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Premises of Agricultural Biotechnology in Ethiopia

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Abstract

Biotechnology is one of the sectors with significant contribution in modernizing agriculture. Developed nations have been using biotechnology in the areas of health, agriculture, industry and environment. It has tremendous potential in better responding to emerging agricultural problems. Ethiopia has started research in agricultural biotechnology a few decades ago. However, research and public awareness on biotechnology is inadequate. This paper is meant for reviewing the historical developments, progress of agricultural biotechnology, identify gaps and indicate key action points. All the information in this paper was obtained from published papers and other accessible resources. There are significant achievements and progress since the establishment of full-fledged agricultural biotechnology research at the Ethiopian Institute of Agricultural Research (EIAR). Several molecular researches were undertaken by many Ethiopians and scholars but not documented. To progress in this sector, the country needs to exploit the potential advantage of this science and invest in research and developments in the area. All the debates and voices against this science should be based on scientific evidences and improving public awareness is compulsory.

Key words: Bioscience; Genetic engineering; Genetic Modification; Molecular Research

Introduction

Ethiopia is among the most populous nations in Africa with agriculture being the base of its economy. Agriculture accounts for a significant portion of the GDP and employs about 85% of the population. This sector is supplying food for the ever-increasing human population and feed for animals. However, it is epitomized as a predominantly low-input low-output system dominated by smallholder producers generating agricultural products that are far less than enough. The major reasons accounting for these less production and productivities are biotic and abiotic stresses of, which most of them have successfully been solved through modern techniques in developed nations. "Biotechnology" is any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use (CBD, 1992). Agricultural biotechnology is one of the best technologies in solving agricultural problems these days. In Agenda 21 of the United Nations Conference on Environment and Development in 1992, it was stated that biotechnology makes a significant contribution in enabling the development of, for example, better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes and supports sustainable methods (UN, 2004).

The biotechnology industry is estimated to have generated at least $34.8 billion revenues and employed about 190,000 in publicly traded firms worldwide in 2002 (Ernest and Young, 2002). According to the report, the number of modern biotechnology based drugs and vaccines approvals have also increased from about 23 in 1990 to over 130 by 2001. There are about 350 biotechnology-derived drugs and vaccines in clinical trials targeting over 200 diseases (UN, 2004). The use of biological catalysts or enzymes has become common in every industry. There are at least 600 different products and more than 75 types of enzymes that are used in industries (UNCTAD, 2002) and the global market for industrial enzymes is about $1.6 billion. Based on the report, the demand for other biotechnology-related products, such as feed additives, has continued to grow, with vitamins and amino acids accounting for about $3 billion and digestive enhancers about $1.3 billion.

There is a substantial contribution of biotechnology in each sector in developed nations as can be easily inferred from the annual revenue of biotech companies. However, the contribution of this technology to the majority of developing nations is negligible as compared with the potential scientific and economic advantages that biotechnology could provide. By 1992, through Agenda 21 of the (UN, 2004), the international community recognized the important role that biotechnology would play in all bioscience areas. A number of countries considered biotechnology as a vehicle through which developing countries could leapfrog in this modern bioscience field. However, there are recent beginnings in terms of adapting technologies particularly in genetically modified crops in Africa. The economic contribution of only genetically modified crops was 186 $ billion five years ago (Brookes and Barfoot, 2018). Some African countries like South Africa and Sudan have started benefiting from this technology some years back. Similarly, some other African countries like Nigeria, Ghana, Kenya, Malawi including Ethiopia are slowly embarking on adaptation of GM crop technologies while others remain sceptical to the technology.

In the Agricultural Development-Led Industrialization strategy of the Ethiopian government (EDSE, 1994), the leading role of enhancing the agricultural sector was emphasized. This national development strategy specified the information and communication technology, and biotechnology as the two key sectors that are identified as essential for rapid economic transformation (FDRE, 2002). The agricultural sector is dominated by traditional practices entailing failure in satisfying the food security needs of the ever increasing population. The classical agricultural research has made remarkable improvement of the country's agricultural productivity in the past and if properly complemented with biotechnology, speeds up many processes and provides best alternative solutions to agricultural challenges. Agricultural biotechnology is more precise and cost effective with attested practical applications in resolving many agricultural problems worldwide. Being acquainted with the diverse benefits of biotechnology, the UN highly recommended the technology for developing nations. In other aspects of agricultural biotechnology, like plant tissue culture, marker assisted selections, genetic diversity studies and non-target mutagenesis in plants have been started long ago in Ethiopia. In livestock, assisted reproductive biotechnology like multiple ovulation and embryo transfer (MOET), artificial insemination, vaccine development and molecular technique based disease diagnosis techniques began nearly five decades ago. Characterization of bio-fertilizers (mainly Rhizobia), microbial and enzyme characterization activities were started many years back in universities and EIAR under microbial biotechnology research program. However, the majority of these efforts and the current support from the Ethiopian government in human resource and molecular laboratory capacities development were not well documented. Hence, the purpose of this paper is to review the processes, the historical developments, global achievements and potential applications of agricultural biotechnology in Ethiopia. It also provides insights into some of the global achievements and indicate the potential of agricultural biotechnology in modernizing the agricultural sector and its potential benefit for the country.

Historical Developments of Agricultural Biotechnology

There are various ways of defining biotechnology but according to (CBD, 1992), it is any scientific application that uses biological systems, living organisms or derivatives thereof, to produce or alter products or processes for particular utilization of living organisms, systems or processes. It has diverse applications in medicine, pharmaceuticals, cosmetics and other major sectors essential for human life and wellbeing. The research and development in biotechnology was begun in ancient times of fermentations for food and alcoholic drinks. In plant or crop breeding, it calls memories back to selection and domestication of crops from their wild relatives. However, the discovery of DNA structure and biochemistry in 1953 by Crick and Watson is the springboard for modern molecular studies and applications (Bhatia, 2018a).

This science can be categorized as traditional and modern biotechnology. However, there are various development stages of this technology. In prehistoric times, a basic form of biotechnology was practiced in agriculture for the establishment of better-quality species of plants and animals through cross-pollination or cross-breeding. Preceding forms of biotechnology include selective breeding of animals, crop cultivation and utilization of micro-organisms for the production of cheese, yogurt, bread, beer and wine. Primary agriculture concentrated on food production and the earliest type of biotechnology, the domestication of animals dates back to over thousands of years, when human beings started maintaining plants like rice, barley and wheat as a dependable source of food and controlling wild animals to produce milk or meat. There were also ancient products using microorganisms developed after discovering the process of fermentation. Later, it was discovered that microorganisms, e.g. bacteria, yeast or molds, hydrolyze sugars when they lack oxygen and are ultimately responsible for fermentation of foods and drinks. This process results in the formation of products (food and drink). Fermentation was perhaps first explored by chance, since in earlier times nobody knew how it works (Bhatia, 2018a).

In the primordial era, some considered fermentation to be a gift from their gods. As described by Science History Institute, Louis Pasteur first described the scientific evidence of fermentation through demonstration of a theory known as germ theory clarifying the survival of microorganisms and their further functions in fermentation process in the late 1800s (Bhatia, 2018a). Several traditional products such as honey are considered to be the products of biotechnology for it contains many antimicrobial properties and effectively used in wound healing and similarly, soybean curds were used to treat boils in China as far back as 600 BC (Steinberg and Raso, 1998). Ukrainians utilized moldy cheese to treat infected wounds and later understood that there are antibiotics in such molds that kill bacteria (Bhatia, 2018a). In 1928 Alexander Fleming extracted penicillin, the first antibiotic, from mold (Steinberg and Raso, 1998). These discoveries have revolutionized the potential treatments of infectious diseases in medicine. In agriculture, selective breeding of plants and animals was practiced in the past without awareness of the basic concepts of biotechnology.

In the 1920s the production of useful chemicals through biological processes was started using *Clostridium acetobutylicum* by Chaim Weizmann for the conversion of starch into butanol and acetone that has been a component of explosives during World War (Kloot, 2014). The production of antibiotics from microorganisms became possible after the discovery of penicillin, which was later produced at a large scale from cultures of *Penicillium notatum* that proved useful for the treatment of wounded soldiers during World War II (Gaynes, 2017). The focus of biotechnology shifted to pharmaceuticals and the Cold War years were ruled by microorganisms for the preparation of biological products along with antibiotics and fermentation processes (Bhatia, 2018b). Biotechnology is now being used in numerous disciplines including bioremediation, energy production, food processing and agriculture. According to a Science History report, the development in biotechnology has brought agriculture and industry in the early

18th century and in the 1930s the processes of biotechnology moved more into utilizing surplus agricultural goods to supply industry as a replacement for imports of petrochemicals.

In the agricultural sector, biotechnology has passed through different development stages. In plants, tissue culture is considered to be a traditional biotechnology after primitive biotechnology like domestication and selection. Likewise, fermentation in microbial biotechnology is also regarded as one of the oldest biotechnologies. Despite its slow application and use in developing nations, artificial insemination in livestock is also among the old biotechnologies. Molecular breeding and genetics both in plants and animals has come as the next generation in the development of agricultural biotechnology. This has immense applications and contributed a lot in agricultural production and productivity enhancement in various ways in the world. There were some great beginnings in Ethiopia that needed to be strengthened for practical and wide-scale use.

In the third generation of its development, recombinant DNA (rDNA) technology has evolved and enabled organisms to confer the traits of interest that is not naturally possible. In this technology, the role of microorganisms is enormous. The rDNA technology has contributed to the health, pharmaceutical and industrial sectors apart from agriculture. Many vaccines and drugs synthesized and saved millions using this technology. This technology has never been developed in Ethiopia so far but research institutes and universities are making serious struggles to practice this relatively modern technique.

Agricultural Biotechnology

Plant Tissue Culture

The primary idea of plant tissue culture (PTC) has begun from understanding the basics of plant cells. Schleiden and Schwann proposed a cell as a basic structural unit of living organisms in 1838 (Hussain *et al*. 1998). Like other multicellular organisms, a plant grows through increasing its cell population while cells specialize in functions. The mother cell makes an exact copy of its genome before it divides into daughter cells. Hence, every living cell contains all the genes that the mother plant processes and has the capacity to grow to a full plant (Hussain *et al*. 1998). This basic natural principle is cell totipotency and the functional specialization process is differentiation, which is accompanied by morphogenesis (PSSeL, 2021). For cell differentiation, some genes are turned off and on at certain times. Hence, for a cell to grow to full plant, reverse differentiation process should occur and repeat (Hussain *et al*. 1998).

This natural phenomenon would happen in all living cells theoretically. Nevertheless, the more differentiated a cell has been, the more difficult it will be to induce its de-differentiation therefore, the younger or the less differentiated a cell is, the easier to culture it into a full plant (PSSeL, 2021). The ease of cell totipotency is variable among various tissues and genotypes. In 1902, the first tissue culture attempt of leaf knop was made by a German scientist on sucrose enriched salt solution (Hussain *et al*. 1998). The science of plant tissue culture has been gradually understood and *in-vitro* mass propagation protocols have been developed for various plants. Currently, plant tissue culture is widely utilized for commercial multiplication of fruit and forest trees, for the production of disease free planting materials, generating somaclonal genetic variations and a pre-request for agrobacterium-mediated transformation (Bhatia and Bera, 2015). Even though it is considered as an old biotechnology, plant tissue culture is an interesting science with many challenges and practical difficulties at all stages as depicted in Fig.1 below.

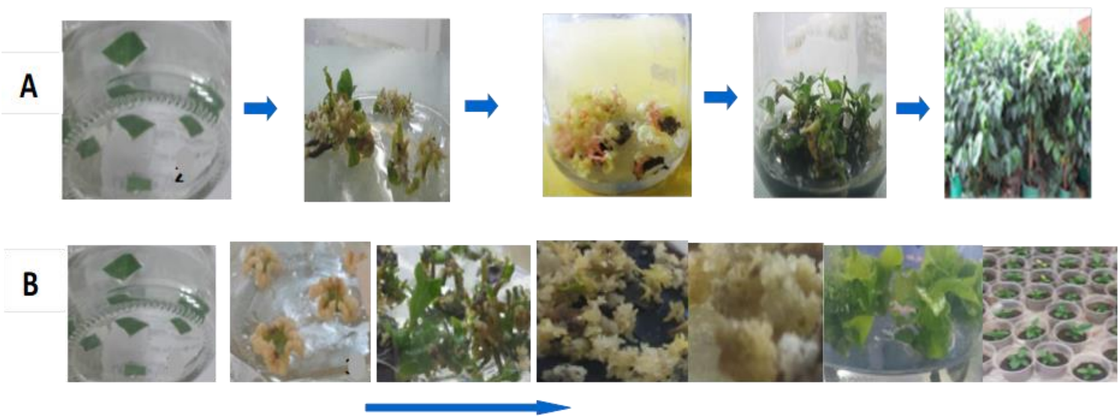

Figure1. Steps of plant tissue culture A, direct somatic embryogenesis and B, indirect somatic embryogenesis

In Ethiopia, plant tissue culture activities started in 2000 at EIAR as a single research unit under horticultural crops research based on unpublished fact. The first crop considered for tissue culture was potato, with the purpose of producing disease free micro-tubers for the already released and adapted potato varieties. At that time, the highest priority was given to plant tissue culture for the production of disease free planting materials and for mass propagation of selected planting materials in a short time. There were some tissue culture research activities by postgraduate students in 1980's at Addis Ababa University (Abraham, 2009) with special focus on indigenous forest tree species. *Podocarpus sp*., *Cordia africana*, *Hagenia abyssinica* and *Annengeria sp*. These were followed by micropropagation research on *endod* (Demeke and Huges, 1990), tef (*Eragrostis tef*) (Assefa *et al*.

1998) and enset, *Enset ventricosum* (Negash *et al*. 2001; Birmeta and Welander, 2004). The plant tissue culture was upgraded to a biotechnology research program under crop research in 2006 and a coordination unit was established at EIAR headquarter.

Currently, more than 64 plant *in-vitro* mass propagation protocols have been developed in EIAR and assumed to be more than 100 protocols for high value crops in the country. Moreover, short to medium term *in-vitro* maintenance protocols were developed for many crops in EIAR. In this regard, EIAR is a pioneer institute in providing protocols and mother plants even to the commercial tissue culture firms. Some of the well utilized mass propagation protocols are potato, banana, pineapple, ginger, sugarcane, apple, peach, bamboo etc. On top of mass propagation and *in-vitro* conservation and disease cleansing planting materials, PTC is useful for multiplication of hybrid crops and *in-vitro* production of diploid plants. This helps to significantly reduce the breeding cycle and obtain genetically uniform pure lines. In this regard, the studies on improvement programs of indigenous crops, Tef & Niger by (Gugsa *et al*. 2006; Tesfaw, 2008) are referable. The PTC protocols for various plants developed in the country, the purpose and institutes that have developed the protocols reviewed (Yemisrach *et al*. 2021) and other unpublished sources are described in Table 1 below.

Table 1. Some plant tissue culture protocols developed in Ethiopia

Crop/Plant	Techniques	Purposes	Institutes engaged
Potato (*Solanum tuberosum* L.)	*Shoot tip culture*	*Disease free multiplication*	*NABRC, ATARC, ARARI, SARI, TBC*
Sweet potato (*Ipomoea batatas* L. Lam.)	Meristem culture	Disease cleaning	AAU-IoB, TBC, ATARC, ARARI, NABRC, SARI
Anchote (*Coccinia abyssinica*)	Nodal culture?	Micropropagation	AAU-IoB, NABRC
Yam (*Dioscorea bulbifera*)	Nodal culture	Micropropagation	JARC, SARI
Ethiopian/Oromo dinich (*Plectranthus edulis)*	Nodal/ shoot tip	Micropropagation	AAU-IoB, TBC, ARARI, JARC, SARI
Ginger (*Zingiber officinale*)	Meristem culture	Disease cleaning	
Cassava (*Manihot esculenta* Crantz)	Meristem culture	Disease cleaning	NABRC, SARI, AAU-IoB
Enset (Ensete ventricosum) (Welw.) Cheesman	Shoot tip culture	Disease free multiplications	NABRC, WKU, SARI TBC
Taro (*Colocasia esculenta*)	Nodal culture	Micropropagation	SARI
Banana (*Musa* spp.)	Shoot tip culture	Disease free multiplications	AAU-IoB, TBC, ATARC, ARARI, MARC, SARI
Grape vine (*Vitis vinifera L.*)	Nodal culture	Micropropagation	AAU-IoB, TBC, NABRC
Apple (*Malus domestica* Borkh)	Shoot tip/nodal culture	Micropropagation	AAU-IoB, TBC, NABRC,WKU
Citrus (*Citrus sinensis*)	Meristem	Disease free multiplications	TBC, MARC
Pineapple (*Ananas comosus*)	Shoot tip	Micropropagation	TBC, JARC, SARI
Date palm (*Phoenix dactylifera*)	Shoot tip	Micropropagation	MARC
Plum (*Prunus cerasifera* Ehrh.)	Nodal	Micropropagation	NABRC

Crop/Plant	**Techniques**	**Purposes**	**Institutes engaged**
Peach (*Prunus persica* (L.) BATSCH	Nodal	Micropropagation	NABRC
Artemisia (*Artemisia vulgaris*)	Shoot tip	Micropropagation	JARC
Stevia (*Stevia rebaudiana*)	Shoot tip	Micropropagation	JARC
Korarima (*Aframomum corrorima*)	Axillary bud	Micropropagation	AAU-IoB, JARC
kebericho (*Echinops kebericho*)	Leaf	Micropropagation	AAU-IoB
Frankincense (Boswellia)	Nodal	Micropropagation	ARARI
Turmeric (*Curcuma longa*)	Rhizome bud	Micropropagation	JARC, TBC
Vanilla (*Vanilla planifolia*)	Nodal	Micropropagation	
Lemmon verbena (*Aloysia triphylla*)	Shoot tip	Micropropagation	NABRC
Rosa abyssinica, Rosa damacena	Shoot tip	Disease free multiplications	NABRC
Geranium (*Pelargonium graveolens)*	Shoot tip	Micropropagation	NABRC
Moringa stenopetala, Moringa oleifera	Shoot tip	Micropropagation	AAU-IoB
Eucalyptus gradis	Shoot tip	Micropropagation	TBC
Giant bamboo (Dendrocalmus giganteus)	Bud culture	Micropropagation	ARARI
Lowland bamboo (*Oxytenanthera abyssinica* A. Rich. Munro	Bud culture	Micropropagation	NABRC, TBC
Highland bamboo (*Yushania alpine* (k. Schum))	Bud culture	Micropropagation	NABRC
Hybrid coffee (*Coffea arabica L.)*	Somatic embryogenesis	Micropropagation	JARC, NABRC, TBC, ATARC, AAU-IoB
Endod *(Phytolacca dodecandra*)		Micropropagation	TBC, JARC
Sugar cane (*Saccharum offcinarum* L.)			MARC, DZARC, NABRC,TBC
Aloe vera	Suckers	Micropropagation	ESC, MARC
Jatropha (*Jatropha curcas* L.	Nodal	Micropropagation	NABRC
Eragrostis tef and *E. pilosa*	Anther/Microspore	DH development	AAU-IoB
Wheat haploid	Anther culture	DH development	AAU-IoB
DT Wheat (*Tritium aestivum* L.)	Another culture	DH development	WKU
Guizotia abyssinica (Noug)	Anther culture	DH development	AAU-IoB, NABRC
Mustard (*Brassica carinata A.braun)*	Anther culture	DH development	AAU-IoB, NABRC
Sesame *(Sesamum indicume)*			WKU

NABRC= National Agricultural Biotechnology Research center, SARI= Southern Agricultural Research Institute, AAU-IoB= Addis Ababa University, Institute of Biotechnology, WKU= Wolkite University, TBC= Tigrai Biotechnology Center, JARC= Jimma Agricultural Research Center, ATARC= Adami Tullu Agricultural Research Center, ARARI= Amhara Regional Agricultural Research Institute, MARC= Melkassa Agricultural Research center

The Tigray Biotechnology Center (TBC), the largest tissue culture facility in the country, has obtained most of the *in-vitro* propagation protocols for the aforementioned crops, from EIAR. Banana, ginger and sugarcane are among the most utilized protocols by the commercial tissue cultures including Narus Tissue Culture located at Modjo but not functional currently. Disease cleaning from coffee berry disease and mass propagation of hybrid coffee varieties is one of the prior areas of plant tissue culture research in the country. The nature of the plant, skill gap and associated constraints has challenged coffee tissue culture protocol. The plant biotech programs of NABRC and JARC have been distributing tissue culture produced coffee plantlets to farmers. However, with joint effort made by

EBTi/BETin, NABRC and JARC, the protocol for the Aba *Buna* hybrid coffee variety was recently developed.

Molecular Research and Recombinant DNA technologies

Molecular research specifically in health and agriculture started after the discovery and understanding of DNA structure in 1953. In the 1970s, scientists began to study the detailed structure of DNA/RNA and the function of genes and their association with traits/behaviors (Bhatia, 2018a). The visible, phenotypic characteristics of organisms are guided by a gene or multiple genes. Identification of such specific genes of interest has gradually been achieved using various molecular markers like Restriction Fragment Length Polymorphisms (RFLPs), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP) Single Sequence Repeats (SSR) and Single Nucleotide Polymorphism (SNP) (Zhang *et al*. 2001). The application of these markers became important for diversity studies, gene mining, identification of genes responsible for stress (disease, frost, and drought) tolerance and quality parameters in crops. In microorganisms, this helped scientists to characterize important microbes for pharmaceutical, food & feed, cosmetic industries. There are various molecular techniques for diversity studies and sometimes analyses are supported by sequencing conserved gene(s) to infer the phylogeny of species. Such molecular studies are vital in germplasm conservation, DNA fingerprinting and identification of useful genes for crop improvements.

Identifications and improvement of traits in crops using molecular markers started years back in Ethiopia and there are beginnings in microbes and livestock. In this regard, practical activities in Marker Assisted Breeding (MAB) were not to the level expected in the country so far except that there are few independent and fragmented activities by plant biotechnologists and plant breeders. However, EIAR, Ethiopian Agricultural Research Council Secretariat (EARCS), BETin and Haramaya University have recently established MAB platform and are preparing strategic documents on implementing MAB to practically modernize crop breeding using this modern tool. For instance, molecular markers, such as restriction fragment length polymorphism (RFLP), and simple sequence repeats (SSRs) are potential tools for the indirect selection of both qualitative and quantitative traits, and also for studying genotypic diversity (Yu *et al*. 2007).

There were molecular studies in Ethiopia on different crops like tef (*Eragrostis tef*) using various markers (AFLP, SSR, EST-ISSR, ISSR and RAPD) used for diversity analysis (Abraham, 2009). Moreover, genetic linkage map has also been developed using various crops for the identification of genes that control useful traits and quantitative trait loci (QTL) (Bai *et al*. 1999; Bai *et al*. 2000; Yu *et al*. 2008; Zhang *et al*. 2001; Yu *et al*. 2007). Similarly, there were studies on molecular markers linked with wheat rust resistance (Mebrate *et al*. 2007). Genes associated with wheat rust resistances were studied using microsatellite markers recently in EIAR. In barley, there were many studies on diversity using various molecular markers (Misganaw *et al*. 2017). There were detailed studies on yellow dwarf and other foliar barley resistance (Bekele *et al*. 2019).

Molecular research had stunning achievements in the livestock industry through reproductive biotechnology that includes embryo transfer, multiple ovulation, chromosome sorting in sexed semen production and various aspects of animal health like monoclonal antibodies production. Among which, the common technological tool used in livestock for decades in Ethiopia is artificial insemination (AI). According to some evidence, the time that USA and Ethiopia began using this technology was not far apart. However, the livestock production in the USA today is highly modernized using other biotechnological advancements but it is yet underutilized in Ethiopia. According to National Artificial Insemination Center, NAIC (NAIC, 1995), the center was established in 1981. This center was meant for the production, preservation and distribution of selected cattle semen mainly from exotic (Holstein Friesian) sires. It also produces semen from selected indigenous sires to some extent.

The International Livestock Research Institute (ILRI) started embryo transfer in 1990 at Debre Zeit Research Station on Zebu cattle and the first calf was born (Tegene, 1991). Then using supper ovulation and embryo-splitting, eight pairs of identical twins of Boran calves were obtained (Tegene, 1994). Unluckily, there was no systematic transfer of this technology to the national research system. Recently, the animal biotechnology research program of EIAR is making huge progress in the area of livestock reproductive biotechnology. The uses of synchronization, sexed semen, AI and embryo transfer technologies are successfully being undertaken particularly at Debre Zeit research center of EIAR. This should be supported with a strategic extension system for the wider impact of the technologies in the country.

Table 2. Examples of animal biotechnology works in Ethiopia

Area	Activity	Reference
Reproductive	AI	(NAIC, 1995)
Reproductive	Embryo transfer	(Tegene, 1991)
Reproductive	Embryo splitting	(Tegene, 1994)
Animal health	Ruminants and chicken vaccines	(Yoseph, 1996)
Animal health	rDNA-based vaccines	(Yilma *et al*. 1988; Berhe *et al*. 2003)
Animal health	ELISA, cDNA probes and PCR-based	(Abraham *et al.* 2005; Roeder *et al*. 1994)
Animal health	Molecular characterization and phylogenetic of pathogens	(Sahle *et al*. 2007)

There are few examples of hitherto animal biotechnology works in Ethiopia. There is no enough published evidence though there were molecular studies at various universities by postgraduate students.

In microbial biotechnology, many of the studies are conducted at universities, plant protection and animal health sectors in Ethiopia. There were also efforts of characterizing and studying rhizobial species for the use of bio-fertilizer with many successes (Asfaw and Angaw, 2006; Beyene *et al*. 2004; Woldemeskel *et al*. 2004) The majority of microbial characterization studies so far in the country are related to pathogens. A number of viruses from various crops have been diagnosed to species or strain level (Abraham and Assefa, 2000). In EIAR, Ambo Plant Protection Research Center (APPRC) was founded for this purpose. According to information on EIAR website, the center was established though bilateral agreement between the Ethiopian and the then Union of Soviet Socialist Republics (USSR) governments in 1977. After some years, Agricultural Entomology and Weed Science researches were launched in the center in addition to plant diseases. This center is a pioneer in microbial studies and has many outputs. There were many plant pathogens isolated using nucleotide sequences as indicate in (Abraham, 2009). There were various studies on the identification of indigenous and introduced biocontrol agents for insect pests and weeds (Abraham, 2009). Some of these efforts have passed field trials of which, *Beavaria bassiana* and *Metarihizium anisiphole* are among the promising indigenous microbes for locust control (Kassa *et al*. 2002; Kassa *et al*. 2004; Tadele and Pringle (2004. *Trichoderma viridae* was found to be effective against faba bean root rot (Beshir, 1999) so is *Bacillus thurigiensis* against diamondback moth on cabbage (Ayalew, 2006)

Recombinant DNA technology has become a breakthrough technology especially in the pharmaceuticals. Historically, Paul Berg and Peter Lobban conceived approach to create rDNAs *in-vitro* and use to manipulate genes across species in 1969 (Bhatia, 2018a). Then Douglas Berg with colleagues isolated the first plasmid bacterial cloning vector, λdvgal 120 (Lenzi *et al*. 2010). Gradually, transferring genes from organisms to organisms (transgenic), with in species (cis-genic) and has been started in 1970s. This genetic transformation can be undertaken through agrobacterium-mediated or direct gene transfer using the gene gun (Gao and Nielsen, 2013). The technology has highly transformed the global agriculture nowadays particularly in the areas of insect resistant and herbicide tolerant genetically modified crops.

Genetically Modified (GM) Crops

In the ancient times when people were not conscious about genetics, they have been manipulating the genetic makeup of organisms in the practices of artificial selection or selective breeding. Selection was coined by Darwin to describe intentional selection of organisms with desired traits that could propagate through offspring. The use of this practice over decades entailed genetic changes to a species. Though selection breeding is not genetic modification (GM), it is an earliest example of impelling genetics. This has been utilized in plants since 7800 BC according to archaeological evidences in southwest Asia where varieties of wheat were found (Balter, 2013).

After the birth of modern genetics, GM technology came to picture in 1973 when successfully created Genetically Modified Organism (GMO) by Boyer and Cohen (Cohen *et al*. 1973). They have developed technique of cutting specific antibiotic resistance gene from one bacterial strain into another. This technology has been applied in mouse after a while (Jaenisch and Mintz, 1974). Given the ample possibilities that world can benefit from this new technology, media, officials and some scientists started worrying too much about the potential human and environmental safety issues related to this technology. This worry is acceptable for appropriate safety management. The Genetic Engineering (GE) activities were universally known in the early 1970s and scientists have discussed it at the Asilomar Conference (Berg *et al*. 1975). After this conference, the conclusion was to proceed with this technology using some guidelines (UN, 2004). All the process of GE technology was so transparent and, hence, decision makers at global level have supported the technology launching the modern era of genetic modification (Rangel, 2015). Though many countries have developed their biosafety laws based on Convention for Biodiversity (CBD) and Cartagena Protocol, the majority of African countries have not yet developed biosafety laws. However, the adoption of GM crops is steadily increasing recently as shown in Fig. 2 below. There are other African countries who have adopted biotech crops after the report by ABNE (ABNE, 2019).

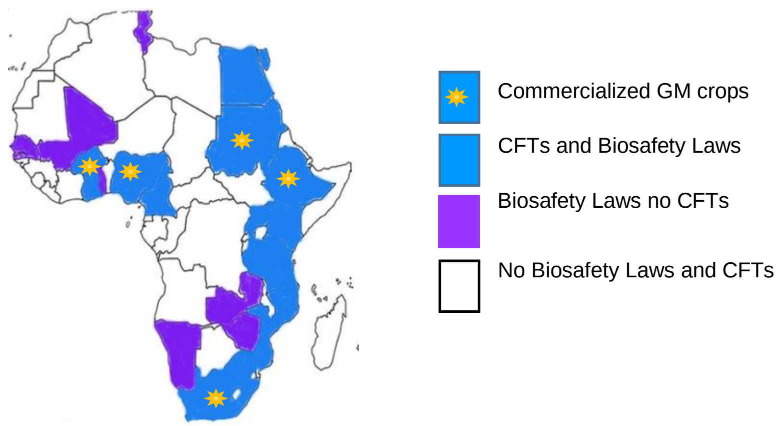

Figure 2. African countries with Biosafety Laws and biotech crops adoption. Source: (ABNE, 2019)

The first genetically engineered organism patented by the US in 1980 was bacteria that can break down crude oil and alleviate oil spill glitches and in 1982 GE a bacterium producing human insulin or Humulin was developed (Altam, 1982). Gradually, research on GE food crops began using rDNA technology in 1987 and the first genetically modified food crop was Calgene's Flavr Savr tomato (Rangel, 2015). In this tomato, a natural protein production inhibitor DNA sequence was modified resulting in a firm tomato with extended shelf life. Golden rice, rice enriched with *beta*-carotene, for vitamin A intervention (Dubock, 2017) is a good example of nutritional enhancement through this technique. 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. In animals, the first genetic modification approved was meant for a blood clotting drug, ATryn (Ye *et al*. 2000). The other is increasing the size and reducing the maturity period in salmon fish. Even though not so far 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).

Global Controversies Over Genetically Modified Crops

The reasons for the controversies on GMOs particularly GM 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 recommended strict follow up of biosafety procedures on GMOs. This is why serious safety investigations on the plant health, environment and food and feed aspects are thoroughly undertaken and approved before use of any GMO event worldwide. The other one is either ideological or blind opposition based on personal perception or unwillingness to accept the technology considering it unnatural. As it can be referred from "anti-GMO advocacy tracker" online, the major and popular one is because of strong push and funding from companies because of various interests, which are mainly economical.

Some are objecting this technology associating with religion or philosophies. People do refer some negative cases of the technology as evidences of the effect of *Bt* toxin on butterflies, which was eventually proved wrong (Heeter, 2018). 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 that was Indian farmers' suicide because of poor cotton yield and crop failure. This has been confirmed that it was not the real cause based on structured studies by the Indian government (Gruère *et al*. 2011).

According to ISAAA (Heeter, 2018) report, 26 countries are cultivating 191.7 million hectares of Genetically Modified crops (GM) directly benefiting 17 million farmers globally. In Africa, 12 countries are either cultivating or undertaking confined field trials of 10 crops for 16 traits. This makes GMOs the fast adopted agricultural technologies in recent years despite various companies and organizations opposing the adoption of this technology. The annual increase of global GM crops cultivation in both industrialized and developing countries is indicated in Fig. 3 below.

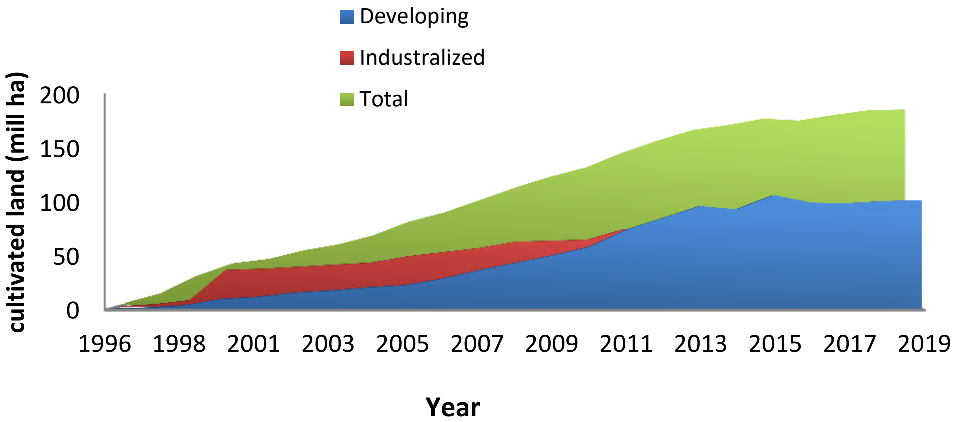

Figure 3. Annual Trend of Global area (million ha) of GM Crops Cultivation. Source: (ISAAA, 2018)

New technologies always face opposition and controversies are obvious but persistence of activism on GMO is basically derived by companies' financial backstopping. The scenario is similar elsewhere in the world but this controversy increases as the use of the technology is enhanced particularly in developing countries where the majority of the populations are unaware of the technology. However, people demand technologies as they provide the greatest solution against emerging problems. In Ethiopia, there wasn't an issue of opposition but has come to picture after trials on the adoption of GMO crops began. 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 reduced after engaging many stakeholders in various stages of discussion and awareness enhancing but requires continuous public awareness building.

Public Awareness and Challenges

Agricultural Biotechnology offers a prodigious potential contribution to sustainable agricultural growth and food security. It has many applications in all bioscience sectors of agricultural research and development. Yet there are restraints at global level that hinder access to appropriate biotechnological innovations by the poor (Qaim and Braun, 2000). Any new technology gets challenges emanating from lack of knowledge and fear in addition to the reasons mentioned in section 2.3 above. The case of hybrid maize in Ethiopia can be mentioned as a good example (Beshir and Wegary, 2014). There is a similar perception still persisting on the use of commercial fertilizers.

In the early 1990s, the awareness of the GE foods' existence was raised and the regulation of such products has been started with the reinforcement of GE foods labeling in many countries. Currently, more than 60 countries have mandatory labeling laws (Label GMO Foods, 2013). Nevertheless, many countries still have no nationwide mandatory labeling law despite many pushes from advocacy groups to enact with the justification that labeling food is important for the consumer choice and monitoring risks (EU, 2010).

The controversies on GMOs are still active and stronger in developing countries, which may continue as the technology advances and ultimately reduces with increasing public awareness. The safety issues of GE have been dealt with for decades by the regulatory agencies, technology developers and international organizations like WHO. For instance, the most popular content in terms of resisting agricultural biotechnology is the EU. Conversely, the EU has already permitted 202 GM events until 2018 for food and feed (ISAAA, 2018). The summary research result of 81 separate scientific researches conducted for 15 years on the safety of GMOs has been reported in 2001. The aim of the study was to investigate if GMOs are not safe, the tastes were unsatisfactory or generally under regulated (Kessler and Economidis, 2001). The final conclusion of the study press-briefed by the EU DG for Research and Innovation was that GMOs which have passed through usual risk assessment did not have any sign of risk to human health or the environment (Paarlberg, 2001). After processes of GMO debates and many years of discussions, the scientific community came together with a conclusion on no danger of consuming GMO than conventionally selected crops (Berg *et al*. 1975).

Technology generators were reluctant on the public awareness of GMOs because of their strong belief that fact is always unchanged and users will ultimately accept the scientific facts though the advocacy groups continuously voice against the technology using the general advantage of human behavior of easily accepting the negative advocacies. Hence, lately scientists have agreed that public awareness is a key to technology adoption. This is largely influencing developing nations where the majority of the public is unaware of this technology. The advocacy groups against biotech do speak to the soft part of the public in a more sympathized manner. Normally, negative messages are stronger and do persist longer in any scenario. Evidence shows that these groups do have magnificent support from companies and foundations and their advocacy is professional because of internationally linked support. There is citable evidence like “Mapping contributions by foundations to anti-biotech advocacy groups’’ up-to-date data online. Nonetheless, this will gradually subside as the level of awareness and confidence on the technology is built among scientists, influencers and the general public. However, proper biosafety regulations by countries should never be compromised.

Potential Importance of Agbiotech Applications in Ethiopia

The use of agricultural biotechnology is remarkable in research and development. Plant tissue culture is very essential in mass production of disease free and true-to-type genetic materials in a shorter time. This indicates that it is more important for hybrids and plants that have difficulties or lengthy seed germination. Hybrid coffee, ginger, banana, date palm, apple and so on can be good examples, where tissue culture is important. The technique is important not only in *in-vitro* mass production or conservation of plants but has significant involvement in genome editing technologies as mentioned in section 2.1 and applications of biotech in the livestock industry. In the conventional selection of a crop variety for a given trait, it takes about a decade and the selection is mainly based on phenotypic characterizations. However, if the selection is assisted using molecular markers, the time is significantly reduced to a few years with more precision of selection of the targeted trait (Weyen, 2021). Besides, crossbreeding of crops takes many years and the use of doubled haploids (DH) is another important biotech aspect to consider in crop improvement programs. In addition to the lengthy time requirement, inefficiency of selection in early generations because of heterozygosity is another drawback in conventional breeding. These disadvantages can be solved by DHs, and more elite crosses can be evaluated and selected in much less time. In DH technique, genetic uniformity is easily developed, which is the basic requirement in cultivated variety development (Tycooly, 1988).

Genome Editing (GE) technology has recently developed a new technique called CRISPR-cas9, which has been adapted from bacterial systems used for gene editing, allowing easier development of GE organisms (Gurian-Sherman, 2014). This technology accelerates the development of intended genetically engineered organisms. Interestingly, modern improvements in plant breeding practices may enhance the use and rebound the reputation of the more traditional GMO method of breeding. This way, insect resistant, draught and herbicide tolerant crop varieties have been developed.

In order to produce 70% more food by 2050 and feed the abruptly increasing world population, the use of new innovation is mandatory. This new technology enables the development of stress tolerant crops, high yielding and better in quality. Ethiopia is one of the top African countries with fast population growth that requires technological solutions for improving agricultural production. Besides the visible effects of climate change and other human made problems, the country demands 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 in the country. Hence, the use of agricultural biotechnology will benefit the country in various ways.

Opportunities

Agricultural biotechnology research and development has many opportunities in the country. This is due to the international and national trend of research and development in all bioscience. Currently, many prominent companies in the areas of medical, pharmaceuticals, cosmetic, food and feed are utilizing this technology for various purposes. Apart from the biological applications, the analytical solutions for research in this area are generating tremendous resources for advanced countries. The price of one latest DNA sequencer machine currently is comparable with the annual export value of developing countries' some agricultural commodities.

Agricultural biotechnology has significant contributions and applications in all biological sectors of research. Hence, the Ethiopian government has given deserving possible attention to strengthen in human resource and physical capacity. Currently, the National Agricultural Biotechnology Research Center at Holetta is fulfilling almost all required facilities and human resources. One of the witnesses of the government's commitment and understanding of the importance of biotechnology is the establishment of the Ethiopian Institute of Biotechnology (EBTi/BETin) in 2016. This is huge progress in centrally coordinating all biotechnology sectors in the country. In addition, more than 13 public universities are providing post-graduate courses in biotechnology. There are also other big institutes like National Veterinary Institute (NVI), the pioneer in beginning biotech in the country, National Animal Health Diagnostic and Investigation Center (NAHDIC), which are using biotechnology. These all national institutes are big opportunity for research in the country. The Ethiopian Society of Biotechnology (ESoB) was established in 2020 to bring all biotech stakeholders together and annually review and evaluate the progress of the sector.

Prospects of Agricultural Biotechnology in Ethiopia

Agricultural biotechnology products have been used in all Africa in various ways either deliberately or unknowingly. Some countries have adopted GM crops and it is literally difficult to think of improving agriculture without modern technologies. These modern sciences in all agricultural sectors (crop, livestock, microbial) use mainly biotechnology. The technology is not at infancy; it is moving fast and playing significant roles in agriculture (NASEM, 2021). The abrupt population increase in the world particularly in Sub-Saharan Africa, the unpredictable climate changes and induced stresses on crop production urges the mandatory use of agricultural biotechnology.

This modern technology is more precise, time saving and cost effective in crop variety development. The challenge is most of technological in Sub-Saharan Africa (SSA) and high initial investment for the establishment of molecular study facilities. This is a must and most countries are dwelling and seriously working on it. The various aspects of crop improvement, livestock production and use of microbial resources mentioned in the previous sections and the favorable research policy in Ethiopia currently encourages the development of agricultural biotechnology. There were many molecular research activities underway with great achievements mainly in crop and livestock research. Currently, the public awareness level about the technology is unsatisfactory and there are challenges in some areas of biotechnology mainly in GMOs. However, this scenario will be reversed with increasing the biosafety regulatory capacities and improved public awareness. This could be judged from the trend of biotechnology adoption in the world, which goes hand in hand with technological advancement.

Conclusion

The agriculture sector in Ethiopia is based on traditional or conventional subsistence agriculture that is liable to biotic and abiotic factors. This is why the global climatic effect is severe (FSIN, 2021) in developing countries though it is a worldwide issue. Research in agricultural biotechnology has been started decades ago in Ethiopia beginning with an Artificial Insemination (AI) in livestock and plant tissue culture. The research and capacity building activities have been progressively improved and a full-fledged research center and institute have been established in the country. Using agricultural biotechnology is a choice to feed the ever increasing population with limited resources and alternative ways of life. For instance, the use of genetically modified crops, which has been more than 20 years, is a hot debate and a current issue in Africa. Through this technology, the world could solve the issue of pests, moisture stress, weed control and improved nutritional values. Improvements of these traits are tedious and often impossible through conventional techniques.

There are more acceptable and precise agricultural technologies like genome editing in crops, livestock and microbes that could alleviate the major agricultural problems and enhance the natural qualities of crops. This indicates that agricultural biotechnology will have great premises in Ethiopian agriculture. The negative debates on new technologies may persist or even intensified because of many reeasons in Africa but it is necessary to accept modern agricultural biotechnological applications. Otherwise, the achievement of the zero hunger goal by 2030 may slide back in many developing countries including Ethiopia. Currently, Ethiopia is in support of agricultural biotechnology without compromising the biosafety issues and the trend will continue and the country is expected to maximize the use of the state of the art new techniques that can practically contribute to the improvement of agricultural production and productivity that ultimately leads to the global goal of nutrition security by 2030.

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