the ancient practices and the base of innovations in human development history. It is still a key economic sector in most developing countries and basic for life in every nation. Ethiopia is an agro-based economy with the sector engaging more than 85% of the population. The majority of the agricultural practices are yet traditional and characterized as a predominantly low-input low-output system dominated by smallholder producers generating agricultural products that are less than enough for the ever-increasing demand for agricultural products in the country. Agricultural research has a long history made efforts for decades with remarkable positive impacts on the agricultural modernization of the country. The Ethiopian Institute of Agricultural Research (EIAR) is mandated for technology innovation and adaptation that relieves deciphers agricultural problems in all agricultural sub-sectors. Among these, agricultural biotechnology is one of the newest sectors working in the areas of plant, microbial and animal biotechnologies. In plant biotechnology, the focus is on the development of tissue culture protocols for economically important crops/plants, molecular breeding and genetics as well as mutation breeding and genetic engineering.

People have been improving plants for centuries using various techniques. This has begun through selection for desired traits of plants, which was followed by conventional breeding techniques, particularly in crops. In EIAR and various public universities in Ethiopia, there have been various conventional researches with great achievements in the improvement of crops. But artificial selection and conventional breeding strategies are limited to the traits naturally existing and variations that can be used to breed subsequent generations (Phillips, 2008). However, recent advances in the field of genetic engineering have enabled accurate control of genetic manipulations for the desired trait and trans use of genetic materials across organisms of different species. This significantly improves the agricultural system by providing naturally unavailable and conventionally impossible traits to organisms (Datta, 2013). Plants mainly crops, animals, and soil bacteria are the prominent examples improved so far through this technique.

Like other developing African countries, Ethiopia has begun adopting and use of genetically modified (GM) crops since 2016. However, the other aspects of agricultural biotechnology techniques have been exercised in the country for decades. In agricultural biotechnology, non-GM research, there are various useful outputs like reliable tissue culture protocols for economically important crops, livestock reproductive technologies, and in animal health areas. Genetic modification and genome editing are recent techniques in bioscience research, especially in developing world. In Agenda 21 of the United Nations Conference on Environment and Development in 1992, it was stated that biotechnology contributes in to the development, better health care, enhanced food security, more efficient industrial development processes for transforming raw materials, support for sustainable methods (UN, 2004). It has been recommended for developing countries to invest in biotechnology.

Despite huge contributions of biotechnology in transforming agriculture, there have been negative messages and oppositions on Genetically Modified (GM) crops worldwide (Blagoevska et al., 2021). The arguments either in support or opposing the use of genetically engineered organisms were changed since the technology emerged in the 1980s. The critics express anxieties that it inflicts negative environmental effects and affects the consumers. The supporters on the other hand emphasize the potential advantages that the nations can get out of this advanced technology (Barrows et al., 2014). Genetic engineered crops are the most rapidly adopted agricultural innovation in history planting few acres in 1996 to 191.7 million hectares in 2018 (James, 2011). In this paper, the advancements in modern plant breeding, discourses of genetically modified crops and biosafety frameworks in the world and in Ethiopia are discussed. The potential advantages of GM technology globally and in Ethiopian context in reference to developed nations were reviewed. The progress of research in GM crops, controversies, and scientific realities are elucidated in detail. Finally, views in support and opposition of the technology are addressed and better ways of handling issues associated with GM have been suggested.

2. Modern Techniques in Agricultural Biotechnology

The ever-growing population, the current political unrest in major cereal-producing countries, and the impact of climate change have resulted in grand challenge of getting enough food, feed, and industrial raw materials mainly in developing countries like Ethiopia. The existing effort mostly in developing countries to improve the productivity of crops through conventional breeding methods is ineffective in most cases. The conventional approach particularly hybrid development has improved the productivity of some crops to some extent for the last many years in the country (Abate et al., 2013). However, these approaches alone can’t serve as a strategy to address the problems associated with the increasing pressure on agriculture and limited natural resources. This compels the application of modern agricultural technologies complementing the conventional approaches.

2.1 Marker-Assisted Breeding (MAB)

The advancements in the next-generation sequencing (NGS), high-throughput marker genotyping, and high-throughput phenotyping technologies have created excellent opportunities for improving productivity, quality, and nutritional values of crops. Modern biotechnological tools range from marker-based selection to gene editing for incorporating important physiological and morphological traits including biotic, and abiotic stresses resistance and compositional traits for added food and industrial values.*Marker-Assisted Breeding (MAB)*

Marker-assisted breeding comprises of two plant selection techniques such as Marker-Assisted Selection (MAS) and Genomic Selection (GS). MAS requires molecular markers that are known to be linked with a trait of interest. It has drawbacks as it is efficient only for those traits that are controlled by fewer numbers of Quantitative Trait Loci (QTLs) having a major effect on trait expression. Whereas it is less useful for complex quantitative traits, which are governed by a large number of minor QTLs (Zhao et al., 2014). On contrary, GS uses a prediction model to estimate the genetic value based on a large set of marker information distributed across the whole genome.

2.2 Marker-Assisted Selection (MAS)

Ethiopia has diverse crop genetic resources. However, the productivity of crops in the country is challenged by several biotic and abiotic stresses. Among the biotic factors diseases caused by: fungi, bacteria and viruses, weeds, and insect pests are the major ones that are severely affecting the productivity and quality of crops. The conventional plant breeding approach requires several steps and takes longer time to develop new crop varieties. On the contrary, molecular marker-based selection considerably shortens the time to develop varieties (Hasan et al., 2021). Researchers conventionally select plants based on their phenotype, which is time taking and influenced by environment, and costly to generate a large number of phenotypic data from multiple environments. Besides, it is difficult to screen a large number of germplasm for their desirable traits in replicates. It is possible to minimize the number of breeding materials using molecular markers that are linked to the trait of interest. Marker-assisted breeding involves various areas including collection and characterization of diverse groups of germplasm, identifying and mapping of quantitative trait loci, and introgression in to elite selected crop varieties. Marker-based genetic diversity study plays a vital role in breeding programs to ensure adequate sources of novel traits and it explains the level of genetic variation among crop species.

Several molecular tools were developed and used in the study of parental selection, population genetics, linkage analysis, association studies, and QTL analysis. Most of the past researches have largely been undertaken based on linkage or family mapping of quantitative trait loci (QTL), which involves mapping populations, identification of polymorphism, and linkage analysis of markers (Collard et al., 2005). However, nowadays bi-parental-based QTL mapping is considered to be one of the conventional approaches. This type of mapping requires generation of at least one type of mapping population from several possible populations (Paterson, 1996) such as Recombinant Inbred Lines (RILs), Near-Isogenic Lines (NILs), Double Haploid (DH), Back Cross (BC) and second filial generation (F2). This type of QTL identification is limited by small population size or polymorphism and low-resolution power because only two alleles per locus can be sampled in any given bi-parental population and a few recombination events. These estimate the genetic distances between marker loci and identify the causative genomic regions for QTL (Soto-Cerda & Cloutier, 2012).

2.3 Genomic Selection

MAS depends on segregating populations derived from two contrasting parents for the trait of interest. These populations are not representative of the given gene pool and variations controlled by many genes with minor effects cannot be detected. As the result, the genomic selection was designed as a new approach to simultaneously estimate all loci, haplotypes, or marker effects across the entire genome to calculate genomic-breeding values (GEBVs). The GEBV is derived from the combination of useful loci that occur in the genome of individual of the breeding populations (Bhat et al., 2016). It provides direct estimation of the likelihood of each individual having a superior phenotype. Selections of new breeding parents are made based on the GEBV calculated from training and breeding populations. This leads to shortening breeding cycle duration as it is no longer necessary to wait for late filial generations to phenotype quantitative traits (Bassi et al., 2016). Training populations are those genotyped using high-density markers and phenotyped over a range of environmental conditions whereas breeding populations are those with only genotypic data.

Unlike MAS, recently more effective mapping techniques have been developed and applied in plant breeding programs. Some of these include association mapping and nested association mapping (Hu et al., 2018). These are multidisciplinary fields that require adequate knowledge of genomics, molecular biology, statistical genetics and bioinformatics. Several studies conducted globally using GWAS (Table 1). However, only a limited number of GWAS were studied domestically using Ethiopian crops: bread wheat germplasms as source materials (Shewabez et al., 2022), durum wheat (Leta et al., 2013; Alemu et al., 2021; Kidane et al., 2021; Negisho et al., 2022), sorghum (Cuevas et al., 2019; Girma et al., 2019) and common bean (Tigist et al., 2019).

Table 1. Some association mapping studies in major cereal crops

Crops	Phenotype	Marker	Association Level	Association panel	References
Oryza sativa	14 agronomic traits	3.6 million SNPs	GWAS	373 accessions	Huaug et al., 2010
	34 agronomic traits	44100 SNPs	GWAS	413 domesticated Asian rice varieties	Zhao et al., 2011
	Flowering time & 10 grain-related traits	4.1 million SNPs	GWAS	950 worldwide collections	Haug et al., 2011
	12 agronomic traits	5291 SNPs	GWAS	523 germplasm accessions	Lu et al., 2015
	Grain length and size	16 million SNPs	GWAS	125 genotypes	McCouch et al., 2015
	Agronomic and biofortification traits	14,242 SNPs	GWAS	144 MAGIC Plus lines	Descalsota et al., 2018
	Canopy temperature	45, 000 SNPs	GWAS	293 accessions	Melandri et al., 2020
	Digestibility in rice straw	328,915 SNPs	GWAS	151 genotypes	Nguyen et al., 2020
	Apparent amylose and protein concentration	872,556 SNPs	GWAS	207 diverse rice accessions	Alpuerto et al., 2022
Zea mays	Provitamin A comp.	Markers in lcyE gene	Candidate	288 lines	Haries et al., 2008
	Provitamin A	Markers in crtRB1 gene	Candidate	681 diverse inbred lines	Yan et al., 2010
	Nouthern leaf blight disease	1.6 million SNPs	GWAS	500 RILs nested in 25 populations	Poland et al., 2011
	Leaf length, width, and upper leaf angle	1.6 million SNPs	GWAS	500 RILs nested in 25 populations	Tian et al., 2011
	Southern leaf blight disease	1.6 million SNPs	GWAS	500 RILs nested in 25 populations	Kump et al., 2011
	Genetic architecture of kernel row number	42,667 SNPs	GWAS	639 inbred lines	An et al., 2020
	Grain quality traits	83,057 SNPs	GWAS	248 diverse inbred lines	*Zheng* et al., 2021
Triticum aestivum	Resistance to strip rust	9000 SNPs	GWAS	181 synthetic hexaploid wheat	Zegaye et al., 2014
	Agronomic traits	10938 SNPs	GWAS	298 accessions	Rahimi et al., 2019
	Agronomic traits	15,178 SNPs	GWAS	200 accessions	Yang et al., 2020
	Phosphorus efficiency	35000 SNPs	GWAS	82 accessions	Soumya et al., 2021
	Yield and drought related traits	90,000 SNPs	GWAS	96 spring accessions	Ahmed et al., 2022

Note. SNPs: Single Nucleotide Polymorphisms; GWAS: Genome-Wide Association Studies; Candidate: Target genes.

2.4 Genome Editing

There is tremendous interest and support from the government in using modern biotechnological tools to improve the production, productivity, and quality of crops in Ethiopia. This is evidenced by the amendments made to biosafety law and the commencement of biotechnological research and training in more than 35 higher education and research centers. Besides, recurrent drought and newly emerging insect pests lead to the immediate use of advanced technologies like genome editing in the national crop improvement programs. Several countries have started genome editing research using their staple crops. Rice, maize, wheat, and potato are some of the major food crops that have been improved through genome editing techniques. Some of the genome-edited crops have already been commercialized and made available on the international market.

Ethiopia has started conducting genome editing research mainly on indigenous crops such as *Tef* and Ethiopian Mustard. Besides, there are some initiatives to implement the technologies using major food and industrial crops including coffee. Maize resistant to Maize Lethal Necrosis (MLN), sorghum resistant to striga, and Tef for reduced lodging and grain shatter are some of the traits that the country is targeting to address using this technology.

3. GM Crops

3.1 Historical Development of Genetically Modified Organisms

In the early times, when people were not aware of genetics, indirectly have been affecting the genetic makeup of organisms in the practices of artificial selection or selective breeding. The concept of modern selection was devised by Darwin to describe an intentional selection of organisms with desired traits that could propagate through offspring. The use of this practice over decades entailed genetic changes to species. Though selection breeding is not Genetic Modification (GM) it is the earliest example of impelling genetics. This has been utilized in plants since 7800 BC according to archaeological pieces of evidence in southwest Asia where varieties of wheat were found (Balter, 2013). The phenotypic characteristics of organisms are controlled by genes. Identification of such specific genes of interest was gradually developed using various markers like Restriction Fragment Length Polymorphisms (RFLPs), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP), and Single Sequence Repeats (SSR) (Zhang et al., 2001).

After the birth of modern genetics following the investigation of DNA structure in 1953, GM technology came in to picture in 1973 when GMO was successfully created by Boyer and Cohen (Cohen, 1973). These scientists have established techniques for cutting specific antibiotic resistance genes from one bacterial strain and transfer into another. This GM technology has been applied to mice after a while (Jaenisch et al., 1974). Genetic Engineering (GE) activities were universally known in the early 1970s when scientists have discussed on Asilomar Conference (Berg, 1975). After this conference, the conclusion was to advance this technology with some precaution guidelines (UN, 2004). All the processes of GE technology were transparent and, hence decision-makers at a global level have supported the technology launching the modern era of genetic modification (Rangel, 2015). A bacterium that can break down crude oil and lessen oil spill hitches was the first genetically engineered organism patented by the US in 1980. GE bacteria producing human insulin or humulin was then developed (Altman, 1982).

Gradually, research on GE of food crops has begun using rDNA technology in 1987 with the first GMO food crop, Calgene's Flavr Savr tomato (Rangel, 2015). In this modification, a natural protein production inhibitor DNA sequence was altered entailing firm tomato with extended shelf life. On top of improving the nutritive and aesthetic values of crops, this technology enabled the production of pest resistant and herbicide tolerant crops that are easy for management and improved productivity. In animals, the first genetic modification approved was for blood clotting drug, ATryn (Ye et al., 2000) and increasing the size and reducing the maturity period of salmon fish. Even though, not so far been commercialized in many countries, GE cows producing humanized milk were produced in China and hornless or polled bulls were also created using this technology (Yang et al., 2011). Though many countries have developed their biosafety laws based on the Convention for Biodiversity (CBD) and Cartagena Protocol, many African counties have not yet developed biosafety laws. The number of African countries cultivating GM crops and engaged in GM crops research is depicted in the following figure.

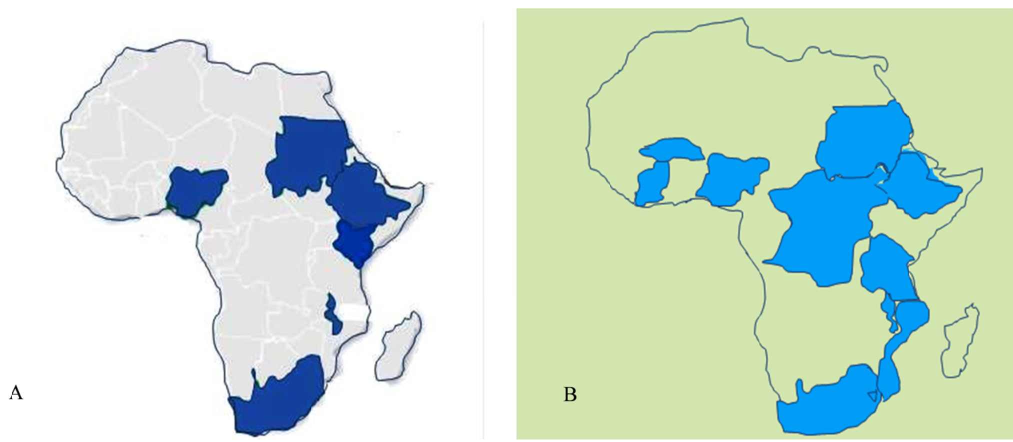

Figure 1. African counties handling GM crops. A. countries that have commercialized GM crops, B. countries involved in GM crops research. Source (Akinbo et al., 2021)

Based on ISAAA's report, currently, 71 countries adopted GM crops. The number of countries planted biotech crops has increased from 26 in 2018 to 29 in 2019 including three African countries. Globally, the top five countries producing biotech crops are USA, Brazil, Argentina, Canada, and India. The adoption rates of biotech crops are high in these countries, approximately 1.95 billion people (26%) of the world are estimated to gain the benefits of biotechnology in total. In total, 190.4 million hectares of biotech crops were grown in 2019, contributing significantly to food security, sustainability, climate change mitigation, and improving the livelihood of 17 million biotech farmers worldwide (ISAAA, 2019).

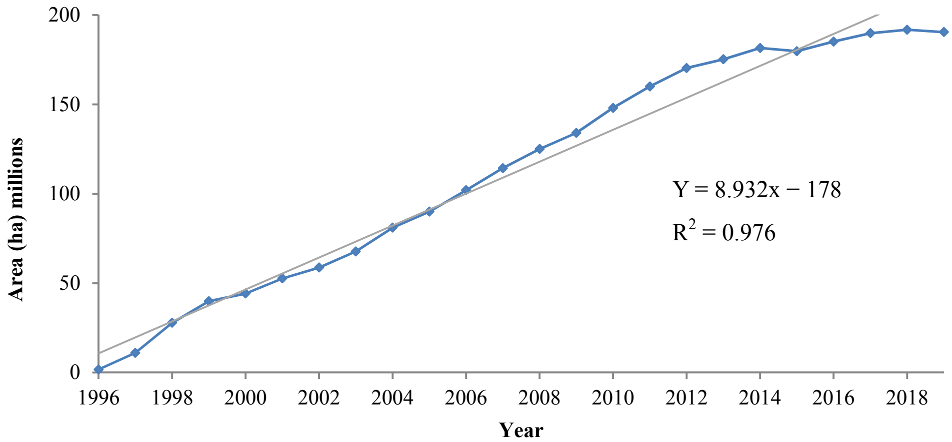

Figure 2. Global trend of GM crop cultivation. Source: ISAAA 2020

In Figure above, the area of GM crop cultivation has been steadily increasing from 1996-2019 with R^2 of 0.97, which clearly indicates the increment is almost linear. However, the conditions in each country and areas of production are affected by many factors. For instance, the challenges associated with seed systems, companies' interests and internal conditions affected the continuation of the anticipated increments in *B*t-cotton cultivation in Ethiopia and in almost all African countries. On the other hand, farmers are demanding and informally cultivating GM crops importing from neighboring countries.

The first GM crop officially imported into Ethiopia was *Bt*-cotton (Bollworm resistant) in 2016 for Confined Field Trial (CFT) with special permission from the regulatory authority. However, there were rumors and suspicions of GM alfalfa and cotton informally cultivated around peripheral borders a decade ago. In the same year, bacterial wilt resistant *enset* has been started with a special contained lab permit and the transformation was undertaken at BecA-ILRI, Nairobi by EIAR researcher in collaboration with IITA. The second GM crop permitted for CFT was Water Efficient Maize for Africa (WEMA/TELA) maize, which is drought tolerant and insect (stem borer and partly fall armyworm) resistant maize. Late blight resistant *cis-genic* biotech potato and insect resistant and glyphosate tolerant cotton are prepared for CFT evaluations. Researches on GMOs are conducted in strict compliance with biosafety guidelines and serious regulations and follow-ups by the Ethiopian biosafety regulatory authority. These crops provide special advantages to farmers that can never be obtained through other means. For the protection of bollworms, is the greatest challenges in cotton farming, farmers have been using non-healthy, expensive, and environmentally unfriendly pesticides. They use multiple sprays of pesticides, which are often unavailable in the market. *Bt*-cotton if properly managed is a perfect solution to this problem. Most of insect pests in maize are systemic that affect the internal part of the crop to use pesticides. The other GM crops mentioned have their own proven significances that will be evaluated under confined or contained conditions.

3.2 Advantages and Areas of GM

Genetically modified organisms confer special traits through GE technique that is not possible through natural breeding schemes. In natural phenomenon, genetic materials can only be transferred among related species. However, the transfer of genes controlling the traits of interest from any organism is possible in this modern technique. In crop breeding, biotechnology increases genetic gain (R) through enhancing genetic variation, selection intensity, and reducing breeding interval (Lush, 1936). So far globally commercialized GM crops, there are tremendous advantages gained through this technology. GM crops such as *Flavr savr* tomato, golden rise, herbicide tolerant soybean, virus resistant papaya, and cassava, insect resistant cotton, insect resistant, and drought tolerant maize are few examples. Each of these has targeted traits conferring advantages like longer shelf life, enhanced nutritional quality (ß-carotene), and pest and herbicide resistance as the names indicate. Most of these modifications are impossible without this technique.

3.3 Genetic Transformation Research Status in Ethiopia

Some indigenous crops such as *Eragrostis tef* and *Ensete ventricusum* have experienced serious problems of lodging and devastating bacterial wilt, respectively. The efforts to address these problems using conventional breeding alone were found to be insufficient to solve agricultural problems. Complementing the existing conventional practice with advanced technologies such as molecular breeding and genetic transformation enables to develop tolerant/resistant crop varieties.

There are reports on reference draft genome sequences for indigenous Ethiopian crops such as Tef (Cannarozzi et al., 2014) and Enset (Harrison et al., 2014). Continued improvements in different genetic and genomic technologies would be excellent indicators to realize the potential offered by genetic engineering in introgression of new genes underlying complex traits for the improvement of crops in the country. As genomic technologies continue to evolve, more genetic engineering studies are expected in different crops. This will help to design specific breeding and selection strategies as well as efficient utilization of the vast available germplasm diversity in crops (Sukumaran & Yu, 2014). Efforts have been made to develop genetically engineered *Enset* in the country. Recently, an efficient and simple agrobacterium-mediated transformation protocol for *Enset* has been developed and used for a successful transformation of novel genes from the donor plant to protect the crop from the devastating *Enset* bacterial wilt disease (Matheka et al., 2019). Similarly, there is an initiative to develop and commercialize *Bt*-cotton hybrids domestically that plays a significant role in improving the supply of cotton raw material in the country.

Table 2. Major GM crops and modified traits

No.	GM Crop	Traits/Advantages
1	Alfalfa	herbicide tolerance, product quality
2	Apple	modified product quality
3	Bean	disease resistance
4	Canola (*Brassica napus*)	product quality, herbicide tolerance, pollination control system
5	Carnation (*Dianthus caryophyllus*)	herbicide tolerance, flower color, delayed senescence
6	Cassava	virus resistance
7	Cotton	herbicide tolerance, insect resistance
8	Flax	herbicide tolerance
9	Maize	herbicide tolerance, drought tolerance, insect resistance, male sterility, fertility restoration, phytase, amino acid, ear biomass
10	Potato	insect resistance, starch, reduced acrylamide
11	Linseed	herbicide tolerance
12	Eggplant	insect resistance
13	Creeping Bentgrass	herbicide tolerance
14	Chicory	herbicide tolerance, male sterility
15	Soybean	herbicide tolerance, insect resistance, product quality
16	Plum	virus resistance
17	Petunia	product quality
18	Papaya	virus resistance
19	Melon	delayed ripening/senesce
20	Rose	product quality
21	Rice	quality, insect resistance, herbicide tolerance
22	Squash	virus resistance
23	Sugar beet	herbicide tolerance
24	Sugarcane	insect resistance, drought tolerance
25	Sweet pepper	virus disease
26	Tobacco	nicotine reduction
27	Tomato	delayed ripening/senescence, insect resistance, delayed fruit softening, virus resistance, quality
28	Wheat	herbicide tolerance

Note. Carnation, petunia, and rose are not edible crops but they are ornamental crops.

Source: Nazir et al. (2019).

In Ethiopia, the first environmentally released GM crop is bollworm resistant, *Bt*-cotton in 2018 followed by insect resistant and drought tolerant maize in 2022. Late blight resistant biotech potato, bacterial wilt resistant *enset*, insect resistant, and glyphosate tolerant cotton are under confined or contained evaluations in the country as mentioned earlier. In order to produce enough food by 2050 and feed the abruptly increasing country's population, the use of new innovation is mandatory. The summarized significances of GM crops is shown in Figure below.

Figure 3. Contribution of Biotech Crops to Food Security, Sustainability, and Climate Change mitigation
Sources: (ISAAA, 2019; Brookes & Barfoot, 2020)

Ethiopia is one of the populous African countries with agrarian economy. Besides, the visible effects of climate change and other human-made problems in the country demand quick and reliable agricultural solutions. The booming agro-industrial parks all over the country are waiting for sustainable agricultural raw material supply. The newly emerging crop diseases and pests are highly affecting the sector. Hence, biotechnological solutions will never be a choice but mandatory to mitigate the aforementioned challenges existing and may be more to come. Given the ample possibilities, the world can benefit from this new technology, media, policymakers, and some scientists are worried too much about the potential human and environmental safety issues. This worry is acceptable for appropriate safety management but deliberate and unrealistic oppositions often happen and misinform the public.

3.4 Global Controversies over Genetically Modified Crops

In most cases, new technologies and innovations face opposition and resistance including the Nobel findings that have changed our world. The precautions and potential risks were pointed out by the scientists themselves before anyone knew about the technologies. For instance, electricity is a good example. It is an excellent innovation with proper care and management systems and skills developed to avoid devastating risks and the world is using it. Like in almost all new techniques, GMO technology especially in agriculture is facing opposition globally and in Ethiopia as well. The reasons for the controversies on GMO particularly on food crops can be associated with many interests. One is fear of the potential unforeseen risk of the technology associated with environmental and human health safety. However, it was the scientists who indicated the possibilities of risks associated with genetic modification and biosafety procedures have to be seriously followed. This is why serious safety investigations on the plant health, environment, and food and feed aspects are thoroughly investigated and approved before the use of any GMO event worldwide.

On the other hand, oppositions arise from either ideological or blind obstruction based on personal perception or unwillingness to accept considering it unnatural. The major and popular one is because of strong push and funding from companies because of various interests, which are mainly of economic and socio-political. Some are objecting this technology associating it with religion or philosophies. People do refer to some negative cases of the technology as evidences like effect of *Bt* toxin on butterfly, which was eventually proved wrong (Heeter, 2018). In Africa, poor cotton fiber quality of Burkina Faso was another allusion, which was not the problem of the technology but application and some other practical influences. The other common reference is the anti-GMO campaign in 2015 of Indian farmers' suicide because of poor cotton yield and crop failure that was confirmed not to be the case based on structured studies (Gruère & Sengupta, 2011).

As mentioned, new technologies always face opposition and controversies obviously but persistence of activism on GMO is basically derived by non-genuine financial backstopping. The scenario is similar elsewhere in the world but this controversies increase as the use of the technology is enhanced particularly in developing countries where majority of the population are unaware and trust such sympathizing narratives. However, people demand technologies as they provide greatest solution against emerging problems. According to ISAAA 2019, GMO crops are the fast adopted crop improvement technologies in the world. In Ethiopia, there wasn't an issue of opposition before but has appeared after trials on GMO crops have begun. Currently, there are some locally established private associations advocating against new technologies, they use private media outlets, most frequently on online and print media. The issue and debate is reducing after engaging many stakeholders in various stages of discussion and awareness enhancement but seems never stop easily in short period of time.

4. Public Awareness and Challenges

4.1 Public Cognizance About Biotechnology

In agricultural biotechnology, genetic modification of crops has advanced in recent decades with crop improvement for high yield, abiotic and biotic stress tolerance and nutritional attributes. However, there have been misplaced debates among the supporters of the technology and those do not care for the technology who continuously advocates only the potential risk of the technology. Lack of understanding about biotechnology believed to be the primary reason for the anxiety about GMO. Most of these debates are due to limited outreach of the importance of the technology that has led to frequent public resistance to its adoption (Amin et al., 2011; Tegegne et al., 2013). Some scientists hold that better knowledge makes people more sympathetic to genetic engineering while others focuses on potential negative outcome. This is one of the factors modulating risk perception (Amin et al., 2011). Thus, people's perception is related to adequate understanding of the fundamental concepts of biotechnology and increasing public awareness has been reported to tilt opinion towards creating conducive environment in adopting the technology (Fritz et al., 2003). Therefore, more effort is required to disseminate adequate and the right information on modern biotechnology to the target groups so that the public can make inform decision on modern biotechnology issues. People who have knowledge tend to accept and people who lack knowledge easily reject technologies.

Studies revealed that consumers' perceptions and attitudes on agricultural biotechnology are influenced by friends, family members, the existing environment and culture. Bioscience scientists view on the potential benefit and risk of GM crops is quite different from consumers view. From the producers' perspective, an increase in acceptance results in increased production of GM crops whereas consumers would most likely be impacted by accurate and unbiased information delivered through dependable media outlets (Fritz et al., 2003; Tegegne et al., 2013). Report showed that consumers' response is largely influenced by the decision processes in approval of GM crops for cultivation and consumption (Sendhil et al., 2022).

4.2 Cartagena Protocol on Public Perception

According to Cartagena Protocol on Biosafety in 2000 (Article 23), it is important to promote and facilitate public awareness and education about biosafety and biotechnology. The article clearly described the necessity to promote broad public awareness on the safe transfer, handling and use of living modified organisms (LMOs) and encourages all parties to share their experiences in this area. Transparent, clear, relevant and up to date information are very useful for the public acceptance as well as for decision makers in adopting the technology

Commercialization of GM products has been practiced mostly by developing countries since nearly three decades while awareness creation effort is lagging behind. According to some reports on public opinion and perceptions, US consumers have fewer concerns about GM food than European consumers (Fritz et al., 2003; Amin et al., 2011). There have been few studies on the public perceptions on biotechnology in developing counties as compared to Europe, USA and Canada where they have a high level of awareness (Fritz et al., 2003)

4.3 Discourses on GMOs: International Scenario

Although GM crops have been widely commercialized for the last couple of decades, the biosafety concern remains a point of argument. The international scientific community has proved that food produced from GM crops is as safe as non-GM counterpart, and that no specific safety risks or health concerns can be attributed to consumption of GMOs. However, public opinion across the world has been markedly skeptical of GMOs since they were first introduced into the food supply in 1994. Some of their major arguments include human and animal health safety, IPR concerns which focuses on ethics and corporate control of seeds and the food supply, concern on biodiversity and environmental conservation and the welfare of smallholder farmers. Media coverage on GMO issues does not arise in a vacuum. Instead, it reflects political, ideological, and economic contests in the societies (Blagoevska et al., 2021). According to Terefe (2018) some of the concerns like risks to environment, human health, food/feed safety, social, economic and political concerns should be studied case-by-case analysis. There is no mysterious and undetectable risks that can escape from these scientific evaluations with high precisions. Reliable biotechnological methods have also be developed for identification of GM crops for biosafety and legitimacy of concerns on transgenes (Fraiture et al., 2015; Lin & Pan 2016; Nazir et al., 2019).

Some of these issues and views of the anti- and Pro-GMO wings are also similar to the cases happened in Ethiopia in 2020-2021. Such kind of argument can be considered as misplace debate since there are research studies that are generated from 130 projects involving more than 500 independent scientists that have been done for more than 25 years. The result revealed that GMOs, are not per se more risky than conventional plant breeding technologies (EU, 2010). Similar study targeting 15 years of intense research on risk assessment in similar countries indicated that GM crops do not cause greater risks for human health or the environment than conventional improved crop varieties (Adenle, 2015). Many studies support that GM crops are not different from the existing cultivated varieties (Vincelli, 2018). Indeed, rigorous scientific risk assessment and risk-management regulations/guidelines are in place that nullifies the "fear of unknowns". The safeties of GM crops are confirmed by high level studies usually and consume most of the product development cost.

Some of the concerns due to limited knowledge on the safety of GM crops are used as arguments to wrongly ban them, or demand stringent regulation process. Many individuals, politicians and countries in general select those arguments to reinforce misconceptions about GM crop. There are studies that anti-GMO groups are reporting wrongly about the divers effect of the GM crops (Sanchez and Parrott, 2017; Valentinov et al., 2018). These authors analyzed the critiques on anti-GMO advocacy and scientific studies usually cited as evidence of adverse effects. Accordingly, a total of 35 studies represent fewer than 5% of all published studies assessing GM food/feed safety were analyzed by Sanchez & Parrott (2017). On the other hand Valentinov et al., (2018) reported that the anti-GMO advocacy usually involve NGOs having diverse competitive agendas. A comprehensive global meta-analysis of 147 published biotech crop studies over the last 20 years worldwide found that on average GMO technology adoption has reduced chemical pesticide use by 37 percent, increased crop yields by 22 percent, and increased farmer profits by 68 percent (Klümper & Qaim, 2014). GM crops are continued to be adopted as they proved to offer multitude of advantages and benefits in food and nutrition security as well as mitigation of the inevitable climate change effects.

4.4 Polemic of GMO in Ethiopia 2020-2021

Ethiopia enacted the Biosafety Proclamation 655/2009, which was prohibitive as it contained articles that cannot be easily fulfilled. However, it is noted that except this hurdle, there was no ban of GMO in Ethiopia unlike other countries. The emerging agricultural production constraints strongly urged the use of modern biotechnological tools, such as genetic engineering products or GM Crops. In order to harness such advanced technology, series of consultative discussions were conducted among various actors and stakeholders during 2010-2015 to identify the shortcomings of the Biosafety Proclamation 655/2009 and make it enabling for the benefit of the country. These efforts have ultimately resulted in the Amended Proclamation 896/2015 that enables provision of granting special permit on GMO for research and education purposes. Furthermore, the previous seven Biosafety Directives were amended and reduced into five by the Environment, Forest and Climate Change Commission FCCC (currently Environmental Protection Authority, EPA).

Lastly, the National Biosafety Advisor Committee (NBAC) was established based on the Proclamation number 411/2017. These biosafety frameworks and legal instruments that enabled research and education were widely publicized to engage in GMO R and D activities. Accordingly the progress and achievements of GM research projects have been publicized through various mass media channels (Radio, TV, Newspaper and Internet). There was no responsible organization or individual posed questions on the GM crop research process. This is due to the fact that all three GM research activities were conducted following the biosafety directives and procedures in close monitoring by the regulatory. There is no clear data concerning the changes in the public acceptance of GM technologies in Ethiopia (Kedisso et al., 2022) as it has not been studied so far.

USDA-Ethiopia posted a report on 17 April 2020 online entitled "USDA pleased with Ethiopian Gov't for its willingness to approve GMOs", USDA Report 2022 (Kedisso et al., 2022). Since then series of articles from the opponents of GMO (Anti-GMO camp) were publicized on internet, radio, TV and newspapers. There were also some opponents who sent petitions opposing GMO R and D to the Prime Mister Office (PMO). There were equivalent counter clarifications on the series of articles by proponents (Pro-GMO camp). Considering the online available repots alone, there were 27 articles and 3 petitions of the anti-GMO reports aired during the five months period (*i.e.*, 17 April 2020 up to 15 August 2020). During this period there were also satisfactory explanation and justifications from scientists and regulators.

These efforts were further corroborated by conducting 2 serious of workshops on GMO issues involving higher officials of relevant institutions. These were moderated by the Minister of Ministry of Agriculture and Director General of EIAR. The heads of the institutions witnessed their efforts to strengthen their capacities and safely handle the GMO issues. Furthermore, a third discussion workshop on GMO issues was also conducted with senior plant breeders and plant protection professionals. In all these three series of GMO workshops concerns were raised and explained by biotechnologists. All of these awareness raising efforts and those wagged in the internet by the Anti- and Pro-GMO wings were compiled by OFAB-Ethiopia team. In addition to these efforts, Government officials of biotech affiliated institutions and the biosafety regulatory institutions conducted a live TV panel discussion. This effort has finally cleared the doubts of the community, witnessing that the GM research is on the right track being conducted following the available legal frameworks. There were also similar efforts on the Radio channels. After broadcasting this firm stands of the Government, there were no more media reports afterwards against GMOs. The summary of the concerns raised by the Anti-GMO campaigners and the clarification by the scientists made during the above mentioned five months period are summarized as follows. It is noted that the first six are of the international scenarios while the last four are specific to Ethiopia.

Table 3. Issues of anti-GMO campaigners and clarification by the scientists 2020-2021

No.	Concern or issues raised by anti-GMO camps	Explanation and justification provided by scientists and references
1	**Socio-Economic concern**	
	• Multinational companies interests dominate	Among 17 million farmers planted 190.7 ha of GM crops, the majority are smallholder farmers (ISAAA, 2019)
	• Seeds will be patented and become unaffordable by Ethiopian farmers	Out of the total production costs, the price of the seed is only 10% that will pay back. Ethiopia has also started to develop its own GM seeds, and won't depend on import for long
	• Terminator gene (suicidal gene)	There is no terminator gene technology or Genetic use restriction technologies (GURTs) currently as it was banned several years ago internationally and there no more in use
2	**Health safety to human and animals**	Based research on livestock health, it has been concluded that GM foods are as safe as non-GM (CGE-NSA, 2016; Vincelli, 2018). Risk assessment studies on food/feed and environment are always undertaken before any GM approval for use
	• *Bt*-cotton toxins	*Bt*-toxins affect only Lepidoptera and some Sodoptera, which cause 60% yield loss, humans and animals have no receptors for this protein (Koch et al., 2015), the upper gut environment of humans is different.
	• Cancer causing compounds	There are scientific witnesses that shows there is no addition risk of GM crops to human or environment (Sanchez and Parrott 2017; Valentinov *at al.,* 2018)
3	**Environmental safety & biodiversity**	
	• Resistant pest will occur	Avoiding resistance development by insects like proper use of refugia is among strategies that should always be taken, not for safety but for the technology (Li et al., 2017). Moreover proper stewardship program need to be in place always (ETS, 2013)
	• Effect on non-target organisms	
	• The huge genetic diversity (biodiversity) will be treated by the gene flow & contamination	*Bt* crop varieties reduced application of synthetic insecticides in those fields (CGE-NSA, 2016) and properly managed GM crops conventional and organic seeds co-exist (Pearsall, 2013; Bodiguela, 2016)
4	**Influence of international and regional scenarios with controversial reports**	
	• The long term effect of *Bt*-cotton in India	Indian is the leading *Bt*-cotton producer as the long term effect is simply speculation that did not retard the industry and has been studied and disproved by Indian Government (Gruère & Sengupta, 2011)
	• *Bt*-cotton failure story in Burkina Faso	The failure is not due to the technology but attribute to the technology owner conflicts with the local arrangements

5	**Scientific knowledge on the processes of GE is in not fully understandable**	
	• Complex and difficult to understand what will happen and fear of the unknown	There is nothing in life that cannot be investigated and explained by scientific methods particularly man-made technologies.
6	**Misunderstanding and distorting the international treaties**	
	• Ethiopia is bridging the Cartagena Protocol and plan to be out of the treaties	Influential figures tried to distort the fact that as if being signatory for Cartagena Protocol prohibits from engagement in research. Which is never stated in the Protocol and because of individuals' popularity many innocent people were misled and spread this false claims
7	**Political and ideological predisposition**	
	• Use the chance to oppose the Government	Misinterpret the root causes of the current problems of the country as a pretext to GMO. It is obvious that public institutes represent the government
8	**Distorting and misinterpreting the Biosafety instruments**	
	• Mislead the public as if Ethiopia is an anti-GMO country by law	Biosafety Proclamation 655/2009 contains clauses and articles that are difficult to fulfill but never state that GMO is banned in Ethiopia
	• Ethiopia Pan-African leadership will be lost	The Pan-African leadership that Ethiopia is aspiring is not related to the scientific advancements but other socio-political issues attributed history and its role to strengthen African Union in many ways.
9	**Legal process of Biosafety law is not satisfactory and transparent**	
	• No public consultation made and voices of the anti-GMO group were not considered	The biosafety amendment processes engaged all stakeholders in the consultations and listened to the voices of the environmentalists and NGOs
	• 3 petitions were sent to the Prime Minster Office	All of the signatories are NGOs, people inclined to the biodiversity, environmental safety concerns
	○ Petition-1: Stop Roll-out of GMO Crops in Ethiopia ○ Petition-2: Stop the Spread of GMO Crops in Ethiopia ○ Petition-3: Ethiopian Civil Society Statement: Moratorium for 5 years	There are no Governmental Organizations who signed these petitions. The signatories used this chance to confront the Government for various reasons as if they were not able to fulfill their social roles. The arguments have been at the core of NGOs' successful campaigns for banning GMOs Europe (Valetinove et al., 2018). There is public hearing by the regulators before GMOs approval.
10	**Low capacity of Ethiopia and unable to engage in GMO R & D**	
	• Ethiopia has low capacity and cannot conduct GM research is just referring one of the factors listed by Cohen (2002)	Ethiopia has established a full-fledged, competent and well equipped Center of Excellence in Agricultural Biotechnology (NABRC). Moreover it has also a National Biotechnology Institutes catering all sectors of biotechnology (Agriculture, Health, Industry and Environment (Proclamation 388/2016)
	• The capacity of the Biosafety regulatory institution is very weak and unable to fully monitor the GM activity	The regulatory institute is equipped with adequate staffs that receive series of skills upgrading trainings. A GMO detection lab has also been established. The institute is also receiving series of supports from regional and international organizations dealing with Biosafety. There no way in Ethiopia to handle researches on GM without applications and biosafety regulations by the regulatory (Akinbo et al., 2021)

Ethiopia considered biotechnology as one of the priority areas in its National Science and Technology Policy formulated in 1993. Due an interest to tighten the non-GMO stand, the prohibitive regulatory system delayed its overall engagement in modern biotechnology, postponed the use of available products, and hampered the development of the local capacity buildings (Kedisso et al., 2022). Some Ethiopian scholars have reviewed the role of GMO in Ethiopia and revealed the various challenges and polemics mentioned in the Table above (Gebretsadik & Kiflu, 2018; Terefe, 2018; Teferra, 2021; Yali, 2022). On the other hand, the success stories on the GM crops adoption and the strength of the regulatory instruments were reported by Akinbo et al. (2021) and Kedisso et al. (2022).

4.5 Historical Development and Amendment of the Biosafety Legal Instruments in Ethiopia

As mentioned in section 4.2 above, series of consultative discussions were conducted engaging various actors and stakeholders during 2010-2015 to contribute in improving the Biosafety Proclamation 655/2009 and make it enabling for the benefit of the country. Ultimately the restrictive proclamation has been amended with Proclamation 896/2015 that allows GMO for research and education purposes.

5. Potential Applications and Opportunities of GM in Ethiopia

In the last two decades, various applications of biotechnology have provided reliable solutions to agricultural challenges. There are various groups of GM crops developed so far: those with traits of insect resistance and herbicide tolerance, GM crops aimed for added nutritional values and storage and those crops called "green factories" that produce novel pharmaceutical products and biofuels (Caserta & de Souza, 2017). Transgenics enabled to produce novel chemicals and biofuels, and better pest control strategies (Goold et al., 2018; Wang and Zhang, 2019). It has also aided, plant molecular farming for the production of recombinant proteins and other secondary metabolites for commercial and pharmaceutical purposes (Alireza & Nader, 2015; Buyel, 2019).

It is better to be clear that genetically engineering or GMO is not a panacea (cure-all) for every agricultural challenges. Rather, it should be seen as one of irrefutable modern tools available for contributing to food and nutrition security. Biotechnology immensely plays part in the balance of achieving SDG and biodiversity (Björnberg et al., 2015). Knowledge and skills are ever changing and scientific breakthrough innovations always evolve. Most of the natural and human made disastrous challenges have been addressed through scientific innervations globally. Generally, it is always advisable to build capacities to harness new technologies instead of standing against useful innovations. It is only through technological advances and crop improvements that emerging challenges are addressed and modernizes agriculture to plays its expected role in SDG and nutrition security as anticipated.

6. Conclusion

Genetic engineering is a modern technique that has incredible applications in all bioscience fields. The application of this technology has started with genetic modification in agriculture. Even though modern biotech research is relatively new in Ethiopia, there is significant advancement in agricultural biotechnology. The history of GM crops is more than 30 years in the world with innumerable contribution in economic, environmental and agricultural transformations. GM technology has been adapted in Ethiopia since 2016 with *Bt*-cotton and other crops with important traits have then followed. Handling GMO research in Ethiopia is so strict and with compliance to biosafety guidelines and regulatory follow-ups. GM technologies are important in solving the existing and emerging agricultural challenges. However, controversies and misunderstandings arise as the use of the technology advances. This is happening in the continent and in Ethiopia. Therefore, provision of realistic scientific information and continuous awareness enhancement activities are vital to promote the use of this technology and benefit out of this modern bioscience research.

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