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Review

Benefit from the applications of biotechnology in increasing agricultural productivity in Ethiopia

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Ethiopia is an agrarian country that can have enormous benefit from the applications of biotechnology for increasing its agricultural productivity. The country is at initial stages of research and development in agricultural biotechnology with scattered efforts underway in various public institutions. Research efforts and applications in crop production include plant tissue culture, biofertilizers and biopesticides, molecular markers for disease diagnosis and genetic diversity. Livestock related applications include artificial insemination, molecular diagnostics, vaccine production and molecular genetic analysis. Infrastructure and skills in recombinant DNA and other cutting edge technologies such as proteomics and bioinformatics are still limited and need to be strengthened. A number of crop production constraints can be solved by using advanced biotechnology tools/products including genetically modified organisms. Cognizant of this, Ethiopia has recently given a due emphasis for capacity building in agricultural biotechnology extending from promoting research, development and education in various public institutions to setting up of an independent agricultural biotechnology research center. The constraints holding back progress in agricultural biotechnology are numerous ranging from poor technical and regulatory capacity to lack of appreciation of opportunities provided by agro-biotechnology by the public and decision makers.

Key words: Ethiopia, biotechnology, tissue culture, molecular markers, diagnostics, GMOs.

INTRODUCTION

With its population currently estimated at 77 million, Ethiopia is one of the most populous nations in Africa. The country has agrarian economy with agriculture contri-buting to about 50% of the GDP, providing employment for about 85% of the population and accounting for about 90% of total foreign exchange earnings. In the last decades however, the productivity of this sector domina-ted by traditional practices failed to satisfy the food security need of the population at times resulting in severe food shortage. The development strategy of the Ethiopian government recognizes the dominant role of agriculture in the economy and stipulates that for the country to register rapid economic prosperity, it should follow the path of Agricultural Development- Led Industria-lization. This strategy specifies that two key technologies, namely the information and communication technology and biotechnology are essential for rapid transformation of the agrarian economy from largely subsistence mode of production to market-oriented production enterprises leading to industrialization (FDRE, 2002). Application of technologies generated by conventional research has significantly increased the country's agricultural produc-tivity in the past. Biotechnology, if properly integrated into these technologies, would complement these efforts by providing opportunity to speed up such processes and/or giving new solutions to the old or emerging problems in a more precise and cost effective manner. The potential of biotechnology in improving crop and livestock productivity is very huge and rapid progress is being made worldwide on its application. Recognizing the benefit that the safe application of modern biotechnology offers for its agricultural development, Ethiopia has put forward favorable policies to facilitate its use. However, with the current levels of resources, knowledge, skills, infra-structure and awareness, it remained difficult to use such tools to obtain solutions to key agricultural constraints. In this paper, the status of agricultural biotechnology Research and Development (R & D) endeavors in the country is documented along with recent progress in national capacity building.

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Table 1. Status of development of tissue culture protocols at Ethiopian Institute of Agricultural Research (EIAR).

Plant name	Explant used	Main purpose	Status
Banana	shoot tip	micropropagation, virus-cleaning	completed and being scaled up
Cardomom	rhizome lateral bud	micropropagation	completed, being scaled up
Grapevine	shoot tip	micropropagation	completed
Citrus	seed	micropropagation, virus-cleaning	ongoing, good progress
Garlic	meristem	micropropagation, virus cleaning	initial stage
Potato	node	micropropagation, virus-cleaning	completed and being scaled up
Geranium	shoot tip	micropropagation	completed
Enset	shoot tip	micropropagation	ongoing, good progress
Tef	floral part	double haploid line development	ongoing, good progress
Niger	anther	double haploid line development	ongoing good progress
Brassica spp.	anther	double haploid line development	initial stage
Coffee	leaf	micropropagation, *in vitro* disease screening	micropropagation completed, being scaled up
Korerima	rhizome lateral bud	micropropagation	completed
Pineapple	shoot tip	micropropagation	completed, being scaled up
Black pepper	shoot tip	micropropagation	ongoing, good progress
Sweet potato	shoot meristem	micropropagation	initial stage
Ginger	rhizome lateral bud	micropropagation	initial stage
Cassava	meristem	micropropagation, virus cleaning	initial stage

RESEARCH ACHIEVEMENTS AND APPLICATIONS

Modern agricultural biotechnology R & D endeavors are recent developments as compared with the long-established conventional agricultural research in Ethiopia. Public institutions with significant activities in the area at present include the Ethiopian Institute of Agricultural Research (EIAR), the Addis Ababa University, National Veterinary Institute, The National Animal Health Research Laboratory, Institute of Biodiversity Conservation, the International Livestock Research Institute and the Regional Agricultural Research Institutes. R & D achievements in various fields of agricultural biotechnology in these institutions are described below.

Plant tissue culture

Plant tissue culture has been given the highest priority in biotechnology R & D in Ethiopia because it can provide large quantities of disease-free planting materials in short time. Tissue culture activities first started in Ethiopia in 1980's at Addis Ababa University with focus on micropropagation of indigenous forest species like *Podocarpus* sp., *Cordia africana, Hagenia abyssinica* and *Annengeria* sp. that are either difficult to regenerate vegetatively or require long time or have viability problems (Feyissa et al., 2005). This was followed by micropropagation works carried out on some Ethiopian plant species like endod (Demeke and Hughes, 1990), tef (*Eragrostis tef*) (Assefa et al., 1998) and enset (*Enset ventricosum*) (Negash et al., 2001; Birmeta and Welander, 2004). A more comprehensive and concerted plant tissue culture research activities started at the EIAR in 2000 with emphasis on protocol optimization for mass propagation, disease cleansing and/or *in vitro* conservation of economically important crop species. The major achievements from these works include the distribution of large number of tissue culture plants of banana, hybrid coffee, pineapple and potato to farmers in various parts of the country. The current status of tissue culture activities at the EIAR is summarized in Table 1. The table also shows that in addition to micropropagation and virus cleansing, *in vitro* techniques are also being used for production of dihaploid plants to reduce breeding cycle by obtaining pure line for further improvement in crops like tef and Niger (Gugsa et al., 2006; Tesfaye, 2008) and for *in vitro* screening of crops like coffee for resistance to coffee berry disease.

The advantage of tissue culture for rapid and large scale multiplication of plants has been widely recognized in the country in recent years and research efforts are now being extended to other institutions as well. The regional agricultural research institutes like Amhara Agricultural Research Institute and Southern Agricultural Research Institute and some higher learning institutions have recently developed their capacity and initiated tissue culture work for micropropagation of selected crops of importance in the respective geographical areas. In addition, private enterprises such as Mekele Plant Tissue Culture Laboratory have recently emerged and are engaged in large scale multiplication and distribution of tissue culture plantlets of crops such as banana, sugarcane, grapevine and flowers to producers in northern-Ethiopia.

Table 2. Application of molecular markers to study the genetic diversity and/or phylogeny of agricultural organisms from Ethiopia.

Organism	Marker type used	Reference
Crops/plants		
Barley	RFLP	Demisse et al., 1998
Brassica carinata	RAPD	Teklewold and Becker, 2006
Coffee (cultivated, forest)	RAPD, ISSR, AFLP, SSR	Aga et al., 2003, Aga et al., 2005, Silvestrini et al., 2007.
Coffee	Sequence of part of chloroplast genome	Tesfaye et al., 2007
Enset	AFLP, RAPD	Negash et al., 2002, Birmeta et al., 2002
Guizotia spp.	ITS sequence	Bekele et al., 2007
Guizotia spp. (weedy and wild)	AFLP; RAPD	Geleta et al., 2007
Hagenia abyssinica	ISSR	Feyissa et al., 2007
Highland maize	AFLP	Beyene et al., 2006
Linseed	AFLP	Wakjira et al., 2005
potato	SSR	Abebe et al., 2004
Sorghum	AFLP, SSR, RAPD	Geleta et al., 2006, Ayana et al., 2000a
Sorghum, wild	RAPD	Ayana et al., 2000b
Tef	RFLP, AFLP, SSR, ISSR, EST-SSR, SNP	Bai et al., 1999, Bai et al., 2000, Yu et al., 2006, Yu et al., 2007, Zhang et al., 2001
Wheat (tetraploid)	SSR, EST-SSR	Yifru et al., 2006, Wang et al., 2007
Yam	AFLP	Tamiru et al., 2007
Endod	AFLP, RAPD	Semagn, 2002
Mustard	AFLP	Genet et al., 2005
Livestock		
Cattle	RAPD, SSR	Hassan et al., 2007, Dadi et al., 2008
Goats	SSR	Alemu et al., 2004b
Sheep	SSR	Gizaw et al., 2007
Chicken	SSR	Dessie, 2001
Plant pathogens		
Fusarium oxysporum	AFLP, SSR	Bogale et al., 2006
Gibbrella xylarioides	RAPD	Adugna et al., 2005
Puccinia triticina	SSR	Mebrate et al., 2007
Xanthomonas campestris undulosa in wheat	RFLP	Bragard et al., 1995
Xanthomonas campestris musacearum in banana & enset	REP-PCR	Aritua et al., 2008
Ralstonia solanacearum in potato	REP-PCR	Lemesa and Zeller, 2007

AFLP, amplified fragment length polymorphism; RFLP, restriction fragment length polmorphism; RAPD, Random amplified polymorphic DNA; SSR, single sequence repeats; SNP, single nucleotide polymorphism; EST, Expresses sequence tag; ISSR, Inter-simple sequence repeats; REP-PCR, repetitive extragenic palindromic PCR; ITS, internal transcribed spacer.

The demand for tissue culture-derived planting materials by farmers and government development agencies is already huge and set to increase in the coming years. The future strategy of EIAR is to transfer the available tissue culture technologies to regional research institutes, private companies and agricultural development agencies through training and technical backstopping. EIAR's strategy should also include optimization of protocols for new crops or varieties of high demand.

Molecular markers

In recent years, some significant works were done on the use of molecular markers such as Restriction Fragment Length Polymorphisms (RFLPs), Random Amplified Polymorphic DNA (RAPD), Amplified Fragment Length Polymorphism (AFLP) and Single Sequence Repeats (SSR) to analyze genetic diversity of many agricultural species (Table 2). The table also shows that molecular diversity

Table 3. Nucleotide sequences of the Ethiopian isolates of pathogen of crop plants sequenced and/or available in public databases.

Pathogen	Host (Disease)	Sequenced gene	Accession No.	Reference
Xanthomonas campestris musacearum	Enset, banana (bacterial wilt)	Gyrase	DQ 676938-53	Aritua et al., 2008
Xanthomonas vasicola pv vasicola	Maize, sorghum (bacterial stripe)	Gyrase	DQ 676938-53	Aritua et al., 2008
Phytoplasma	Papaya	16S rDNA	DQ 285659	Arocha et al., 2007
Phytoplasma	Citrus	16S rDNA	DQ 286576	Arocha et al., 2007
Phytoplasma	Napier grass	16S rDNA	DQ305977	Jones et al., 2007
Maize streak virus	Maize (streak)	V2 gene for coat protein	X71956	Briddon et al., 1994.
Pepper veinal mottle virus	Pepper (mosaic)	Coat protein/NIb	AJ780970	Moury et al., 2005
Tomato yellow leaf curl virus	Tomato (yellow curl)	DNA-A	AY502934	Shih et al., 2005
Chickpea chlorotic stunt virus	Chickpea, faba bean (stunt)	Complete genome, coat protein	AY956384, AY956385, EU541255-EU541275	Abraham et al., 2006 Abraham et al. 2009
Lentil stunt virus	Lentil (stunt)	Coat protein	GQ118158	Abraham et al., 2008
Soybean dwarf virus	Faba bean (yellows)	Coat protein, partial	GQ118156	Abraham et al., 2008
Faba bean necrotic yellows virus	Faba bean (necrotic yellows)	8 genomic DNAs	AJ749894-901	Katul et al., 1999
Fusarium oxysporum	Soilborne, many species	TEF-1 and -tubulin	DQ220021- 80 DQ220145-152	Bogale et al., 2006
Gibbrella xylarioides	Coffee (wilt)	TEF-1 and -tubulin	AY707101–AY707173	David et al., 2005
Armillaria fiscipes	Coffeee and wood spp. (rot)	rRNA (IGS)	AY172029-AY172033	Gezahegne et al., 2004a
Botryosphaeria parva	*Eucalyptus* spp.	ITS rDNA EF1alpha	AY210474-84	Gezahegne et al., 2004b
Coniothyrium zuluense	*Eucalyptus camaldulensis*	ITS , 5.8 gene	AY244413-15	Gezahegne et al., 2005

analyses were in some cases supported by sequencing of conserved gene(s) to infer the phylogeny of some indigenous species. These efforts are likely to open possibilities for applications in germplasm conservation, DNA fingerprinting and utilization of useful genes in breeding. An important gap in molecular marker research carried out in the country so far is that the studies were not geared towards more important practical applications such as Marker Assisted Selection (MAS). This is partly due to lack of close integration of the research activities with the existing conventional breeding research programs. For instance, extensive molecular studies were made on an Ethiopian cereal tef (*Eragrostis tef*) focusing on the genetic diversity analysis using different markers (RAPD, AFLP, SSR, ISSR and EST-ISSR). In addition, the genetic linkage map was developed to identify the location of markers linked to genes that control important traits and the identification and confirmation of quantitative trait loci (QTL) (Bai et al., 1999a, 1999b; Bai et al., 2000; Yu et al., 2006; Yu et al., 2007; Zhang et al., 2001). How-ever, the synthesis and use of this information for prac-tical application of MAS to ease and shorten the process of breeding is yet to be realized. In another work on wheat leaf rust, molecular markers linked to resistance in wheat were developed (Mebrate et al., 2007). The markers developed and related information obtained in these and other Ethiopian crops should be used to tag specific agronomically important traits for use in marker assisted breeding.

Diagnostics and characterization of crop diseases

Crop disease diagnostics and characterization is one of the areas whereby biotechnological tools are widely used, particularly with viruses. Using Enzyme-linked immunosorbent assay (ELISA), a number of viruses from various crops have been diagnosed to species or strain level (Abraham and Assefa, 2000; Alemu, 2004a; Shih et al., 2005). ELISA is also applied but in a limited scale for

Table 4. The potential of genetic engineering in solving crop production constraints in Ethiopia.

Commodity	Constraints	Candidate transgenes	Application status worldwide
Cotton	Boll worm	Insect resistance (Bt) gene	commercialized
Wheat, barley, tef	Grass weeds	Herbicide resistance gene	commercialized
Maize/sorghum	Stem borer, striga, abiotic stress (drought, frost and salinity tolerance)	Bt gene, striga resistance gene, stress genes & promotors	commercialized and/or being attempted
Tef	Lodging resistance	dwarfing gene from wheat or rice	future plan
Tomato	Tomato Yellow leaf curl virus	Viral rep protein C1 gene	being attempted elsewhere
Potato	Late blight	Resistance genes from wild potato	being attempted elsewhere
Enset/banana	Bacterial wilt	hrap gene from bacteria (*Xanthomonas*)	being attempted elsewhere
Enset	Protein deficiency	Protein enhancement via amino acid modification	future plan
Pepper	potyiruses (Potato virus Y and others)	Viral replicase or protease gene	future plan
Grasspea (*Lathyrus sativum*)	High ODAP* content	Gene silencing with antisense gene for low ODAP content	future plan
Sesame	Sesame seed bug	Bt gene	future plan
Faba bean	Chocolate spot	Chitinase or glucanase gene	future plan
Chickpea	pod borer, stunt virus	Bt gene, Viral coat protein gene	being attempted elsewhere
Sweet potato	weevil	Bt	being attempted elsewhere

*ODAP (-oxalyl-L- , -diaminopropionic acid) is a toxic amino acid of great significance reported from the genus Lathyrus whose presence in high amount causes a medical problem called neurolathyrism. Low ODAP content is a major breeding target in *Lathyrus* (greasspea) improvement in Ethiopia.

identification of bacterial pathogens as in the detection of *Ralstonia solanacearum* in seed potatoes (Kassa and Bekele, 2008). Efforts were also made to replace the major components of standard ELISA with locally available alternatives like Petri dishes and cheaper enzymes to minimize the associated cost without compromising the efficiency of the system (Abraham and Albrechtsen, 2000, 2001). In some instances, PCR-based methods were used to identify viral pathogens in legume crops, pepper, tomato and sweet potato (Abraham et al., 2006; Alemu, 2004a; Shih et al., 2005) or bacterial plant pathogens in crops like potato, enset and banana (Aritua et al. 2008, Lemessa and Zeller, 2007). Nucleotide and/or predicted amino acid sequences of the whole or part of the genome of a number of Ethiopian viral, bacterial or fungal pathogens affecting different crops were obtained and in most cases deposited in public database (Table 3). Such molecular data can have application in other studies including development of diagnostic PCR primers or cDNA probes or act as references for elucidating the phylogenetic and taxonomic relationship of the pathogens under study to others.

Animal production and health

The most commonly used reproductive biotechnology tool in Ethiopia for over three decades is artificial insemination. The National Artificial Insemination Center (NAIC) established in Kaliti in 1981 is a national center for the production, preservation and distribution of cattle semen mainly from selected exotic (Holstein Friesian) sires (NAIC, 1995). To a limited extent, it also produces semen from selected sires of indigenous breeds and their crossbreeds with Holsteinn Freisians. It has an average capacity of producing 170 thousand doses of semen per year. The manipulation of animal reproductive biology by embryo transfer is targeted as an area of focus in biotechnology in Ethiopia. The International Livestock Research Institute initiated embryo transfer program at Debre Zeit Research Station in 1990, primarily on zebu cattle and the first calf was born in 1991 (Tegegne, 1991) . Refinement of superovulatory regimes for Boran cattle has been undertaken and eight pairs of identical twins calves were produced using embryo- splitting tech-nique (Tegegne et al., 1994). Unfortunately, however, this technology has not been systematically transferred to the national agricultural research and extension system. Efforts are currently underway to apply multiple ovulation and embryo transfer technology using indigenous breeds at the EIAR. Biotechnological advances in the area of animal diseases in Ethiopia mainly involve the development of vaccines and disease diagnostic tools. The National Veterinary Institute based at Debre Zeit is involved in large scale production of vaccines for major diseases of large and small ruminants and chicken (Yoseph, 1996). The institute produces vaccines for about 17 types of viral and bacterial diseases including rinderpest, sheep fox, Newcastle, African horse sickness, foot and moth diseases, contagious bovine pleuropneumona, anthrax, blackleg, pasteuellosis (for bovine, small ruminants and poultry and contagious caprine pleuropneumona. At present, the institute fully satisfies the national demand for livestock vaccines and also exports to some African and Middle East countries. Recombinant DNA-based vaccines have also been produced in collaboration with oversee laboratories and used against rinderpest (Yilma et al., 1988) while dual recombinant vaccine for capripoxvirus and peste des petits ruminants virus in small ruminants is under evaluation (Berhe et al., 2003) in collaboration with foreign institutions. ELISA, cDNA probes and PCR-based methods have been used at Animal Health Research Laboratory, Sebeta in livestock disease diagnosis (Abraham, 2005; Abraham et al., 2005; Roeder et al., 1994). Molecular characterization and phylogenetic studies of Ethiopian isolates of many animal viruses has been done among others for peste-des-petits virus (Abraham, 2005) and foot and mouth disease virus (Sahle et al., 2007) by reverse transcriptase PCR analysis and sequencing parts of the viral genome.

Biofertilizers and biopesticides

Research on biofertilizer in Ethiopia has focused mainly on *Rhizobium* and related genera. Much effort has been devoted to identify and characterize efficient forms of indigenous Rhizobia as soil inoculant for faba bean, field pea, chickpea and fenugreek (Asfaw and Angaw, 2006) and selected strains are mass produced and supplied to farmers in various parts of the country. In addition, a superior strain *Bradyrhizobium japonicum* introduced, selected, tested as soybean inoculants, produced in large scale and used by farmers in western soybean growing areas of the country. Molecular genetic analysis of local Rhizobia associated with cultivated and woody legumes in the country has shown huge diversity including the occurrence of previously unknown species (Beyene et al., 2004; Woldemeskel et al., 2004). A vast volume of research has been carried out on the exploration, identification and screening of local and introduced biocontrol agents for the control of crop diseases, insect pests and weeds in Ethiopia. However, only in few cases have biopesticides passed field trials and none has been commercialized. The most promising biopesticides based on indigenous microbes are *Beavaria bassiana* and *Metarihizium anisiphole* for the control of locusts, grasshoppers and storage pests (Kassa et al., 2002; Kassa et al., 2004; Tadele and Pringle, 2004). Some progress has been made in developing the storage, formulation and application technologies for these biopesticides. Similarly, *Trichoderma viridae* has been found to be effective against root rot disease of faba bean (Beshir, 1999) while *Bacillus thurigiensis* was efficient in controlling diamondback moth on cabbage from under field conditions (Ayalew, 2006). Despite demonstrations of effectiveness under field conditions, the biofertilizers and biopesticides developed locally are not yet commercialized. The main reasons appear to be lack of expertise in the crucial stages of product development and inadequate technical capacity of public institutions to efficiently manage the production process. Future work should focus on addressing these problems to make use of indigenous and introduced microbial products as economically and environmentally better alternatives to chemical fertilizers and pesticides.

THE POTENTIAL BENEFITS OF GENETICALLY MODIFIED CROPS TO ETHIOPIA

Genetic engineering offers several benefits when used responsibly by addressing the environmental and food safety concerns with rigorous biosafety regulations. Until recently, guidelines with genetic engineering research and deployment of genetically modified organisms (GMOs) do not exist in the country. This situation discouraged Ethiopian scientists from initiating genetic engineering projects and participating in similar network activities at regional and international level and consequently significantly hampering the research and capacity building process in modern biotechnology R & D in the country. A big step taken this year by the Ethiopian government is the approval of biosfaety law by the parliament on 7th of July 2009 which is expected to encourage genetic engineering research as well marketing of its products in the country in a responsible way. A wide range of crop production problems that are either difficult or impossible to address using conventional research techniques are likely to be solved using crops genetically engineered for specific traits and adapted to local conditions. The major crop production constraints in Ethiopia that can be addressed by genetic engineering are indicated in Table 4. For some of these constraints, transformation technology is already developed elsewhere and commercially available and only needs to be introduced and adopted to local conditions with minimum technical inputs. Recently for example, the private sector has expressed keen interest in introducing *Bt* cotton to boost its production and thus satisfying the booming textile industry in the country. These efforts will help boost cotton production in Ethiopia as many cotton producing farmers in western Ethiopia are abandoning their cotton fields due to heavy boll worm infestation pressure. By partnering with commercial companies like Monsanto, such technologies can be accessed relatively easily. It is also possible to use such transgenic plants as parents to transgress the desired genes to locally preferred cotton varieties by conventional breeding. On the other hand, to address constraints on indigenous crops like tef and enset that are not of interest to foreign companies, there is a need to develop local capacity in genetic engineering technologies in terms of infra-structure and manpower.

NATIONAL CAPACITY BUILDING EFFORTS

In addition to building its biotechnology capacity at its various research centers in different areas, the EIAR has established an independent national agricultural biotech-nology laboratory with assistance from the World Bank. The laboratory complex located at Holetta, 28 km west of Addis Ababa will cater plant, animal and microbial R & D. It will serve as a national center of excellence for agricultural biotechnology research, technology genera-tion and human resource development. When fully furnished, the laboratory will have facilities for sequenc-ing and genotyping, protein analysis, microbial and animal biotechnology, bioinformatics and genetic engineering including containment greenhouses. The biotechnology teaching and research capacity of Addis Ababa University has been strengthened through training of individuals, acquisition of equipments by the govern-ment and foreign funded projects sponsored by countries like Sweden. The regional agricultural research institutes like the Amhara and South Agricultural Research Institutes have also developed facilities for plant tissue culture research and are at initial stages of research and development. Many bigger public higher learning institu-tions including Addis Ababa, Debub, Haramaya and Jimma Universities are also strengthening their capacity in biotechnology particularly in plant tissue culture. Concerning biotechnology education in the country, most universities teaching life sciences in undergraduate and postgraduate degree programs have included a biotechnology course. The Addis Ababa University is a leading institution in Ethiopia that offers an MSc degree in biotechnology and PhD degrees in biotechnology related areas in collaboration with foreign Universities while Gondar University has an undergraduate program with a biotechnology major subject. Jimma University has more recently launched an MSc program in plant biotechnology. In addition, a good proportion of scientists educated abroad have studied biotechnology subjects and gained reasonably good laboratory skills in special-ized areas such as molecular biology, tissue culture, genetic engineering, bioinformatics and biosafety. Upon return to Ethiopia, these scientists are acting as teaching and research staff in various agricultural research and higher learning institutions in the country. The undergraduate and MSc courses offered in Ethiopia however focus more on theoretical aspects mainly due to constraints in acquiring the necessary laboratory equip-ment, chemical supplies and running expenses associa-ted with practical experiments. This situation has to be improved so that the local graduates can meet the demand for highly skilled experts in the field.

RECOMMENDATIONS FOR FURTHER IMPROVEMENT

It is evident that there are real prospects for the benefit of biotechnology tools and products in Ethiopia. However, a close look at the current situations reveals a number of constraints and gaps that contributed to the under-development of agricultural biotechnology. The following steps are recommended to strengthen the national bio-technology capacity in the country and realize its benefits. Effective biotechnology policy directives and biosafety system as well as regulatory and monitoring mechanisms need to be in place, in particular, for the introduction, research and release of GMOs; current applications such as plant tissue culture, microbial products development, vaccine production and diagnos-tics should be expanded; the wise utilization of the country's biodiversity by *in vitro* conservation, molecular characterization and introduction of marker assisted breeding and isolation of potentially useful genes should be promoted; there is a need to develop a strong national capacity in recombinant DNA research such as GMOs including containment greenhouse facilities; sufficient financial resources should be made available by mobilizing public and private sector and from local and external sources; establishing and sustaining institutional linkage within the country as well as strengthening colla-boration among Ethiopian and foreign institutions should be improved; policies and incentive mechanisms should be developed to encourage private sector investment and their participation in agricultural biotechnology R & D; Universities offering biotechnology courses should upgrade their laboratory in terms of manpower and facilities to acquaint the students with practical skills and produce competent manpower; and finally an active and honest interaction between scientist and other society members including the public and decision makers should be encouraged.

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