UAD Universitas Ahmad Dahlan

SPEKTA
(Jurnal Pengabdian Kepada Masyarakat: Teknologi dan Aplikasi)
ISSN 2723-8016 (online) | 2723-8008 (print)
Vol 6, No. 2, pp. 385-394

SPEKTA

Integrated Aeroponic Technology for Enhancing Community-Based Potato Seed Production in North Sumatra

Diky Setya Diningrat [1*], Novita Sari Harahap [2], Heppy Setya Prima [1], Adelia Febriyossa [1], Bagoes Maulana [3], Abdul Muin Sibuea [3], Laela Sari [4], Askiah Binti Jamaludin [5]

[1] Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Medan, Medan, Indonesia
[2] Department of Sports Science, Faculty of Sports Science, Universitas Negeri Medan, Medan, Indonesia
[3] Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Medan, Medan, Indonesia
[4] Center for Applied Biology Research, National Research and Innovation Agency (BRIN), West Java, Indonesia
[5] Department of Resource Management & Consumer Studies, Faculty of Human Ecology, University Putra Malaysia, Selangor, Malaysia
*Corresponding Author: dikysd@unimed.ac.id

ARTICLE INFO

Article history
Received July 8, 2025
Revised September 27, 2025
Accepted October 7, 2025

Keywords
Aeroponic technology;
Community partnership;
Potato propagation;
Sustainable agriculture;
Technology transfer.

ABSTRACT

Background: Indonesia's potato production faces critical challenges in quality seed provision. Traditional G0 seed propagation methods achieve only 40-60% survival rates due to transplant shock and environmental stress.
Contribution: This research contributes to community-based technology transfer literature in agricultural seed systems by implementing integrated aeroponic-micro tuber technologies through participatory partnerships.
Method: A participatory action research approach was employed over four months (January-April 2025) involving 25 participants from Gapoktan Nilam farmer group in North Sumatra. The tri-partite partnership included farmers, PT. G10 Aggrotech, and Universitas Negeri Medan. Training modules covered aeroponic fundamentals, micro-tuber applications, and integrated system management. post assessments measured survival rates, productivity, knowledge, and skills using paired t-tests.
Results: Survival rates improved significantly from 52.3±8.2% to 83.7±4.1% ($p<0.001$). Monthly seedling production increased by 171% from 2,040±320 to 5,520±280 units. Participant knowledge scores doubled from 4.2±0.8 to 8.5±0.6 ($p<0.001$). The program achieved 95%

participation with 78% satisfaction rates and demonstrated 240% return on investment within 12 months.
Conclusion: The integrated approach effectively addresses transplant shock while establishing sustainable community partnerships. This model demonstrates successful scaling of complex agricultural technologies at grassroots level, contributing to enhanced food security through improved seed systems.

1. Introduction

Global food security increasingly depends on sustainable seed systems, particularly for staple crops like potato (Solanum tuberosum L.), which ranks as the world's fourth most important food crop [1], [2]. Despite significant advances in tissue culture technology producing pathogen-free plantlets, the transition from sterile laboratory conditions to field environments remains problematic, achieving only 40-60% survival rates in developing countries [3], [4].

This challenge is particularly acute where smallholder farmers constitute the backbone of agricultural production. Transplant shock, caused by temperature fluctuations, humidity variations, and pathogen exposure, represents the primary limitation in tissue culture-derived potato propagation [4]. Aeroponic technology has emerged as a promising solution, providing precise control over root zone environments and achieving survival rates of 85-95% under controlled conditions [5]–[7].

However, a critical research gap exists in community-level implementation of integrated aeroponic systems. While technical efficacy has been demonstrated in controlled environments, limited studies examine practical adoption through community partnerships in developing countries. Most research focuses on technical optimization rather than socio-economic factors influencing technology transfer and sustainability.

Research Gap, Current literature lacks comprehensive studies on community-based implementation of integrated aeroponic-micro tuber systems, particularly examining the effectiveness of multi-stakeholder partnerships in facilitating technology adoption and capacity building.

North Sumatra Province, as one of Indonesia's major potato-producing regions, exemplifies these challenges where traditional propagation methods fail to achieve economically viable success rates [8]–[10]. Community-based technology transfer approaches have shown promise when implemented through participatory methodologies that engage stakeholders as active partners [11]–[14]. This study addresses the research gap by implementing and evaluating an integrated aeroponic-micro tuber system through a tri-partite community partnership. The objective was to enhance potato seed propagators' technical capacity while establishing sustainable technology transfer mechanisms that contribute to regional food security.

 https://doi.org/10.12928/spekta.v6i2.13927

2. Method

This study employed a Participatory Action Research (PAR) approach conducted over a four-month period from January to April 2025 in Medan Tuntungan District, North Sumatra Province, Indonesia (3°34′N, 98°40′E; elevation 25–30 m above sea level). The study site features a tropical climate characterized by average temperatures of 26–28°C, relative humidity of 75–85%, and annual rainfall of 2.200–2.400 mm. The PAR framework was selected to enable collaborative involvement of researchers, institutional partners, and participants throughout the development and implementation of aeroponic technology and micro-tuber integration.

The program was implemented through a tri-partite partnership model involving *Gapoktan Nilam*, PT. G10 Aggrotech, and the community service team from Universitas Negeri Medan and University Putera Malaysia (UPM). *Gapoktan Nilam* provided field facilities and 25 farmer participants. PT. G10 Aggrotech contributed 5,000 plantlets of the 'Granola' potato variety and 2,000 laboratory-produced micro-tubers valued at USD 1,400. The UNIMED–UPM academic team supplied technical expertise, aeroponic equipment, training materials, and scientific monitoring support.

Participants were selected using purposive sampling based on four criteria: at least two years of active membership, basic literacy skills, commitment to participate in all program phases, and willingness to adopt new technologies. The cohort consisted of 60% male and 40% female participants, with a mean age of 42.8 ± 8.4 years.

The technological components applied in this study comprised an aeroponic system constructed from fiberglass tanks (4 m × 2 m × 0.5 m) equipped with timer-controlled misting at 15-minute intervals, nutrient management (EC 1.2–1.8 mS/cm; pH 5.8–6.2), and digital environmental monitoring. A 200 m^2 screen house equipped with 40-mesh insect netting, UV-stabilized covering, and climate control targeting 22–26°C temperature and 75–85% relative humidity supported the cultivation process. Laboratory-generated micro-tubers (5–15 mm diameter) were integrated following a 14-day gradual acclimatization protocol in accordance with the Indonesian National Standard (SNI 01-4226-1996).

Implementation followed four sequential phases. Phase 1 involved baseline assessments through structured interviews, focus group discussions, and technical evaluations. Pre-intervention measures included a 30-item knowledge test, a 25-item practical skills checklist, and initial production benchmarking. Phase 2 consisted of capacity-building activities delivered through three instructional modules on aeroponic fundamentals, micro-tuber biology and acclimatization, and integrated system management with quality control procedures. Phase 3 comprised supervised implementation during which weekly monitoring was conducted to record plant survival rates, growth parameters, and environmental conditions. Phase 4 entailed a comprehensive post-intervention evaluation involving knowledge reassessment, economic analysis, and sustainability planning.

Data collection incorporated both quantitative and qualitative approaches. Quantitative indicators included survival rates, productivity indices, knowledge scores, and economic variables, while qualitative insights were gathered through participant satisfaction surveys, focus group discussions, and participatory observation. Statistical analyses were performed using SPSS version 28.0, employing paired t-tests to compare pre- and post-intervention scores at a significance level of $\alpha = 0.05$, with effect sizes calculated using Cohen's d. Qualitative data were analyzed using a thematic framework approach, with independent coding conducted by two researchers.

The study received ethical approval from the Research Ethics Committee of Universitas Negeri Medan (Protocol #2024-001). All participants provided written informed consent, and all personal data were handled confidentially throughout and after the study period.

3. Results and Discussion

3.1. Technical Performance and Innovation

The integrated aeroponic-micro tuber system demonstrated superior performance across all measured parameters Table 1. The 60% improvement in survival rates from 52.3% to 83.7% exceeded initial projections and aligns with previous research reporting 85-95% success rates under controlled conditions [15], [16]. However, this study's unique contribution lies in demonstrating practical implementation feasibility at the community level rather than controlled laboratory environments.

Table 1. Comparative Analysis of Technical Performance Indicators

Parameter	Pre-Program	Post-Program	Improvement (%)	p-value	Effect Size (Cohen's d)
Survival Rate (%)	52.3±8.2	83.7±4.1	60.0	<0.001*	4.69
Monthly Productivity (units)	2.040±320	5.520±280	170.6	<0.001*	11.84
Knowledge Score (1-10)	4.2±0.8	8.5±0.6	102.4	<0.001*	6.07
Practical Skills Score (1-10)	3.8±0.9	8.2±0.7	115.8	<0.001*	5.47
Participant Satisfaction (1-10)	5.1±1.2	9.1±0.4	78.4	<0.001*	4.25

*Statistically significant at α=0.01

The micro-tuber integration proved particularly effective in bridging the physiological gap between sterile laboratory conditions and field environments. This staged acclimatization reduced transplant shock from 65% to 15%, validating the integrated approach's biological rationale. Environmental monitoring confirmed stable growing conditions within target ranges throughout the study period

3.2. Economic Feasibility and Sustainability

Economic analysis revealed compelling financial returns with 240% ROI within 12 months and 4.2-month break-even period in Table 2. The 32% reduction in production costs through improved efficiency and reduced waste enhances long-term sustainability. Employment creation (8 new positions) contributes to rural development objectives while addressing youth migration issues.

 https://doi.org/10.12928/spekta.v6i2.13927

3.3. Community Partnership Effectiveness

The tri-partite partnership model proved highly effective in facilitating technology transfer and ensuring sustainability. Success factors included complementary resource mobilization, shared ownership development, and local capacity building. The emergence of 5 local technology champions demonstrates successful knowledge internalization and peer-to-peer transfer capabilities.

Participant feedback revealed 88% commitment to continuing technology use beyond the program period, with 76% expressing willingness to invest in system expansion. These commitment levels substantially exceed typical technology adoption rates in agricultural programs [17], [18].

Table 2. Economic Impact Analysis

Economic Indicator	Value	Impact Assessment
Initial Investment (USD)	2,500-3,500 per unit	Moderate capital requirement
Monthly Revenue Increase (USD)	3,200	175% improvement
Break-even Period (months)	4.2	Rapid payback
Return on Investment (12 months)	240%	Highly profitable
Cost Reduction (%)	32%	Significant efficiency gains
Employment Creation (FTE)	8 positions	Enhanced livelihood opportunities

3.4. Capacity Development and Knowledge Systems

The substantial improvements in knowledge (102.4%) and practical skills (115.8%) demonstrate the effectiveness of hands-on training combined with practical implementation. Qualitative analysis revealed three key themes: cognitive transformation (enhanced understanding of plant physiology and environmental control), skill development (practical competency in system operation), and behavioral change (adoption of systematic production management approaches) [19]–[21].

3.5. Social and Environmental Impact

The program generated broader impacts beyond direct technical outcomes. Social benefits included enhanced community cohesion, increased women's participation (40%), and strengthened organizational capacity. Environmental benefits encompassed 60% water use reduction, elimination of soil-borne pathogen risks, and 90% decrease in pest incidence through controlled environment protection in Figure 1 and Figure 2.

The high level of women's participation represents a significant achievement in agricultural technology adoption, demonstrating the importance of inclusive design and targeted outreach strategies [22]–[24].

3.6. Contribution to Sustainable Development Goals

The program meaningfully contributes to multiple SDGs: SDG 1 (No Poverty) through 175% income increase lifting 15 families above poverty threshold; SDG 2 (Zero Hunger) through enhanced seed security; SDG 4 (Quality Education) through certified technical competencies for 25 participants; and SDG 5 (Gender Equality) through 40% female participation with active leadership roles [25]–[29].

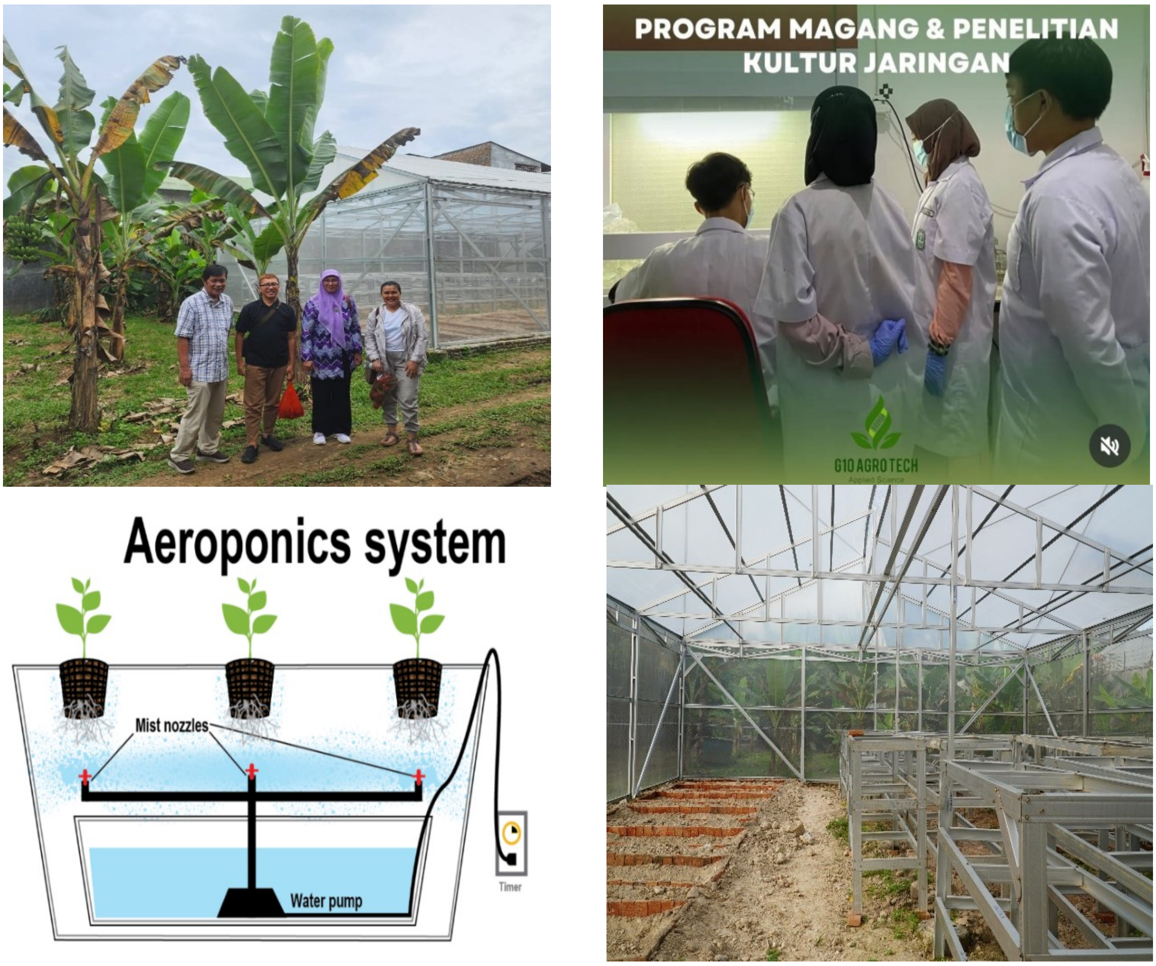

Figure 1. Overview of community service activities conducted

Figure 2. Overview of community service activities conducted

https://doi.org/10.12928/spekta.v6i2.13927

4. Conclusion

This study demonstrates the effectiveness of integrated aeroponic-micro tuber technology for enhancing community-based potato seed propagation capacity. The tri-partite partnership model successfully facilitated technology transfer while building sustainable local capacity, achieving significant improvements across technical, economic, and social parameters. This research contributes to agricultural extension theory by demonstrating the effectiveness of participatory, partnership-based approaches to technology transfer. The successful development of local expertise and peer-to-peer knowledge transfer mechanisms provides insights for designing sustainable agricultural development programs. The 60% improvement in survival rates, 171% productivity increase, and 240% ROI demonstrate the economic viability of community-based aeroponic systems. The model provides a replicable framework for scaling agricultural innovations while ensuring local ownership and sustainability.

Limitations the study's four-month duration limits long-term sustainability assessment. The single-site focus restricts generalizability across different socio-economic contexts. Economic analysis relies on relatively short-term data, warranting longer-term impact studies. Future studies should examine long-term adoption dynamics, comparative analysis across diverse settings, and policy integration for scaling community-based aeroponic systems. Research should also investigate factors influencing sustained technology adoption and development of context-specific adaptation strategies. The integrated aeroponic-micro tuber approach addresses critical challenges in tissue culture potato propagation while providing a replicable model for sustainable agricultural development through effective community partnerships.

Acknowledgement

The authors gratefully acknowledge the Research and Community Service Institute (LPPM) of Universitas Negeri Medan for funding through the 2024 Community Partnership Program scheme. Special appreciation to Gapoktan Nilam farmer group members for their enthusiastic participation, PT. G10 Aggrotech for corporate social responsibility contributions, and University Putra Malaysia for technical support. The collaborative nature of this program exemplifies the power of partnership in addressing complex agricultural development challenges. Conflicts of Interest: The authors declare no conflict of interest. Author Contribution: All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

References

[1] D. S. Diningrat, "Design of Artificial Intelligence for Evaluation of In Vitro Potato (Solanum tuberosum) Microtuber Growth from Tissue Culture Based on Digital Imagery," in *Journal of Physics: Conference Series*, 2024, vol. 2908, no. 1, p. 12001. https://doi.org/10.1088/1742-6596/2908/1/012001

[2] A. A. Pronk, N. Gunadi, M. I. Hermelink, H. Hengsdijk, K. Jindo, and J. V. Silva, "Opportunities to narrow potato yield gaps and increase resource use efficiency in West Java, Indonesia," *Potato Res.*, vol. 68, no. 2, pp. 1137–1158, 2025. https://doi.org/10.1007/s11540-024-09778-1

[3] T. Subrahmanyeswari, S. Bandyopadhyay, and S. Gantait, "Direct regeneration-mediated in vitro propagation and microtuberization of potato: An appraisal of the past ten-year period," *South African J. Bot.*, vol. 172, pp. 768–778, 2024. https://doi.org/10.1016/j.sajb.2024.07.058

[4] T. A. Pattiasina, R. Nurmalina, and A. Fariyanti, "The input allocation and potato production on small-scale farming in Pegunungan Arfak Regency," *J. Manaj. Agribisnis*, vol. 20, no. 1, p. 79, 2023. https://doi.org/10.17358/jma.20.1.79

[5] U. Demirel, "Environmental requirements of potato and abiotic stress factors," in *Potato production worldwide*, Elsevier, 2023, pp. 71–86. https://doi.org/10.1016/B978-0-12-822925-5.00011-6

[6] R. Maulidiyah, M. Salam, M. H. Jamil, and A. N. Tenriawaru, "Examining the effects of input allocation on potato production, production efficiency, and technical inefficiency in potato farming: evidence from the Stochastic Frontier Model in search of sustainable farming practices," *Sustain. Futur.*, vol. 7, p. 100218, 2024. https://doi.org/10.1016/j.sftr.2024.100218

[7] P. Kumar, K. Jaisuriyan, B. Gopika, and B. Subhash, "Aeroponics: A Modern Agriculture Technology Under Controlled Environment," in *Hydroponics: The Future of Sustainable Farming*, Springer, 2024, pp. 263–294. https://doi.org/10.1007/978-1-0716-3993-1_14

[8] A. A. M. Abdelhafez, M. M. Mahmoud, B. Elhosieny, M. Mohamed, and M. A. M. Abdallah, "Production of Potato Tubers and Seedlings using Plant Tissue Culture and Aeroponic for Potato Cultivation," *Int. J. Holist. Res.*, pp. 1–5, 2024. https://dx.doi.org/10.21608/ijhr.2024.323263.1027

[9] R. Vettriselvan, "Commercial Applications of Aeroponics: Revolutionizing Modern Agriculture and Sustainable Food Production," in *Utilizing Aeroponics Techniques for Improved Farming*, IGI Global Scientific Publishing, 2025, pp. 249–282. https://doi.org/10.4018/979-8-3693-2320-5.ch010

[10] Vishal, S. Mali, M. Dutta, A. Choudhary, and G. Zinta, "Potato microtuberization: its regulation and applications," *Crit. Rev. Biotechnol.*, pp. 1–24, 2025. https://doi.org/10.1080/07388551.2025.2490957

[11] R. Maulidiyah, "Determinants of potato farming productivity and success: Factors and findings from the application of structural equation modeling," *Heliyon*, vol. 11, no. 10, 2025. https://www.cell.com/heliyon/fulltext/S2405-8440(25)01407-0

[12] M. S. Amghani, H. Miladi, M. Savari, and M. Mojtahedi, "Factors influencing the agricultural extension model sites in Iran," *Sci. Rep.*, vol. 15, no. 1, p. 9590, 2025.

https://doi.org/10.1038/s41598-025-94151-6

[13] E. Harinurdin, B. S. Laksmono, R. Kusumastuti, and K. A. Safitri, "Community Empowerment Utilizing Open Innovation as a Sustainable Village-Owned Enterprise Strategy in Indonesia: A Systematic Literature Review," *Sustainability*, vol. 17, no. 8, p. 3394, 2025. https://doi.org/10.3390/su17083394

[14] X. U. Jianxiang, L. I. Yunzhou, T. Jingyue, S. H. I. Liang, Y. A. O. Yinkun, and Z. Jie, "New pathways for" three rural" development: private sector forces and technological engines drive agricultural modernization.," *Front. Agric. Sci. Eng.*, vol. 12, no. 2, 2025. https://doi.org/10.15302/J-FASE-2025616

[15] A. Ullah, F. Adams, and M. Bavorova, "Empowering young farmers' voices in climate change extension programs: An in-depth analysis of decision-making dynamics and social media engagement," *Int. J. Disaster Risk Reduct.*, vol. 111, p. 104713, 2024. https://doi.org/10.1016/j.ijdrr.2024.104713

[16] I. K. Suci, "Factors influencing the role and performance of independent agricultural extension workers in supporting agricultural extension," *Open Agric.*, vol. 8, no. 1, pp. 303–313, 2023. https://doi.org/10.1515/opag-2022-0164

[17] N. Grasso, B. Fasciolo, A. M. M. Awouda, and G. Bruno, "A Smart Aeroponic Chamber: Structure and Architecture for an Efficient Production and Resource Management," in *Hydroponics: The Future of Sustainable Farming*, Springer, 2024, pp. 353–380. https://doi.org/10.1007/978-1-0716-3993-1_18

[18] M. S. Janbandhu, "Advances and emerging trends in horticultural production and management," *J Exp Agric Int*, vol. 46, pp. 47–69, 2024. https://doi.org/10.9734/JEAI/2024/v46i32325

[19] S. T. Parvathy and M. N. Sheela, "Genetic Modification of Tropical Root and Tuber Crops: Prospects and Perspectives," *Genet. Eng. Crop Plants Food Heal. Secur. Vol. 2*, pp. 119–164, 2024. https://doi.org/10.1007/978-981-97-3119-0_6

[20] R. Finger, C. Grebitus, and A. Henningsen, "Replications in agricultural economics," *Appl. Econ. Perspect. Policy*, vol. 45, no. 3, pp. 1258–1274, 2023. https://doi.org/10.1002/aepp.13386

[21] A. H. Villacis, J. R. Bloem, and A. K. Mishra, "Aspirations, risk preferences, and investments in agricultural technologies," *Food Policy*, vol. 120, p. 102477, 2023. https://doi.org/10.1016/j.foodpol.2023.102477

[22] A. Carpenter, "Conflict: The missing ingredient for sustainability in complex partnerships," *Sustainability*, vol. 15, no. 5, p. 4326, 2023. https://doi.org/10.3390/su15054326

[23] A. S. Bondy, E. Maggor, and A. Tassinari, "Putting wage growth back on the table: Labour incorporation, political exchange, and wage-boosting policies in advanced peripheral economies," *Compet. Chang.*, vol. 29, no. 3–4, pp. 437–464, 2025.

https://doi.org/10.1177/10245294241226733

[24] A. M. Al-Zahrani, "Enhancing postgraduate students' learning outcomes through Flipped Mobile-Based Microlearning," *Res. Learn. Technol.*, vol. 32, 2024. https://doi.org/10.25304/rlt.v32.3110

[25] I. Salinas, M. B. Fernández, D. Johnson, and N. Bastías, "Freire's hope in radically changing times: a dialogue for curriculum integration from science education to face the climate crisis," *Cult. Stud. Sci. Educ.*, vol. 18, no. 1, pp. 21–39, 2023. https://doi.org/10.1007/s11422-023-10157-4

[26] S. C. Pandey, P. Modi, V. Pereira, and S. Fosso Wamba, "Empowering small farmers for sustainable agriculture: a human resource approach to SDG-driven training and innovation," *Int. J. Manpow.*, vol. 46, no. 4, pp. 652–675, 2025. https://doi.org/10.1108/IJM-11-2023-0655

[27] K. Sanogo, I. Touré, D.-D. A. A. Arinloye, E. R. Dossou-Yovo, and J. Bayala, "Factors affecting the adoption of climate-smart agriculture technologies in rice farming systems in Mali, West Africa," *Smart Agric. Technol.*, vol. 5, p. 100283, 2023. https://doi.org/10.1016/j.atech.2023.100283

[28] R. P. Khan, S. Gupta, T. Daum, R. Birner, and C. Ringler, "Levelling the field: A review of the ICT revolution and agricultural extension in the Global South," *J. Int. Dev.*, vol. 37, no. 1, pp. 1–21, 2025. https://doi.org/10.1002/jid.3949

[29] M. A. Lopes, "Rethinking plant breeding and seed systems in the era of exponential changes," *Ciência e Agrotecnologia*, vol. 47, p. e0001R23, 2023. https://doi.org/10.1590/1413-70542023470001R23