Journal of Engineering Science and Technology
Special Issue on 3rd BPNIC2025 Vol. 21 No. 1 (2026) 89-96

INTEGRATING SCIENCE, TECHNOLOGY AND ENGINEERING IN A SMART BIO – CIRCULAR AGRO-TECHNOPRENEURSHIP MODEL FOR YOUTH FARMER EMPOWERMENT

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Abstract

This study offers the Bio-Circular Integrated Agro-Technopreneurship Model as a local palliative policy to address the urban food security issues in Serang City. This golden melon production-centred model connected the Black Soldier Fly (BSF) larvae bioconversion, aquaponics, and nutrient recycling systems to not only raise organic farming activities but also to energize the marketing of environmentally friendly food products. A mixed methods design with a primary focus on quantitative analysis was implemented through Structural Equation Modeling (SEM) using SmartPLS 3.0. Information was collected from 161 young farmers in Serang City through purposive sampling. The findings reveal that the application of this system has a major effect in production management leading to various changes such as the improvement of the production process, the reduction of conventional-agriculture inputs, and the conversion of organic waste to valuable products. Feasibility studies of the model also demonstrate that it is suitable and can be practically implemented in actual farm settings. The high intention of young farmers to apply it further reveals its potential for far-reaching effects and the possible extension of its use. Apart from the model's technical aspects, it also helps to build an eco-friendly agropreneurship concept through the green branding and the sustainable horticultural value chains promotion. In brief, this study demonstrates the model's potential to facilitate circular, health-conscious, and environmentally friendly agricultural practices in a powerful way. The model is a replicable tool of innovation-driven youth empowerment in the agricultural sector.

Keywords: Agro-technopreneurship, Golden melon, Maggots, Smart bio-circular, Young farmers.

1. Introduction

Worldwide agriculture is faced with various pressures such as climate risks, supply chain disruptions, resource depletion, and rising food insecurity. Meanwhile, population growth and unsustainable consumption continue to threaten food availability in the long run [1, 2]. In Indonesia, national and regional policies like RPJPN 2025–2045 and Banten's RPD 2023–2026 emphasize the significance of food security and youth engagement. Nevertheless, districts such as Serang are still encountering a severe generational gap in agriculture. Most farmers are over 50, and only around 4% of the youth are involved [3].

In response to these issues, this research presents a Smart Bio-Circular Agro-Technopreneurship Model that combines biological science, circular engineering, and digital entrepreneurship. The model uses golden melon (Cucumis melo L.) as a high-value crop suitable for controlled and circular farming systems. This model is an extension of the previous work on the Bio-Circular-Green (BCG) framework [4], UTAUT-based technology adoption [5], and integrated BSF–aquaponic systems [6]. There are several studies that demonstrate the effectiveness of BSF larvae in the conversion of organic waste to feed and fertilizer [7], and the aquaponic nutrient cycling that promotes water efficiency and crop quality [8]. However, very few research works have combined biological [9], technological [10], and entrepreneurial factors into a single model aimed at empowering young farmers [11].

This research addresses the discrepancy by focusing on the actual implementation of an integrated BSF–aquaponic–hydroponic system in the real world. It goes through the interactions of technology adoption, collaboration, and entrepreneurial readiness within bio-circular agriculture. The paper also models the regeneration of agriculture, primarily focusing on the youth. A mixed-methods approach was used to conduct interviews and field observations that helped understand the implementation of the system and its limitations, including a newly integrated BSF–aquaponic–hydroponic technique for the quality enhancement of golden melon. Quantitative data of 161 young farmers were subjected to PLS-SEM (SmartPLS 3.0) for testing the key constructs of technology adoption, collaboration, and entrepreneurship readiness.

The research uncovers four major points. First of all, it supplies a rare fully integrated ecological-technological-entrepreneurial model. Secondly, it brings methodological innovation by the integration of qualitative insights and SEM analysis. Thirdly, it determines the golden melon as a renewable youth-led circular agribusiness supply chain strategic commodity. Fourthly, it implements a sophisticated integrated growing technique that not only enhances the crop quality but also decreases the environmental emissions [12]. These contributions altogether create a way, according to the data, for the empowerment of young farmers and the facilitation of sustainable agricultural development, which is compliant with SDG 2, SDG 8, and SDG 12.

2. Literature Review

The Bio-Circular-Green (BCG) concept is acclaimed as a leading global solution to the interconnected sustainability challenges that arise from the interaction of social, economic, and environmental aspects of production and consumption systems [13]. Most prominent to the frame is the use of renewable biological resources and the generation of waste-derived valuables through closed-loop processes supported by reduction, reuse, and recycling (see Fig. 1).

The unified theory of acceptance and use of technology (UTAUT) frameworks, combined with structural equation modelling, identifies key behavioral factors influencing technology adoption [14]. The study shows that farmers adopt modern agricultural tools based on perceived usefulness (PE), ease of use (EE), social influence (SI), and facilitating conditions (FC). While digital innovations like precision farming and smart monitoring boost youth farmer [15].

Recent studies, far beyond the question of individuals, emphasize the decisive role of collaboration in the speeding up of technology diffusion in agriculture [16]. Agriculture ecosystems powered by technology need farmers, technical service providers, digital platform developers, and government institutions to work together in a coordinated way [17].

When different stakeholders of the agriculture sector collaborate, they make the results for fast technology transfer and strengthened innovation capacity [18]. Such cooperative arrangements are essential in preparing farmers, particularly the youth, for the agritech industry as they obtain access to managerial support, digital business models, and strategic planning tools [19].

Besides that, cross-sector collaborations are necessary steps in dismantling institutional and technical challenges related to environmentally friendly agriculture [20]. Therefore, the collaborative business models, community-based technology networks, and continuous knowledge sharing emerge as not only vital mechanisms to strengthen innovation ecosystems [21]. Collectively, this literature body indicates that the successful move towards smart, bio-circular, and youth-driven agrifood systems depends not only on advanced technologies but also on integrative frameworks that bridge behavioural, institutional, and collaborative dimensions.

Fig. 1. Bio-Circular-Green (BCG) concept in agriculture.

3. Research Methodology

The research has been designed using a mixed-method development approach that combines qualitative and quantitative techniques and aims to investigate the Smart Bio-Circular Agro-Technopreneurship Model (see Fig. 2) [22]. The qualitative part of the study is centred around the tech. development. It also focuses on the observation of the implementation of the integrated BSF–aquaponic–hydroponic system and, through semi-structured interviews with young farmers, agritech practitioners, and green marketing specialists. The model is a closed-loop system that integrates BSF bioconversion, aquaponic water enrichment, and precision hydroponic cultivation. The integrated flow of the bio-circular system is illustrated in Fig. 2, where it starts with BSF larvae converting organic waste into high-protein feed and nutrient-rich frass [23]. These products are then used to support the aquaculture component; whose nutrient-enriched effluent becomes the main input for precision hydroponic cultivation of golden melon.

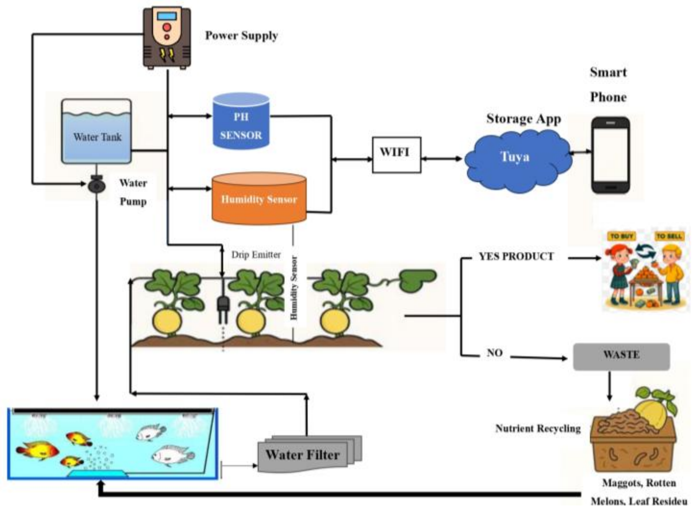

Fig. 2. Integrated bio-circular agro-technopreneurship model.

The quantitative phase deepens these insights with the help of Partial Least Squares Structural Equation Modeling (PLS-SEM) through SmartPLS 3.0 on survey data from 161 young farmers in Serang City. It thereby makes it possible to empirically test the relationships between technology adoption, collaboration, entrepreneurial readiness, and perceived environmental value in agriculture.

4. Results and Discussion

The assessment of the model starts with checking convergent validity, discriminant validity, and composite reliability. In exploratory research, loading values of 0.60 are considered acceptable, however, a confirmatory study requires loadings of 0.70 or more. It can be seen from Fig. 3 that in this case, all the indicators were above the 0.70 limit which is a clear demonstration that the measurement model is valid and reliable.

Hypothesis Testing: Through hypothesis testing, one can identify the impact of exogenous variables (Technology Adoption and Collaboration) on the endogenous variable (Agro-technopreneurship Readiness). The bootstrapping outcomes that every facet not only has a considerable effect along the direct and indirect routes but also the tested relationships are strong. All t-statistic values, as shown in Table 1 exceed the critical threshold of 1.960, indicating that each hypothesis is statistically supported at the 5% significance level.

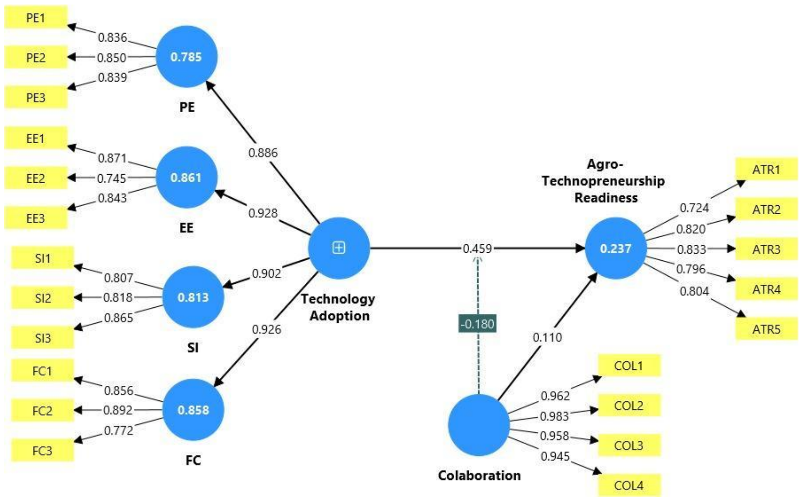

Fig. 3. Measurement model (outer model) results.

Table 1. Direct and Indirect Effect Bootstrapping Test

	Original Sample	Sample Mean	Standard Deviation	T Statistics	P Value
Technology _Adoption → EE	0.928	0.928	0.011	80.738	0.000
Technology _Adoption → FC	0.926	0.927	0.012	76.802	0.000
Technology _Adoption → PE	0.886	0.887	0.021	42.929	0.000
Technology _Adoption →SI	0.902	0.902	0.017	53.772	0.000
Collaboration → Agro-_Technopreneurship _Readiness	0.110	0.119	0.068	2.612	0.000
Technology _Adoption→Agro-_Technopreneurship _Readiness	0.459	0.463	0.074	6.163	0.000
Collaboration x Technology _Adoption → Agro-_Technopreneurship _Readiness	0.180	0.176	0.082	2.207	0.027

Hypothesis testing serves as a tool to measure the impact of certain exogenous variables, namely "Technology Adoption" and "Collaboration", on an endogenous variable "agro-technopreneurship Readiness". The changes in the width of confidence intervals between each of the three dimensions strongly regional over the direct and indirect pathways, corresponding to the interaction tested robustness. The outcome was that the technology adoption is the main factor that leads to the positive empowerment of youth farmers' agro-technopreneurship readiness. The bootstrapping result ($t = 6.163$; $p = 0.00$) is convincing that the increased use of technology among youths has a direct impact on their preparedness to run techno-savvy agribusiness venture es The influence in turn is due to the combined effects of performance expectancy, effort expectancy, social influence, facilitating conditions, and hedonic motivation which all contribute to forming perceptions of technological usefulness and ease of application. The authors have found out that these findings are in line with those presented by [24] that argue that easy to use technologies which are supported by social networks would help the youths to become more open to the innovative agricultural practices The research also identifies that collaboration has a significant impact on agro-technopreneurship readiness ($t=2.612$; $p=0.00$). This correlates with the thoughts of 25 who emphasize the role of such ecological systems in particular that consist of the higher education institutions for the strengthening of entrepreneurial competences, network expansion, and knowledge sharing support.

Proper collaboration provides the partners with unlimited resources improves the problem solving capacity and increases the system resilience which in combination prepares the young farmers for entrepreneurial engagement. Moreover, the study uncovered that collaboration is a major factor that guides the interdependence between technological adoption and agro technopreneurship readiness ($t = 2.207$; $p = 0.027$). This means that by the support of vigorous partners' relations technology adoption would become more effectual. Collaborating with universities, research institutions, and private sector actors makes the process of technology transfer, capacity - building, and advisory support more efficient, thus young farmers are enabled to take up modern technologies in a more efficient manner. This is in accordance with the research that states that young people' ability to handle and keep technology - driven agricultural ventures is greatly strengthening by strategic partnerships [25, 26].

5. Conclusion

The research reveals that the use of technology and collaborative practice have a significant impact on the youth farmers' agro-technopreneurship readiness. Technology adoption alone would not have the same positive effect without collaboration, which, among others, facilitates access to knowledge, resources, and a network of supporters.

The authors acknowledge that their findings are only applicable to Serang City and thus cannot be generalized to other regions, but they can be confident about them due to the use of SEM-PLS for the analysis.

The model of Smart Bio-Circular Agro-Technopreneurship presented in this paper is a comprehensive framework that addresses the issues of sustainable production and value-based agribusiness by integrating the aspects of smart tech, circular production, and market-oriented business. In addition, it fosters the entrepreneurial mindset of the young farmers, thereby, turning them into one of the main agents of sustainable agricultural transformation.

The continuation of collaboration between universities, government, and industry, along with the provision of training and digital infrastructure, is, therefore, very important in enabling young people to embrace this model and thus, be able to build a more resilient agricultural future.

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