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Research Article

Analysis of Emerging Research Areas in Selected African Countries: A Case of Biotechnology-Applied Microbiology Discipline

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ABSTRACT

Mapping of research has become important across the world and any new technology requires a new institutional framework for mapping appropriate outcomes of research. It involves analyzing linkages between various actors, stakeholders, agencies, and institutions to map potential research domains. Over the years, Biotechnology Applied Microbiology has emerged as a niche area, and this sector is recognized as the key driver for economic growth and development. Biotechnology has emerged as a promising area of research in selected African countries but requires expanding its S&T base. To enhance S&T-based and capacity building Africa has initiated to expand its collaborative efforts with other countries including Europe, Asia, the US, the Middle East, and Africa with promising results in different areas like nanotechnology, biotechnology, agriculture, pharmaceuticals, etc. Biotechnology is one of the emerging areas and African biotechnology has the potential to transform the economy. Therefore, this paper presents an analysis of the emerging pattern of research areas in selected African countries and in particular biotechnology research activities in Africa. More than 56000 research articles were analyzed, using SPSS software, indicates that R&D collaboration and national as well as international networks could be helpful in enhancing publication output and research competency in the field of biotechnology research in Africa.

Keywords: S&T base, Biotechnology, Economic growth, Bibliometric analysis, Emerging research areas.

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INTRODUCTION

Africa is the second-largest continent home to 1.3 billion people constituting nearly 16 percent of the world population[1] and a natural resource-rich region.[2] It is observed that in the past African countries did not perform well economically as other countries have been performing. Recently, Africa has shown considerable growth due to business conditions in most of the African economies have improved significantly in the last decade despite several challenges as argued by Ernst and Young.[3] Another study highlighted a surplus of workers, more stability and technology are transforming Africa's economies, making it less dependent on extractive industries[4] resulting in attracting investors to contest with technology. To overcome economic backwardness and emerging challenges Africa needs to be more rigorous in research activities by expanding its Science and Technology (S&T) base and developing S&T linkages within Africa and other countries. The academic linkages may create new opportunities for developing required R&D professionals to meet emerging sectors' needs. Concurrently, it is imperative to develop a mechanism and strategy for developing dynamic S&T collaborations in the African region and a future roadmap for how the African governments effectively interact with their African counterparts in S&T initiatives to develop a pool of researchers to cater for the needs of local requirements.

Study shows that Africa faces limited S&T capacity in terms of the size of the S&T human resource and interconnectedness of institutions as well as the existence and availability of infrastructure and equipment.[5] This requires stimulating collaboration and funding resources for catalyzing R&D activities. Achachi, H. *et al.*[6] found that the majority of researchers prefer to collaborate preferentially with their peers in their own research groups, with foreign partners and with national collaborations from other universities. They found that scientific collaboration is very profitable in collaborative research papers with high-impact factors and follows the core-periphery structure attributed to most scientific collaboration network. Adams, J. *et al.*[7] also show that

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international research collaboration suggests a comprehensive global network centred on a group of core countries and driven by generic socio-economic factors where the global system influences all national and institutional outcomes. The External collaborative links catalyses research productivity that varies significantly by country. In another study, he further emphasized that the Governments need to develop an industrial policy that complements science policy for developing S&T competency in the African region.[8] Pan, J. *et al*.,[9] argued that incentives for collaborative innovation investment that draws directly on the science base would be a good start. He analyzed evidence synthesis publications study and found that African institutions have become more connected between 2008 and 2019, although the amount of intercontinental collaboration continues to exceed that of regional collaboration, the tendency for African institutions to collaborate with partners in Africa is increasing network analysis could provide a useful tool to evaluate the effectiveness of capacity-building strategies and programmes in the future.[9] The study also shows that publications from those few African countries whose scientific communities demonstrate higher levels of specialization and integration in international networks have a higher impact than the world average. The potential applications of the new knowledge that has been produced by African researchers highlight that so far, South Africa seems to be the only African country where a reasonable part of that new knowledge seems to be connecting with innovation.[10] Therefore, in this paper, an attempt is made to provide brief glimpses of S&T in selected African countries by analyzing research output and emerging research areas, in particular growth of the Biotechnology Sector in African countries.

Methodology and rationale behind the Study

According to Michael,[11] the top 10 most technologically advanced countries in Africa[11] are: South Africa, Egypt, Nigeria, Kenya, Ghana, Rwanda, Botswana, Angola, Uganda and Zimbabwe and these countries are considered for analysing emerging areas for this study. African countries appeared facing several challenges on the S&T front and lagging behind in research output as compared to developing countries. However, during the last two decades, Africa has registered remarkable progress in the production of scientific knowledge with a total share of 7.6% of contributions to the world of science and one-third of all international publications in tropical medicine. According to Radhamany Sooryamoorthy (2022) publications in science in most African countries have increased from two to 20 times over the past 19 years. South Africa tripled its production in the period 2001-18, Egypt grew by 5.4 times, Tunisia 6.4 times, Nigeria 4.7 times, Algeria eight times, Morocco twice, Kenya 3.6 times, Ethiopia 9.5 times, Uganda 6.5 times and Tanzania by five times[12] This study shows that South Africa (128435) is the highly producing country in Africa followed by Egypt (112436) and Tunisia 43883) during 2001-2018. The data shows that South Africa increased its publication three times. Egypt grew by 5.4 times, Tunisia by 6.4 times, Nigeria by 4.7 times, Algeria eight times, Morocco twice, Kenya by 3.6 times, Ethiopia by 9.5 times, Uganda by 6.5 times and Tanzania by five times. However, Africa is still facing many challenges in the field of S&T development. Patra and Muchie[13] in another study shows that South Africa ranks in 35th position and Egypt in 39th position in the global publication landscape in the period from 1990-2019.[13] These studies indicate that Africa is growing slowly in scientific productivity and need to analyse emerging areas to draw policy and roadmap for a future strategy to enhance the scientific base in the African region.

Therefore, the present study focuses on highlighting and analysing different aspects of African S&T and potential niche areas. For collecting related data *Web of Science* databases as well as online sources are used for secondary data. Results are based on empirical studies as well as data collected from the *Web of Science*. For the study, only articles (research articles) are considered to present emerging patterns and collaborations in research publications within selected African countries as well as other countries. The paucity of data pertaining to S&T indicators in the context of the African economy is the limitation of the study. Area/subject categories are adopted from the *Web of Science* categories. For extracting data keywords such as R&D Expenditure as a Percentage of GDP, researchers in R&D per Million, number of research articles in Biotechnology, emerging areas/disciplines, patent filing, number of most Universities in African Countries, joint articles of selected African countries within country and international universities in the area of Biotechnology were used.

Status of S&T Research in Africa

S&T skills and capabilities are considered key drivers of economic growth and development. It is apparent that developed countries are an outcome of technological competency and capabilities. This is also applicable to developing and underdeveloped countries and it was realized that for catalysing their economic growth there is a need to enhance the S&T base in developing countries. S&T capabilities generally include R&D expenditure, level of educational enrolment at different levels, patenting activities, S&T publication output and the number of researchers. Hence, global R&D spending has constantly increased and has reached a record high of almost US$ 1.7 trillion and about 10% of countries account for 80% of R&D spending.[14] The USA (3.1%), Japan (3.2%), Germany (3.2%), South Korea (4.6%), Taiwan (3.5%), Sweden (3.4%), Austria (3.2%), Israel (4.0%) and Denmark (3.1%) are spending more than 3% of GDP on R&D. Developing countries like China (2.2%), India (1.3%), Russia (1.0%) and Brazil (1.3%) have also enhanced expenditure on R&D. However, the intensity of expenditure on R&D in African countries is low except South Africa (0.83%), Egypt (0.72%) and Morocco (0.70%). Most of the African countries namely Botswana (0.30%), Uganda (0.50%),

and Sudan (0.20%), are expanding very low on R&D in 2019. For the rest of the countries, the statistics are not available.

The global R&D expenditure grew faster than the economy between 2014 and 2018 as per the UNESCO report. The report also highlighted that China and the US together account for 63% of the increase in spending, while the EU countries added a further 11% in R&D spending. The low and middle-income economies struggle to catch up to increase their R&D expenditure by other means like incentives i.e. giving tax incentives to the private sector to invest in research as in Indonesia. Comparative spending on R&D in selected African countries is given in Table 1a, and countries spending more than 1.0% on R&D are given in Table 1b.

Table 1a: R&D Expenditure as Percentage of GDP.

	S Africa	Egypt	Ghana	Kenya	Uganda	Ethiopia	Botswana	Sudan
2003	0.76	---	---	---	0.26	---	---	0.34
2004	0.81	0.27	---	---	0.26	---	---	0.30
2005	0.86	0.24	---	---	0.22	0.18	---	0.30
2006	0.90	0.26	---	---	0.30	---	0.53	---
2007	0.88	0.26	0.23	0.36	0.39	0.17	---	---
2008	0.89	0.27	---		0.33	---	---	---
2009	0.84	0.43	---		0.26	---	---	---
2010	0.74	0.43	0.38	0.79	0.36	0.24	---	---
2011	0.73	0.53	---	---	---	---		---
2012	0.73	0.51	---	---	---	---		---
2013	0.72	0.64	---	---	---	0.60	0.26	---
2014	0.77	0.64	---	---	0.14	---	0.54	---
2015	0.80	0.72	---	---	---	---	---	---
2016	0.82	0.71	---	---	---	---	---	---
2017	0.83	0.68	---	---	---	0.27	---	---
2018	---	0.72	---	---	---	---	---	---

Source: https://data.worldbank.org/indicator/GB.XPD.RSDV.GD.ZS; Retrieved on 25.06.2022.

Table 1b: Countries spending more than 1% of GDP on R&D and corresponding Researchers.

Sl. No.	Country of Origin	Expenditure on R&D as %of GDP	Year	Researchers* per million population
1	United States	3.1	2019	4412.44
2	China	2.2	2019	1224.78
3	Japan	3.2	2019	5304.13
4	Germany	3.2	2019	5076.51
5	South Korea	4.6	2019	7497.59
6	France	2.2	2019	4561.11
7	U K	1.8	2019	4341.15
8	Taiwan	3.5	2019	---
9	Russia	1.0	2019	2821.53
10	Brazil	1.3	2017	887.68
11	Italy	1.4	2019	2313.65
12	Canada	1.5	2019	4325.64
13	Australia	1.8	2019	---
14	Turkey	1.1	2019	1379.41

Source: Different online Sources; * Figures represent the year 2017 while for Brazil figures are for 2016.

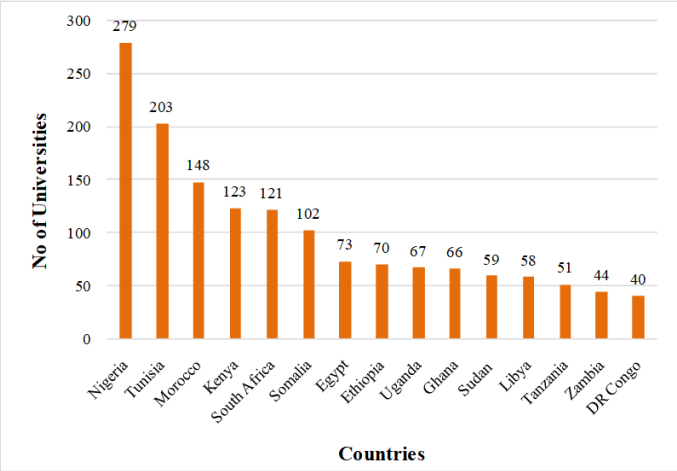

Figure 1: African countries with the most universities as of 2021.

Source: https://www.statista.com/statistics/.

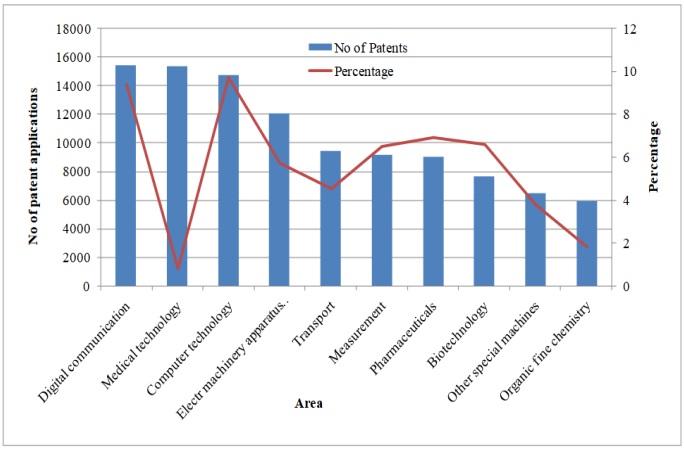

Figure 2: Globally Technical Fields with Most Patent Applications in 2021.

Source: https://www.epo.org/news-events/news/2022/20220405.html; retrieved on 29.06.2022.

The pool of researchers in a country is also one of the tangle indicators of R&D capabilities and most of the developed countries have a higher number of researchers per million people as compared to the developing and underdeveloped countries. The pool of researchers needs extensive university infrastructure to produce good quality human resources; technologists and professionals. Figure 1; shows that Nigeria has the highest number of universities that counts 279 institutions/universities in African countries following Tunisia (203 universities), Morocco (148 universities), Kenya (123 universities), South Africa (121 universities), Algeria (102 universities), Egypt (73 universities) while Djibouti and Niger have one university each.

Available statistics indicate that the distribution of researchers is uneven in African countries. The density of researchers depends upon the university infrastructure and academic ecosystem. According to a UNESCO study[14] the number of researchers per million people increased by 9.9% in 2018 as compared to 2014. A study also shows the number of scientists worldwide reaches 8.8 million, as global research spending grows faster than the economy.[15] However, the number of researchers in developing, underdeveloped and African countries is less as compared to developed countries. It is apparent that S&T indicators are interlinked across the countries. Meo and Usmani,[16] found that spending on R&D, indexed journals, number of universities, number of patents, and high technology exports have a positive correlation with the number of published documents in various science and social science subjects. They established a positive correlation between patent applications and high-tech exports. Table 2 illustrates the Number of Researchers in R&D per million in selected countries.

On the contrary, they also found that there was no association between GDP per capita and research outcomes but they argued the important contributing factors towards a knowledge-based economy are spending on R&D, universities, scientific indexed journals, and research publications. Investment in R&D can boost patents, high technology exports and GDP.[11-16] Similarly, patent statistics is another significant indicator of technological capability which is frequently used as an indicator of economic and innovation activity. Also, patent statistics are helpful to understand the national capability of translating theoretical knowledge into translational knowledge which may lead to product development and translate patents into the commercialization of products. As per the statistics (2021), available China was on the top in filling 69540 patents followed by the USA (59570), Japan (50270), the Republic of Korea (20678), and Germany (17322).[17] It is worth mentioning that Korea has made significant growth in patent activities which may go up in future. Maximum patent applications in the world were recorded in digital communication followed by medical technology, computer technology and so on (Figure 2).

Several studies[18] suggested that innovation plays a key role in success in economic growth and development in developing and threshold countries. Khan, and Sokoloff[19] highlighted that patents promote innovation and economic growth and are effective tools for knowledge-sharing and technology transfer and play a significant role in innovation and encouraging economic growth. Therefore, many countries are encouraging researchers to increase patent filing. So, patent applications have spurred in Europe, the USA and some developing countries but the pace of growth is not comparable in African countries. However, patent filings in African countries have accelerated, mainly, since the mid-1990s, but at different rates within different African jurisdictions.[20] As per the study the most emerging areas are in pharmaceuticals, chemistry, biotechnology, and engineering. Further, the majority of patent filings in Africa are from Europe, the United States, and other high-income countries. A small share of inventions globally is made in sub-Saharan Africa while Egypt and South Africa are the leading countries in filing patents (Figure 3).

Table 2: Number of Researchers in R&D per Million.

Year	S Africa	Egypt	Nigeria	Ghana	Kenya	Uganda	Ethiopia	Zimbabwe	Botswana
2003	302.46	---	---	---	---	---	---	---	---
2004	378.81	---	---	---	---	---	---	---	---
2005	361.38	---	---	---	---	---	21.06	---	---
2006	383.03	---	---	---	---	---		---	---
2007	393.33	630.98	38.79	17.08	54.39	---	20.02	---	---
2008	389.40	438.60	---	---		---		---	---
2009	392.12	433.33	---	---				---	---
2010	365.50	492.41	---	37.96	221.39	38.94	42.23	---	---
2011	386.80	491.76	---	---	---	---		---	---
2012	404.72	517.14	---	---	---	---		---	172.44
2013	434.85	539.02	---	---	---	---	44.73	99.52	185.21
2014	432.16	675.24	---	---	---	27.84	---	---	---
2015	472.31	672.94	---	89.11	---	---	---	---	---
2016	492.04	689.25	---	---	---	---	---	---	---
2017	517.72	677.10	---	---	---	---	90.53	---	---
2018	---	686.72	---	---	---	---	---	---	---

Source: https://data.worldbank.org/indicator/SP.POP.SCIE.RD.P6; Retrieved on 24.06.2022.

Similarly, developing economies are gradually increasing marks in global research articles and publications. African countries are also emerging in the publication of research articles and have shown steady growth as reflected in Figure 4.

Biotechnology Applied Microbiology: A Case Study

Biotechnology provides diverse applications and significant potential in all spheres of the economy to improve labour supply, education and investment opportunities resulting in substantially increasing the sustainable development of economies. R&D organisations and universities play an important role to develop S&T capabilities and providing trained human resources needed for national development and economic growth. Universities are not only meant for imparting higher education but their role is more critical to train students for highly skilled professionals and prepare them for research which can fulfil the national requirement in different spheres of the economy. Africa is rich in natural resources such as various minerals, oil, natural gas, and metals. Despite rich natural resources, Africa is not able to exploit the resources for development and economy. Apart from other reasons inadequate S&T capabilities and well-trained professionals may be one of the important factors in this direction. That requires a large infrastructure to develop an S&T base, which is an important tool for fostering and strengthening economic development. For producing a quality pool of professionals not only in the S&T area but also in all spheres of economic activities are required. S&T infrastructure includes R&D institutions, better government policies, investment in education, and researchers. Also, it requires a comprehensive analysis of the workforce required for an emerging market to cater to the need of the industry. It is observed over the years that the service sector, contributing the largest share of a country's economy, has emerged as a key player in economic growth.

Due to the scarcity of resources, Africa could not able to pursue high-tech research that requires huge infrastructure and large funding. Geographically, agriculture has a massive social and economic footprint in Africa, and the majority of the population of sub-Saharan Africa is smallholder farmers, and a considerable share of sub-Saharan Africa's GDP comes from agriculture. For this study, we considered biotechnology as an area because biotechnology and allied areas have significant potential in Africa and approximately contribute 7 per cent of patents across the world. Moreover, Information and Communications Technology (ICT) and biotechnology, and innovation processes themselves have become centred less on individual firms and more dependent on interactions among global networks of actors in the public and private sectors and in many countries patentable subject matter including biotechnology and software), are more robust and more valuable patents are filing (OECD, Patents and Innovation: Trends and Policy Challenges, 2004). So, Biotechnology Applied Microbiology is considered for analysis in selected emerging countries i.e. South Africa, Egypt, Nigeria, Kenya, Ghana, Rwanda, Botswana, Angola, Uganda and Zimbabwe. Current bibliometric analysis indicates that environmental science followed by material sciences are emerging areas in Africa as reflected from the data collected (Figure 5). However, biotechnology could be a potential area where Africa can emerge as a global leader by integrating biotechnology into Africa's agricultural development. This was emphasised by the experts during a Roundtable on "*Agricultural*

Biotechnology, Innovation and Emerging Technologies for Africa's Rural Economic Transformation" conducted by the African Union Development Agency (AUDA-NEPAD) in October 2020.

Figure 6 depicts research articles in the area of Biotechnology Applied Microbiology in selected countries; similarly, Figure 7 represents country-wise published articles.

Africa exhibits a poor international network of joint publications as well among African countries. Figure 8a-8c highlights international as well as regional collaboration in research articles Biotechnology Applied Microbiology.

Policy initiatives and discussions

The Biotechnology industry is knowledge-intensive, that needs investment and a pool of researchers to create an R&D ecosystem for stimulating R&D activities. Also, the paucity of data pertaining to R&D indicators in Africa is a major obstacle to assessing the future potential of the area. Data suggests that there is considerable research in the area of Biotechnology Applied Microbiology. The main constraints facing the biotechnology industry in the African region are poorly skilled human resources, lack of modern facilities, poor public perception and weak political will by some governments. More vigorous practical actions are needed in order for biotechnology to benefit the people of this region in terms of food security, economic growth, improved health and environmental protection.[13] Despite several obstacles, African leadership has always given priority to the technological and economic development and African Union (AU) and played a vital role in this direction with the objectives to promote sustainable development through advancement of science and technology. Accordingly, to achieve the desired goals Africa's Science and Technology Consolidated Plan of Action (CPA) were developed in 2006 under the New Partnership for Africa's Development (NEPAD). Subsequently, NEPAD and the AU Commission established a high level African panel on biotechnology. One of the key objectives of NEPAD was to bridge the technological divide between Africa and the rest of the. This aspired to increase network and partnership with global community in the field of biotechnology. Under the AU-NEPAD Africa's S&T Consolidated Plan of Action (CPA) five major

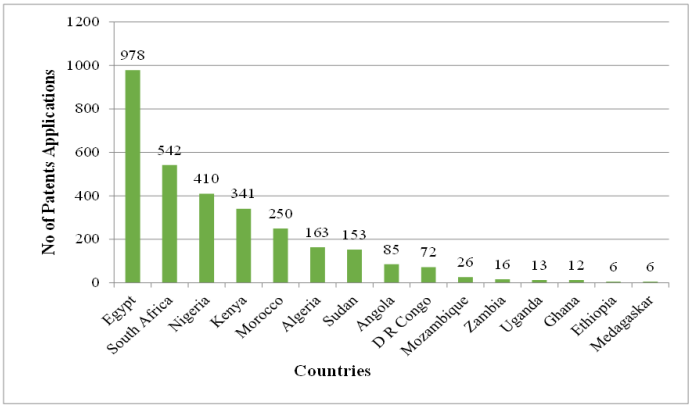

Figure 3: Pattern of patent filing in selected African countries.

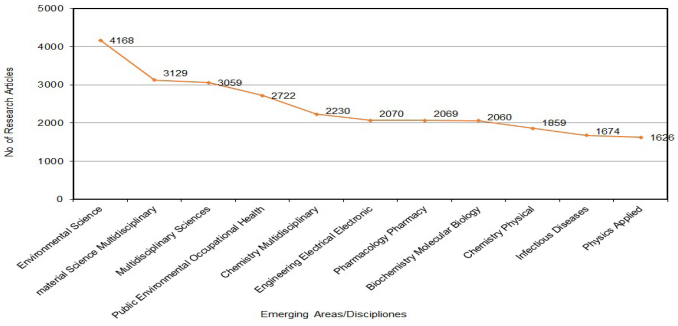

Figure 5: Emerging Areas/Disciplines in Selected African Countries; South Africa, Egypt, Nigeria, Kenya, Ghana, Rwanda, Botswana, Angola, Uganda and Zimbabwe (2002-2021).

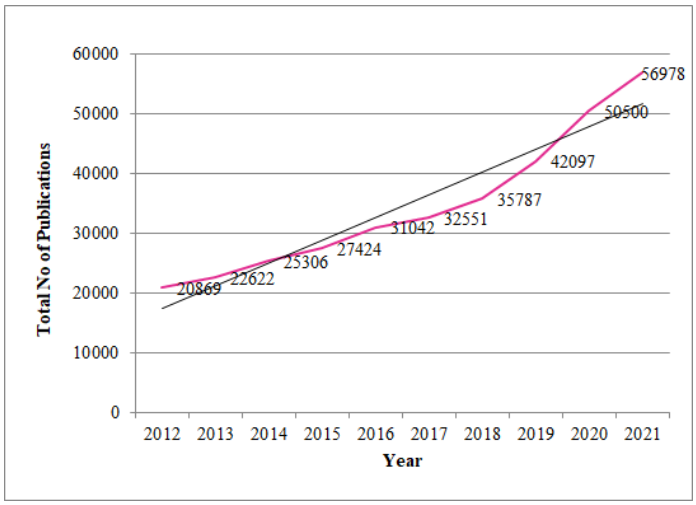

Figure 4: No of total articles published from 2012-2021 (The figure shows publications from South Africa, Egypt, Nigeria, Kenya, Ghana, Rwanda, Botswana, Angola, Uganda and Zimbabwe only).

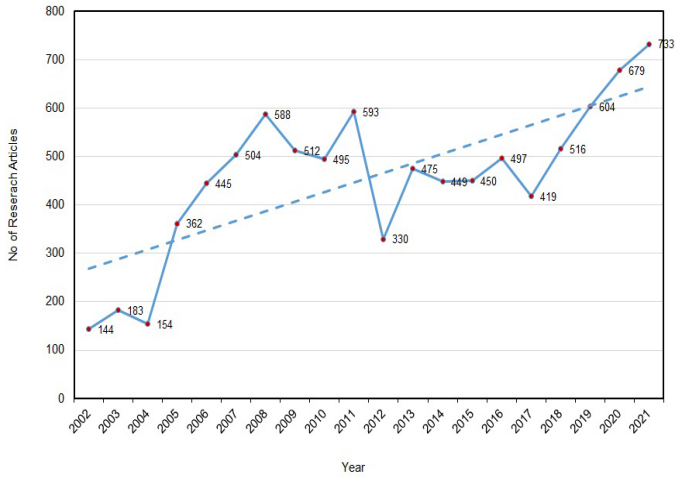

Figure 6: No of Research Articles in Biotechnology Applied Microbiology in Selected African Countries; South Africa, Egypt, Nigeria, Kenya, Ghana, Rwanda, Botswana, Angola, Uganda and Zimbabwe (2002-2021).

clusters were identified to boost the African S&T capabilities as (i) Biodiversity, Biotechnology and Indigenous Knowledge (ii) Energy, Water and Desertification (iii) Material Sciences, Manufacturing, Laser Technology and Post Harvest Technology (iv) Information and Communication Technologies; and Space Science and Technologies and Mathematical Sciences world.[21] For bridging the gaps in biotechnology area the AU and the NEPAD Office of Science and Technology established the African Biosciences Initiative in 2005 to encourage of networks of centres of excellence around the continent in biotechnology (Table 3).

Innovation and technological competence is strongly associated with university-industry-government interactions that catalyze the incubation of technology-based firms. Therefore, the creation of academic knowledge in entrepreneurial ecology is interactive rather than a linear model of innovation by raising the technological level closer to an academic model and engaging in higher levels of training and in sharing of knowledge.[22] This requires undertaking reforms in partnership with various segments of the R&D system for creating a pool of trained manpower. Due to the paucity of resources for trained manpower in African countries, there is a need for the reorganisation of Africa's development agenda to other levels of learning, such as colleges, research and technical institutes and polytechnic schools.[23] Universities may take this role in promoting innovation with a network of other academic/R&D institutions. This will facilitate the development process by creating an entrepreneurial environment in Africa.

Biotechnology Policy Initiatives in Africa

African policy makers identified diverse policy initiatives to expand research, development and commercialization of biotechnology products at the regional, sub-regional and national levels, an indication that biotechnology considerations are at the core of the development agenda. Table 1 captures some of these policy initiatives.[24] Karembu *et al.* argued that agricultural biotechnology holds great potential in raising farm productivity and developing environmentally sustainable agriculture in Africa. As a result, African leaders realized the importance of investment in new agricultural techniques and have made substantial improvements in setting up special governance and capacity-building mechanisms to proceed with the application of biotechnology in agriculture. Consequently, African Union leaders initiated vital steps in acknowledging the potential of biotechnology to assist agricultural development. To achieve the desired goals the African Union began a policy for encouraging innovation in African countries by introducing "Freedom to Innovate" in 2008., wherein about 40 out of the 54 African states

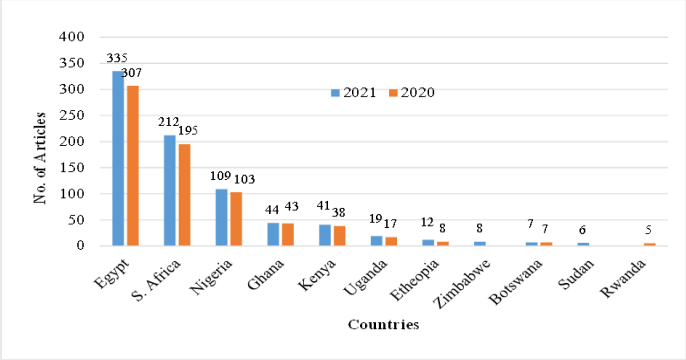

Figure 7: No of Research Articles in Biotechnology Applied Microbiology in Selected countries.

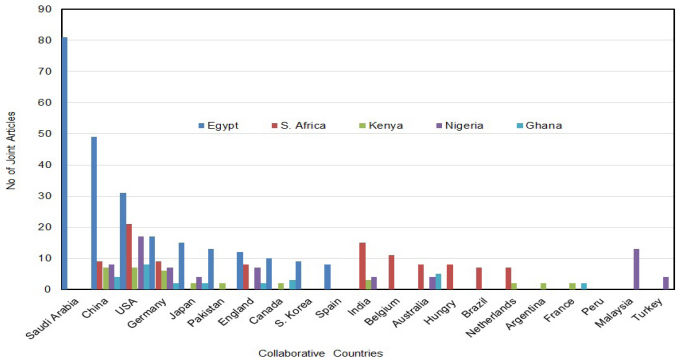

Figure 8b: Country-wise Joint Research Articles in Biotechnology Applied Microbiology with other countries (2021).

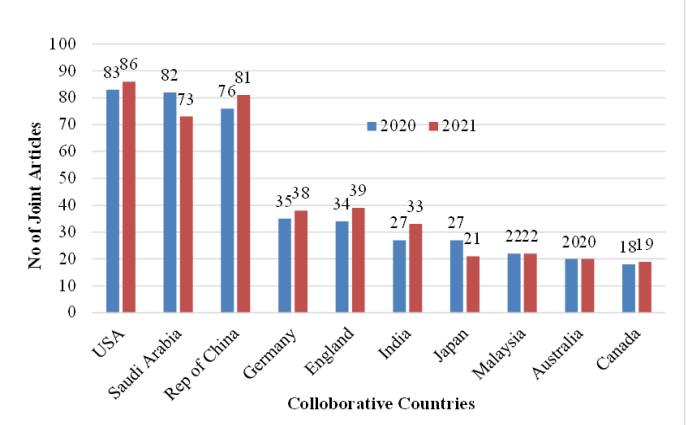

Figure 8a: No of Joint Research Articles of selected African countries in Biotechnology Applied Microbiology with other countries.

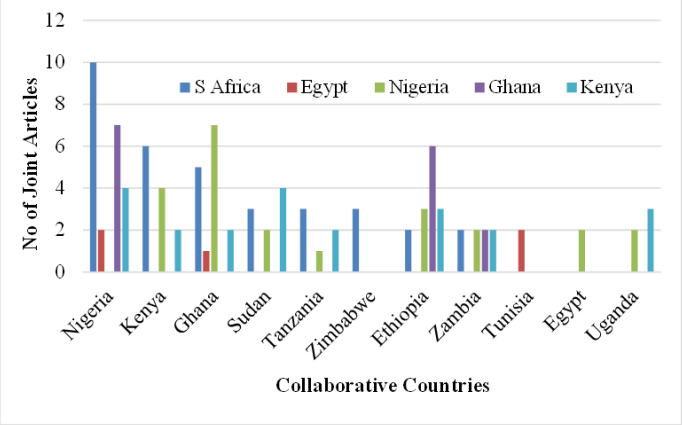

Figure 8c: Joint Research Articles in Biotechnology Applied Microbiology within Selected African Countries.

have developed draft national biosafety frameworks to responsibly exploit and utilize biotechnology applications on the continent.[25]

Research articles, patent applications and R&D spending in a few countries have grown over the years. However, very few countries are doing fair in terms of research articles. Egypt, South Africa and Nigeria are better performers in publishing research articles but other countries selected for study are performing poorly. In terms of international collaboration for joint articles, Egypt has the most international joint papers followed by South Africa. Egyptian researchers are active in collaboration with Saudi Arabia, China, the USA, Germany, Japan and Pakistan, while South Africa has more joint articles with USA, India and Belgium. Further, among African countries South Africa, Ghana, Nigeria and Kenya have emerged with joint author articles contrary to Egypt which reflects lesser joint articles with African researchers.

Policy recommendations

The application of biotechnology represents a niche area and has numerous opportunities but is associated with human health risks and environmental hazards. The East African Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development have made a joint effort to empower four countries-Ethiopia, Kenya, Tanzania and Uganda-to meet the challenges of modern biotechnology and assist them in realising its potential under local conditions.[4] Similarly, to exploit the potential of biotechnology in the African regional there is a need for an integrative approach and strategy. The inter-consultative mechanism between the emerging countries is to generate a pool of highly skilled professionals, a joint fund pool for developing and expanding the quality infrastructure of R&D institutions, and universities and a policy for reverse brain drain to be initiated. The development of biotechnological parks may help to integrate research in biotechnology. Policy to encourage start-ups with funding provisions and suitable technology with tax holidays for those start-ups which are performing better may develop a suitable ecosystem for the growth of biotechnology in Africa. Facilities of loans to young researchers for setting up entrepreneurs and students for establishing MSMEs and incentives for export will lead to developing manufacturing hubs in the African nations.

Potential sectors of biotechnology may include agriculture biotechnology, environmental biotechnology, industrial

Table 3: New Partnership for Africa's Development (NEPAD) Office of Science and Technology (OST) networks of centers of excellence in biosciences, 2009.

Networks	Nodal Point	Hub	Centre Focus	Area of Work
NABNet (North African (North African Network)	Egypt	National Research Centre (NRC)	Bio Pharmaceuticals	North Africa: to lead the continent in research into bio-pharmaceuticals, drug manufacturing and test kits.
WABNet (WestAfrican Biosciences Network	Senegal	Senegalese Institute of Agricultural Research (ISRA)	Crop Biotech	West Africa To carry out research using biotechnology tools to develop cash crops, cereals, grain legumes, fruits / vegetables and root / tuber crops.
SANBio (Southern African Network for Biosciences	South Africa	CSIR, Bioscience Unit	Health Biotech	Southern Africa To deliver benefits from health biotechnology by researching into the causes and prevention methods of a range of disease, in particular, TB, malaria and HIV/AIDS.
BecANet (Biosciences East and Central Africa)	Kenya	International Livestock Research Institute (ILRI)	Animal Biotech	East Africa: To focus on research into livestock pests and diseases in order to improve animal health and husbandry. Central Africa: to build and strengthen indigenous capacity by identifying, conserving and sustainably using natural resources and also researching into the impact on biodiversity of events such as climate change and natural disasters.

(Adapted from Makinde, D., Mumba, L. and Ambali, A., Status of Biotechnology in Africa: Challenges and Opportunities, Asian Biotechnology and Development Review, Vol. 11 No. 3, pp 1-10, 2009).

biotechnology and health biotechnology sector. For achieving desired goals research capacity to adapt and develop appropriate technologies, positive bio-safety regulations for assessment of capacity in handling biotechnological issues, and formulation of efficient biotechnology policies to meet the future demands at the regional and international level may be major initiatives for the development of biotechnology sector in Africa. Likewise, strong national and international networks and collaborations for capacity building and creating quality pools of S&T professionals will be the priority areas.

RESULTS AND DISCUSSION

Earlier studies, empirical data and analysis of W*eb of Science* data indicate that African countries are gradually emerging and enhancing S&T capabilities. *Web of Science* data suggests that Environmental Science, Material Science, Multidisciplinary Sciences, Public Environmental Occupational Health, Chemistry Multidisciplinary, Engineering Electrical Electronics, Pharmacology Pharmacy, Biochemistry Molecular Biology, Chemistry Physical, Infectious Diseases and Physics Applied. Biotechnology-Applied Microbiology is not found as an emerging area as per the *Web of Science* database however the emerging field may vary as per the search key word(s)/methodology in the database. For this study, only research articles are considered for analysis and presentation.

It was observed that Egypt was the leading country in expenditure on R&D as a percentage of GDP 2017-2018, followed by Tunisia. In patent filing also Egypt was the leading country by filing 978 patents followed by South Africa (542), Nigeria (410), Kenya (341) and Morocco (250). The research output reflects a continuous increase in the number of research articles (2012-2021). Biotechnology-Applied Microbiology is not an emerging discipline however; it shows an incremental growth over the period (2002-2021). In the area of Biotechnology-Applied Microbiology Egypt, South Africa and Nigeria were found the leading countries. The USA, Saudi Arabia, Republic of China was the major collaborator for joint research papers at international context among the selected countries. On the other hand, Egypt was found most dynamic country with international joint papers followed by South Africa while among the African countries; South Africa produced more joint research papers. Thus, the present study explores the advancement in selected African countries in the area of biotechnology particularly in research collaboration within African universities and international universities, creating a pool of R&D human resources and investment in R&D. However, the present study didn't analyze the regulatory complexities connecting to capacity building, knowledge, and skills and observed risks linked with the embracing and use of the technology, which is imperative in developing and strengthening the capacity building and creating a balanced ecosystem in the area of biotechnology as emphasized by Masehela Barros (2023).[26] The analysis and available data indicate that collaboration may crucial to increase research output in terms of research papers and enhancing collaborative initiatives can improve competency in research activities in African countries.

CONCLUSION

Advancement in the biotechnology field has opened new challenges and opportunities for collaboration and enhancing capacity building in African countries. The analysis illustrates a range of phenomena related to research activities including patterns of growth in research publications, patents, and collaboration within and outside African countries. Countries like Egypt, S. Africa, Nigeria, and Ghana have shown considerable growth in research publications, joint research papers, and patent filing. Since biotechnology is a more applied research area that can attract more joint and collaborative programs and projects that can be helpful to the strengths of the African S&T base. The available data shows less investment in higher education and R&D which needs more spending and more collaboration in the area of biotechnology. Also, comprehensive Bibliometric analyses may be applied to examine biotechnology research output and collaboration in African biotechnology research to discourse the emerging challenges.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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