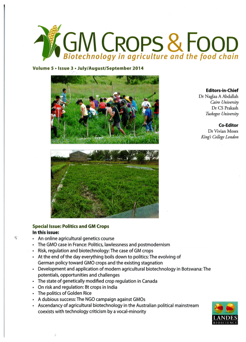

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Development and application of modern agricultural biotechnology in Botswana: The potentials, opportunities and challenges

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Keywords: agriculture, biosafety, genetic engineering, GMO, human resources, infrastructure

In Botswana, approximately 40% of the population live in rural areas and derive most of their livelihood from agriculture by keeping livestock and practising arable farming. Due to the nature of their farming practises livestock and crops are exposed to diseases and environmental stresses. These challenges offer opportunities for application of biotechnology to develop adaptable materials to the country's environment. On the other hand, the perceived risk of genetically modified organisms (GMOs) has dimmed the promise of the technology for its application in agriculture. This calls for a holistic approach to the application of biotechnology to address issues of biosafety of GMOs. We have therefore assessed the potentials, challenges and opportunities to apply biotechnology with specific emphasis on agriculture, taking cognisance of requirement for its research, development and application in research and teaching institutions. In order to achieve this, resource availability, infrastructure, human and laboratory requirements were analyzed. The analysis revealed that the country has the capacity to carry out research in biotechnology in the development and production of genetically modified crops for food and fodder crops. These will include gene discovery, genetic transformation and development of systems to comply with the world regulatory framework on biosafety. In view of the challenges facing the country in agriculture, first generation biotech crops could be released for production. Novel GM products for development may include disease diagnosis kits, animal disease vaccines, and nutrient use efficiency, drought, and pest and disease resistant food and fodder crops.

Introduction

In Botswana, the rural populations derive their livelihood from agriculture, which provide food, income, employment and investment opportunities. The sector comprises of livestock and crop production. Beef cattle production dominates the livestock, but small stock is also important especially to poor and subsistence rural households.[1] The recent livestock population are approximated as 2.7 million cattle, 1.9 million goats and 0.3 million sheep.[2] The major challenges to livestock production include lack of superior breeds, quality feed, drought and animal disease prevalence. In terms of diseases, the intermittent outbreaks of foot and mouth disease has affected beef export to lucrative markets.[3] With about 6 thousand dairy cattle[4] in the country, numerous challenges besiege the industry of which unavailability of animal feed in both quantity and quality as well as climatic stress for lactating cows is mostly associated with low performance of lactating dairy cows.

Despite the dominance of the livestock sub-sector in the rural economy, arable farming is also an important practice among smallholder farmers. In 2004, there were around 60,000 smallholder households engaged in arable farming.[5] During the last decade, the area planted with rain-fed crops by both smallholders and commercial farms totaled about 150,000 hectares annually.[6] Recent reports show that these figures have jumped to almost 300,000 ha on 90,000 holdings.[6] The major rain-fed crops grown by these small holder and commercial farmers include cereals (maize, sorghum, and millet), pulses and sunflower. The Horticultural subsector is another important farming enterprise that produce mainly vegetables and to a lesser extent fruits. The environment in which crop production takes place in Botswana is characterized by low and unreliable rainfall, very high summer temperatures and relatively poor soils and saline irrigation water.[1] The major biotic factors that constraint crop production are pests and disease.[7-10] These environmental factors pose both biotic and abiotic stresses to crop plants, resulting in low production and quality of produce.

Biotechnology is defined as the use of living organisms and bioprocess to make or modify a product, improve plants or animals or develop products for specific uses. Biotechnology has enabled the generation of genetically modified (GM) crops, which are crops into which one or several genes coding for

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desirable traits have been inserted through the process of genetic engineering (GE). The genes may originate from the same or other species and organisms unrelated to the recipient organism.

In animal systems, GM organisms are used extensively in in vivo study of gene function, models for human diseases and production of biopharmaceuticals. The use of these animals promises a revolution in the production of heterologous proteins in milk. Studies have demonstrated that genetically engineered farm animals, notably cattle, goats and pigs have been able to produce the heterologous proteins in milk.[11-13] However, the principal applications of biotechnology in animals to-date has been in the production of vaccines for human and animal diseases[14] and animal disease diagnosis.[15] Some of the vaccines include the vCOGnGc and vCOGnGcγ, which are used against the Rift Valley fever, a disease of both humans and livestock. In animal diseases detection, monoclonal antibodies and nucleic acid probes are widely used in diagnostic tools. For example, PCR used in combination with hybridization analysis has been shown to provide a sensitive diagnostic assay to detect Bovine leucosis virus.[15] PCR coupled with Restriction Fragment Length Polymorphism (RFLP) eliminate ambiguity and subjectivity in the identification of certain parasites.[16] In addition to biopharmaceutical products and vaccines, other applications of biotechnology in animal systems can also be envisaged for forage improvement through, agronomic and nutritional quality traits. Notable examples to that end are herbicide tolerant alfalfa,[17] maize,[18] and other forage and fodder crops (rye grass and tall fescue).[19]

In Botswana, the Ministry of Agriculture has for many years come up with strategies to mitigate the effect of biotic and abiotic factors on crop production so that yields could be improved. The strategies involved coming up with policies that support farmers to increase arable crop production and productivity at the farm level.[20] Despite these efforts yields have fluctuated after implementation of these mitigation strategies. This calls for new innovative methods that are scientifically based and proved to work elsewhere. Biotechnology has been hailed as one technology when incorporated into other practices can improve agricultural production. In addition to agronomic traits, biotech crops have also resulted in environmental benefits, which include reduction in pesticide usage and greenhouse gas emissions.[21] These reductions were associated with less frequent pesticide and herbicide applications and fossil fuel use.

The technology has been used over several years to produce first generation biotech crops which were insect resistant

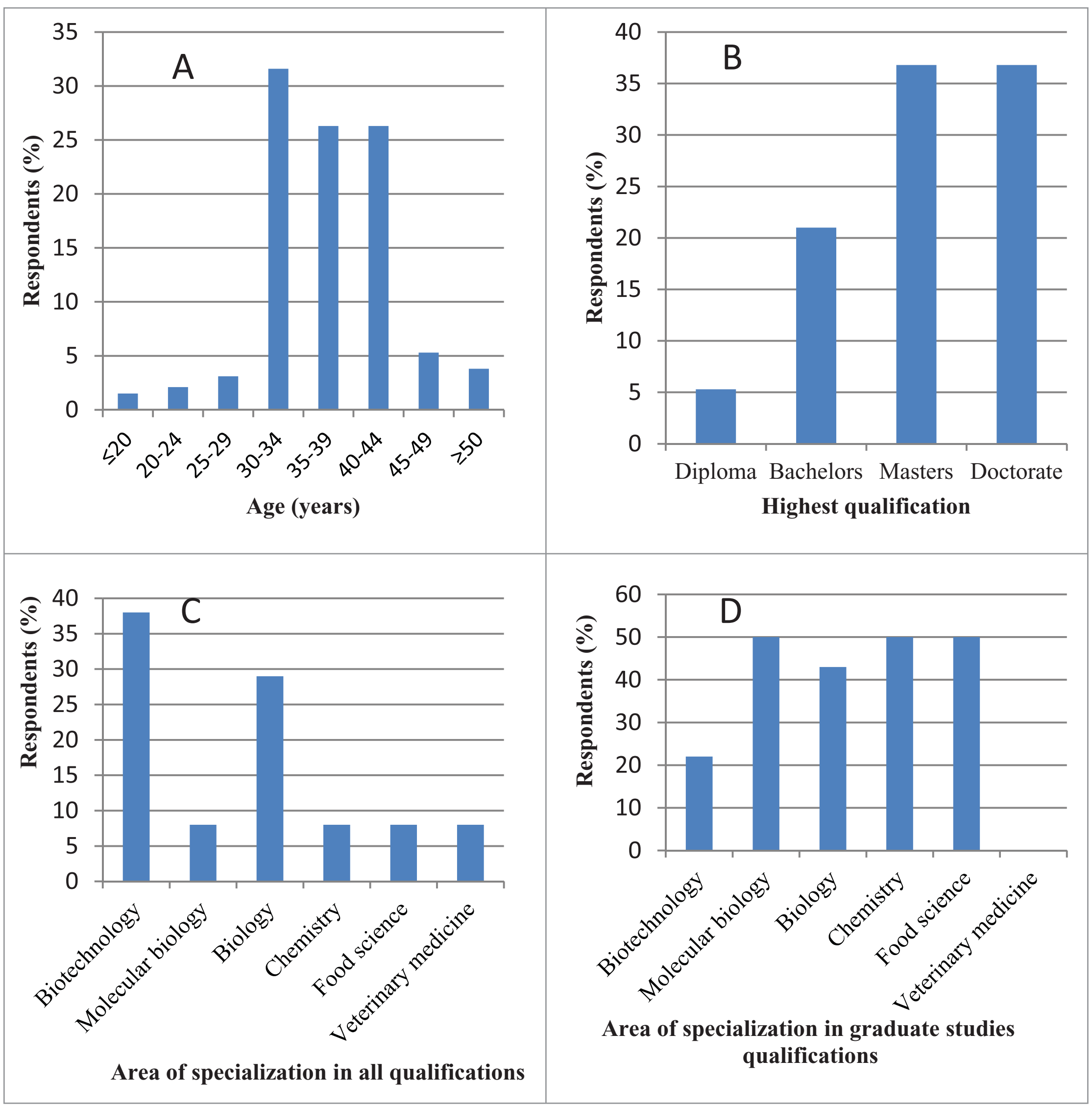

Figure 1. Demographic characteristics of respondents for biotechnology in surveyed institutions in Botswana.

(IR)[22] and herbicide tolerant (HT) plants[23] expressing bacterial genes CRY and CP4 EPSPS, respectively. Some of the successfully developed and commercialized GM crops are IR (maize, cotton, canola) and HT (soybean, cotton, maize, sugar beet, alfalfa).These crops were later joined by those with a combination of the two traits in the same plant (IR/HT), known as stacked IR/HT cotton and maize. In addition to this, biotechnology has been successfully applied to generate virus resistant fruits and vegetables such as papaya, plum and squash by coat protein mediated resistance (CPMR).[24] Recently, the United States Department of Agriculture allowed the agricultural biotechnology company Monsanto to sell the first generation drought tolerant maize MON 87460. This has been genetically engineered with the cspB gene from the soil bacterium Bacillus subtillis.[25] The other success was the genetically engineered tomato and sweet pepper for longer shelf life that prevent them from rotting and degrading. The crops have since been released for commercial production by farmers in the USA and China.[26,27]

According to James (2012),[27] the year 2013 marked a 100-fold increase in biotech crops hectarage from 1.7 million hectares in 1996 to 170 million in 2012, making them the fastest adopted crop technology in recent history. Of the 28 countries which planted GM crops in 2012, there were three times as many developing countries growing the crops as there were industrial countries. The five lead developing countries are China and India in Asia, Brazil and Argentina in Latin America and South Africa in Africa, which collectively account for 46% the global production.[27] According to Okeno et al. (2012),[28] apart from South Africa, Burkina Faso and Egypt are the other African countries involved in commercial production and field trials of GM crops with Uganda, Kenya and Nigeria as examples that are carrying out confined trials on a number of first generation GM crops.

The next generation of biotech crops is likely to include those with diverse traits such as enhanced nutrition, increased yield, nutrient use efficiency and stress tolerance.[29] Some of the developed crops undergoing confined field trials in South Africa, Burkina Faso, Egypt, Uganda, Kenya and Nigeria are bio-fortified sorghum, banana and cassava; virus resistant (VIR) sweet potato, potato and cucumber; drought tolerant (DT) maize and salinity tolerant wheat.[28] Various reports indicate that high yielding,[30] enhanced nutrition,[31-33] biotic stress tolerant[34,35] and nitrogen use efficient[36] crops are being developed throughout the world.

It is against this background that Botswana can therefore move toward adopting biotechnology to enhance agricultural growth and improve quality of life by fully exploiting the advantages.

The purpose of this study was, therefore, to evaluate the capacity of existing local institution to undertake research and development in biotechnology and effectively monitor and evaluate GM products and their use. We focused on the availability of infrastructure, human resource and support services applicable to biotechnology and its allied fields for gene discovery and GE and availability of biological resources.

Results

Institutions involved in biotechnology: Their status and achievements in the field of academic institutions: The University of Botswana (UB) and the Botswana College of Agriculture (BCA)

These are institutions that are traditionally involved in offering of tertiary level education and generation of new knowledge through research and development. One of them is the University of Botswana (UB), which is a national university under the Ministry of Education, and Botswana College of Agriculture (BCA) an institution under of the Ministry of Agriculture and currently an associate institution of UB. The UB and BCA are currently the only Academic institutions of higher learning that are actively involved in biotechnology related research and teaching. Laboratory space and some support services are provided in various departments in both institutions to support teaching and research.

The UB houses among others, the Faculty of Science where research and teaching in biotechnology are done in the Department of Biological Sciences. The Department offers courses at undergraduate, Masters and PhD levels. Over the years staff in the department has published work on bacterial[40,41] and human molecular genetics.[42,43] The Department is currently collaborating with Pitzer's Vaccine Development Institute in the USA, and locally with Botswana Vaccine Institute (BVI) and Botswana National Veterinary Laboratory (BNVL) on developing methods for cattle lumpy skin disease vaccines (Grill, unpublished). The UB and BNVL will be responsible for advancing the candidate vaccines for clinical trial, production and distribution, while Pitzer's College will provide potential vaccine leads.

Botswana College of Agriculture being a faculty under UB houses among others, two departments that are actively involved in biotechnology research and training: Animal Science and Crop Science departments. The two departments have academic and technical staff members trained in various fields that directly and indirectly support research in biotechnology. Research outputs in the area of biotechnology have been published for plant[44] and animal breeding,[45] plant functional genomics,[46] plant disease diagnosis[47] and plant-microbe interactions.[48] Activities in both academic institutions suggest that they have the required infrastructure and human resources at the minimum to carry out teaching and research in biotechnology and areas that support it.

Research and development institutions: The National Food Technology Research Company (NFTRC) and Department of Agricultural Research (DAR)

These are establishments, whose mandate is to generate new knowledge and products in order for the country to attain food security by means of applied research. One of them is NFTRC, which was established in 1987 as a food laboratory and transformed in 1997 into an independent Government of Botswana company limited to generate food technologies. These technologies were meant to enhance economic diversification, food

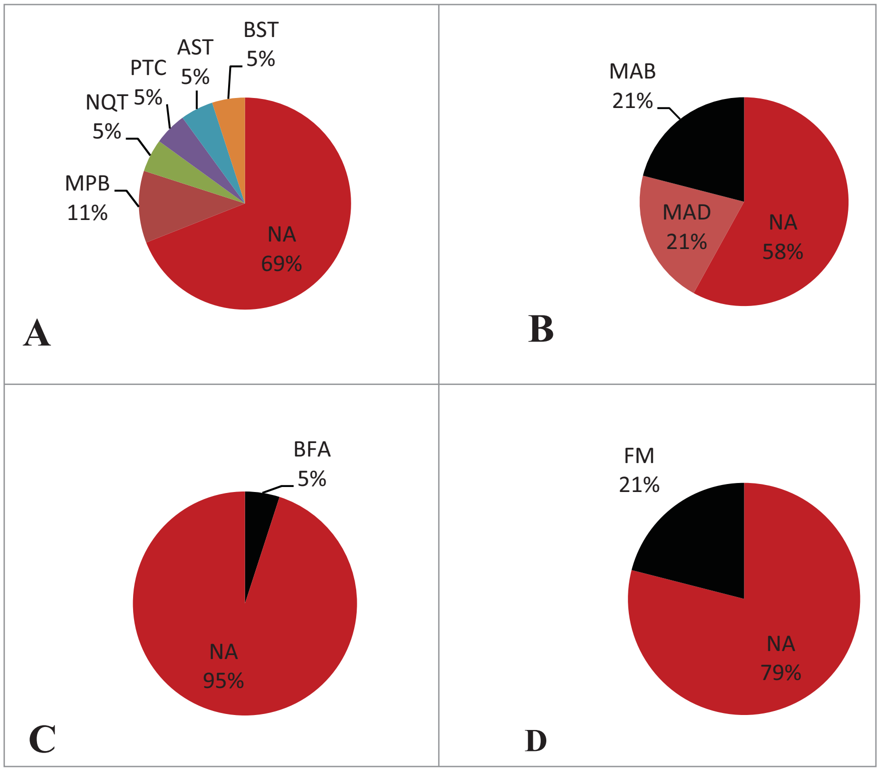

Figure 2. Expertise availability for biotechnology applications in the different Institutions surveyed in Botswana. **A** = Crop, **B** = Animal, **C** = Environmental, **D** = Industrial. The Institutions surveyed were BCA, DAR, BNVL and NFTRC. NQT = nutritional quality transgenic plants, MPB = molecular plant breeding, PTC = plant tissue culture, AST = abiotic stress transgenic plants, BST = biotic stress transgenic plants MAD = molecular animal disease diagnosis, MAB = molecular animal breeding, BFA = bio-fertilizer production, FM = Food manufacturing applications, NA = not applicable.

security and quality through research and development in food technology, food biochemistry, food microbiology and biotechnology, nutrition, extension and training. The Biotechnology unit at NFTRC conducts research on the use of biological processes, organisms and their products for the production of materials and services. The unit carries out GMO testing by determining the presence of 35S promoter and NOS terminator sequences in processed soybean and maize based products. The unit also participates in proficiency testing in the genetically modified material testing scheme. The scheme is an essential part of laboratory quality procedures that gives confidence in equipment, methods, staff and quality assurance.

The other institution is the Department of Agricultural Research (DAR) which is the research organ of the Ministry of Agriculture with a mandate to carry out research for generation of improved crop and livestock production technologies to promote a productive and sustainable agriculture sector. The department addresses this through focused programmes in arable and horticultural production under the division of Arable Research Division.[49] Animal Production and Range Research Division conducts research mainly on development and improvement of cattle, sheep, goats, range and pastures. In recent years, DAR has moved toward undertaking research in GMO testing of maize based products. Activities in these institutions indicate that DAR can participate in biotechnology development through GMO testing and risk assessment.

Disease diagnosis institutions: Botswana Vaccine Institute (BVI), Botswana National Veterinary Laboratory (BNVL) and Botswana-Harvard HIV Reference Laboratory (BHHRL)

These are institutions which are involved in the application of molecular techniques to diagnose livestock and human diseases. One of them is Botswana Vaccine Institute, established in 1979 by the Ministry of Agriculture, and responsible for genotyping of foot and mouth disease virus and conduct research on the potency and safety tests of its flagship product (FMD vaccine) and others against blackleg, anthrax and contagious bovine pleuropneumonia (CBPP). In collaboration with other reference laboratories, it is also involved in virus identification and testing of diagnostic reagents. The laboratory provides services to the whole of Sub-Saharan Africa with vaccines.

In the same Ministry of Agriculture, BNVL was established to provide laboratory services for animal disease surveillance, monitoring of abattoir hygiene, agrochemical residue in meat, milk and their by-products.[49] These are for purposes of facilitating trade in these products in local and international markets. The laboratory applies serological and PCR based disease diagnosis tools for various diseases including, foot and mouth, African horse sickness (ASH), contagious bovine pleuropneumonia (CBPP). Research in disease surveillance and diagnosis is also carried out by the laboratory and the findings were widely published in various journals.[50-52] In 2007, the BNVL was accredited to the international standard for ISO:17025 by the South African National Accreditation System (SANAS) making them the first government laboratory to achieve such status in Botswana.

In the Ministry of Health is the Botswana-Harvard HIV Reference Laboratory (BHHRL), which is a research facility for processing and testing clinical specimens for monitoring of HIV prevalence in the country. Laboratories in the facility are fully equipped for research and development in DNA isolation, amplification, cloning and sequencing and analysis for the diagnosis of HIV and other sexually transmitted diseases. The BHHRL, in collaboration with the Harvard Aids Institute, has conducted and widely published their research findings. Some of these publications are in reputable journals.[53] These applied molecular biology based techniques such as structural genomics, drug resistance mutation, viral strain genotyping were used to study the HIV and associated virus causing human diseases. The ability of these institutions to apply molecular biology techniques such as DNA sequencing and analysis and the reputable publications demonstrate capacity to develop and apply biotechnology.

Institutions involved in provision of infrastructure and service: Botswana Innovation HUB (BIH)

Established in 2010, The Botswana Innovation Hub, which is still under development is to be the nation's center of excellence for innovation in biotechnology, ICT, energy/environment among other areas. The BIH is mandated to support new ventures and existing companies, universities, research institutions to establish hubs by making available among others services and laboratory space for other institutions. The intention is to transform the country into a technology-driven and knowledge based economy by promoting a culture of innovation. In the field of biotechnology, the focus is on catalyzing research and development in testing and manufacturing, with emphasis on food security and indigenous natural products. In ICT, the BIH is expected to conduct research in software and hardware development, data networks, and high tech computing, which will complement the area of biotechnology. The ICT component will enable computer based biotechnological techniques such as bioinformatics and computational biology, which are requirements for high through put gene discovery.

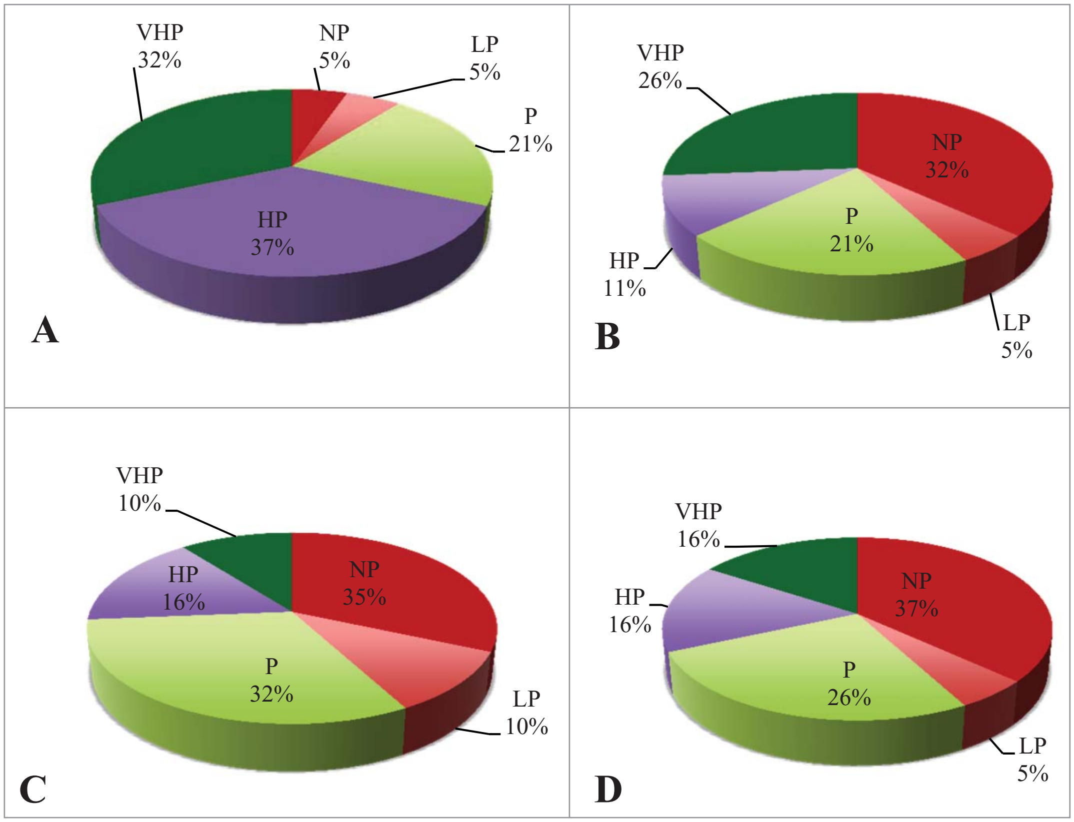

Figure 3. Staff proficiency in molecular biology and recombinant DNA techniques. **A** = DNA isolation and analysis, **B** = RNA isolation and analysis, **C** = Protein isolation and analysis, **D** = Recombinant DNA technology. NP = not proficient, LP = low proficiency, P = proficient, HP = high proficiency, VHP = very high proficiency.

Analysis of Resources Important for Biotechnology in Research and Development Institution

The results presented in this section describe demographic characteristics of respondents such as gender and age and level of education (**Fig. 1**). The results showed that more than 5 times males are involved in the field of biotechnology than females. Age of respondents involved in biotechnology research and development show that the majority (84%) are in the age category of 30–44 y, while below 5% of the respondents are below and above this range (**Fig. 1a**). The survey further showed that most of the staff is within the experienced and below early retirement age of 45 y of age. Staff members in the surveyed institutions were trained up to graduate levels (**Fig. 1b**) in relevant fields of biotechnology and those that support it (**Figs. 1c and 1d**).

The survey indicated that application of biotechnology expertise in the country was available in four broad areas, namely crop, animal, environmental and industrial biotechnology (**Fig. 2**). As shown in **Figure 2a**, expertise in crop biotechnology was dominated by molecular plant breeding (11%), while others aggregated as plant tissue culture and transgenic plants were also significantly represented accounting for 20%. In animal biotechnology applications expertise was largely in molecular animal breeding and disease diagnosis (**Fig. 2b**). In other applications such as environmental and industrial biotechnology (**Figs. 2c** and **d**), the staff is underrepresented except staff trained in bio-fertilizer and food manufacturing applications.

The results on proficiency, which assessed the mastery of staff on ability to follow established laboratory protocols and procedures, are presented on **Figure 3**. These assessments were based on knowledge of molecular and systems biology based techniques. The analysis indicated that 73% of the respondents were proficient in molecular biology based techniques while 27% of

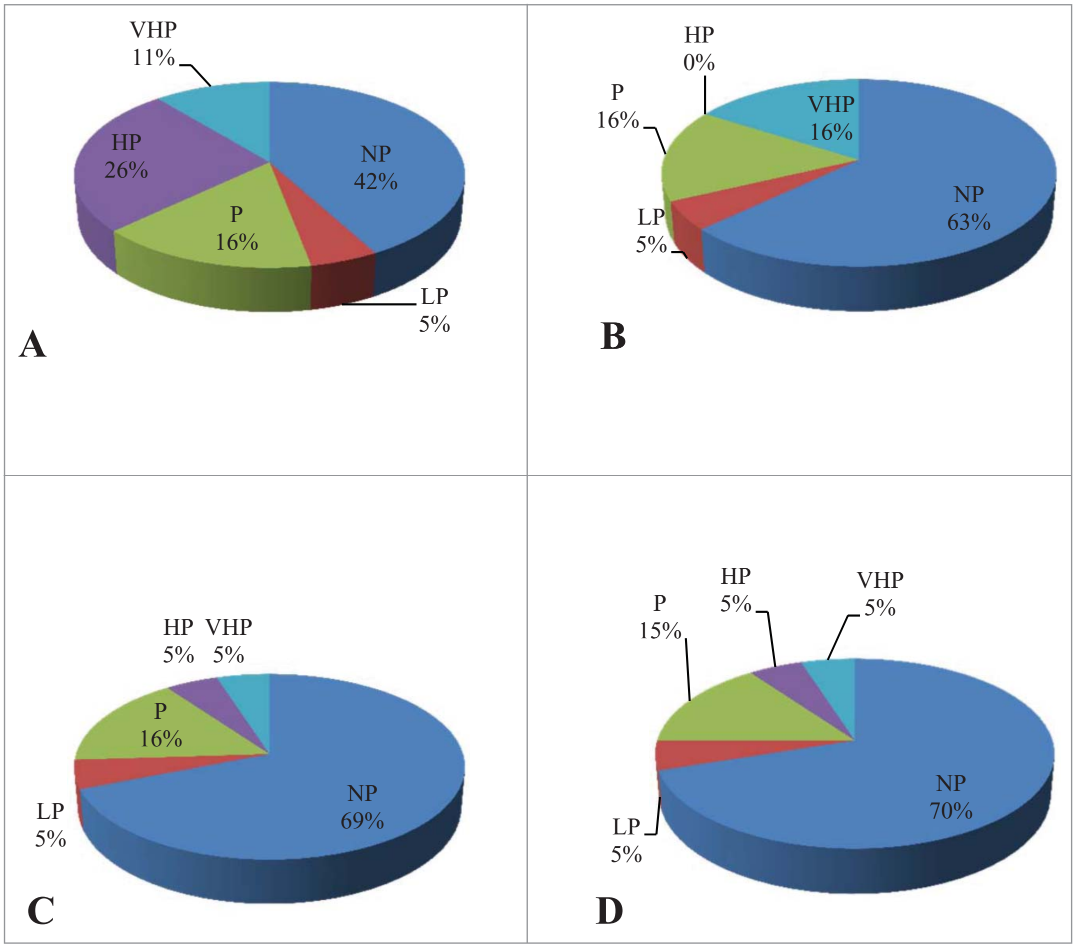

Figure 4. Staff proficiency level in bioinformatics based techniques applied to biotechnology. **A** = Genomics, **B** = Transcriptomics, **C** = Proteomics, **D** = Metabolomics. NP = not proficient, LP = low proficiency, P = proficient, HP = high proficiency, VHP = very high proficiency.

the respondents were not (**Fig. 3**). This analysis can therefore be described as good by any standard for a system of laboratories to perform both basic and applied research and development in biotechnology.

In systems biology based techniques, proficiency levels averaged 39% across surveyed institutions (**Fig. 4**). This can be described as relatively low but adequate to support molecular biologists and other scientists to apply systems biology based techniques in their research and development in biotechnology. When assessing the ways in which molecular and systems biology skills were acquired, it was observed that majority of staff acquired skills through normal training during studies for both molecular and systems biology (**Fig. 5**). Other training methods reported in the survey were short courses, attachment to specialized laboratories and post-doctoral training.

Research and development in biotechnology requires access to basic equipment, library and internet resources. Equipment enables workflow for nucleic acids and protein isolation and advanced equipment for analysis of the molecules. The survey results showed that basic equipment was available to enable isolation of nucleic acids (DNA, RNA) and proteins (**Fig. 6**). On the other hand, while equipment to allow advanced analysis of DNA, RNA and proteins were available, DNA and next generation sequencing systems were not available (**Fig. 5b**). Just like any other, research in this field requires access to literature in the form of books, journal articles and web based resources. The capacity to provide such by respective institutions was also assessed.

The results showed that access to these sources of literature and information is generally low in these institutions (**Fig. 7**). The assessment of research output and quality during the past 20 y showed that publications were in the form of book chapters, journal articles, conference proceedings and very few patents (**Fig. 8a**). Owing to the importance of journal article publication in research, those that were accessed through the data bases were further analyzed for their quality by way of the impact factor of journals in which articles were published (**Fig. 8b**). Journal quality analysis indicated that most of the articles were published in journals with low to average impact factors. Some of the reputable journals in this category were FEMS Microbiology Letters (IF = 2.049),[40] Journal of Animal Breeding and Genetics (IF = 1.654)[45] and Journal of Plant Physiology (IF = 2.960).[48] It was found that researchers in these institutions co-authored articles in high-level international journals (IF greater than 5) and very high (IF greater than 10) impact factors over the last 20 y. For example, staff at the UB, BCA co-published articles in life sciences and biotechnology in Nature Communications (IF = 10.015),[43] Plant Physiology (IF = 7.084),[46] Molecular Biology and Evolution (IF = 10.353)[42] journals.

Discussions

In recent years, biotechnology has brought a promising prospect of a worldwide growth in such areas as agriculture, environmental protection, industrial processing, medicine and pharmaceutical industry. As a field of great importance to the whole of society, which could change the pattern of future industry and economy, biotechnology has been drawing increasing attention from every country of the world. In agriculture, application of biotechnology has been applied in crops than in animal development. These applications are in the development of herbicide tolerant and insect resistant crops and a combination of both traits.[22,23]

Recent analysis of biotech crop production trends indicates that other developing countries such as South Africa and Burkina Faso in comparison with the USA, displayed an exponential increase in the production of biotech crops for the 3 y 2010–2012 (**Fig. 9**). This trend presents a challenge to Botswana, especially that the neighboring South Africa is showing advancement in technology application with regards to crop biotechnology. The challenge can also be viewed as an opportunity since Botswana can tap on biotechnology built by South Africa in the field.

In Botswana, pests, diseases, weeds, nutrient stress and drought are major causes of low productivity. This is indicated by low productivity displayed by crops; maize, sorghum, millet, pulses, sunflower and groundnuts in the country the region (**Fig. 10**). The use of biotech over conventional varieties has been reported to increase production and yield in the following crops and locations; soy bean in USA,[54,55] cotton in India[56] and maize in South Africa.[57] These indicate a range of agro-ecological zones where the 4 main biotech crops have increased yields. Therefore, it will be incumbent upon Botswana, to consider investing in the biotechnology for abiotic and biotic stress management in crop production.

It is against the above background that this paper was set to determine the potentials, challenges and opportunities for Botswana, a developing country to develop agricultural biotechnology, by focusing on infrastructure and human resource. One of the main ingredients for technology development is creating an appropriate frame work of scientific and technical infrastructure and institutions.[58] Creating such a frame work involves investment in both physical and human capital. In general these include laboratories, scientific equipment, trained scientific and technical manpower, industrial and institutional linkages, industry training facilities, and public policy analysis to align initiatives with public vision. Establishment of public tertiary, research and development institutions such UB, BCA, DAR, BIH, BVI, BNVL and BHHRL (all except NFTRC) in the capital presents an opportunity for the establishment of an integrated facility to provide molecular biology, genetic transformation and bioinformatics services. This will enable application of genomics, bioinformatics, gene discovery related to major diseases, molecular biology, biochemistry, cell and developmental biology, systematics and coevolution of animals and plants for gene discovery for use in generation of biotech crops. In China, investment in such facilities such as National Institute of Biological Sciences (NIBS) in Beijing, served as one catalyst in attracting Chinese life science and biotechnology scientists from overseas to pursue world-class research at home.[59] This investment in biotechnology has

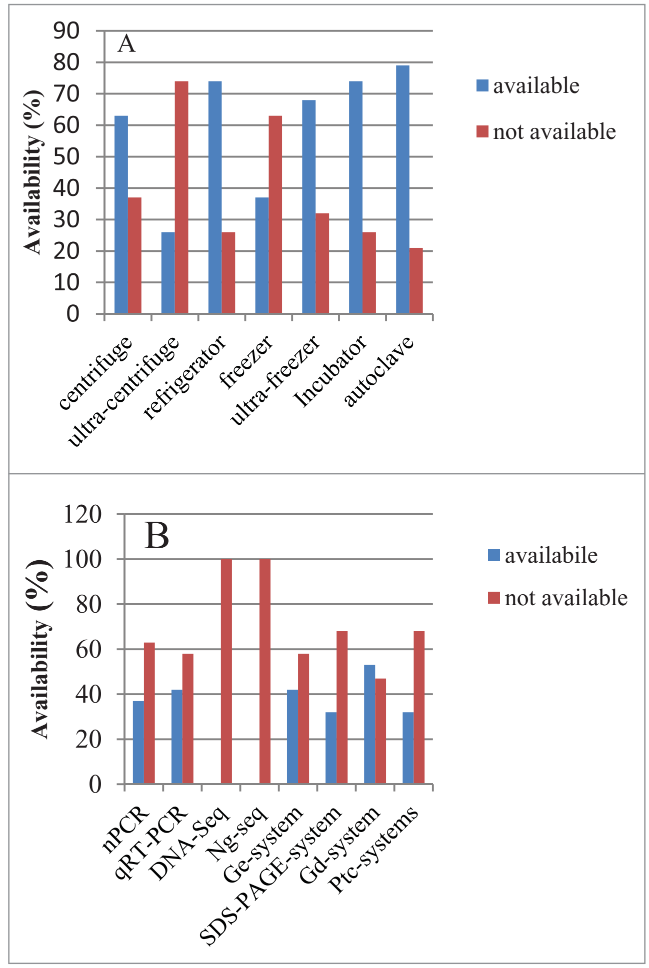

Figure 5. Availability of major equipment required to perform workflow and advanced operations in biotechnology research and training. **A** = Work flow equipment for molecular biology. **B** = Advanced analysis equipment in biotechnology nPCR = normal PCR system, qRT-PCR = quantitative real time PCR system, DNA-seq = DNA sequencing system, NG-seq = Next generation sequencing system, Ge-System = Gel electrophoresis system, GD-system = Gel documentation systesm, Ptc-system = Plant tissue culture system.

enabled the country to generate an array of technologies to become one of the major producers of GM crops in the world among other developing countries such as Brazil, India and Argentina.[60] In neighboring South Africa, the National Biotechnology Strategy of 2001 established the innovation centers LIFElab, Cape Biotech, BioPAD, PlantBio and the National Bioinformatics Network.[61] These Innovation Centres collaborate with research institutions and universities to conduct biotechnology research to increase production of crops suited to local conditions, enhance crop nutritional value and improve preservation and processing methods resulting in novel and improved food products.

Elsewhere in Latin America, infrastructure development (research institutions, science parks), are some of the

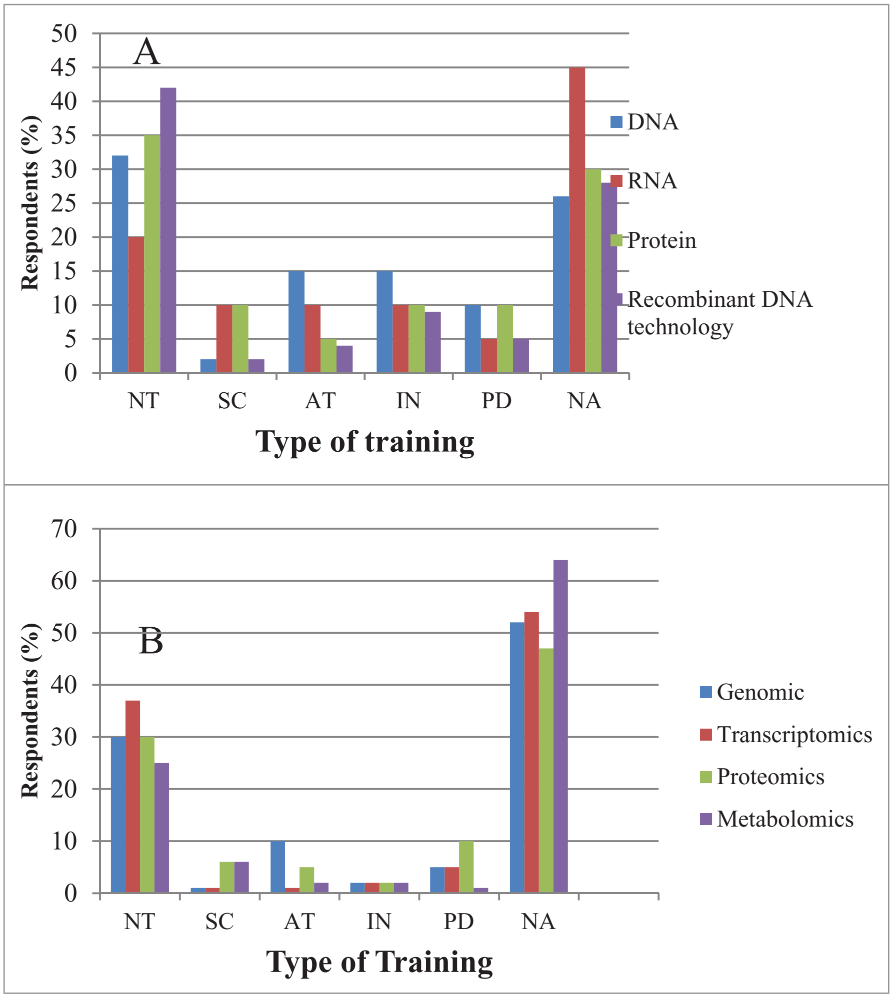

Figure 6. Ways in which respondents acquired techniques necessary for biotechnology in surveyed Institutions. **A** = Molecular biology based techniques **B** = Systems biology based techniques. NT = normal training during studies, SC = short course, IN = inhouse, PD = post doctoral training, NA = not applicable.

characteristics that position Brazil, Argentina and Chile as the best candidates in terms of their potential to develop biotechnology. Countries like China, Brazil, Argentina, Chile, South Africa and Burkina Faso are in the league of the 18 mega biotech countries in the world.[27] In South Africa, establishment of robust infrastructure in biotechnology enabled it to make huge strides in agricultural biotechnology. South Africa is beginning to move into health biotechnology and is now described as "a trail for African biotechnology."[61] Botswana should follow the likes of China, Brazil, Argentina, Chile and South Africa in biotechnology infrastructure investment. However, the establishment of the BIH along the lines of the South African innovation centers is viewed as a step in the right direction, as it aims to act as a catalyst in research and development in biotechnology and other areas.

Biotechnology is a cross-cutting technology and an amalgam of a variety of disciplines -biochemistry, molecular biology, genetics, microbiology, and bioinformatics. These disciplines require reasonably equipped laboratories. Our findings indicate that laboratory equipment was available for isolation and routine analysis of nucleic acids (DNA and RNA) and proteins. However, gene discovery, which is an important aspect of biotechnology, pose a challenge because researchers had no access to DNA sequencers.

Research and development is on-going worldwide for the discovery of the next generation crops with increased yield, stress tolerance, nutrient use efficiency.[29] Low yield and plant stress such as infertile soils, drought, weeds, pests and diseases are some of the challenges facing maize and other arable crops in Botswana and is a challenge to be turned into an opportunity by going into research and development targeting genes controlling adaptation for the above traits.

Successful delivery of existing and next generation biotech crops to market will depend on establishing their food, feed, and environmental safety. Establishment of regulatory authorities and safety assessment framework for biotechnology-derived crops designed to identify any potential food, feed, and environmental safety risks prior to commercial use is one of the major challenges in the country. However, information of infrastructure and human resources availability indicates that well-functioning regulatory systems can be put in place for public

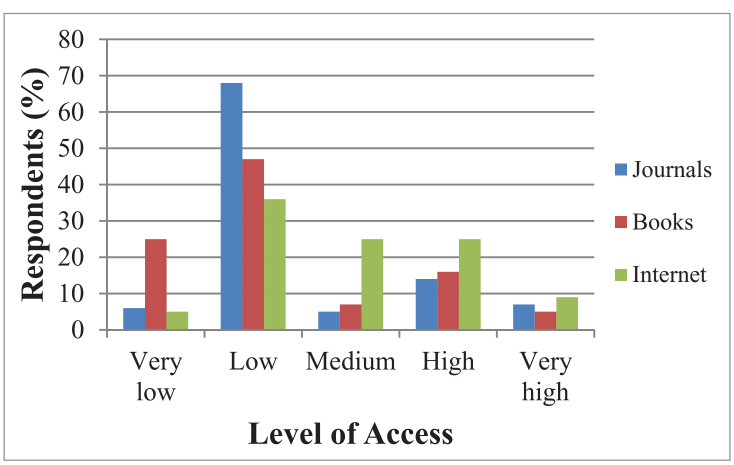

Figure 7. Access to library resources and information resources by staff in surveyed institutions involved in biotechnology in Botswana.

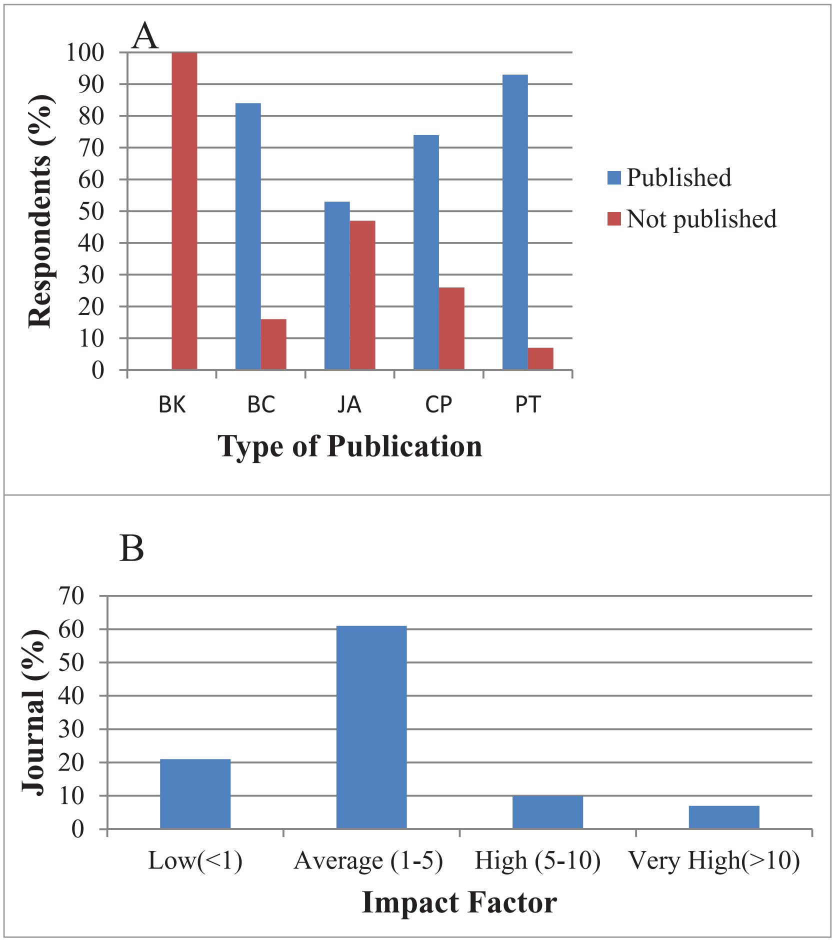

Figure 8. Publication types and quality of journal articles where research was published by staff involved in biotechnology in Botswana. **A** = Research output **B** = Quality of journal publications. The publication types are; BK = Books, BC = Book chapters, JA = Journal articles, CP = Conference proceedings, PT = Patents. The impact factor was rated as; Very low = (<1), Low = (1-2), average = (2-3), High = (3-4), Very high = (>10).

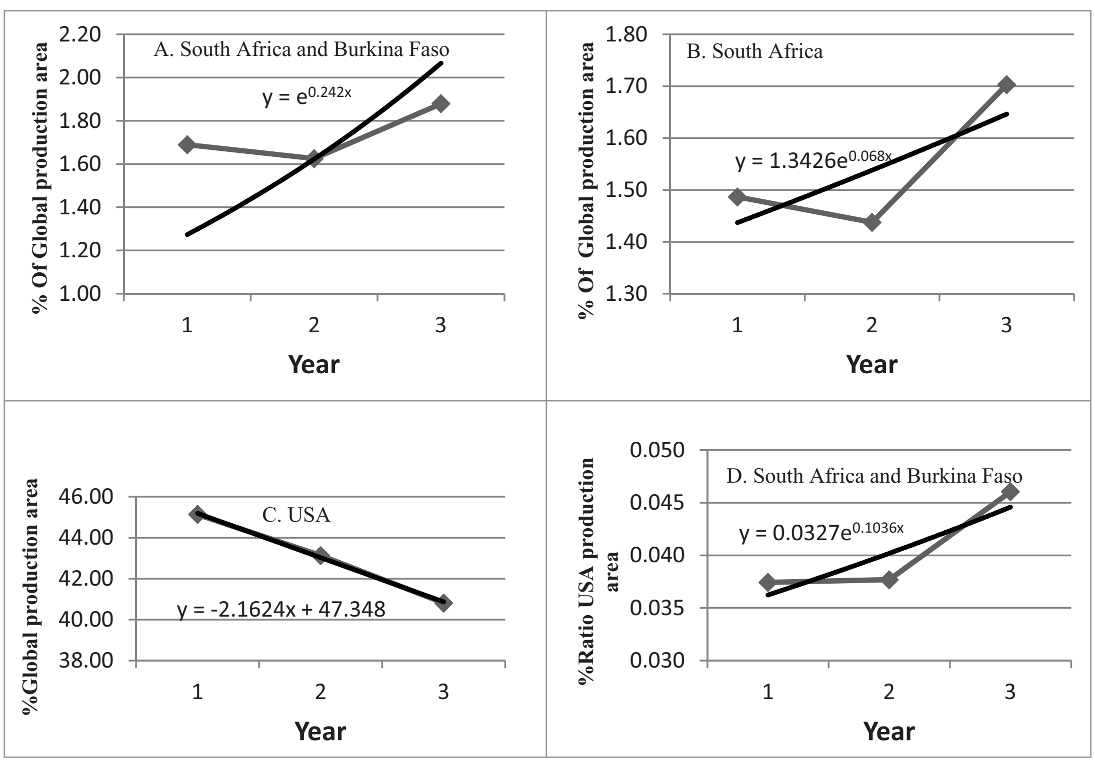

Figure 9. A three-year comparative production trends of GMO crops between 2010 and 2012 in USA and South Africa and Burkina Faso between: Source: ISAAA crop biotech update, 2012.

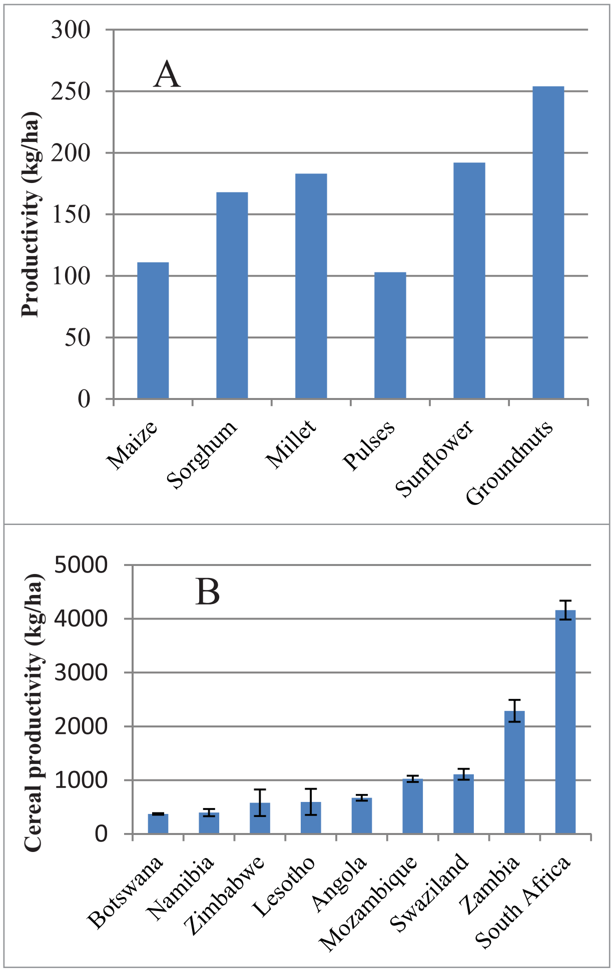

Figure 10. Productivity of common arable crops grown in Botswana and cereals in the Southern African region developing countries during Period 2000–2012. **A** = Local crop productivity (Source: Statistics Botswana 2012). **B** = Regional cereal productivity (Source: World Bank 2012).[62]

sector research to generate data for GM crops safety and risk assessment to export market.

In Botswana arable crop production is challenged by environmental factors such as infertile soils, drought, weeds, pests and diseases. Current world research efforts are focused on development of GM crops resistant to these factors. Therefore the country should take advantage of these development and venture into biotechnology. In Botswana, basic infrastructure in the form of research and teaching institutions is available. While we acknowledge some deficiencies in the availability of human and laboratory resources, available information indicate that the country has the capacity to apply biotechnology in the development and production of genetically modified crops. These will include gene discovery, genetic transformation, development and implementation of a national biosafety framework on biosafety. In view of the challenges facing the country in agriculture, the target novel GM products could be nutrient efficient and drought and pest and disease resistant food and fodder crops, and production of animal disease vaccines and diagnostic tools for various diseases.

Materials and Methods

Primary data collection

This study focused on institutions in Botswana that are involved in applications and development of biotechnology. These were Botswana College of Agriculture, The University of Botswana (UB), Ministry of Agriculture, Department of Agricultural Research (DAR), Botswana National Veterinary Laboratory (BNVL), National Food Technology and Research Center (NFTRC) and The Botswana Innovation Hub (BIH).

To gather the data for this research from the above institutions, a 5-page 104-closed question survey was developed and administered to staff in each institution. This questionnaire required 50–60 minutes to complete by each respondent. The survey was comprised of six major areas of focus: demographic information of the respondent, institutional arrangement and mandate, the various field of biotechnology each institution is involved in, level of proficiency in the biotechnology techniques and how each was acquired, availability of equipment that supports the carrying out of relevant applications, easiness of accessing literature by researchers in their institutions, and the variety and level of publications by research staff in each institution. Where a quantification response was required, a four-five point scale was used to determine the level of skill and access to resources. At the time that the questionnaire was administered, personal observations and guided tours to individual laboratories belonging to respective institutions was made.

Secondary data collection

A desk-top study was conducted to access relevant literature, official documents and publications by staff in the different Institutions. The National Center for Biotechnology Information (NCBI), which develops information systems for molecular biology[37] was used for publication information retrieval. The NCBI suite database resources houses among others the PubMed Central (PMC), which is a digital archive of over 160 peer reviewed journals in the life sciences.[38] According to the same source, PMC allows access to over 300000 full text journal articles in the life sciences. In addition, other scholarly publications by local researchers that might have not yet been deposited in the PMC were accessed through the Google Scholar and Scirus[39] (Science Direct) search engines. Full-text journal articles, technical reports, preprints, theses, books, patents and other documents, including selected Web pages that are deemed to be "scholarly" were retrieved through the 2 search engines. Particular emphasis was placed on obtaining the following information about the publications: author, their affiliation and impact factor of journal articles published.

Data Analysis

The data collected was analyzed using the Statistical Package of Social Sciences (SPSS) programme. Qualitative data was transcribed and meaningful themes and patterns extracted. Graphical analysis was used to extract trends and themes, whenever necessary and cross-tabulation was used to derive specific relationships between themes.

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

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