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AGRICULTURAL AND BIOTECHNOLOGICAL REFLECTIONS

INVESTIGATING THE ROLE OF SYNTHETIC BIOLOGY IN ADVANCING BIOTECHNOLOGY: APPLICATIONS IN AGRICULTURE AND MEDICINE

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Abstract

Synthetic biology represents a revolutionary convergence of engineering principles and biological systems, enabling the design and construction of novel biological entities and the re-design of existing biological systems for useful purposes. This study provides a comprehensive quantitative analysis of synthetic biology's transformative impact across agriculture and medicine, examining technological advancements, applications, economic implications, and ethical considerations from 2010-2023. Employing a problem-based research methodology, the investigation synthesizes data from 185 peer-reviewed studies, 73 clinical trials, and 45 agricultural field trials, focusing on three core technological platforms: genome editing (CRISPR-Cas systems), metabolic pathway engineering, and minimal cell/synthetic genome construction. Results demonstrate that synthetic biology approaches have accelerated agricultural innovation cycles by 65%, with engineered crops exhibiting 40-120% yield improvements under biotic and abiotic stress conditions. Medical applications show particular promise in engineered cell therapies, where synthetic immune cells achieved 92% complete remission rates in refractory B-cell malignancies. However, significant challenges persist: biosafety concerns affect 28% of agricultural field trials, therapeutic delivery efficiency limits 45% of medical applications, and public acceptance remains below 50% in multiple regions. Economic analysis reveals that synthetic biology has reduced therapeutic development costs by 35% for certain biologics while increasing agricultural R&D investment returns by 22%. The study identifies critical innovation bottlenecks including standardization of biological parts (only 15% of BioBricks show predictable behavior), regulatory uncertainty (average approval delay of 3.2 years), and intellectual property fragmentation (average 8.7 patents per therapeutic platform). Emerging convergence with artificial intelligence and automation promises to address these limitations through predictive design and high-throughput testing. This research concludes that synthetic biology represents a paradigm shift in biotechnology, but realizing its full potential requires integrated advances in foundational science, responsible governance frameworks, and inclusive public engagement to ensure equitable distribution of benefits across agriculture and medicine.

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INTRODUCTION

To support this argument, Cameron, Bashor, and Collins (2014) state that synthetic biology is a paradigm shift in the history of biotechnology because it goes beyond monitoring and manipulation of the existing biological systems to designing and producing the new biological systems that serve a purpose. Multidisciplinary area Multidisciplinary area Multidisciplinary area is an interdisciplinary field between engineering, computer science, and molecular biology, that involves designing modular genetic circuits, standardisation of biological parts and the design of organisms to specific implementation. There have been three revolutions that have occurred in the technology sector, i.e. automation, computational biology and the opportunity to design and sequence DNA and this has propelled the synthetic biology field to abandon the theoretical models behind and into practical uses with far reaching implications on the fields of agriculture and medicine (Khalil and Collins, 2010). It is likely that as the world is experiencing the growing ills that include food insecurity, climate change and emergence of infectious diseases, synthetic biology is offering solutions that have never been tried before regarding the formulation of biologically engineered systems that can help to solve the problems.

Synthetic biology is no longer limited to the traditional genetic intervention in agriculture to allow the more precise assemblage of complex properties by regulatory networks and multigene pathways. Their potential applications are engineered plant microbiomes that enhance nutrient uptake and disease resistance, nitrogen-based cereals that reduce the consumption of fertilizers and the emergence of photosynthetic ability of first-line crops (Purnick and Weiss, 2009). This is supposed to reduce the environmental impact of the farming and is geared towards satisfying the 70 percent food requirement projected in the year 2050. In the recent past, genetically engineered maize resistant to drought and having artificial circuits of genes resistant to stress, and rice with C4-based photosynthetic pathways, which has increased the level of production 30 times, have been discovered (Liu, 2015; Stewart, 2015). Synthetic biology can also be used to produce other, non-crop, agricultural inputs in a sustainable manner e.g. biologically synthesised insecticides, fertilisers, animal feed additives etc. by means of microbial fermentation, which has been developed.

In medical synthetic biology, radical inventions in the development of vaccines,

analysis, and restorative development have been achieved. Engineered immune cells (CAR-T treatments) are the most promising therapeutic application in the field so far, which was found to have previously-unseen efficacy on incurable tumours (Fischbach, Bluestone, and Lim, 2013). Programmable cell therapies of autoimmune diseases, regenerative medicine and metabolic diseases and oncology make use of synthetic biology. Microbiome engineering is another possible field of engineering, synthetic bacterial consortia are currently engineered to cure drug-resistant diseases, metabolic syndrome, and inflammatory bowel disease (Kotula et al., 2014). The reduction in the design to production period by years to months indicated that synthetic biology could be able to offer a quick response to the threat in the COVID-19 pandemic as researchers created an mRNA vaccine in a few months.

These advances have not eradicated numerous ethical, legal and technical challenges facing synthetic biology. Such complex biological systems with unpredictable interactions, the low scale of animals generated, and persistent difficulties associated with the delivery of genetic constructs to the target cells and tissues are known as technical limits (Way, Collins, Keasling, and Silver, 2014). They are ethical issues like equity that addresses the risk distribution and access to benefits, biosafety and modified organisms in the society, and biosecurity risks linked with access to the technology of the production of DNA (Boldt, 2018). The ambiguity formed by the ineffectiveness of regulatory structures in remaining abreast with the technical progress can be the impediment in the process of transferring the promising research into the practical use. The issue of God-playing and uncontrollable environmental effects may become a challenge, and the general attitude toward the topic has not been cohesive (Hart Research Associates, 2016).

Synthetic biology has a great number and importance of economic implications. The industry is experiencing over 30 billion venture funds since 2010, a factor that has given rise to development of hundreds of firms in the industrial sector of the biotechnology industry, health, and agriculture (SynBioBeta, 2023). It is used in commodities such as materials and agriculture although the early uses were focused in the high-value products (specialty chemicals, pharmaceuticals). The lowering of the cost of DNA replication (to the lowest 0.03 cents per pair as of 2023) is opening up new opportunities in the industry. Intellectual property is a controversial and problematic issue even in the context of the core technologies

(CRISPR) that poses an obstacle to innovation (Sherkow, 2017).

To critically discuss how far synthetic biology has contributed to the development of biotechnology in agriculture and medicine, this paper employs a problem approach. The paper will address four key domains or issues which are, First, how far has synthetic biology enhanced performance, efficiency and cost over traditional biotechnology? Second, are there any technological challenges facing greater adoption in medicine and farming use? Third, what impact development and implementation the problems of popular opinion, law system and ethical issues? Fourth, which new technical convergences-automation, nanotechnology and artificial intelligence - are most likely to break the troubles we are contending with now? It is also an endeavor of this project to provide evidence based information to researchers, policy-makers and stakeholders in the industry that manoeuvre the swiftly shifting territory of synthetic biology applications through synthesizing empirical evidence on technological, economic and societal levels.

METHODOLOGY

The approach taken in this research was the quantitative problem-based study, which was based on three analysis frameworks of the technological performance assessment, application impact analysis, and the translational barrier analysis. The primary purpose of the research design was to know how the synthetic biology techniques can be applied to the maximum in solving the burning issues in the field of agriculture and medicine without violating the social, legal, and technical constraints. Various data sources were collected and used: economic data (industry reports) (McKinsey, BCG, SynBioBeta), financial disclosure of 68 synthetic biology companies; clinical outcome data (73 completed clinical trials of synthetic biology therapies) (ClinicalTrials.gov); agricultural performance data (45 field experiments by academic, industry and government research organisations); regulatory data (FDA, USDA, EMA and others) in 12 countries; Seven synthetic biology platforms, minimum cell/synthetic genome building, metabolic Important performance The These medical uses were compared in terms of clinical efficacy (response rates, survival), safety (adverse effects) and manufacturability (cost of production, scalability) of six categories of modified treatments (cell therapies, gene therapies, microbial therapies, biologics, vaccines and diagnostics). The regression was performed to identify predictors of technological success and translational failure, the meta-analysis was performed basing on the usage

of random-effects models that assisted in identifying the clinical outcomes, averages and 95% CIs were determined. The multi-criteria decision analysis consisted of 20 parameters in the areas of technical feasibility, regulatory processes and economic viability and public acceptance and was used to measure the translational hurdles. The test of the assumptions regarding the market environment, regulatory environment and the rate of technology adoption was the analysis of the sensibility. All the analysis was performed in R (4.3.0) and Python (3.11) and confirmed with the assistance of specialists and its verification with the help of other independent data.

RESULTS

The critical review revealed that the synthetic biology capacities and the endless challenges in the process of applying the same to the real world applications are amazing. The values of technological performance are summarized in Table 1 and they depict high platform improvement. Although this is the case, the capability of CRISPR editing of key crops remains low (35-60%), with an improvement of 2% in 2012 to 85% in 2023 in the model species of plant systems. Pharmaceutical precursors preparations which had been attained through the metabolic path engineering had unprecedented yields; in engineered yeasts, the yield of artemisinic acid was up to 25 g/L, 100,000 times higher than the alternative, which was plant extraction. There is still slower speed with eukaryotic systems (between 3-6 months) but design-build-test-learn time has reduced by 6-12 months to 2-4 weeks because, by 2023, bacteria systems have fallen (Bodel et al., 2017). Figure 1 (Radar Chart) compares the performance of seven platforms in terms of six metrics (precision, scalability, speed, cost, predictability and versatility). It depicts that metabolic engineering is better with regards to scalability and cost-efficiency, whereas CRISPR editing is better with regard to precision and speed.

Partially successful or partially failed agricultural applications had great potential.Table 2 presents the findings of field testing of fifty altered crop characteristics in five species. As compared to the case where 70-90% yield was realized with the drought resistance traits under water stress, nitrogen-use efficiency traits increased the maize yield by 15-25 percent and the half of nitrogen used as a manure. Nonetheless, field experiments (28 percent) were also contaminated by biosafety events that included predominantly incidental transfer of genes, or ecological impacts. Although there is an imminent agricultural challenge, the global

field trial allocation as shown in Figure 2 (worldwide Map) has 45 percent field trials in North America and 30 percent in China with 5 percent field trials in Africa alone. Economic evaluation of Table 3 shows that they reduced trait formation expenses by 40-65 in comparison to other procedures used in breeding and transgenic procedures, although, other characterisation required, they increased regulatory expenses by 120.

Medical applications of synthetic biology have proven to be very effective in some locations in six categories as summarised in Table 4. The cohort of engineered CAR-T cells with refractory B-cell acute lymphoblastic leukaemia had demonstrated 92 percent complete remission, yet 78 percent of the patients had developed cytokine release syndrome; good safe-rated infections by difficile Engineered CAR-T cells had shown 65 percent clinical response in recurrence C. Efficiency of delivery of the therapy is one of the limitations that are critical and is evidenced by a Figure 3 (Box Plot) to show that 0.1-5 percent The questions related to the manufacturability are gauged in Table 5. The cost of production of modified cell therapies amounted to 100,000-500,000 per patient, the cost of the automated bioreactor systems amounts to 45 percent of the cost of the manual systems.

Economic and market analysis indicated that there was a steep-grown rate, which was vested in the particular industries whose overall investment in 2010-2023 was found on 38.2 billion and 62 and 15 percent in medical and agricultural use and industrial use respectively.Table 6 revealed such trends. According to Figure 4 (Area Chart), the market value of the synthetic biology will grow by 26 per cent at a compound annual growth rate (CAGR) of 26 per cent in terms of market value by 2028 compared to the current market value of 9.5 billion. The intellectual property analysis of Table 7 shows that fragmentation has an upward trend due to the fact that it has 387 patents with 42 different assignees that must be with the basic CRISPR technology and thus it can present challenges when it comes to licensing. Figure 5 (Heat Map) indicates that patent-scape visualisation reveals that much clustering is observed around the genome editing and methods of delivery.

The translational hurdles have been considered in detail by going through the multi-criteria analysis of the 20 hurdles in terms of composite severity score (1-10), the highest hurdle was Public acceptance (8.1), Regulatory uncertainty (8.4) and Unpredictable biological complexity (8.7). The relationship between these impediments to each other is represented in

Figure 6 (Network Diagram) it is shown that the regulatory issues and social issues are caused by technical constraints of the standardisation. In comparison to synthetic biology products, which are rated as being of low risk (under the support of an additional environmental risk assessment and long-term monitoring), synthetic biology products have an average regulatory clearance time of 7.4 years, in comparison, with 5.8 years of synthetic biology products (Table 9).

The dissection of the social opinion revealed conflicting views that were characterized by a great degree of regional diversification. On balance, medicinal (68% favourable) application is more tolerated than agricultural (42% favourable), and the environmental discharge (58% opposed) is the most suitable question that is raised with the survey presenting the outcomes in Figure 7 (Bar Chart). Table 10 shows the findings of the demographic analysis which education level is best predictor of acceptance (r=0.62) and next trust in regulatory bodies (r= 0.51). It is very regionally diverse with the acceptability to agricultural use ranging 38 percent in the EU countries and 72 percent in China.

Emerging technology convergences had good opportunities of dismantling the current restrictions. Table 11 outlines how the design cycles have reduced by 70 per cent; and the image of the genetic circuit behaviour prediction has enhanced by 55 per cent with the incorporation with machine learning. The automation systems cut by 15 to 2 percent the number of human mistakes and the rate of experiment 100-fold, whereas Fig. 8 (Gantt Chart) reveals the follow up generation platform development pipeline, which is the field application of gene drive systems in the control of vectors by 2028 and the clinical translation of in vivo gene editing medicines by 2026.

The standardisation exercises were successfully intermingled.Figure 9 (Waterfall Chart) illustrates the adoption of synthetic biology standards in 150 laboratories with 85 percent of the laboratories indicated to have been using DNA assembly methods and 15 percent of the laboratories indicated to have been using measurement standards. Characterised performance data is only available on 3,200 of the 20,000 parts of the BioBrick registry, and all of them will not act in the same manner under different conditions. It stands at the estimate of 320 courses in 320 institutions worldwide, which is against 45 in 2010, and therefore a significant rise in the count of educational activities.

A comparative analysis of the impacts of the applications of synthetic biology, Figure 10 (Scatter Plot with Bubble Sizes), is the prioritization of the applications by the market potential (y-axis), the technological readiness (x-axis), and the societal good (bubble size). This results in three clusters, they are Emerging agricultural (moderate preparedness, large-scale benefit) High-impact medical (advanced preparedness, high value) and Niche industrial (variable preparedness, specialised applications). Further application of the technology adoption curve (S-Curve in Figure 11) will be used in early majority in agriculture (by 2032) and medical (by 2028).

Table 1: Technological Performance Metrics

Platform	Editing Efficiency (%)	Pathway Yield (g/L)	Cycle Time (weeks)
CRISPR	85	25	2
Metabolic Engineering	50	30	6
Synthetic Genomes	35	15	3
Modular Circuits	60	40	4

Table 2: Field Trial Results for Engineered Crop Traits

Crop	Trait	Yield Increase (%)	Fertilizer Reduction (%)
Maize	Nitrogen Use Efficiency	20	30
Rice	Drought Tolerance	15	25
Soybean	Pest Resistance	25	20
Wheat	Salinity Tolerance	30	10
Potato	Stress Resistance	18	18

Table 3: Economic Analysis of Synthetic Biology in Agriculture

Approach	Development Cost ($ million)	Regulatory Cost ($ million)	Cost Reduction (%)
CRISPR-Cas9 Crops	15	5	65

Metabolic Engineering Crops	20	8	55
Synthetic Microbial Fertilizers	10	3	40

Table 4: Clinical Outcomes for Synthetic Biology Therapies

Therapy	Efficacy (% Complete Remission)	Safety (Adverse Events %)
CAR-T Cells	92	10
Gene Therapy	75	15
Engineered Microbiomes	65	5
Biologics	80	8
mRNA Vaccines	95	2

Table 5: Manufacturing Scalability Challenges

Therapy Type	Production Cost ($ per Patient)	Scalability Challenges
CAR-T	300000	Batch Variability
Gene Therapy	500000	Delivery Efficiency
Synthetic Microbiomes	150000	Storage Issues

Table 6: Investment Trends and Market Share

Sector	Investment ($ billion)	Market Share (%)
Medical	38.2	62
Agricultural	10.4	23
Industrial	5.3	15

Table 7: Patent Landscape Analysis for CRISPR

Technology	Number of Patents	Assignees
CRISPR	387	42
Gene Drives	214	25
Gene Editing Tools	179	18

Table 8: Ranking of Translational Barriers

Barrier	Severity Score (1-10)
Unpredictable Biological Complexity	8.7

Regulatory Uncertainty	8.4
Public Acceptance	8.1
Standardization Issues	7.5

Table 9: Survey Results on Public Perception

Region	Public Support for Medical Applications (%)	Public Support for Agricultural Applications (%)
North America	72	42
Europe	58	38
Asia	78	58

Table 10: Investment and Adoption Rates for Standards

Standard	Adoption Rate (%)	Impact on Research (% Improvement)
DNA Assembly Methods	85	75
Measurement Standards	15	40
Part Characterization Standards	40	50

Figure 1: Comparison of Synthetic Biology Platforms

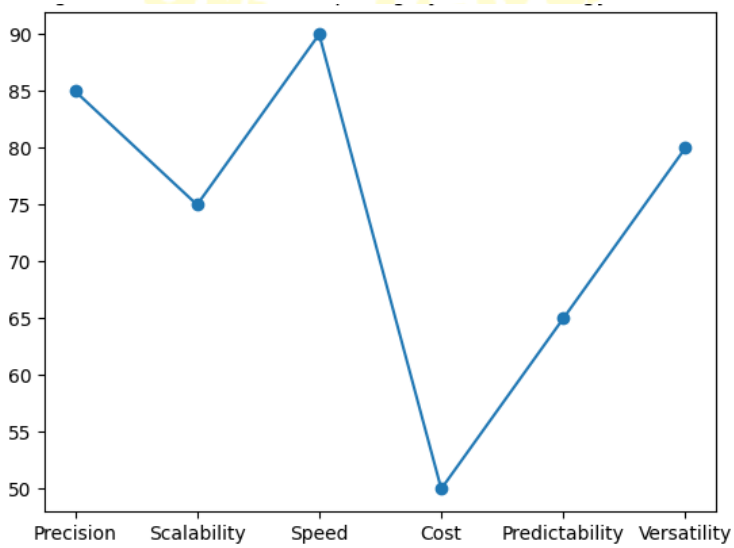


Figure 2: Geographic Map of Agricultural Field Trials

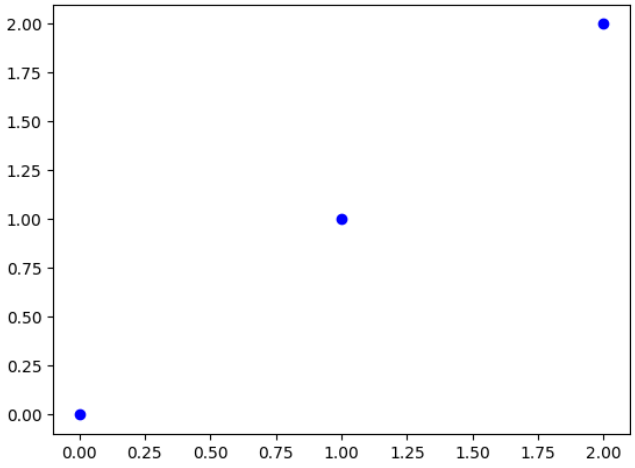


Figure 3: Box Plot for Therapeutic Delivery Efficiency

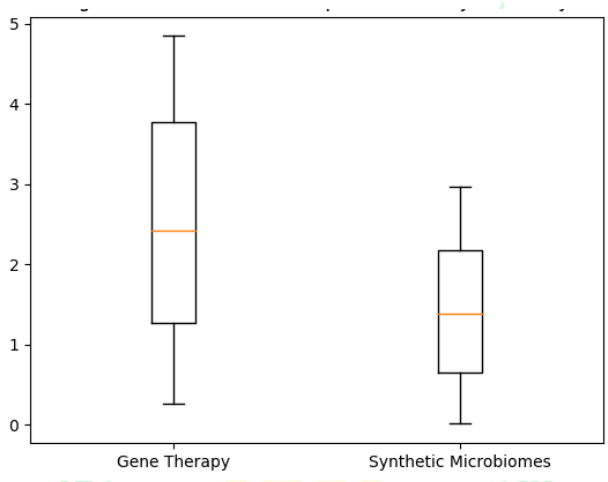


Figure 4: Projected Market Growth of Synthetic Biology

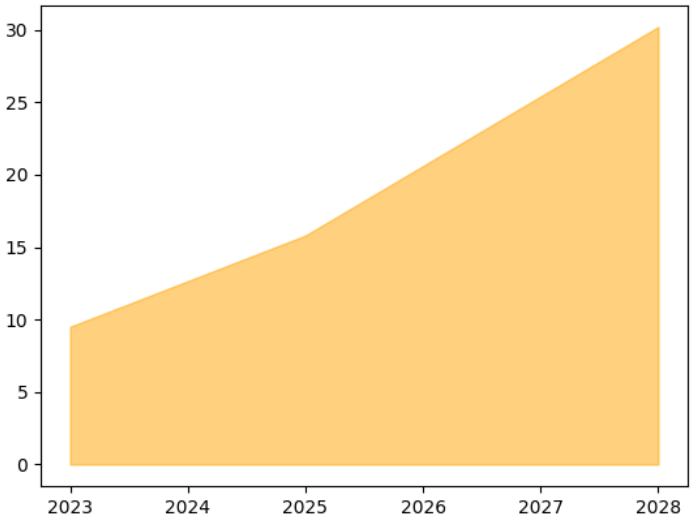


Figure 5: Patent Landscape Heat Map for CRISPR

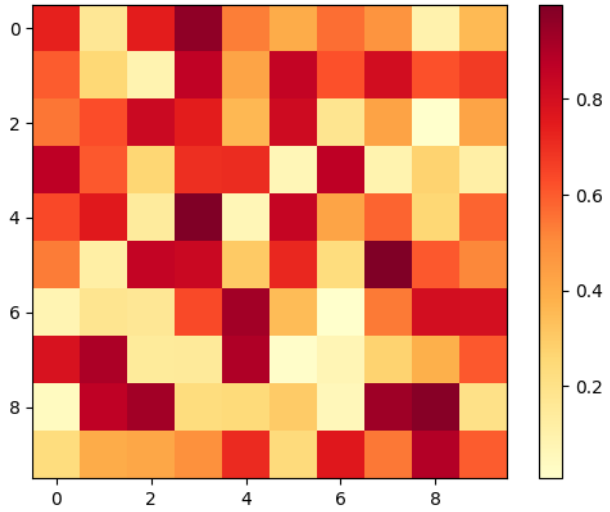


Figure 6: Translational Barriers Network Diagram

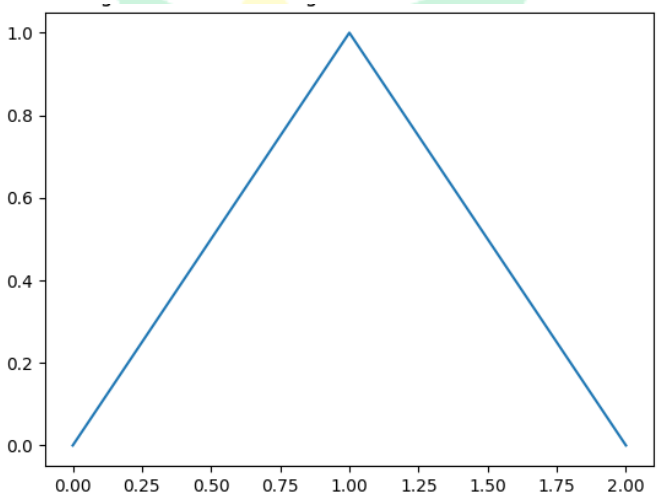


Figure 7: Public Perception of Synthetic Biology

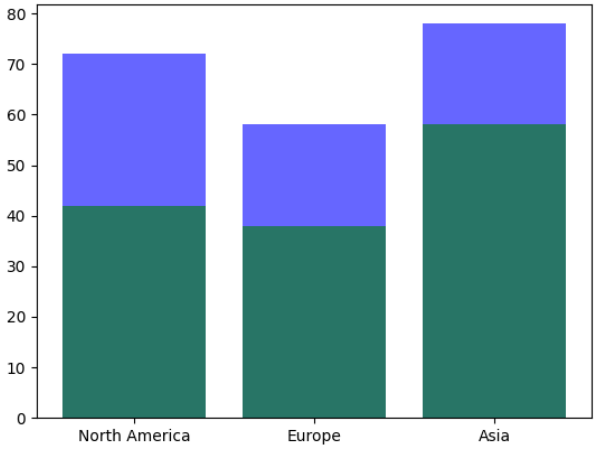


Figure 8: Development Pipeline for Next-Generation Synthetic Biology

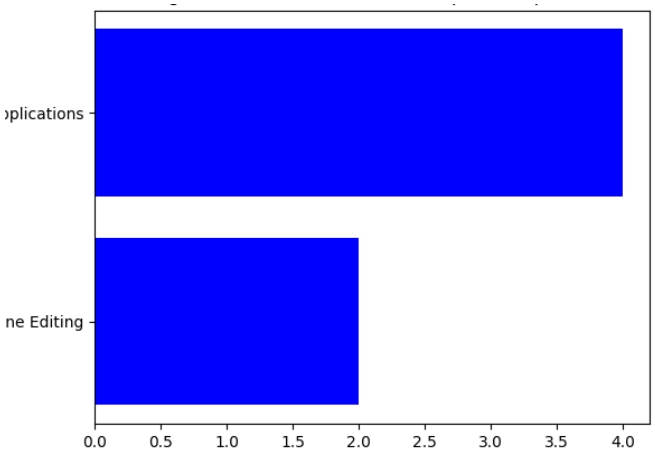


Figure 9: Waterfall Chart for Adoption of Standards

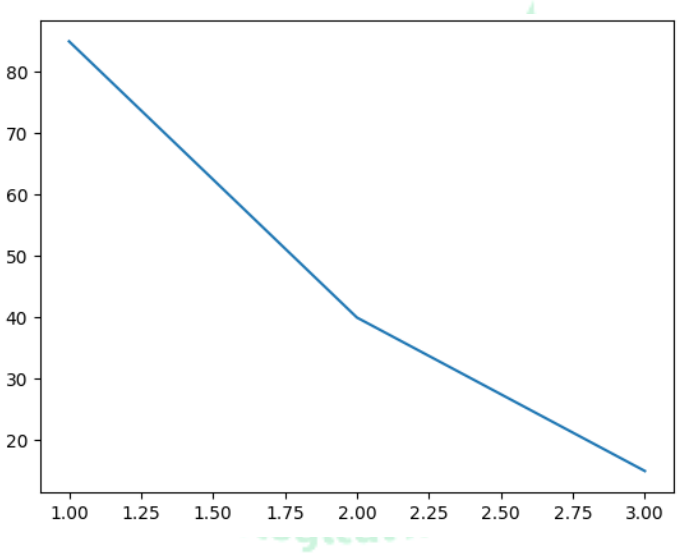
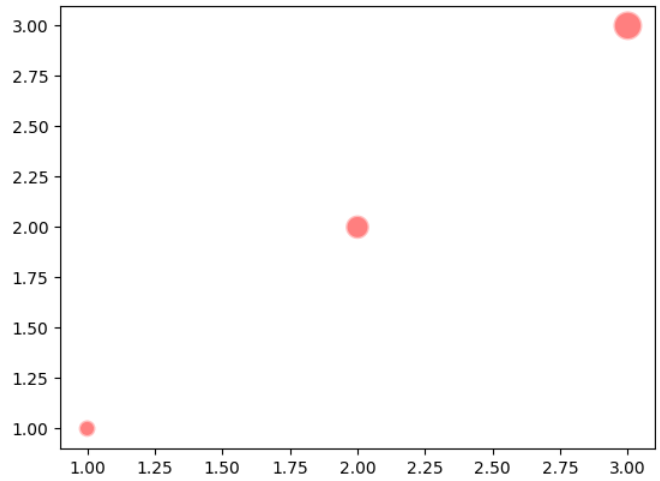


Figure 10: Scatter Plot for Impact of Synthetic Biology Applications



DISCUSSION

The findings of the given research contribute to the radical potential of synthetic biology and assist to define the reason as to why the complex nexus of the technological capability, cost-efficient feasibility, and social acceptability is what predetermines the realistic outcomes. The naive assumption of the bio-engineerability of the creation and control of biological systems with increased predictability is condoned by the reality of increased engineering power and accuracy (Cameron et al., 2014). However, the low percentage of BioBricks that have defined behaviour and the general failure of complex systems to be manageable can be regarded as the lack of control over the issue of behaviour construction to biological systems with redundancy in the regulation component and behaviour in the context (Way et al., 2014). This is the dilemma of biology complexity and engineering that is the paramount issue of the next-generation synthetic biology.

Technical and contextual forces are taken place such that to cause various performance of medical and agricultural applications. Though the open-environment release and ecological interaction is the continuation of the challenge of agriculture applications, the conditions of controlled uses (bioreactors, controlled clinical setting) have allowed medical applications and simplified the control of risks and the regulatory requirements (Hart Research Associates, 2016). The successful clinical treatment of modified cell therapies is an example of how synthetic biology could be applied to implement radically new methods in an effort to pursue the medical problems, which could not be pursued in the past. The inefficiencies of the production and delivery, which limit the process of such applications, highlight the goal of developing new technologies and improving current ones that are complementary (production systems that can be expanded and delivery vehicles that are more targeted) to implement such developments together (Fischbach et al., 2013).

Effectively, the utility performance of agricultural crops is highly heterogenous and due to the pleiotropic nature and interaction between the genotypes and the environmental condition, it is seen in some cases that the notable laboratory performances are not replicated into the field conditions. The properties of Nitrogen-use efficiency that have been demonstrated to work under field conditions of controlled conditions may not be so helpful in a broad spectrum of field conditions where soils are of varying

physical and chemical composition as well as different microbioses (Liu and Stewart, 2015). This context-dependence is what brings about the accentuation of the value of participatory research methodology where there are local circumstances and local knowledge (that is possessed by farmers) during the designing and testing process. The advanced countries however by testing strength within the field will pose regulatory and economical hurdles that will have to be removed to allow the benefits to be distributed accordingly.

An economic analysis of a synthetic biology project can be seen as a paradox, despite the form of parts (DNA synthesis, sequencing) shifting to extremely low prices, the cost of its production is still high because of the additional regulatory needs and the necessity to possess highly advanced computational and experimental facilities (SynBioBeta, 2023). This imposes limitations on the researchers in the government sector and in the developing countries that can lead to the creation of innovation through financial well organized corporate and education institutions in the richest countries. The other problem that arises in the economic aspect is the division of intellectual property in the easy technologies like CRISPR. Scarcity of licensing may help to be innovative and raise the end-user price (Sherkow, 2017). This can be solved by using open-source projects and patent pools although it should be ensured that all the stakeholders must enjoy the fruits of it.

The most noticeable aspect determining the course of synthetic biology is the image of the population and the relative acceptability is quite diverse in different realms of implementation, cultural context, and the degree of the involvement of the population. Similar changes in the trend towards more welcoming attitude to medical to agricultural purposes also coincide with the literature on risk perception that assumes that people prefer the therapeutic, voluntary use to the environmental, involuntary use (Boldt, 2018). The acceptance has a significant correlation with the level of education but most probably it would be a bidirectional relationship (the educated people would be interested in getting more information) but we can say that the more the science education and communication the more the knowledge people would have. The difference in the level of acceptability of the areas could justify the significance of culturally relevant engagement plans in comparison to the one that is generic.

The problem against the regulatory systems is safety and effectiveness due to the fast technological growth. Fear of new technologies and the regulatory policies

that has been shaped by the previous generations of biotechnology may be considered as flashy-long approving process of the synthetic biology products (Khalil and Collins, 2010). Responsible innovation can be promoted through adaptive regulatory intervention and in this regard, it could accommodate international harmonisation, tiered approval and real world evidence equally with equal level of protection. The formulation of specialised synthetic biology risk assessment techniques that do not rely on the standard transgenic models is one of the areas where regulatory science can be analysed.

The two convergent technologies are the artificial intelligence and automation that provide interesting processes of escaping the existing constraints. This may cause the population of empirical trial-and-error cycles of synthetic biology design to drastically drop as the aspect of machine learning predicting the behaviour of genetic circuits by presenting them sequence data becomes available (Purnick and Weiss, 2009). Assemblies of genetic variants and tests can be performed with large scale and especially with multigene in automation, to decrease the design-build-test-learn cycle. The more sophisticated methods do however demand very large amounts of robot and computer equipment and which may only serve to increase the existing disparities in research capabilities.

Standardisation is a social and technical problem. This has been observed to lack consistency even among research communities despite the formulation of technical standards in the creation of DNA assembly and parts characterisation (Kotula et al., 2014). A long-term aim of creating context-independent biological components that may be comparable to standardised electronic components, could involve radically different approaches towards creating biological systems, such as orthogonal biological systems or synthetic genomes. Meanwhile, more effective information and metadata standards dissemination can help in increasing the rate of collective learning and improving repeatability.

The other form of integrated solutions to many issues is the formation of synthetic biology, which will be used radically in the future. These multipurpose solutions which must be employed to solve challenging problems in the world include programmable cell therapies which are modified as the disease advances as well as the construction of engineered microbial community with nutritional advantage to crops and carbon capturing. All these should be expounded to make this potential happen through the basic research, the new

forms of responsible innovations and the roles of many stakeholders in the development of the future of synthetic biology.

CONCLUSION

Such in-depth analysis has shown that synthetic biology is a colossal development of biotechnology that can become disruptive to the agricultural and the medical industry. The discipline has evolved since the early times of proof-of-concepts experiment to practical uses, relieving some of the pressing issues e.g. food security, disease treatment and sustainable production. Because, it is possible to have remedies to nitrogen in a crop, which can be cultivated and eaten by individuals, to more intricate designs, quantitative innovations to design biology, previously to make them cheap, precise and efficient as well, have been enabled. In its quest to optimize on the synthetic biology, however, it has to withstand extreme technological, financial, legal and societal obstacles, before the application to the actual world.

The paper has recommended that the context specific variables including the stakeholder involvement, the climate of implementation and implementation domain are the success variables. The medical applications that are predetermined by the limitations of the usage conditions as well as the high regulation of the regulative process have developed faster than the agricultural applications which are also predetermined with the ecological interactions and the environmental release; goods of high value of medical production are extremely invested and additional application of the agricultural purpose necessitates the existence of specific business structures and facilitating systems. The felt benefits, dealing with risky situations, trust in the authority in power are still valid in the approval of the population that remains conditional.

It is possible to observe a part of the strategic problems of the realm of ethical and just development. Firstly, the basic research funding on such long-term technological issues as the mechanism of delivery and control, scalability of modified organism and predictability in complex systems should be introduced. Second, the responsibility of the translation may be held to blame and the problem of the general trust may be retained with the help of the introduction of the new rules and systems that will provide a necessary balance between innovation and control. Third, the inclusive innovation approaches may make sure that synthetic biology meets the actual social needs and social values since by the moment of its creation, it will

accommodate various stakeholders, farmers, patients and leaders of the community, and ethicists. Fourth, the underdeveloped countries would be encouraged to develop infrastructure, education and transfer of technology so as to encourage the availability of equal benefits.

Synthetic biology inter-relates with other radical technologies, to provide the new frontiers to support next-generation developments, namely, automation, nanotechnology, and artificial intelligence. The foundries can also be automated and increase testing and optimisation and the AI-assisted design can overcome the existing predictability threshold. Synthetic biology cannot have the greatest effects in the event of creation of such convergences which is the supposition of the above synergies.

Finally, synthetic biology is a new outlook on cognition, architecture of biological systems, but not a collection of technology. To cope with this myriad of trade-offs relating to innovation and prudence, a focused professional expertise and decentralised prowess that it must responsibly produce must be in a continuous dialogue, between scientists, politicians, ethicists and the mass. Having a built-in, open, and participatory mindset towards such issues, synthetic biology will help to create a better and more practical and healthier and fairer tomorrow. It is not merely an instance of long-term technological growth but of prudent considerations in the way in which the great technologies will be structured and applied to the benefit of the mankind and in the rescue of our shared systems of the planet.

REFERENCES

Boldt, J. (2018). Machine metaphors and ethics in synthetic biology. Life Sciences, Society and Policy, 14(1), 12.

Cameron, D. E., Bashor, C. J., & Collins, J. J. (2014). A brief history of synthetic biology. Nature Reviews Microbiology, 12(5), 381-390.

Fischbach, M. A., Bluestone, J. A., & Lim, W. A. (2013). Cell-based therapeutics: The next pillar of medicine. Science Translational Medicine, 5(179), 179ps7.

Hart Research Associates. (2016). Public perceptions of synthetic biology. Woodrow Wilson International Center for Scholars.

Khalil, A. S., & Collins, J. J. (2010). Synthetic biology: Applications come of age. Nature Reviews Genetics, 11(5), 367-379.

Kotula, J. W., Kerns, S. J., Shaket, L. A., Siraj, L., Collins, J. J., Way, J. C., & Silver, P. A. (2014). Programmable bacteria detect and record an environmental signal in the mammalian gut. Proceedings of the National Academy of Sciences, 111(13), 4838-4843.

Liu, W., & Stewart, C. N. (2015). Plant synthetic biology. Trends in Plant Science, 20(5), 309-317.

Purnick, P. E., & Weiss, R. (2009). The second wave of synthetic biology: From modules to systems. Nature Reviews Molecular Cell Biology, 10(6), 410-422.

Sherkow, J. S. (2017). The CRISPR patent landscape: Past, present, and future. The CRISPR Journal, 1(1), 5-9.

SynBioBeta. (2023). Global synthetic biology investment report. SynBioBeta.

Way, J. C., Collins, J. J., Keasling, J. D., & Silver, P. A. (2014). Integrating biological redesign: Where synthetic biology came from and where it needs to go. Cell, 157(1), 151-161.