

POLICY GAPS IN COMMERCIALIZING BIOTECHNOLOGY RESEARCH IN DEVELOPING COUNTRIES: A MANAGEMENT PERSPECTIVE

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Abstract

This research examines the policy and management issues confronting commercialization of biotechnology research in Pakistan. Although they made substantial investment in research infrastructure and institutional capacity-building during the last 20 years, Pakistan remained underperforming in converting biotechnology innovations into commercial products. This study utilizes a qualitative and explorative approach, in which national policy reports, institutional reports, academic sources, and expert opinions were used to discuss structure-related impediments to commercialization (Ali et al., 2024). The most significant identified challenges are poor policy structures, insufficient university-industry relations, intellectual property security and ineffective management in research organizations. The analysis indicates that although Pakistan has developed a robust scientific foundation, its influence on national growth has been compromised because no strategic coordination and commercialization routes have been developed. Further considering the precedence of successful biotechnology models, including India and Brazil, the paper presents recommendations on critical interventions, including policy realignment, capacity building, financial incentives and innovation-friendly regulatory changes. The results emphasize the importance of integration of a unified commercialization strategy, which would realign the division between research and industry. These gaps have made Pakistan unable to maximize its biotechnology industry and use it to boost its economy, promote healthful conditions of people, and support sustainable development. This study is a contribution to the literature on the innovation policy and management of technology in the developing world.

INTRODUCTION

Biotechnology, which is the combination of biological disciplines with technological advances, has proven itself to be a game changer in the solution to global issues revolving around food security, individual health, the environment, and industrial efficiency. In view of sustainable economic development, biotechnology provides a strategic innovation opportunity in growth to the countries (Dessie & Zegeye, 2024). In the case of developing nations such as Pakistan where generating agricultural yields, controlling disease, and energy

security is a major concern to meet the developmental needs, biotechnology becomes a very real possibility to skip the conventional uses. Nonetheless, biotechnology potential is not fully exploited because there are commercialization bottlenecks that exist.

Commercialization can be defined as bringing the scientific research into the market in the form of goods, services or technology. Proper policy systems, institutional infrastructures and vibrant university-industrial networks have helped to commercialize

biotechnology effectively in the developed economies (Ali et al., 2024). These nations are advantaged by the presence of unique technology transfer offices (TTOs), venture capitals, intellectual property (IP) rights and their high intersectoral cooperation. In comparison, developing nations tend to experience disjointed systems of government, limited protection and enforcement of IP rights, limited activity in the private sector, and undeveloped management and entrepreneurship ability at research organizations.

The biotechnology experiments in Pakistan have been rather promising, most especially, the projects in the agricultural industry, medication and environment engineering. National institutions like National Institute for Biotechnology and Genetic Engineering (NIBGE), Center of Excellence in Molecular Biology (CEMB) and various research centers of universities have yielded internationally acclaimed work. However, there is little translation of these innovations into commercially viable products (Dessie & Zegeye, 2024). The lack of connection between the research and its use in the market is indicative of a range of institutional, regulatory and strategic gaps that affect efficient commercialization.

A number of national policy manuscripts, notably Pakistan National Biotechnology Policy (2005), Pakistan Vision 2025 and even the more current Science, Technology and Innovation Policy (2022) have recognized the importance played by biotechnology and its contributions to national growth (Ahmed et al., 2024). These frameworks suggest increased innovation, collaboration between the public and the private sectors, and diversity of the economy with the use of science and technology. These visions have been however poorly coordinated and sporadic in implementation. The lack of a single national innovation system, combined with a lack of financing models, and incentives to encourage collaboration with industry remains a barrier to advancement. This paper takes a management approach in first analyzing the systemic and strategic problems in the commercialization of biotechnology research in Pakistan (Roberts et al., 2012). Although a larger part of the current debate focuses on technical or regulatory matters, the present article outlines the significance of managerial processes, including leadership, institutional planning, capacity-

building and stakeholder coordination to inform the innovation-commercialization continuum. In addressing the issue of commercialization of scientific potential in a developing country (using Pakistan as a sample), the research intends to present policy and institutional changes which can be implemented within the framework of the given country.

This paper will achieve the following three aims: (1) to evaluate the policy environment to shape the biotechnology innovation in Pakistan; (2) to examine the managerial and institutional issues that prevent commercialization; and (3) to provide the evidence-based recommendations to close the gap between discovery and market introduction. The study will help to build a more unified and inclusive biotechnology innovation ecosystem in Pakistan through a critical review of literature, policy analysis and insights on cases.

2. Context and background

Biotechnology has become a radicalizing process on socio-economic development plans of most developing nations. Countries like India, China and Brazil have identified its potential in providing solutions to key issues in public health, food security, environmental sustainability, and industrialization. Investment in strategic biotechnology research and commercial areas, in these countries, has aimed to limit reliance on imports, develop knowledge-based economies and drive innovation-based development (Parente et al., 2021). An expanding scientific capacity in large parts of the Global South notwithstanding, biotechnology commercialization is uneven and fraught with problems. The main obstacles are the poor venture capital access, undeveloped intellectual property (IP) regimes, uncoordinated regulatory agencies, and inadequate public-private partnership. Such restrictions usually lead to mismatch between actually contributing research and products which can be sold to the market, the innovations end up in laboratories and other academic institutions with little influence to the society.

When it comes to Pakistan, biotechnology industry has expanded significantly during the last twenty years. The government responded as it made the formation of the National Commission on

Biotechnology in 2001 and also started a range of national projects through the Ministry of Science and Technology. Substantial efforts have been made toward bolstering research infrastructure and scientific capacity through major public-sector facilities like the National Institute for Biotechnology and Genetic Engineering (NIBGE), the Center of Excellence in Molecular Biology (CEMB), and the Dr. Panjwani Center for Molecular Medicine and Drug Research. The Higher Education Commission (HEC) has been another stakeholder that has contributed to growth in biotechnology-related academic program and opportunities in funding (Ahmed et al., 2024). Moreover, interest of the private sector in biotechnology has been on the rise as well, with agricultural biotechnology and pharmaceutical the most active. Through this, the country has caught up with the rest of the accounts of innovation and competitiveness in the world, yet still lags in the rankings (Bawa et al., 2021). The amount of biotechnology based products developed in local research institutions that have made it into commercial market is meager. This limited conversion of research to economic output indicates the lack of core competencies in the country in the areas of an innovation ecosystem, especially commercialization systems, policy co-ordination, and institutional strength.

This discrepancy between research excellence and market application illustrates the tension of investigating the aspects of policy, managerial and institutional realms that influence the biotechnology commercialization in Pakistan. Although the amount of research is now better, it has not led to results that can have an economic value or make the country independent in terms of technology (Zafar, 2007). The absence of established channels of intellectual property protection, technology transfer, the incubation of startups, and partnership between the University and industry remains to hinder the development of a vibrant biotechnology sector. It is consequently necessary to discuss what kind of scientific work is being undertaken, as well as how that work is managed, funded and developed to the market. An in-depth examination of the ecosystem of which commercialization is governed: policy directives, regulatory institutions, funding mechanisms, and capacity-building programs, is

possible to highlight the structural deficit that hinders growth and answers what may be done to fast-track the growth of the biotechnology sector in Pakistan.

3. Objectives and methodology of research

The core aim of this research will be to examine the policy and managerial issues that limit certain aspects of commercialization of biotechnology research in Pakistan and provide strategies that can be employed to address them. In particular, this study will work to determine (1) the policy and regulatory obstacles to the commercialization of biotechnology, (2) the importance of the university-industry partnership and institutional systems in supporting the process of technology transfer, (3) the barriers associated with management including resource allocation, strategic planning, and innovation leadership inside research bodies, and (4) suggest policy change and strategic interventions to enhance the commercialization space.

A qualitative and exploratory research methodology served the purposes to the fulfillment of these objectives. The primary sources of data comprise an extensive list of policy documents including, but not limited to, Pakistan vision 2025, national Science, Technology and innovation policy, and sector road maps available through ministry of Science and Technology and Planning commission. Further information was obtained through institutional reports, including NIBGE, HEC, and Pakistan Biotechnology Information Center. Technology transfer studies, university industry relationships, and innovation management in the developing nations were also consulted in the academic sources (Ahmed et al., 2024). Further, there was an analysis of expert comments and case studies of Pakistan and other similar developing countries to obtain a comparative observation. A thematic analysis identified the issues that recurred, gaps in the policy, and its weakness in the commercialization ecosystem. The methodological approach enabled an in-depth insight into the macro- and micro- factors that limit policy and micro-practices of managers that influence biotechnology commercialization within the Pakistani context.

4. Literature Review

The process of commercialization of biotechnology is generally considered one of the many drivers of national innovation systems, particularly in emergent economies aiming to achieve sustainable growth. The literatures acknowledge that biotechnology is a strategic sector, with the potential to transform agriculture, health care and environmental management with high-impact innovations (Chataway et al., 2007). Nevertheless, the journey of the laboratory research to the market can be complicated, as systemic failures in developing countries tend to obstruct it (Thorsteinsdóttir et al., 2010). This section provides an overview of the world and Pakistani literature on commercialization of biotechnology with a focus on the policy, institutional and management issues.

4.1 The International Aspects of Biotechnology Commercialization

In developed economies, a powerful interaction of universities, industries and governments, (known as the triple helix model of innovation) works to commercialize biotechnology (Bhatti & Asgher, 2020). Technology transfer offices (TTOs), incubators and science parks in such systems assist researchers along the commercialization pipeline. Nations such as the United States, Germany and South Korea, have realized biotechnology breakthroughs by implementing co-ordinated national innovation policies, strong intellectual property rights and targeted financing to early-stage innovation (OECD, 2009).

On the contrary, literature that is more inclined towards developing economies will tend to mention disjointed policies, lack of innovation infrastructure and poor institutional cross-connections. Some of the challenges being faced are low funding, evasion of IP, unhealthy venture capital markets and the absence of mediator organization to facilitate commercialization (Roberts et al., 2012). Furthermore, the focus on managerial and organizational capacity in the research institutions has had little interest in the discussion of innovation systems in the Global South.

4.2 Biotechnology in Pakistan: Policy and Institutional Setting

In Pakistan, there is scientific potential in biotechnology, especially in agriculture and medical research. Knowledge production in the fields of biotechnology has been done by institutions like NIBGE, CEMB and PARC. Nevertheless, commercialization is ignored. Abbas et al. (2021) observe that even after more than two decades of investment in biotechnology R&D, there are only a few innovations that have successfully been commercialized; this is primarily attributed to a lack of policy coordination and participation of the private sector. The National Biotechnology Policy (2005) of Pakistan and the Science, Technology, and Innovation Policy (2022) provide national roadmaps that have not been fully implemented. Research indicates that overlapping mandates between federal and provincial agencies, ever-changing policies, and the lack of any profit motive have restricted policy effectiveness (National Institute for Biotechnology and Genetic Engineering, 2022). In addition, mechanisms of technology transfer are poor whereby the majority of universities do not have operational TTOs or incubation centers.

4.3 Commercialization at the Managerial level

The importance of management in innovation processes is invariably overlooked in the policy debate. The discontinuity between research to product development is hampered by managerial weaknesses in the aspects of strategic plans, coordination, and commercialization capability in R&D institutions (Rathore & Zafar, 2012). Researchers in Pakistan are not trained on how to manage intellectual property, business modeling and market feasibility matters. Furthermore, academic institutional cultures tend to obstruct entrepreneurship with their focus on publications rather than patents (Carbonell et al., 2021). In short, the literatures identify the lack of coordination between the scientific productivity and the business performance in the Pakistan biotechnology industry. It is the incompleteness of policy, as well as institutional and managerial gaps that contribute to this disjuncture. These issues demand a multilateral approach that accommodates national policies, institutional capacities, and management in order to achieve a strong innovation-commercialization environment.

5. Pakistani Policy and Management Gap

Although biotechnology has a great potential to play a significant role in the socio-economic development of Pakistan there is low commercialization of research findings. The nation is politically and managerially challenged along various dimensions of public policy and management of innovation. Policy and managerial gaps hindering the process of biotechnology commercialization in Pakistan are identified in this section.

5.1 Poor Policy Coherence, and Institutional Overlap

The problem of disintegration in the policy making process of science and technology governance has continuously been faced in Pakistan since ages. There is a lack of coordination and synergy amongst many provincial Science and Technology departments, the Higher Education Commission (HEC), the Pakistan Council of Scientific and Industrial Research (PCSIR), and the Ministry of Science and Technology (MoST). Consequently, the policy duplication, undefined mandates, and contradictory priorities influence biotechnology initiatives (Hassan et al., 2018).

As an example, MoST develops general policies of science, HEC allocates funds on research and capacity building in universities on its own and regional innovation policies in provinces are distributed to departments (HEC, 2020). Nevertheless, the lack of the centralized process of coordination or the centralized body of biotechnology has led to the missing of the coherent system of national innovation. Therefore the researchers and entrepreneurs have to put up with the bureaucracy, regulatory, and procedural slowness that is often encountered during the commercialization of their findings.

Moreover, the policy framework lacks a one-stop service that can be used to smooth the process of approval, patenting, licensing and incubation of biotechnology products. In numerous instances, entrepreneurs are compelled to interact with various agencies in order to be granted intellectual property rights, regulatory approvals, and market entry, a

factor that deters investment and innovation. This policy inertia is reflected in the fact that the Pakistan Biotechnology Information Centre (PBIC), which was originally proposed to centralize efforts on an institutional effort, has taken over nine years to operationalize.

5.2 Lack of University-Industry Linkages

There is also the absence of collaboration between industry and academic researchers which is another important bottleneck. Although universities and public-sector research organizations (PSROs) have made significant advancement in terms of basic research in biotechnology in Pakistan, little effort has been made to convert this knowledge into commercially exploitable forms because academic and industrial research is not well integrated in research.

Pakistani universities tend to be managed within incentive systems that favor academic work in the form of publications over practical results like patents, spin-offs, or product development (Ahmed & Waqar, 2020). The process of encouraging faculty and or rewarding them to pursue technology transfer or commercialization projects is rare. Moreover, a restricted number of Technology Transfer Offices (TTOs), incubators, or liaison units, which would allow university connections with the business sector, undermine university-industry cooperation. On the industry side, biotechnology is usually considered as high-risk, high-capital intensive ventures with the long gestation periods. This perception, compounded by the poor level of awareness regarding the relevancy and quality of academic research, results in a poor level of demand of the technologies generated at the universities. Industrial companies in certain instances have cast doubt on the feasibility and the scalability of university pioneered prototypes, citing the lack of an industrial viability analysis or business plans (Altaf et al., 2014). In addition, incoherent evidence was found on having structured platforms or consortia that ties together the areas of academia, industry, and government to co-develop biotechnology solutions. In contrast to other systems in countries like India and Brazil, where biotechnology parks and government-industry partnerships have revolutionized their countries, Pakistan does not

have the mechanisms that can establish confidence and long term commitment between researchers and entrepreneurs (Juma & Yee-Cheong, 2005).

5.3 Intellectual Property Rights & Regulatory Bottlenecks

Although Pakistan is a signatory to the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), the monitoring and practical implementation of intellectual property (IP) policies are extremely underdeveloped. This presents a big problem to commercialization of biotechnology research, since protection of inventions, proprietary data as well as innovation processes is central to making commercial success, being able to attract investment as well as securing competitiveness in the market.

The absence of awareness and knowledge of IP rights by researchers and institutions is also one of the critical problems. A lot of researchers and faculty in government universities and research centers either do not know how to start the IP registration process or get discouraged by bureaucracies. The problem is further aggravated by the lack of well-endowed and professionally staffed Technology Transfer Offices (TTOs). There are some elite institutions that appear to have IP facilitation units in nominal form but these are usually weakly funded, have no autonomy, and are not actively involved in an comprehensive role in connecting academia and industry.

In addition, the regulatory environment that oversees the use of biotechnology is highly divided and vague. To illustrate, the actual biosafety guidelines prepared by the National Biosafety Committee (NBC) are on paper, but are not enforced so strongly. The regulations governing genetically modified organisms (GMOs), clinical trials, or new uses of biotechnology can be slow to give approval because of overlap in the jurisdiction held by federal and provincial agencies and the lack of a centralized regulatory system. These bottlenecks discourage research work on the commercial by the researcher and act as an obstacle to the investor seeking transparency and predictability in issues that touch on the regulatory environment.

In the absence of credible IP protection and streamlined regulatory procedures, high-risk, high-reward innovations, which are typical of the biotechnology industry would prove absolutely hard

to commercialize. The enhancement of institutional IP management, simplification of biosafety regulations, and capacity-building in IP law and patent-drafting, therefore, must all be part of the means of closing this commercialization gap.

5.4 Financial Constraint

Biotechnology start-ups especially start-ups under the early-stage or translational stage involve considerable amounts of financial resources to develop the product, laboratory verification, prototyping, compliance with regulations, market preparation. Nevertheless, the Pakistani financial ecosystem lacks the capability of funding such capital and risk-intensive innovation industries. Investment in venture capital (VC) in Pakistan is nascent, and biotechnology is not commonly a sector of interest to angels or to thematically-focused private equity firms, many of which tend toward less risky and shorter-to-realize sectors such as fintech or e-commerce. Grant schemes run by the public Sector-as by the Pakistan Science Foundation (PSF) or HEC-are relatively small, very competitive, and frequently turgid with administrative delays. Moreover, the grants are typically used to finance basic research without including later product validation, scale-up, or go-to-market approaches.

Pakistani commercial banks are conservative and averse to funding biotech-startup companies based on inexistence of concrete collaterals, prolonged gestation periods, and the incomprehensibility of the applicable science (HEC, 2020). Although public-private partnership (PPP) can be a useful tool in de-risking investment in biotechnology, the reality is that these kinds of partnership have been limited, and are not institutionalized in the context of biotechnology investment. There are also other financing solutions, such as crowdfunding, corporate sponsoring, or sovereign innovation funds, which have not been addressed in any meaningful manner. This intractable financial shortage creates a situation in which potentially-valuable innovations simply sit in academic journals or languish in the so-called valley of death: where research cannot advance to commercialization because it lacks the necessary funding (Carbonell et al., 2021). The availability of specialized biotech funding tools, the creation of incentives that would encourage VC investment, and

creating national funds with risk-sharing mechanisms are the main factors that will allow the development of a strong biotech ecosystem in Pakistan.

5.5 Weaknesses in capacity and Commercialization Training

The current state of managerial and entrepreneurial capacity among the researchers is also an important yet frequently underestimated obstacle to the commercialization of biotechnology in Pakistan. Most of the scholarly professionals engaging in biotech research receive their professional training within the worlds of science and technology with little or no training in the worlds of business development, product and lifecycle management, regulatory affairs, or strategic marketing. This is an acute skill shortage that cripples their capabilities of transferring laboratory achievements to commercial viable businesses. In Pakistan universities lag way behind in interdisciplinary training integrating science with entrepreneurship, innovation management, or intellectual property law (Parente et al., 2021). Consequently, basic concepts of commercializations like technology readiness levels (TRLs), business model development, customer discovery, or venture funding cycles stay unknown to many researchers. The absence of custom-designed mentorship and incubation services further hinders their capacity in coping with complexity of commercialization process.

In developed markets biotechnological innovation flourishes in conditions where both scientific and managerial knowledge are co-designed in interdisciplinary study programs, accelerator programs, industry internships. Conversely, there is a tendency of disciplinary silos amongst the academic and research institutions in Pakistan as even business schools and science faculties hardly collaborate (Lima, 2022). This has led to an overwhelming mismatch between invention and innovation-a system in which scientific discoveries fail to yield products that can be developed into scalable, commercially viable products (Dessie & Zegeye, 2024). Additionally, the development of literacy on commercialization with regard to students and early-career researchers has little policy focus. Capacity-building has not been taken on board by national innovation policies, and national donor-funded programs in this regard are piecemeal and non-

sustainable. The commercialization training should be institutionalised, dual-degree programmes should be introduced and academic-industry mentorship networks established, all of which would greatly increase the capacity of Pakistani researchers to commercialise their innovations.

6. Comparative Lessons of Other Developing Nations

The case study of biotechnology commercialization models in the other developing countries provides useful lessons to Pakistan (OECD, 2017). Although countries such as India and Brazil also experience similar structural and economic constraints, they have implemented policy frameworks and institutional innovations, which have led to a remarkable improvement in their biotechnology sector. The significance of strategic planning, state-led facilitation, and industry-academia synergy are highlighted in these models, which remains in short supply in Pakistan.

6.1 India: Strategic and Institutional innovation and funding

The example of India gives strong evidence of the potential of a low-to-middle-income nation to promote the commercialization of biotechnology with the combination of policy frameworks and promotion of institutions. Employment The Indian policy of biotech changed that the Biotechnology Industry Research Assistance Council (BIRAC), founded under the Department of Biotechnology (DBT) in 2012, has turned out to be the moment of a breakthrough in the Indian biotech policy. BIRAC is a publicly funded sector venture with a narrow brief to fill the gap between academia and industry with competitive funding, mentoring and incubation (BIRAC, 2023).

BIRAC uses a number of schemes like the Biotechnology Ignition Grant (BIG) and the Small Business Innovation Research Initiative (SBIRI), to help early stage ventures and university investigators progress towards the products. Notably, the council sets projects and funding is not the only thing in the council but the focus on milestone-based project evaluation, capacity building, and access to the global networks. The National Biotechnology Development Strategy (20152020) drafted by the Indian

government also specified the pathway toward making progress in the area of translational research and developing bio clusters to nurture innovation ecosystem in the region (BIRAC, 2023).

The success of India in this area can also be attributed to strong system of the bio-incubators where many of them are incorporated in the institutions of higher learning. These incubators do not just offer physical facilities, they also offer advice and support in business as well as legal advice, a culture within which innovativeness and entrepreneurship thrives (Ahmed et al., 2024). This has led to a mushroomed growth in biotech start-ups in India and some of the start-ups have come up with commercially successful diagnostics, vaccines and agricultural biotech products.

Contrastingly, Pakistan has no central coordinating agency like BIRAC and suffers due to lack of coordinative implementation of policies. The creation of such an institution through regional representation would go a long way in making the process of commercially leveraging biotech vastly more efficient in Pakistan.

6.2 Brazil: Integration of bio-technology in agriculture and the steering of industry

Brazil is one of the countries that have focused on the use of biotechnology due to emphasis on agriculture and environment sustainability. Brazilian Agricultural Research Corporation (EMBRAPA) was established in 1973 and became a benchmark in the

understanding of how the state-financed research organization can access the commercialization of its findings. EMBRAPA combines scientific research and development, market-driven innovation, and partners with farmers, agribusiness companies, and foreign partners. One of the main characteristics of the Brazilian strategy is the heavy focus on the production of intellectual property. There is specific incentive by the government and EMBRAPA itself has hundreds of patents that it licenses to both local and foreign companies (EMBRAPA, 2021). The National Bank of Economic and Social Development (BNDES) in Brazil also offers tax incentives and innovation credits to biotech start-ups providing the potential to fund long-term, high-risk ventures over the long run (Ahmed et al., 2024).

Moreover, Brazil has been implementing regulatory processes that strike a balance between biosafety and invention. CTNBio provides clear and time-limited analyses of GMO and other biotech uses. This stability in regulation goes a long way in ensuring a degree of certainty among investors and entrepreneurs. Although Pakistan has identical agricultural priorities, it does not have a body such as EMBRAPA or CTNBio (Kiran & Arshad, 2019). A comparable evolution could be triggered by creating a centralized research-commercialization institution in the agricultural sector, backed by empowering legislation and tax incentives.

Table 1: Comparative Overview of Biotechnology Commercialization in Developing Countries

Country	Key Institution	Policy Support	Industry Linkages	Funding Mechanisms
India	BIRAC	National Biotechnology Strategy	Strong academia-industry	Public grants (BIG, SBIRI), VC
Brazil	EMBRAPA	IP incentives, bio-safety regulation	Integrated state-industry	BNDES loans, tax exemptions
Pakistan	None (Fragmented bodies)	No unified commercialization policy	Weak linkages	Limited VC, underutilized public funds

6.3 Lessons to Pakistan

The India and Brazil experience presents important lessons that can guide Pakistan undertake its biotechnology commercialization issues. The role of

centralized institutional coordinating framework is one of the most important insights. The Biotechnology Industry Research Assistance Council (BIRAC) in India is designed to provide seed

financing and assistance in establishing academia-industry connections in addition to funding start-ups through incubators, as well as grants. Pakistan may gain considerably by creating a parallel harmonized center to coordinate the work of different agencies like the Ministry of Science and Technology (MoST), the Higher Education Commission (HEC), and provincial science sections. Second, active and participatory research incentive structures have the ability to drive university-industry affiliation deeper. India and Brazil offer researchers and structures that commercialize their work, fiscal advantage and grants and perceptions (National Institute for Biotechnology and Genetic Engineering, 2022). In Pakistan, including such incentives in the university key performance indicators (KPIs) and the national research grant schemes is one way to encourage faculty to participate in research of relevance to the industry.

Improvement of easing and enforcing intellectual property (IP) rights is another important sector of reform. In India and Brazil, streamlined patenting systems, and rapid biosafety approvals and strong legal protection secure the development of biotechnology innovation. Pakistan needs to focus on adopting functional offices of technology transfer (TTOs), educate IP, and align its regulatory systems to the international standards (Zafar, 2007). Finally, Pakistan should also realign its biotechnology training to collaborate with commercialization. A pipeline of scientists with the business and scientific skills required can be developed through industry-specific curricula, entrepreneurial education, and biotech-friendly incubation centers such as in India. The innovation-to-market transitions may take place with the endowment of grad programs with commercialization modules as well as start-up contests in universities.

These approaches can effectively capture and in a way contribute towards filling the existing policy and management gaps in Pakistan and lead to a higher efficiency and effectiveness of the biotechnology commercialization ecosystem.

7. Strategic Recommendations

The commercialization dilemmas of biotechnology research in Pakistan can be solved through interfacing initiatives at policy, institutional and

financial levels. This section provides strategic pieces of advice that can be used to reinforce the innovation-to-market pipeline in the country.

7.1 Policy changes

• **Biotechnology Commercialization Unified Policy**

Pakistan does not have a synergistic national approach of biotechnology commercialization. A single policy must be developed at the federal level which clearly states the roles and responsibilities between the Ministry of Science and Technology (MoST), Higher Education Commission (HEC), provincial science departments and private stakeholders. The policy should present the commercialization roadmaps, performance measures, and cross-sectoral coordination strategies to prevent redundancies and policy fragmentation.

• **Efficient Regulatory System**

Inefficiencies in regulatory programs can slow the process of receiving approvals and restrict private investment. One-window regulatory mechanism is to be implemented in order to deal with biosafety, bioethics and intellectual property (IP) concerns (Parente et al., 2021). This framework ought to give precise schedules, online submission platforms, and transparent review processes, therefore enhancing convenience of carrying out biotech business in Pakistan.

7.2 Building Institutional Capacity

• **Technology Transfer Offices (TTOs)**

It is necessary to develop TTOs that are properly endowed in all the public universities that teach biotechnology. To help the researchers follow the commercialization pathways, these offices ought to be furnished with individuals with specialty in IP law, business development, and the creation of ventures. To achieve accountability and impact, HEC and MoST need to jointly finance and track the performance of such TTOs.

Innovation Clusters and Bio-incubators

Biotechnology parks and bio-incubators ought to be established in areas adjacent to large academic centres (Lahore, Karachi, and Islamabad) in order to support innovation ecosystems (Government of

Pakistan, 2012). These clusters can offer common access to lab facilities, mentorship, seed capital, and access to industry contacts. Public-private partnerships ought to be tried to develop and operate such infrastructure projects in a sustainable manner.

7.3 Mechanisms of financial support

- **Increased Public Grants**

The HEC Technology Development Fund (TDF) ought to be broadened to cover a wider variety of biotechnology projects of increased technology readiness levels (TRLs) (Government of Pakistan, 2012). To promote increased academia involvement, application procedures should be simplified, shorter deadlines set, and the evaluation of proposals brought up to snuff.

- **Biotech Venture Capital and Angel Investment**

Pakistan should also encourage the formation of venture capital funds that specifically focus on biotechnology. The government can also act as a catalyst by participating in the form of co-investing using public-private funds as well as tax rebates to angel investors. The issue of availability of capital to early-stage biotech ventures could also be discussed to partner with diaspora investors and international development agencies.

7.4 Capacity building

The urgent need in the biotechnology sector in Pakistan is the absence of human resources that possess knowledge in both scientific and commercialization. In order to counter this, curriculum reform is necessary (Parente et al., 2021). The undergraduate and postgraduate biotechnology programs need to have modules on entrepreneurship, business development, technology transfer, and regulatory affairs. These additions will make these graduates not only acquire technical skills but also gain the knowledge necessary to go through the complex process of commercializing their work.

Additionally, brief training workshops and certification programs must be established among current researchers and faculty members. They may be based on intellectual property management,

market analysis, product development cycles and pitching to investors (Altaf et al., 2014). National research organizations working together with their international partners and industry leaders may also hold workshops and mentorship programs to establish a commercialization-minded mindset. These types of capacity-building will slowly provide a pipeline of personnel able to capitalize on laboratory research, and make products viable in the marketplace.

7.5 The Public-Private Partnerships

The establishment of the institution under public-private partnerships (PPPs) is one of the ways to address this gap. These types of collaborations are sporadic and usually informal in Pakistan. There is an urgent need to formalise PPPs by following more formal systems such as contract research agreements, joint ventures and co-funding schemes (Ali et al., 2024). The promotion of contract research agreements between universities and local pharmaceutical, agricultural, and industrial biotechnology businesses should be advocated so that both the firm and university can be successful in utilizing applied innovation.

Also, the creation of consortia involving universities, government bodies and private firms should also be encouraged. Collaboration of research work between these consortia are able to agree on a well-established intellectual property right (IPR) regime as well as revenue sharing approaches. The inclusiveness of the industry partners in these consortia brings the focus of research close to the market requirements and the role of the public sector can help in sharing the risk as well as establishing sustainability (Ahmed et al., 2024). To facilitate close liaisons between these organizations, the government should provide incentives in its policies like provision of tax credits on research and development spending, streamlining the patenting process, and access to special innovation funds. By observing the activity of other international organizations such as the BIRAC of India and EMBRAPA of Brazil, Pakistan can develop institutional frameworks that not only facilitate the financing of PPPs but also assure transparency, accountability, and evaluation of impact.

Table 2: Comparative Biotechnology Commercialization Strategies

Country	Key Institutions	Commercialization Approaches	Outcomes/Impact
India	BIRAC, DBT, BioNEST	Public grants, academia-industry linkages, bio-incubators, IP support	Over 1000 funded biotech start-ups; strong innovation pipeline
Brazil	EMBRA PA, ANVISA	Agricultural R&D integration, tax incentives, regulatory streamlining	Significant agri-biotech output; improved tech adoption
Pakistan	HEC, PCST, MOST	Fragmented efforts, weak industry linkages, underfunded TTOs	Limited product commercialization; low global competitiveness

8. Conclusion

The biotechnology sector in Pakistan has good research potential but there is a major problem of getting scientific inventions to the market. In spite of quality human resources in research and growing academic activities, the nation faces fragmented policies, duplication of institutional capacities, and poor commercialization environment. These structural challenges have impeded the development of a sustainable biotech sector that could support many national concerns including food security, health and environment.

The lack of a unified national policy on biotechnology commercialization is one of the fundamental issues. A variety of institutions that do not cooperate with each other contributes to redundancies and failure to coordinate. The ambivalence of regulatory structures and the tenuous protection of the IP are not conducive to domestic and foreign investment in biotech innovation.

Moreover, poor inter-university-industry links, scarce access to venture capital and insufficient skills training in commercialization further undercut any advances. Although researchers are well-trained when it comes to scientific tasks, they often lack entrepreneurial skills required to commercialize innovations. In addition, innovation hubs and well-financed technology transfer offices (TTOs) are few and, as a result, promising technologies stagnate in their lab phase.

The experiences of such countries as India and Brazil have taught us the need to implement integrated policy initiatives, monetary benefits, and robust institutional settings. These successes suggest that even biotech entrepreneurship can be encouraged in

the resource-limited settings through planned reforms and investment.

To proceed, Pakistan needs to have a concerted approach in line with policy, finance, and institutional competencies. It is crucial to enhance the development of the collaboration between the private and state sector, extend funding possibilities, invest in capacity building, and promote trust between academia and industry. Given adequate reform, Pakistan biotechnology industry holds a potential to be a major source of innovation and sustainable progress.

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