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The Science, Acceptance and Support of Modern Biotechnology in Africa

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This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Biotechnology is a science that makes use of biological organisms, or their sub-cellular components in health, agriculture, manufacturing and service industries, and in environmental management. It is increasingly clear that commercial products of modern biotechnology cannot be overlooked in relation to their potential benefits to the African community. In plant biotechnology, the application of plant tissue culture, plant molecular markers and genetic engineering are key to the development of Africa's agricultural sector. Modern biotechnology enables the development of diagnostic test kits for use both in the laboratory and in the field. In a holistic view, modern biotechnology provides the opportunity for better health care, enhanced food security through sustainable agricultural practices, access to improved water quality, efficient methods to process raw materials, and support for sustainable methods of reforestation and detoxification of hazardous wastes in Africa. It has been established that modern biotechnology could offer new opportunities for partnerships between Africa and the developed world. They also hold a bright future in terms of market potential for new products to be developed in Africa. Modern biotechnology has now developed into a global industry that has positively impacted on the lives of Africans. Here, we provide an overview of the place of modern biotechnology, the science, acceptance and support in Africa.

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1. INTRODUCTION

The term ‘Biotechnology’ is a technology that makes use of the practical application of biological organisms, or their sub-cellular components in health, agriculture, manufacturing and service industries, and in environmental management [1]. It also refers to the techniques used to modify the genetic make-up of living organisms. In modern biotechnology, the application utilizes bacteria, yeasts, fungi, algae, plant cells or cultured mammalian cells for industrial activities [2]. It also integrates the disciplines of molecular biology, microbiology, biochemistry, genetics, chemistry, chemical and product engineering. Common commercial products of modern biotechnology include beverages, vinegar, cheese, yogurt, biogas, compost and organic acids (citric acid, amino acids, and acetic acid). Others examples are solvents (alcohols, acetone), gums, plastics, detergents, perfumes, hormones, peptide and steroids. Enzymes (hydrolases, proteases, amylases, peroxidases and oxidases) and vaccines, antibiotics, high fructose corn syrup, cellulose and single cell proteins are also products of modern biotechnology [3]. In plant biotechnology, the application of plant tissue culture, plant molecular markers and genetic engineering are key to the development of Africa’s agriculture sector [4]. The application of modern biotechnology has led to the development of diagnostic kits for use both in the laboratory and in the field. Here, diseases and chronic infections that are caused by microbes can be identified by a unique feature of the microbe, such as its DNA of a specific protein [5]. Modern biotechnology offers comparative advantage compared to non-biotechnology processes in that they are cheaper; they offer long-term benefits as means of solving some major world problems such as those related to food security, novel medical and industrial products, pollution control and the development of new energy sources [6]. Overall, modern biotechnology promises to make a significant contribution in enabling the development of better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials, and support for sustainable methods of reforestation and detoxification of hazardous wastes in Africa [7]. Modern biotechnology also offers new opportunities for partnerships between Africa and the developed world. They also hold a bright future in terms of market potential for new products to be developed in Africa. Modern biotechnology has grown into a global industry that has the potential of affecting many aspects of Africans positively. Here, we provide an overview of the place of modern biotechnology, the science, acceptance and support in Africa.

2. THE PLACE (IMPORTANCE) OF MODERN BIOTECHNOLOGY IN AFRICA

2.1 The Development and Growth of Modern Biotechnology in Africa

Contemporary biotechnology has its forerunners in exploratory attempts in the late 1960s and early 1970s, with exposé in such areas as molecular biology, biochemistry and microbiology forming the foundation for the technology’s fast development into a worldwide industry. The manipulation of genes enhanced scientific knowledge in tertiary institutions in the USA, Asia and Europe in the 1970s. It has given insight into the way we can make productive use of organic matter to forming new products that will boost agriculture, health, environment, and industry [8]. The application of modern biotechnology yields products that are enhanced, more secure, and less costly. Classical examples include pharmaceutical products, rapid diagnostic kits for humans and animals, seeds, whole plants, animals, fertilizers, industrial enzymes, and oil-eating and other pollution degrading microorganisms. Although the application of modern biotechnology with respect to genetic engineering has numerous advantages, there are other challenges. These challenges revolve around ethical issues, the fear of adverse effect on mankind, the impact on the ecosystem and socioeconomic risks. For example, concerns have been raised about the potential natural effects of releasing genetically modified organisms into the environment. There is an assumption that such microorganisms would erode genetic diversity and along these lines undermine socio-economic and cultural sustenance of many households in the developing world.

Three mainstream technological directions or total innovative pathways have risen in biotechnology [9]. These include the pharmaceutical industry, agricultural sector and the diagnostics industry. There are, obviously, different directions, for example, mineral leaching and pollution control. Africa has an abundance of natural resources with the possibility to drive financial development and social advancement: Land, minerals, biological diversity, untamed life, forests, fisheries and water, despite the fact that these are unevenly circulated. Africa's economies and individuals are helpless against ecological perils, for example, dry spells and surges, the recurrence and limit of which is liable to be expanded by environmental change. What's more, sub-Saharan Africa is encountering quicker debasement of numerous ecological assets, essential to destitute individuals, than any other region. One of the focal messages rising up out of the appraisal of Africa's status in the worldwide economy is the requirement for Africa to underline assembling the ability to take care of its own issues. Each issue listed above has one or more solutions in the utilization of science, technology and innovation. The use of science and innovation has contributed fundamentally to characterizing a monetary partition amongst rich and poor countries. The rate of scientific and technological development to a great extent decides the pace of financial improvement. To close the gap between rich and poor countries will require planned measures to assemble experimental and mechanical abilities of the poor nations [10].

Modern biotechnology in the completest sense of the word is basic to Africa's improvement. Yet, to understand the potential that modern biotechnology holds for sustainable development and a superior quality of life, Africa needs a good biotechnology direction. Among its numerous applications, biotechnology likewise incorporates having the capacity to isolate, select and transfer genes from one organism into another, an innovation known as genetic modification. Worldwide agro-industry today is a noteworthy patron of this application, and overall advancements in this innovation continue to be rapid. For instance, about 8.5 million farmers today develop crops that have been produced utilizing genetically modified biotechnology. A long way from being an innovation for the rich, 9 out of each 10 agriculturists who use it originate from some of the poorest nations [10]. One investigation of 13 open establishments in Kenya, Zimbabwe, Egypt and South Africa demonstrated that biotechnology applications have been performed on 21 crops where the qualities fused incorporate those that confer insect, fungal, viral and bacterial resistance, protein quality enhancements, herbicide resistance, and salt and drought resistance [11].

3. THE SCIENCE AND ACCEPTANCE OF MODERN BIOTECHNOLOGY IN AFRICA

The science behind biotechnology has been known since the olden days. The technology was known to brewers as they used yeast cultures to make beer, bread and other fermented foods. Modern biotechnology applications became popular at the time when the structure of Deoxyribonucleic acid (DNA) was discovered in the early 1950s [12]. To appreciate how this technology works, it will be necessary to have a basic understanding of DNA’s central role. DNA is a double-stranded molecule located in the nucleus of a cell. It contains the genetic material that controls the characteristics of a living organism. The genes found in the DNA of a cell can be either turned on or off depending on the cell’s function and needs. Upon activation, the information contained in it is used for the expression of the protein for which it codes. The onset of most diseases are a due to genes that are improperly regulated [13,14].

The production of proteins basically involves two key steps; namely, transcription and translation. Messenger RNA (mRNA) carries the instructions to make a particular protein. The ribosome binds to a ribbon of mRNA during translation. Subsequently, transfer RNA (tRNA), assembles a chain of amino acids into short chains of amino acid complexes called polypeptides to form proteins [15]. The proteins contained in an individual organism interact with each other with specificity. The understanding of protein structure at the atomic level describes how the precise shape of each protein molecule determines its function in a cell. Genetic engineering is the major technique employed in modern biotechnology that enables molecular biologists to locate and identify the gene that produces the protein of interest; place the gene into a desired vector; use the vector to carry the gene into the DNA of the host cells, such as *Escherichia coli* or mammalian cells grown in culture; induce the cells to express the gene and produce the desired protein; and extract and purify the protein for use [16].

Among the areas of modern biotechnology application, pharmaceutical sector is the most economically viable. However, the agricultural biotechnology sector is moving fast in terms of development. With modern biotechnology, the pharmaceutical business has gained ability to move from the utilization of chemical substances to natural products; especially plants and microorganisms. Most African nations are at various stages of modern biotechnology application. Some have climbed the innovation step and are applying more refined strategies. The above can be exemplified by Egypt and South Africa who are actively involved in gene sequencing, characterisation of pathogens and gene promoters, while a country like Tanzania and others are at the infant stages of modern biotechnology application. Table 1 outlines biotechnology research in Africa.

Table 1. Agricultural biotechnology in Africa: Some selected cases. (Adapted from Brink et al. 1998) [17]

Country	Area of research
Egypt	Genetic engineering of potatoes, maize and tomatoes
Morocco	Micropropagation of forest trees, date palms, Development of disease-free and stress tolerant plants, Molecular biology of date palms and cereals, Molecular markers, Field-tests for transgenic tomato.
Cameroon	Plant tissue culture of *Theobroma cacao* (cocoa tree), *Hevea brasiliensis* (rubber tree), *Coffea arabica* (coffee tree), *Dioscorea* spp (yam) and *Xanthosoma mafaffa* (cocoyam). *In vitro* culture for propagation of banana, oil palm, pineapple, cotton and tea.
Cote d'Ivoire	*In vitro* production of coconut palm (*Cocos nucifera*) and yam, Virus-free micropropagation of eggplant (*Solanum* spp), Production of rhizobial-based biofertilizers.
Ghana	Micropropagation of cassava, banana/plantain, yam, pineapple and cocoa, Polymerase chain reaction (PCR) facility for virus diagnostics.
Nigeria	Micropropagation of cassava, yam and banana, ginger, Embryo rescue for yam, Transformation and regeneration of cowpea, yam, cassava and banana, Genetic engineering of cowpea for virus and insect resistance, Marker assisted selection of maize and cassava, DNA fingerprinting of cassava, yams, banana, pests and microbial pathogens, Genome linkage maps for cowpeas, cassava, yams and banana.
Senegal	Well established MIRCEN programme, Production of rhizobial and mycorhizal-based biofertilizers for rural markets, Well established *in vitro* propagation of tree species in cooperation with several international agencies.
Ethiopia	Tissue culture research applied to the micropropagation of forest trees.
Kenya	Production of disease free plants and micropropagation of pyrethrum, bananas, potatoes, strawberries, sweet potato, citrus, sugar cane, Micropropagation of ornamentals (carnation, alstromeria, gerbera, anthurium, leopard orchids) and forest trees, *In vitro* selection for salt tolerance in finger millet Transformation of tobacco, tomato and beans, Transformation of sweet potato with proteinase inhibitor, gene Transformation of sweet potato with feathery mottle virus coat protein gene, Tissue culture regeneration of papaya, *In vitro* long-term storage of potato and sweet potato, Marker assisted selection in maize for drought tolerance and insect resistance, Well-established MIRCEN providing microbial biofertilizers in East Africa.
Uganda	Micropropagation of banana, coffee, cassava, citrus, granadella, pineapple, sweet potato, In vitro screening for disease resistance in banana, Production of disease free plants of potato, sweet potato and banana
	Genetic engineering of cereals: maize, wheat, barley, sorghum, millet, soybean, lupins, sunflowers, sugarcane; vegetables and ornamentals: potato, tomato,

Country	Area of research
South Africa	cucurbits, ornamental bulbs, cassava and sweet potato; fruits: apricot, strawberry, peach, apple, table grapes, banana Molecular marker applications of: diagnostic for pathogen detection; cultivar identification-potatoes, sweet potato, ornamentals, cereals, cassava; seed-lot purity testing, cereals; marker assisted selection in maize, tomato; markers for disease resistance in wheat, forestry crops, Tissue culture for: production of disease free plants, potato, sweet potato, cassava, dry beans, banana, ornamental bulbs; micropropagation of potato, ornamental bulbs, rose rootstocks, chrysanthemum, strawberry, apple rootstocks, endangered species, coffee, banana, avocado, blueberry, date palm; embryo rescue of table grapes, sunflower and dry beans; *in vitro* selection for disease resistance-tomato nematodes, guava wilting disease; long term storage, sweet potato, cassava, ornamental bulbs; *in vitro* gene bank collections, sweet potato, cassava, ornamentals; forest trees, medicinal plants, indigenous ornamental plants
Zimbabwe	Genetic engineering of maize, sorghum and tobacco, Micropropagation of potato, cassava, tobacco, sweet potato, ornamental plants, coffee Marker assisted selection.
Zambia	Micropropagation of cassava, potato, trees (*Uapaca*), banana Hosts SADC Nordic-funded gene bank of plant genetic resources.

4. USAGE (PATRONAGE) OF MODERN BIOTECHNOLOGY IN AFRICA

In Africa, Genetically Modified (GM) crops were first cultivated in South Africa in 1997/98 and currently, South Africa is the only country in Africa growing GM crops on a wider commercial scale. Approximately 500000 ha of GM crops have been planted in South Africa (Africa Centre for Biosafety) (ACB) [18]. Burkina Faso, Egypt, Kenya, Morocco, Senegal, South Africa, Tanzania, Zambia and Zimbabwe have engaged in field trials of GM crops in the past 5 years. In Africa, 20 countries, namely; Benin, Burkina Faso, Cameroon, Egypt, Ghana, Kenya, Malawi, Mali, Mauritius, Morocco, Namibia, Niger, Nigeria, Senegal, South Africa, Tanzania, Tunisia, Uganda, Zambia and Zimbabwe are engaged in GMO research and development [18]. In terms of capacity and institutions to conduct research and development into agricultural biotechnology, Algeria, Benin, Botswana, Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Madagascar, Malawi, Mali, Mauritius, Morocco, Namibia, Niger, Nigeria, Senegal, South Africa, Tanzania, Tunisia, Uganda, Zambia and Zimbabwe have the potential [18].

Agricultural application of modern biotechnology can be grouped into different categories. These include foods containing ingredients processed by enzymes produced through genetically modified microorganisms (GMMs), foods consisting of living/viable organisms, foods containing single ingredients or additives produced by GMMs, and foods derived from or containing ingredients derived from GMOs [19]. Most farmers in Africa aim at primarily increasing productivity, increasing resistance to diseases and pests, and enhancing quality through conventional breeding [19]. Ground-breaking results from cellular genetics and cell biology enhanced the concept of ‘green revolution’ which led to the discovery of varieties of staple foods possessing traits for higher yield and resistance to diseases and pests in a number of both developed and developing countries [19]. The advancements made in the discovery of techniques in molecular biology in the late 1980s saw the introduction of more direct methods for genetic analysis for desired traits. A classical example is the marker-assisted breeding technology which has now become a conventional breeding strategy. Modern biotechnology employs molecular techniques to identify, select and modify DNA sequences for a specific trait from a donor organism, and transfer the sequence to the recipient organism so that it expresses this desired trait [19]. The main areas of patronage of modern biotechnology in Africa are described below.

4.1 Pest, Disease and Virus Resistance

In Africa, commercialised biotechnology crops will continue to concentrate on agronomic trials such as herbicide resistance and insect resistance. The introduction of virus-resistant and herbicide-resistant traits in certain crops such as maize and soybean is being practiced. The application of modern biotechnology provides an important target to virus resistance will contribute to improving agricultural productivity in Africa

[20]. Test trials on virus-resistance on sweet potato, for feathery mottle virus; maize, for maize streak virus; and African cassava, for mosaic virus [20] are rigorously being pursued.

4.2 Improved Nutritional Composition and Removal of Allergens and Anti-Nutrients

The application of modern biotechnology has led to the generation of many crops in which their nutritional value has been significantly improved. A typical example is 'golden rice' [21] which has high level of beta-carotene. This type of rice has been known to contain enhanced nutritional properties [21]. Vitamin A is essential for increasing resistance to disease, protecting against visual impairment and blindness. Vitamin A deficiency is associated with many poor African regions and has been cited as one of the public health problems that contribute to serious illness and death in children [22]. Through modern biotechnology, vitamin A deficiency is being combated through the provision of supplements in the form of pills [23]. Through this approach, large amounts of transgenic rice varieties could make a significant contribution to the daily human requirement for vitamin A in Africa. Cyanide is a naturally occurring toxic chemical in cassava roots. As they are a staple food in tropical Africa, this has led to high blood-cyanide levels which have harmful effects. Application of modern biotechnology has led to a significant reduction in cyanide levels in cassava [24].

4.3 Improved Livestock and Fish Production

The production and consumption of fish and livestock is prevalent in most African countries. Their production is enhanced through modern biotechnology. The production of livestock can be categorised into animal production and human nutrition. Many households along the coast depend on fishing which is the main source of income and it has been suggested that GM fish may become an added advantage. It has been shown that the Atlantic salmon containing a growth hormone gene from Chinook salmon is likely to be the first GM animal on the food market [25]. These fishes grow 3-5 times faster, thereby increasing food availability and income. At least eight other farmed fish species have been genetically modified for growth enhancement. Other fishes in which genes for growth hormones have been experimentally introduced include grass carp, rainbow trout, tilapia and catfish [26]. The use of modern biotechnology (transgenics to vaccine production) in Africa has not only public health benefits, but also national security implications. A lot of novel vaccine components are manufactured from genetically engineered animals. However, this allows for the rapid production of vaccines, and also enables vaccines to be developed in direct and rapid response to any viral outbreaks. It also offers the opportunity for vaccines to be produced at a lower cost because of the efficiency and high capacity of the transgenic methods [27,28].

In Africa, patronage of modern biotechnology as applied in the medical field has greatly seen a significant improvement in the health care sector. The population of Africans living with the human immunodeficiency virus (HIV) is high, coupled with the alarming increase in drug-resistant tuberculosis and malaria [29]. Others include cerebrovascular disease, ischemic heart diseases and lower respiratory infections [30]. Due to these compounding problems, there is an opportunity for the African health biotechnology industry to grow. These and other factors lie behind the relatively recent drive to build a local biotechnology industry to ensure food security and environmental sustainability and subsequently promote job and wealth creation [31]. Compared with other countries previously studied in the world [32], South Africa's health biotechnology industry is still small and activities are very diverse. Recent surveys of the biotechnology landscape in Africa demonstrate this [33,34].

South Africa is one of the leading countries to spearhead modern biotechnology application in the healthcare sector. It is worth noting that the first human heart transplant was performed at the Groote Schuur Hospital in Cape Town (South Africa) in 1967, and since then, the country has developed clinical and scientific expertise in this regard. Few applications of modern biotechnology in Africa is discussed below.

4.4 Production of Vaccines, Biogenerics, Therapeutics and Nutraceuticals

The Biovac Institute, a public–private partnership between the South African Department of Health and the Biovac Consortium (Cape Town), is the only manufacturer of vaccines in sub-Saharan Africa [7]. Biovac's mandate is to supply all of South Africa's Expanded Program of

Immunization vaccines, including DTP (diphtheria, tetanus and pertussis), measles, polio, oral polio, Bacille Calmette-Guérin (BCG) and recombinant hepatitis B virus surface antigen (HBsAg) vaccine, either by importing directly from overseas or by formulating and filling locally under good manufacturing practice (GMP) conditions [7]. As of early 2008, Biovac's production of the HBsAg vaccine using bulk recombinant antigens from Cuba represented the first vaccine to be manufactured in sub-Saharan Africa since 2001 and marked a milestone in African vaccine self-sufficiency and capacity-building. Biovac's vaccine pipeline includes a pentavalent combination vaccine (DPT + HBsAg + *Haemophilus influenza* type b (Hib) vaccine) in one vial, which will be easier to administer than the current regime (which requires two injections and the reconstitution of Hib before use). Biovac also supplies surrounding countries, such as Swaziland, Namibia and Botswana, and in due course, it aims to apply for World Health Organization (WHO; Geneva) prequalification so it can access other markets [7].

African biotechnology companies have the capacity to develop new therapeutics that address local problems [7] and these have been highlighted by three recent Research and Development (R&D) start-ups, all with a focus on infectious disease. iThemba Pharmaceuticals (Johannesburg), a venture founded by Dennis Liotta (who discovered Emtriva (emtricitabine) and 3TC (lamivudine), among others) and several scientific colleagues from around the world, has recently received R30 million ($3.6 million) in financing from Brazil, Russia, India and China (BRIC) Lifelab and BioPad to add to the founders' private investment. Through a license agreement, iThemba has access to the comprehensive compound library at Emory University in Atlanta, which it is screening for activity against local strains of tuberculosis and HIV [7]. Ultimately, it will seek to outlicense or co-develop new chemical entities after positive proof-of-concept. Emory has also licensed to iThemba rights to a more efficient process for manufacturing generic versions of the HIV reverse transcriptase inhibitor Ziagen (abacavir). In a recent move, iThemba will partner in the development of any lead candidates resulting from a collaboration between US biotech Chimerix (Durham, North Carolina, USA) and the Medicines for Malaria Venture public-private partnership (Geneva), which aims to screen Chimerix's chemical library for compounds with activity against malaria [7].

There have been enormous supported ventures in Africa in the nutraceutical field; foods, food constituents or dietary supplements that provide medicinal or health benefits. An example is Sandton-based Natural Carotenoids South Africa, a Council for Scientific and Industrial Research (CSIR) spinoff based on the extraction of natural carotenoids (a source of vitamin A and antioxidants) from algae. Natural Carotenoids South Africa now produces a range of products under GMP conditions, including suspensions, crystals and powders for the nutraceutical and food industries. In Pretoria, Biomox Pharmaceuticals manufactures Bio Boost, an 'immunosupportive' dietary supplement containing l-methionine, magnesium, vitamin B6, vitamin B12 and folic acid. Some companies are attempting to bring increased scientific rigor to the complementary health product field, motivated in part by an attractive potential export market. Cape Kingdom (Cape Town), for example, which manufactures five products based on the herb 'buchu', one of South Africa's best-known healing plants, is carrying out clinical trials to validate the anti-inflammatory properties and has contracted out work on the isolation and chemical characterization of 'buchu's' active ingredient [7].

4.5 Production of Chemical Reagents and the Manufacture of Diagnostic and Medical Devices

Reagent suppliers, diagnostics and medical devices are all active areas of innovation in Africa because of their lower barriers to commercial entry. USA-owned Kapa Biosystems in Cape Town is applying thermo-stable DNA-manipulating enzymes, particularly DNA polymerases and ligases to increase the efficiency of enzymes used in research. Kapa has also been successful in developing new enzyme-based products using bioprospecting platforms. The company launched a variety of enzymes in 2007, with a focus on international markets [34]. Other products include recombinant proteins for use as immunogens to produce monoclonal or polyclonal antibodies or as antigens in diagnostic tests, as well as mouse monoclonal antibodies for use in immunodiagnostics, such as enzyme-linked immunosorbent assays (ELISA) and immunochromatographic tests with close links to the South African National Blood Service. National Bureau of Investigation (NBI) also makes ELISA tests for the in-house screening of plasma samples from blood donors for antibodies to hepatitis B virus, *Clostridium tetani* (tetanus), rabies virus and varicella zoster virus. NBI is now developing a human monoclonal antibody to *Mycobacterium tuberculosis* and a mouse monoclonal antibody to *Trypanosoma brucei gambiense* (African sleeping sickness) to develop new diagnostic tests. For both tuberculosis and African sleeping sickness, early diagnosis and treatment is associated with better patient outcome [34]. The inadequacies of current tuberculosis tests are well known, and at present, it is thought that only 10% of patients with African sleeping sickness are accurately diagnosed [34]. In the area of diagnostics, Vision Biotech (Cape Town) develops and contract manufactures point-of-care diagnostic tests, with a focus on affordability and high reliability in African field conditions. Operating since 1995, Vision has developed 15 types of Gold CE-marked test over the past two years (CE marking indicates conformity to the legal requirements for the manufacture of *in vitro* diagnostic medical devices for sale in the European Economic Area), all but one based on lateral-flow (immunochromatographic strip) technology and preferentially using colloidal gold as a detection reagent. Most of these diagnostics focus on infectious diseases, such as HIV, tuberculosis and malaria. Indeed, Vision is the second biggest manufacturer of malaria tests worldwide, making 8-10 million malaria tests each year and supplying the World Health Organization's (WHO's) 'Pf malaria' test (a rapid immunodiagnostic test for *Plasmodium falciparum* histidine-rich protein 2 antigen) [34].

5. CHANCES OF SUCCESS OF MODERN BIOTECHNOLOGY IN AFRICA

South Africa is the leader of biotechnology in Africa, as it has already developed and commercialised transgenic products such as maize and cotton. Other South African countries (Zimbabwe, Malawi and Madagascar) are doing micro-propagation of disease-free banana, rice, maize, groundnuts and tropical woody trees. North African countries (Morocco and Tunisia) are doing biological research and preliminary trials on palms, potatoes, tomatoes, and maize and forest trees [35]. West African countries (Burkina Faso, Cameroon, Cote d'Ivoire, Ghana, Nigeria, Gabon and Senegal) are doing various projects related to biological nitrogen fixation; production of legume inoculants; fermented foods; medicinal plants; plant tissue culture of cocoa trees, rubber trees, coffee trees, yams, oil-palm, pineapple, cotton, tea, banana, cassava, ginger, eucalyptus and acacia; and production of mycorrhizal-based biofertilizers for rural markets [17]. Out of 53 countries of the African Union, only 16 have laws, regulations, guidelines or policies related to modern biotechnology. Of these, only South Africa, Egypt and Burkina Faso have experiences in commercialisation of GMO crops [36]. The main problems facing biotechnology experts in Africa is the scarcity of resources and slow passage of GM crops from experimental to commercial stages and difficulties in meeting regulatory requirements [37]. Africa's under-development in terms of insufficient good quality food, poor health care, unreliable sources of energy and degraded environments would be greatly reversed if the continent embraces biotechnology.

This paper highlights some successful biotechnological activities carried out by a few African countries to aid in the success of modern biotechnology in Africa. Some of these countries include Kenya, Uganda, Tanzania, Ethiopia, Rwanda, Burundi and Democratic Republic of Congo (DRC). While Kenya, Uganda and Tanzania have already developed and operationalized their biotechnology policies and guidelines, the rest are yet to do so.

5.1 Chances of Success of Modern Biotechnology in Kenya

In the eastern part of Africa, Kenya has the leading economy. Apart from tourism, Kenya's economy is dependent on agriculture where tea, coffee, sisal and pyrethrum are the leading export crops, while the staple food crops are maize and wheat. Coconuts, pineapples, cashew nuts, cotton, sugarcane, sisal and corn are grown in the low-lying areas. Biotechnology is taking roots in Kenya. After the government had passed the national biotechnology policy in 2007 that was developed by the Kenya National Council for Science, many biotechnology projects got a big boost. Kenya employs modern biotechnology in tissue culture to produce pyrethrum, banana, sugarcane, potato, strawberry, cassava, vanilla, oil palm and flowers [38,39]. They have also been successful in using marker assisted selection (MAS) to characterize and map maize streak virus and grey leaf spot resistance genes in maize; develop drought tolerant wheat and aphid resistant maize and wheat; smut resistant sugarcane, breed desirable traits in cassava, rice and sorghum; and characterize indigenous species of cattle, forages and tsetse flies [38,39]. In case of livestock, modern biotechnology is focussed on the development of recombinant DNA vaccines for Newcastle disease, Rift valley fever and Rind pest fever [38,39].

Kenya's Research and development (R&D) institutions are engaged in the GMO research projects, with the Kenya Agricultural Research Institute (KARI) taking the leading role. Notable among the GMO projects are the development of virus-resistant sweet potatoes and cassava; insect resistant maize, cotton, cowpea and sweet potatoes; drought resistant maize; and bio-fortified rice [40]. At the Kenyatta University, research on striga-resistant sorghum is on-going and it has reached a confined field trial stage [41]. Furthermore, the plant transformation laboratory at Kenyatta University is currently exploiting the availability of genes and technologies to improve drought tolerance, nutritional value and adaptability of major food crops [42].

The International Livestock Research Institute (ILRI) in Nairobi is very active in trials using modern biotechnology. Being part of the consultative group on international agricultural research (CGIAR), ILRI works with partners worldwide to help poor people keeping their farm animals alive and productive. It also helps farmers to find profitable markets for their animal products. In the area of biotechnology, ILRI focuses on development of appropriate diagnostics to help identify disease threats and develop specific vaccines; identifying and using genetic adaptations such as disease resistance and developing appropriate marker technologies to facilitate delivery of genetic improvement into farmers' herds/flocks; and genetic adaptations to increase the quality of feeds [39]. The private sector, including the genetic technologies international limited (GTIL) and are involved in tissue culture and mass propagation activities. In Kenya, at least six genetically modified organism projects have been approved and they are under contained laboratory and screen house trials while others are in various stages of application. Kenya is moving fast up the biotechnology ladder. Concerted efforts by the government and other stakeholders in addressing insufficient financial, human resources and infrastructure challenges would sustain it as a leader of biotechnology in the Eastern and Central Africa.

5.2 Chances of Success of Modern Biotechnology in Uganda

Regular rainfall, fertile land, and mineral deposits are some of the natural resources Uganda is blessed with. The eradication of poverty, healthcare improvement, food security, industrialisation and the protection of the environment in Uganda are being achieved through the application of modern biotechnology. The Uganda National Biotechnology and Biosafety (BAB) policy in 2008 was subjected to a thorough review and deliberations by various stakeholders. The policy, which was formulated by the Uganda National Council for Science and Technology (UNCST), aims to build and strengthen national capacity in biotechnology through research and development, promote the utilization of biotechnology products and processes as tools for national development and provide a regulatory and institutional framework for safe and sustainable biotechnology development and application [39]. The objective of the BAB policy is to provide regulatory and institutional framework for sustainable and safe application of biotechnology for national development [39]. Several international and regional bodies have been supporting biotechnology projects in Uganda. They include the Rockefeller Foundation which has been supporting a project on disease-free banana and cassava and striga-resistant maize; the Mexico-based international maize and wheat improvement centre (CIMMYT) that supports insect and striga-resistant maize project; and the Bill and Melinda gates which supports the water efficient maize for Africa (WEMA) Project [39].

The progress of biotechnology activities in Uganda is encouraging. With the biotechnology and biosafety policy in place, the current research-based contained and confined trials will soon move a step further to realise commercial release of GMOs. Uganda is, however, faced with financial constraints, insufficient skilled manpower and inadequate facilities to fully engage in modern biotechnology operations. The government should, therefore, invest more in those lines in order to address the country's food security, improved people's health and overall socioeconomic development challenges.

5.3 Chances of Success of Modern Biotechnology in Tanzania

Over 30% of Tanzania's population lies below the poverty line, with an individual earning less than 1 USD per day [43]. The burden and incidence of poverty is more widespread in rural than urban areas where over 60% of the people live and agriculture forms the main source of livelihood. In view of this, Tanzania considers biotechnology as a means of getting rid of poverty and also improving food security and public health.

5.4 Chances of Success of Modern Biotechnology in Ethiopia

Ethiopia is a country with 41% of its economic activities dependent on agriculture; including marketing, processing, and export. Principal crops include coffee, beans, oilseeds, cereals, potatoes, sugarcane, and vegetables [44]. Ethiopia does not have a national biosafety policy yet. It needs one in order to develop its capacity and apply the technology in agriculture, environment, health and energy sectors. Ethiopia is very rich in biodiversity, and significantly a source of important genes such as the yellow dwarf virus (BYDV) resistance gene found in barley [45] and related genes for powdery mildew resistance [46]; the "stay-green" gene for drought tolerance [47] genes for cold tolerance, high lysine content, disease resistant sorghum [48] and drought tolerance in grass pea [49]. Currently, a total of 65 projects are underway in the country and most of them are in areas of agricultural, industrial, health and environmental biotechnology. These projects are on tissue culture, bio-fertilizers, molecular markers (mainly for crops such as coffee, grass pea, teff and forest trees), embryo transfer, immunology, vaccine and diagnostic kit development and epidemiology [17,44].

Biotechnology research and development in Ethiopia is at its infant stage compared to the neighbouring countries like Kenya and Uganda where modern biotechnology projects are taking roots [50]. The lack of biosafety policy and guidelines and lack of the public's appreciation of opportunities provided by agro-biotechnology and financial constraints suggest that the governments need to move steadfastly to address the situation [51].

5.5 Chances of Success of Modern Biotechnology in Democratic Republic of Congo

Democratic Republic of Congo (DRC) lacks stand-alone policies such as agricultural policy, health policy and industrial development policy as applied to modern biotechnology [52]. Those that are related to biotechnology however, do not address the issue of modern biotechnology. Even the scientific and technology policy fails to set any guidelines regarding biotechnology. The DRC is under pressure from the Southern African Development Community (SADC)'s agricultural research and development committee to set up harmonized legislation on biotechnology and biosafety [52]. Biotechnology in the DRC is limited to conventional technologies such as production of beers and soft drinks, transformation and conditioning of dairy products, and traditional production of fermented foods. Its application is limited to a few experimental trials carried out by some research and teaching institutions such as universities and colleges. The agricultural sector dominates the DRC's economy, with food crops such as cereals, roots, tubers, oilseeds, vegetables, and legumes; commercial crops such as coffee, cotton, tea, rubber, palm oil, cocoa, onion, sugar cane, fruits and vegetables; forest products; and breeding of cattle, sheep, pigs, goats and poultry. In agricultural biotechnology, only a few trials have been carried out to date, such as transgenic banana and transformation of cassava to reduce the level of cyanide [52]. The constrains facing the biotechnology industry in DRC include the lack of a biotechnology policy, poor public awareness and participation in matters related to modern biotechnology and over dependence on donor-driven biotechnological projects. These shortfalls call for the DRC government to invest more in modern biotechnology [52].

6. SUPPORT OF MODERN BIOTECHNOLOGY IN AFRICA

The development of modern biotechnology through research and investment would best be achieved in phases. The first phase involves conventional modern biotechnologies which involves the use of plant tissue culture and breeding since many of the important food crops grown in Africa such as cassava, sweet potato, yam and banana are vegetatively propagated and could be cross-bred with ease to improve its quality [53]. The second would be the application of modern biotechnology tools that would improve the efficiency of selection of varieties through marker applications (diagnostics, fingerprinting and marker-assisted breeding). The third phase will focus on capacity to produce transgenic plants/animals: which would include gene isolation and cloning; gene insertion; regeneration of transgenic plants/animals following the commercialisation of the GM product [53].

National biotechnology and biosafety policy frameworks are crucial so as to give directions on which way the technology should proceed [54,55]. Despite the lack of support of biosafety laws and regulations, most African countries mentioned in this review have formulated biosafety frameworks. Among the countries studied earlier, only Kenya, Tanzania and Uganda have broad biotechnology policies. It has however been suggested that the remaining countries should move fast in preparing their draft biotechnology policies so as to catch up with the rest. Burundi is moving faster in that direction, while Ethiopia, Rwanda and DRC are in the preparatory phases [54,55]. To support modern biotechnology in Africa is not an easy task. This is because adequate infrastructure, well trained technical expertise, and critical mass of researchers with sufficient supporting sustainable funding to cover the high cost of modern biotechnology research and development, is enough to ensure the successful application of modern biotechnology in Africa. African countries must form partnership with government agencies, universities, research institutions and private companies within the countries, and with other African countries like South Africa, Egypt and Burkina Faso (which have already commercialised genetically modified organisms).

African governments should provide strong leadership, effective priority-setting and adequate working opportunities for scientists. They should also strengthen institutions that are required to provide incentives and support for the establishment of biotechnology-based economies. Participatory extension approach programs could be an ideal channel for the implementation of biotechnology products, as well as endowing resource-poor farmers with the confidence to develop and apply solutions to some of their problems. The Eastern and Central African region should take full advantage of its soil fertility, valuable biodiversity and favourable climatic conditions [36,56].

7. CONCLUSION

This review looked at the place of modern biotechnology, the science, acceptance and support in Africa. In summary, modern biotechnology promises to make a significant contribution in enabling the development of better health care, enhanced food security through sustainable agricultural practices, improved supplies of potable water, more efficient industrial development processes for transforming raw materials, and support for sustainable methods of reforestation and detoxification of hazardous wastes in Africa. It has been established that modern biotechnology could offer new opportunities for partnerships between Africa and the developed world. They also hold a bright future in terms of market potential for new products to be developed in Africa. The African region can benefit from previous experiences and results achieved in other developing regions in obtaining benefits from the applications of biotechnology. This can be done through proper planning, interactive cooperation among countries and network participants. Modern biotechnology has grown into a global industry that has the potential of affecting many aspects of Africans positively; hence appropriate policies that regulate its application should be put in place. Governments should also streamline policies to foster the application and growth of modern biotechnology in the sub-region.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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