Medical Biotechnology and Biomimetics: Prospects and Challenges in Sub-Saharan Africa

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Abstract Advancements at the interphase of engineering and biology have produced disciplines that include Biotechnology and Biomimetics. These new disciplines proffer exciting solutions to real life problems. New technologies are available for the purification of water and treatment of sewage; challenges that are common in resource-limited countries. In the medical sciences, tissue engineering methods are rapidly and positively transforming the field of regenerative and restorative Medicine. The importance of Biotechnology and Biomimetics in the management of infectious diseases and in drug development (Pharmacology and Toxicology) is rising exponentially. However, for sub-Saharan Africa (SSA), these advances are yet to make meaningful and significant impact. Biotechnology and Biomimetics are still at very rudimentary stages of development with many challenges militating against progress. The prospects and challenges for SSA are discussed here.

Keywords Infectious diseases · Tissue engineering · Sub-Saharan africa

1 Introduction

Biomimetics or biomimicry is the imitation of the models, systems, and elements of nature for the purpose of solving complex human problems. Drawing largely from physical sciences, the rapidly growing discipline has made significant contributions to large and small scale engineering. Nature has always inspired innovations and creativity [1, 2]. Over billions of years, nature has evolved and overcome challenges that humans are faced with for reasons that include expansion of human populations and migrations to uninhabited lands. From aerodynamics, to the building of submarines, man has copied nature. These awesome engineering feats have inspired

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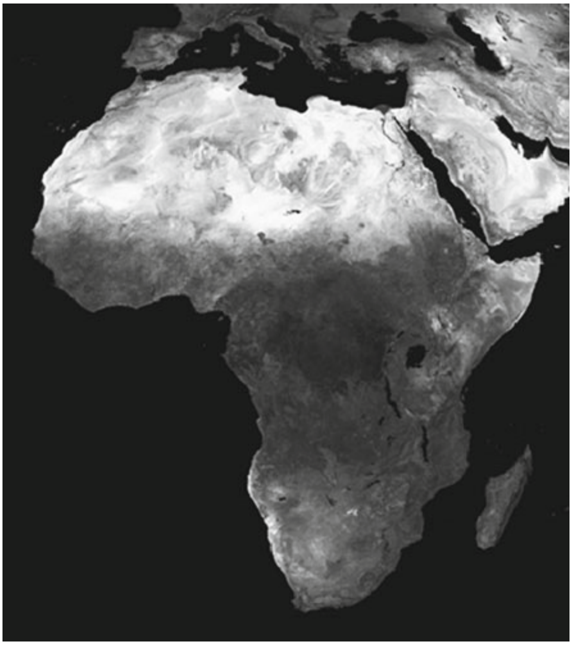
M. Israelowitz et al. (eds.), *Biomimetics and Bionic Applications with Clinical Applications*, Series in BioEngineering,
https://doi.org/10.1007/978-3-319-53214-1_2

more and more discoveries into the inner workings of physical and biological phenomena. More recently, Biomimetics has found more significance in the medical field which holds real and potential benefits for all mankind.

Africa is the second largest continent of the world with a population of 1.136 billion as at mid-2014, Fig. 1 [3]. Sub-Saharan Africa (SSA) is home to a large proportion of the countries in the continent, almost all of them resource-limited. The burden of infectious diseases like malaria, Tuberculosis, HIV, respiratory infections, malnutrition, parasitic diseases, and rapidly rising rates of chronic diseases (Diabetes, cancer) is disproportionately huge. This is a region that stands to benefit greatly from the new discipline of medical biomimetics; the medical applications of biomimetics. This chapter discusses briefly the potential applications of the discipline in sub-Saharan Africa where a lot of peculiarities hamper research and development, and also discusses some of the challenges to technological advancements. Biomimetics has a role to play in our sub-region, but it is wise to examine some approaches that may help overcome the present challenges militating against changes that African traditional systems often perceive as threats to traditional cultural lifestyles.

The potentials of biomimetics research and development in Africa will be in the areas of technologies that will provide cheap methods of producing clean water, disposal of biological waste including sewage, and diagnosis and monitoring of therapeutic approaches to infectious diseases. In this write up, the discussion covers approaches to water and sewage treatment, diagnosis of malaria, HIV, and tuberculosis, special technologies for estimation of drug therapy and drug delivery,

Fig. 1 Africa



engineering bone and skin tissues for management of trauma and extensive burns. Challenges to this approach include poor power supply, lack of infrastructure, socio-cultural resistance to technological advancements, educational systems that do not incorporate the development and deployment of local technology, and mal-adaptation of foreign technology. The current approach of importing foreign technology and planting them on existing traditional systems, without adaptation, has not been sustainable. Thus, there are many institutions with expensive equipment that are lying abandoned because the infrastructure cannot sustain them. Some solutions are proffered so that the development of biomimetics will factor in peculiarities of sub-Saharan Africa, by developing approaches that are sustainable and adapted to the sub-region.

2 Water and Sewage in Sub-Saharan Africa

Water is an essential requirement of life and it drives biological processes in all lifeforms on Earth. Getting clean water for domestic and industrial use has remained a luxury in many communities of sub-Saharan Africa (SSA). Diseases borne by water still rank amongst the major risk factors for morbidity and mortality in sub-Saharan Africa [4]. While it is energy consuming, and thus expensive to purify water traditionally (by boiling or distillation systems), recent advances in biomimetics may solve this challenge. Biomimetics research into water and ionic pore systems have the potential of effective separation of molecules into pure forms. Initial studies have shown the possibility of detecting low weight micro-organisms, heavy metals, and very low concentration of other bio-organic molecules, which are often the contaminants in many sources of water [5, 6]. Using what can be called an electronic nose; contaminants in water may be readily detected and planned for purification processes. The mimicking of water purification systems in plants holds the potential of developing low energy water purifications methods. For a long time, bacteria have been used to decontaminate sewage and recycle water [7, 8]. However, African traditional systems shy away from such natural systems considered ‘unclean.’

3 Biotechnology and Infectious Diseases

Infectious disease significantly affects the economic and socio-cultural activities of nations. There is room for improvements in the detection and diagnosis of the causative agents of Malaria, Tuberculosis, and the Human immunodeficiency virus (HIV). With improvements in biological sensors, this application of biotechnology is becoming more and more feasible. Micro-disc electrode arrays are implantable devices that can monitor biochemical pathways in the body [9]. The malaria pigment hemozoin, and its metabolism, has increasingly become a potential target for development of biotechnological methods of detecting the malaria parasite and potential drug targets non-invasively [10, 11]. With improvements in biomimetic recognition of protein, carbohydrates, and nucleic acids, diagnosis of bacteria (e.g. mycobacterium tuberculosis), and viruses (e.g. HIV), will become simpler and automated [12]. Cell targeting and gene transfers are technologies that can transform the field of infectious diseases [13]. Biosensors may someday be the technological basis of new real time diagnostic methods [14]. These are huge leaps in the medical field and are a few technologies that can change the terrain of management of infectious diseases; the major plagues of the African continent.

Biotechnology offers the possibility of rapid diagnosis of diseases. Chronic illnesses that are prevalent in developed countries are currently hot areas of research. Rapid improvements in infra-red camera technology has already found a place in the characterization on non-viable tissue in major limb neuropathy and ischemia due to diabetes [15–20]. While medical applications of biotechnology in chronic diseases prevalent in developed countries is a much researched topic, the importance of biotechnology still remains largely a theoretical aspect of tropical medicine. Devices that can diagnose infectious diseases earlier, and monitor the pathogens non-invasively are urgently needed in Africa.

The polymerase chain reaction has become a most important method of diagnosis of infectious and non-infectious deceases [21–24]. Green florescent protein is increasingly being used to tag important pathogenic pathways [25]. The culture of cells and micro-organisms will be further developed using bioreactor technologies that can maintain controlled internal conditions for optimal growth and development of cells [26, 27]. These methods have led to unprecedented insights into human pathogenic processes. The capacity for high throughput research needs to be developed, while challenges to technology in the continent must be surmounted.

4 Tissue Engineering

Advances in tissue engineering are providing new therapies for damaged human tissues. Bone and skin are commonly affected in traumatic accidents. In Africa road traffic accidents, major burns, and limb amputations due to complications of diabetes and other diseases are common. Developments in tissue engineering are potential solutions to these physically and emotionally distressing conditions. Biotechnology and biomimetics have made very promising devices and gadgets that can replace loss of human tissues. Artificial heart valves, dialysis machines, different forms of prostheses are life-saving, available readily in developed nations; with some difficulties, these devices are also obtainable in the African continent.

The use of biomimetic systems represents a major area of research in implant surgery. Developing artificially grown bone, teeth, and skin using biomimetic approaches will offer opportunities for restorative medicine and surgery [28, 29]. There are attempts at engineering whole organ systems including the heart and lungs. Nervous tissue is being coerced to regenerate using methods learnt from nature. The diseases of ageing, a good example being Alzheimer's disease, remain incurable, but developments in biotechnology are positive and encouraging. Artificial limbs for amputees, hearts for end stage heart disease, replacement of failed kidneys, and new lungs for those with end stage chronic obstructive lung diseases. All these point to a future that is full of promise; by mimicking nature we may advance to a point where out technology will reverse pathologies that are largely considered irreversible. However, there is very little or no visible research activity along these lines in sub-Saharan Africa to date. Efforts are being made, but much resistance and adverse conditions are mitigating progress.

4.1 Applications of Biotechnology to Pharmacology and Toxicology

Recent advances in biotechnology and bioinformatics have introduced very powerful tools for drug development. Synthetic mimics of endogenous ligands are being explored. One promising area is the management of diabetes where the search for insulin mimetics is being vigorously researched [30]. The scale up in the production of synthetic of artemisinins will reduce the cost of treatment of malaria in sub-Saharan Africa [31]. Antibiotics, antihelminthics, hormones, cancer therapy, and other bioactive molecules are some positive yields of advances in biotechnology and biomimetics [32–36]. Yet there is still much more in plants with potential benefits in human medicine.

Africa has a rich herbal medicines industry but this has remained largely unrefined and as crude extracts. Herbal and traditional medicines in Africa have not benefited from modern tools of biotechnology. Recent efforts at sequencing of genomes of plants, animals, and humans will best be utilized in the continent that harbours a high frequency of genetic polymorphisms. While herbs are generally considered safe, interactions with orthodox medicines are just being researched. In addition, toxicities of herbal medicines are also being discovered [37]. The new tools that are being developed in biotechnology are needed to refine traditional and herbal medicines. Genetic transformation is a powerful tool for enhancing the productivity of secondary plant metabolites and bioreactors are key steps towards commercial production [38]. In China modern tools of genetic engineering are provoding means of breeding of new medicinal plant varieties with high and stable yield, good quality, as well as stress-resistance [39]. These technologies are required in Africa where there is a rich culture of traditional and herbal medicine practice. However, there is overwhelming evidence that there are real challenges that have hampered progress, and continue to slow down attempts at transforming traditional medical practices in sub-Saharan Africa.

5 Challenges in Sub-Saharan Africa

Nature has perfected natural phenomena over billions of years. As exciting as this observation is, it is even more exciting to realise that what nature has built over the millennia, human technology may be able to improve upon and automate. Technological advances in recent times have transformed biology and medicine. Diseases that were previously considered incurable are being detected earlier and being cured. This marriage of engineering and biology is on a rapid rise in developed countries. Unfortunately sub-Saharan Africa (SSA) is lagging far behind in this activity; an activity that holds the most benefit to SSA, perhaps more than to any other region of the world. There are many reasons why this is so, but three will be mentioned: inherent inertia and resistance to change of African traditional systems, general absence of attitude of responsibility and respect for human intellectual effort, and poor infrastructural development.

Across the continent of Africa, in countries of sub-Saharan Africa, African traditional systems co-exist with orthodox, largely, western settings. The majority of the people are rural and have traditional religious and socio-cultural systems that pre-date modern history. With the advent of western education, urban dwellings based on western culture have continued to expand; however, the traditional beliefs are strongly entrenched even in the minds of the educated. One attribute of traditional African systems is resistance to change and often encountered ritualistic practices. The young are not raised to question what has existed or has been inherited. This is a major factor that has limited technological advancements in the sub-region. The use of objective evidence to drive social, cultural, and infrastructural changes in the society is foreign to such settings. Nevertheless, there is hope that, with rising numbers of educated Africans, these practices will not remain for too long. There still remains the need to build into the curriculum of primary schools the need to develop critical thinking, frequent challenge of existing bodies of knowledge, and questioning of effectiveness of long standing traditional systems. There should be no hesitation whatsoever in discarding old systems that are inimical to development.

Another challenge that has mitigated against technological advancements in many African settings is mis-interpretations and mis-applications of religion. The average African is very religious and in religion he or she finds self-dignity. There is no harm in being religious, in fact religions may offer some form of psychological stability, provide moral codes for those who practice different faiths, and may even have some health benefits [40]. These moral codes have in a large extent offered different degrees of social order and security. However, and rather difficult to understand, social responsibility has in recent times been increasingly negated by certain beliefs. The belief that progress comes only from the Divine leads to a form of neglect of social responsibility. When the people believe that God is the one who will rescue them from disease, unfavorable environments, poverty, and famine, not much else can be done. Long term planning is absent, and human intellectual effort is not praised, encouraged, or stimulated. There comes a general lack of curiosity and drive for discovery. Rather than religion inspiring positive actions aimed at producing beneficial changes, it becomes a passive resignation to fate which greatly hampers commitment to efforts aimed at technological and social development.

Finally, drawing directly from the above, long lasting neglect of active planning and good government that improve societal structures have led to huge infrastructural inadequacies. There are no structures or systems that can support the technologies discussed in this chapter. Electricity is absent or erratic in many sub-Saharan African countries [41]. Thus, when machines needed for state-of-the-art research are brought into sub-Saharan Africa, there is a high chance that they will rapidly become redundant and abandoned. Human capacity is also very inadequate; all these continue to fuel a vicious cycle that has become very difficult to break.

Thus, Africa lags behind in technological advances, despite the huge needs for the products. Disease is rampant and poverty continues to increase in the sub-region. Nigeria, the most populous sub-Saharan African nation has a disproportionately large burden of infectious and non-infectious diseases. The country has the highest burden of malaria, and a high burden of HIV [42–44]. However, there is hope. The continent has continued to improve socio-economically, and many sub-Saharan nations have grown educationally, medically, and economically. The recent elections in Nigeria (the 2015 elections) have been generally praised as a victory for democracy. Truly democratic nations are positioned to supporting biotechnological advancements. There is also increasing support from western nations towards empowering researchers of the region for high impact medical research. There are conferences that have been held on bringing biotechnological advances into Africa, and countries are putting in place policies that will encourage and guide developments in biotechnology [45–48]. These are very encouraging developments. Progress may be slow; but with sustained efforts, eventually sub-Saharan Africa will break into biotechnology, biomimetics, and be poised for relief from many burdens of disease.

Acknowledgements The authour acknowledges the valuable contributions of Dr. (Mrs) Afieharo Michael and Dr. Taiwo Lawal of the Department of Surgery, Faculty of Clinical Sciences, University of Ibadan, Nigeria. The author declares no conflict of interest.

References

1. Bar-Cohen, Y.: Biomimetics–using nature to inspire human innovation. Bioinspir. Biomim. **1** (1), P1–P12 (2006)
2. Bhushan, B.: Biomimetics: lessons from nature–an overview. Philos. Trans. A Math. Phys. Eng. Sci. **2009**(367), 1445–1486 (1893)
3. Bureau, P.R.: World population data sheet (2014)
4. Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., Amann, M., Anderson, H.R., Andrews, K.G., Aryee, M., et al.: A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions,

1990-2010: a systematic analysis for the global burden of disease study 2010. Lancet **380** (9859), 2224–2260 (2012)
5. Canhoto, O.F., Magan, N.: Potential for detection of microorganisms and heavy metals in potable water using electronic nose technology. Biosens. Bioelectron. **18**(5–6), 751–754 (2003)
6. Wang, S., Xu, Z., Fang, G., Zhang, Y., Liu, B., Zhu, H.: Development of a biomimetic enzyme-linked immunosorbent assay method for the determination of estrone in environmental water using novel molecularly imprinted films of controlled thickness as artificial antibodies. J. Agric. Food Chem. **57**(11), 4528–4534 (2009)
7. Thomas, J.M., Ward, C.H.: Biotechnology for in situ restoration of ground water contaminated by the petroleum industry. Schriftenr. Ver. Wasser. Boden. Lufthyg. **80**, 345–365 (1989)
8. Janssen, D.B., Witholt, B.: Developments in biotechnology of relevance to drinking water preparation. Sci. Tot. Environ. **47**, 121–135 (1985)
9. Justin, G., Finley, S., Abdur Rahman, A.R., Guiseppi-Elie, A.: Biomimetic hydrogels for biosensor implant biocompatibility: electrochemical characterization using micro-disc electrode arrays (MDEAs). Biomed. Microdevices **11**(1), 103–115 (2009)
10. Egan, T.J.: Haemozoin formation. Mol. Biochem. Parasitol. **157**(2), 127–136 (2008)
11. Egan, T.J.: Recent advances in understanding the mechanism of hemozoin (malaria pigment) formation. J. Inorg. Biochem. **102**(5–6), 1288–1299 (2008)
12. Walker, D.B., Joshi, G., Davis, A.P.: Progress in biomimetic carbohydrate recognition. Cell. Mol. Life Sci. **66**(19), 3177–3191 (2009)
13. Wang, Y., Mangipudi, S.S., Canine, B.F., Hatefi, A.: A designer biomimetic vector with a chimeric architecture for targeted gene transfer. J. Control Release **137**(1), 46–53 (2009)
14. Jelinek, R., Silbert, L.: Biomimetic approaches for studying membrane processes. Mol. Biosyst. **5**(8), 811–818 (2009)
15. Ring, F.: Thermal imaging today and its relevance to diabetes. J. Diabetes Sci. Technol. **4**(4), 857–862 (2010)
16. Parker, M.D., Taberner, A.J., Nielsen, P.M.: A thermal stereoscope for surface reconstruction of the diabetic foot. Conf. Proc. IEEE Eng. Med. Biol. Soc. **2011**, 306–309 (2011)
17. Pafili, K., Papanas, N.: Thermography in the follow up of the diabetic foot: best to weigh the enemy more mighty than he seems. Expert Rev. Med. Devices 2014, 1–3 (2014)
18. Anburajan, M., Sivanandam, S., Bidyarasmi, S., Venkatraman, B., Menaka, M., Raj, B.: Changes of skin temperature of parts of the body and serum asymmetric dimethylarginine (ADMA) in type-2 diabetes mellitus Indian patients. Conf. Proc. IEEE Eng. Med. Biol. Soc. **2011**, 6254–6259 (2011)
19. Balbinot, L.F., Canani, L.H., Robinson, C.C., Achaval, M., Zaro, M.A.: Plantar thermography is useful in the early diagnosis of diabetic neuropathy. Clinics **67**(12), 1419–1425 (2012)
20. Balbinot, L.F., Robinson, C.C., Achaval, M., Zaro, M.A., Brioschi, M.L.: Repeatability of infrared plantar thermography in diabetes patients: a pilot study. J. Diabetes Sci. Technol. **7** (5), 1130–1137 (2013)
21. Gardner, A.F., Kelman, Z.: DNA polymerases in biotechnology. Front. Microbiol. **5**, 659 (2014)
22. Hamilton, S.C., Farchaus, J.W., Davis, M.C.: DNA polymerases as engines for biotechnology. Biotechniques **31**(2), 370–376, 378–380, 382–373 (2001)
23. Kranaster, R., Marx, A.: Engineered DNA polymerases in biotechnology. ChemBioChem **11** (15), 2077–2084 (2010)
24. Lovatt, A.: Applications of quantitative PCR in the biosafety and genetic stability assessment of biotechnology products. J. Biotechnol. **82**(3), 279–300 (2002)
25. Misteli, T., Spector, D.L.: Applications of the green fluorescent protein in cell biology and biotechnology. Nat. Biotechnol. **15**(10), 961–964 (1997)
26. Lavrentieva, A., Hatlapatka, T., Neumann, A., Weyand, B., Kasper, C.: Potential for osteogenic and chondrogenic differentiation of MSC. Adv. Biochem. Eng. Biotechnol. **129**, 73–88 (2013)

27. Weyand, B., Israelowitz, M., von Schroeder, H.P., Vogt, P.M.: Fluid dynamics in bioreactor design: considerations for the theoretical and practical approach. Adv. Biochem. Eng. Biotechnol. **112**, 251–268 (2009)
28. Bellamy, K.E., Waters, M.G.: Designing a prosthesis to simulate the elastic properties of skin. Biomed. Mater. Eng. **15**(1–2), 21–27 (2005)
29. Ashammakhi, N., Ndreu, A., Nikkola, L., Wimpenny, I., Yang, Y.: Advancing tissue engineering by using electrospun nanofibers. Regen. Med. **3**(4), 547–574 (2008)
30. Adachi, Y., Yoshida, J., Kodera, Y., Kato, A., Yoshikawa, Y., Kojima, Y., Sakurai, H.: A new insulin-mimetic bis(allixinato)zinc(II) complex: structure-activity relationship of zinc(II) complexes. J. Biol. Inorg. Chem. **9**(7), 885–893 (2004)
31. Corsello, M.A., Garg, N.K.: Synthetic chemistry fuels interdisciplinary approaches to the production of artemisinin. Nat. Prod. Rep. **32**(3), 359–366 (2015)
32. Ahmed, C.M., Burkhart, M.A., Subramaniam, P.S., Mujtaba, M.G., Johnson, H.M.: Peptide mimetics of gamma interferon possess antiviral properties against vaccinia virus and other viruses in the presence of poxvirus B8R protein. J. Virol. **79**(9), 5632–5639 (2005)
33. Avendano, C., Menendez, J.C.: Peptidomimetics in cancer chemotherapy. Clin. Transl. Oncol. **9**(9), 563–570 (2007)
34. Carmona-Ribeiro, A.M.: Biomimetic particles in drug and vaccine delivery. J. Liposome Res. **17**(3–4), 165–172 (2007)
35. Chen, S., Chen, R., He, M., Pang, R., Tan, Z., Yang, M.: Design, synthesis, and biological evaluation of novel quinoline derivatives as HIV-1 Tat-TAR interaction inhibitors. Bioorg. Med. Chem. **17**(5), 1948–1956 (2009)
36. Denap, J.C., Thomas, J.R., Musk, D.J., Hergenrother, P.J.: Combating drug-resistant bacteria: small molecule mimics of plasmid incompatibility as antiplasmid compounds. J. Am. Chem. Soc. **126**(47), 15402–15404 (2004)
37. Yang, X.X., Hu, Z.P., Duan, W., Zhu, Y.Z., Zhou, S.F.: Drug-herb interactions: eliminating toxicity with hard drug design. Curr. Pharm. Des. **12**(35), 4649–4664 (2006)
38. Khan, Y.M., Aliabbas, S., Vimal, V., Rajkumar, S.: Recent advances in medicinal plant biotechnology. Indian J. Biotechnol. **8**, 9–22 (2009)
39. Huang, H.P., Li, J.C., Huang, L.Q., Wang, D.L., Huang, P., Nie, J.S.: The application of biotechnology in medicinal plants breeding research in China. Chin. J. Integr. Med. (2015)
40. Ferraro, K.F., Kim, S.: Health benefits of religion among Black and White older adults? Race, religiosity, and C-reactive protein. Soc. Sci. Med. **120**, 92–99 (2014)
41. Adair-Rohani, H., Zukor, K., Bonjour, S., Wilburn, S., Kuesel, A.C., Hebert, R., Fletcher, E. R.: Limited electricity access in health facilities of sub-saharan Africa: a systematic review of data on electricity access, sources, and reliability. Glob. Health Sci. Pract. **1**(2), 249–261 (2010)
42. Maiyaki, M.B., Garbati, M.A.: The burden of non-communicable diseases in Nigeria; in the context of globalization. Ann. Afr. Med. **13**(1), 1–10 (2014)
43. Okechukwu, A.A., Okechukwu, O.I.: Prevalence of paediatric HIV infection in federal capital territory. Abuja. Niger J. Med. **20**(4), 409–413 (2011)
44. Uguru, N.P., Onwujekwe, O.E., Uzochukwu, B.S., Igiliegbe, G.C., Eze, S.B.: Inequities in incidence, morbidity and expenditures on prevention and treatment of malaria in southeast Nigeria. BMC Int. Health Hum. Rights **9**, 21 (2009)
45. Cloete, T.E., Nel, L.H., Theron, J.: Biotechnology in South Africa. Trends Biotechnol. **24** (12), 557–562 (2006)
46. Africa moves to strengthen biotechnology: Nature **399**(6731), 6 (1999)
47. Agbo, E.C., Agwale, S., Ezeugwu, C.O., Semete, B., Swai, H., Ikeme, A., Somiari, R.I.: Biotechnology innovation in Africa. Science **321**(5897), 1778 (2008)
48. Andanda, A.P.: Health-related biotechnology in Africa: managing the legislative and regulatory issues. Afr. J. Med. Med. Sci. **36**(Suppl), 55–61 (2007)