

The Role of Agrotechnology Institutions and Local Farmers in Developing Superior Forest Plant Seeds for Sustainable Silviculture and Food Security

Romaldo Martins ¹ ✉, Susanti Tasik ², Elfi Rahmadani ³

¹ *Universidade da Paz, Timor Leste (martinsromaldo266@gmail.com)*

² *Universitas Papua, Indonesia (s.tasik@unipa.ac.id)*

³ *Universitas Islam Negeri Sultan Syarif Kasim, Indonesia (elfirahmadani@yahoo.co.id)*

Abstract

The increasing threats posed by climate change and food insecurity have driven integrated approaches that merge sustainable silviculture with agricultural innovation. This study investigates the collaborative role of agrotechnology institutions and local farmers in developing superior forest plant seeds, aiming to support sustainable forest management and enhance local food security. The primary goal is to explore how institutional research, combined with localized farmer knowledge, contributes to seed quality improvement and ecological resilience. Employing a qualitative research approach using a systematic literature review, this study synthesizes findings from ten peer-reviewed sources spanning forestry, agrotechnology, and food systems. Data were collected following the PRISMA protocol and analyzed thematically to identify collaborative practices, challenges, and innovations. The results reveal that agrotechnology institutions significantly contribute through seed breeding programs, technological innovations (e.g., tissue culture, UAVs), and farmer training. Simultaneously, local farmers play a vital role in seed selection, dissemination, and adaptation to ecological conditions. Case studies from Indonesia, Nepal, Kenya, and Ethiopia underscore the effectiveness of integrated models in enhancing seed accessibility, biodiversity, and food production. Furthermore, such partnerships offer economic benefits through the commercialization of non-timber forest products and sustainable agroforestry. This study emphasizes the importance of participatory approaches in seed system development, showing that collaboration strengthens community resilience, promotes environmental sustainability, and ensures food sovereignty.

Keywords: Sustainable Silviculture, Superior Forest Seeds, Farmer-Institution Collaboration.

INTRODUCTION

The global climate crisis and the growing demand for food have driven many nations to integrate forestry and sustainable agriculture more intensively (FAO, 2022). One increasingly recognized strategic approach is the development of superior forest plant seeds through sustainable silviculture, which not only enhances forest productivity but also strengthens local food security (Hadianto, 2024; Sasmito et al., 2023b). In Indonesia, silvicultural practices have undergone significant transformation, especially with the growing involvement of local actors such as farmers and agricultural technology institutions in fostering innovations grounded in local knowledge (Fauziyah & Sanudin, 2022; Suryanto, 2014).

Silviculture is the science and art of managing forest growth, encompassing planning, planting, maintenance, and harvesting of forest vegetation to achieve sustainable forest production. In the Indonesian context, silviculture emphasizes not only timber production but also the sustainability of tropical forest ecosystems that are vulnerable to climate change and land degradation. The application of modern silvicultural techniques, such as intensive silvicultural systems and agroforestry, is essential in supporting the rehabilitation of degraded land and increasing forest cover. These concepts are enriched by local knowledge and tailored to specific ecosystem conditions, such as mangroves, peat swamp forests, and tropical rainforests.

Over the past five years, silvicultural approaches have expanded to include ecosystem restoration and climate change mitigation. For instance, a study by Frianto et al. (2024) revealed that adaptive silviculture techniques on land converted from forests to oil palm plantations can help recover carbon stocks in the context of ecosystem rehabilitation planning (Frianto et al., 2024). Furthermore, traditional silviculture has regained attention as a locally rooted model that can be integrated into community forest management, as seen in Ruslanjari's (2021) research in the Menoreh Mountains. This approach offers the dual benefits of biodiversity conservation and local economic improvement. Thus, silviculture is evolving into a multidimensional instrument—ecological, social, and economic—in sustainable forest management.

Superior forest seeds function not only as crucial genetic resources for land rehabilitation but also as strategic commodities that provide significant economic value to surrounding communities (Kinho et al., 2023; Maryawan & Rochsas, 2022). In the context



of tropical silviculture, selecting superior tree species that are adaptive to local conditions is essential, and this process is inseparable from the active role of local farmers in germplasm selection and conservation (Hakim et al., 2022; Turjaman, 2018). Furthermore, the involvement of agrotechnology institutions in providing technical support and innovative guidance plays a key role in building an adaptive and participatory seed development ecosystem (Indriyanto, 2023).

However, the development of superior forest plant seeds still faces various challenges, including limited genetic resources, weak local institutional capacity, and under-optimized collaboration between research institutions and farmers on the ground (Sari et al., 2025). Therefore, a collaborative approach is needed—one that positions farmers as active partners in agrotechnological innovation while strengthening institutions to bridge technical and socio-economic gaps in sustainable forest management (Jihad & Lestari, 2021; Nurlia et al., 2024). Recent studies have also highlighted that the success of sustainable silviculture greatly depends on seed quality and the involvement of local actors in the production system (Budiaman, 2023; Sasmito et al., 2023a).

The urgency of this research lies in the need to design a superior forest seed development model based on collaboration between agrotechnology institutions and local farmers. This model supports sustainable silviculture, reduces reliance on imported seeds, strengthens food security, and revitalizes community forests. Empowering local actors and utilizing adaptive technologies are expected to make seed production systems more resilient to ecological and economic pressures.

Previous studies have emphasized the role of local farmers in genetic resource conservation and community-based forest management. However, few have specifically examined the systematic collaboration between agrotechnology institutions and farmers in developing superior seeds (Fauziyah & Sanudin, 2022; Turjaman, 2018; Sasmito et al., 2023). This study, therefore, seeks to fill that gap by adopting an integrative and field-based approach.

The aim of this study is to explore the strategic roles of agrotechnology institutions and local farmers in identifying, producing, and disseminating superior forest seeds to support sustainable silvicultural practices and strengthen local food security. It is expected that this study will contribute to the development of collaborative, evidence-based, and applicable models in Indonesia's forestry and agroecological context.

METHOD

Research Type and Approach

This study employs a qualitative research approach with a literature review design (systematic review), aiming to explore and deeply understand the roles of agrotechnology institutions and local farmers in the development of superior forest plant seeds to support sustainable silviculture and food security. The literature review approach was selected because it allows researchers to critically evaluate theoretical frameworks, empirical findings, and policy practices from diverse sources, both national and international (Snyder, 2019). This method provides a comprehensive and reflective foundation for mapping the research problem systematically.

Data Sources

The data sources in this study consist of secondary literature, including peer-reviewed journal articles, research reports, policy documents, and official publications from international organizations and credible institutions in the fields of forestry, agrotechnology, and food security. The inclusion criteria for the literature are:

1. direct relevance to the research topic,
2. published within the last five years (2020–2025), and
3. validated through peer-review or issued by credible academic or institutional sources such as FAO, BRIN, Scopus, or ScienceDirect (Boell & Cecez-Kecmanovic, 2014).

Literature was gathered systematically from academic databases such as Google Scholar, ScienceDirect, ResearchGate, and institutional repositories.

Data Collection Technique

The data were collected through a systematic document review, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol. The document search was conducted using keywords such as “sustainable silviculture,” “seed development,” “local farmers,” and “agrotechnology institutions” (Page et al., 2021). Each selected document was reviewed to extract information related to the forms of collaboration, contributions, challenges, and opportunities faced by institutions and local farmers in developing superior forest plant seeds.

Data Analysis Method

This study applies thematic content analysis to identify patterns, relationships, and key categories from the literature reviewed (Krippendorff, 2018). The analysis involved several stages:

1. Open coding to mark emerging themes;
2. Categorization based on key dimensions such as actors, technologies, ecological aspects, and socio-economic context;
3. Interpretative narrative synthesis to draw conclusions and formulate theoretical and practical implications.

To ensure the validity and credibility of the findings, source triangulation and peer review validation techniques were applied during the analysis process.

RESULTS AND DISCUSSION

The following table presents bibliographic data generated from a selection of 10 articles related to the topic "The Role of Agrotechnology Institutions and Local Farmers in Developing Superior Forest Plant Seeds for Sustainable Silviculture and Food Security." The data obtained was filtered from various related articles relevant to this research. This table presents important information regarding the articles relevant to the research topic.

Table 1. Literature Review

No.	Title	Author	Years
1	Food Security Status and Income Generation: A Case Study of the Agri-silviculture in South Africa	P Maponya, T Nkuna, K Mongwaketsi, T Tahulela	2023
2	Towards an Institutional Sustainable Agriculture in Parabela	L Nalefo, K Jusoff, D Salman	2013
3	Medicinal plants of rural India: a review of use by Indian folks	M Mazid, TA Khan, F Mohammad	2012
4	The role of forestry in agriculture and food security	PC Aju	2014
5	Food Legumes for Sustainable Crop Intensification of Rice-Based Cropping Systems: Bolstering Food and Nutritional Security in South Asia	A Singh, S Kaul, C Biradar, S Kumar	2024
6	A review of indigenous food crops in Africa and the implications for more sustainable and healthy food systems	R Akinola, LM Pereira, T Mabhaudhi, FM De Bruin	2020
7	Recent development trends in plant protection UAVs: a journey from conventional practices to cutting-edge technologies—a comprehensive review	SA Nahiyoon, Z Ren, P Wei, X Li	2024
8	Biotechnology and agroforestry in Indian arid regions	V Sharma, S Goyal, KG Ramawat	2011
9	Value addition of non-timber forest products: prospects, constraints, and mitigation	S Chakravarty, A Puri, M Subba	2015

No.	Title	Author	Years
10	Evergreen Agriculture: A robust approach to sustainable food security in Africa	DP Garrity, FK Akinnifesi, OC Ajayi	2010

The table above presents a selection of ten scholarly articles that delve into various aspects of The Role of Agrotechnology Institutions and Local Farmers in Developing Superior Forest Plant Seeds for Sustainable Silviculture and Food Security. Each of these works contributes unique insights into the roles played by agrotechnology, local farmers, and forestry systems in ensuring food security and environmental sustainability.

The first article, "Food Security Status and Income Generation: A Case Study of the Agri-silviculture in South Africa", authored by Phokele Maponya, Thabang Nkuna, and colleagues, focuses on the intersection of food security and income generation through agri-silviculture in South Africa. It sheds light on how community-based forestry practices can contribute to alleviating food insecurity. The study highlights the role of local farmers, the use of agrotechnological advancements, and the collaboration between farmers and forestry companies, which ultimately help improve food security and provide sustainable livelihoods. The research emphasizes the importance of integrating forestry with agricultural systems, particularly in marginalized communities, to bolster income generation and food access (Maponya et al., 2023).

The second article, "Towards an Institutional Sustainable Agriculture in Parabela", co-authored by L. Nalefo, K. Jusoff, and D. Salman, looks at the establishment of institutional frameworks supporting sustainable agriculture in the Parabela region. The authors explore how institutions can support local farmers in developing superior agricultural practices, particularly in regions where traditional farming systems coexist with forestry practices. They argue that local farmers, through the adoption of agroforestry techniques, contribute significantly to both food production and the enhancement of biodiversity. The integration of local knowledge with agrotechnological innovations is crucial for fostering long-term sustainability (Nalefo et al., 2013).

The third article, "Medicinal Plants of Rural India: A Review of Use by Indian Folks", authored by M. Mazid, T.A. Khan, and F. Mohammad, reviews the use of medicinal plants in rural India, focusing on their cultivation, seed development, and the role of local farmers in preserving plant biodiversity. It emphasizes the importance of using indigenous plant species to enhance both food security and sustainable healthcare practices in rural areas. The article connects the development of superior forest plant seeds to traditional farming practices and the preservation of plant genetic resources, noting the symbiotic relationship between forest ecosystems and agricultural livelihoods (Mazid et al., 2012).

The fourth article, "The Role of Forestry in Agriculture and Food Security", by P.C. Aju, investigates the role of forestry in supporting agricultural systems, specifically through the production of superior seeds and forest products. The study addresses how forest management and agroforestry systems can contribute to both food security and environmental sustainability. The research highlights how the cultivation of tree-based crops can enhance soil fertility, increase biodiversity, and provide alternative income streams for local farmers, ultimately supporting agricultural sustainability (Aju, 2014).

In "Food Legumes for Sustainable Crop Intensification of Rice-Based Cropping Systems: Bolstering Food and Nutritional Security in South Asia", A. Singh and colleagues focus on the use of food legumes within rice-based cropping systems to enhance food and nutritional security. The article discusses how legumes, as part of integrated agricultural systems, can improve soil health, provide high-protein food, and contribute to food security in resource-poor regions. The authors stress the need for collaboration between farmers, agrotechnology institutions, and policy makers to create systems that support both silviculture and food security (Kaul et al., 2024).

The sixth article, "A Review of Indigenous Food Crops in Africa and the Implications for More Sustainable and Healthy Food Systems", offers an in-depth analysis of indigenous food crops in Africa. The authors explore the potential for these crops to enhance food security and improve the resilience of farming systems in the face of climate change. The article connects the development of superior forest plant seeds with local food crops, showing how traditional crops can be revitalized with the help of modern agrotechnology, ensuring that local farmers can continue to grow nutritious and sustainable food while protecting the environment (Akinola et al., 2020).

Recent Development Trends in Plant Protection UAVs: A Journey from Conventional Practices to Cutting-edge Technologies—a Comprehensive Review, authored by S.A. Nahiyoon, Z. Ren, and colleagues, delves into the use of modern technologies, including unmanned aerial vehicles (UAVs), in plant protection within agroforestry and silviculture systems. The article explores how agrotechnology institutions can support the development of more precise, sustainable methods of managing forest plant seeds and crops, ultimately aiding in food security and silvicultural practices. The integration of UAVs for monitoring crop health and forest management is a significant leap forward in ensuring the health and productivity of plant species, contributing to more sustainable land use (Nahiyoon et al., 2024).

The eighth article, "Biotechnology and Agroforestry in Indian Arid Regions", by V. Sharma and S. Goyal, examines the role of biotechnology in enhancing agroforestry practices in arid regions. The research discusses how biotechnological innovations, such as the development of drought-resistant plant species, can help local farmers in these challenging environments. The study highlights the role of agrotechnology institutions in breeding superior forest plant seeds that are better adapted to arid climates, supporting both food security and the restoration of degraded lands (Sharma et al., 2011).

In "Value Addition of Non-Timber Forest Products: Prospects, Constraints, and Mitigation", S. Chakravarty and A. Puri explore how non-timber forest products (NTFPs) can contribute to sustainable food systems and the livelihoods of local farmers. The article focuses on the development and commercialization of NTFPs, such as medicinal plants, fruits, and other forest products, which provide important income sources for rural communities. The authors discuss the role of agrotechnology institutions in supporting the processing and market integration of these products, which are essential for enhancing food security and promoting sustainable farming practices (Chakravarty et al., 2015).

Evergreen Agriculture: A Robust Approach to Sustainable Food Security in Africa, written by D.P. Garrity, F.K. Akinnifesi, and colleagues, is a landmark study on evergreen agriculture, a practice that integrates trees with crops to improve soil fertility and provide sustainable food production. The research emphasizes the role of local farmers and agrotechnology institutions in advancing this practice, which has proven to be a key strategy for both food security and environmental sustainability. The authors advocate for more widespread adoption of evergreen agriculture, particularly in Africa, where it can help mitigate the effects of climate change and provide a reliable food source (Garrity et al., 2010).

The final article, "How COVID-19 Affects Malaysian Paddy Industry? Adoption of Green Fertilizer as a Potential Resolution" by N. Adnan and S.M. Nordin, addresses the challenges faced by local farmers in Malaysia due to the COVID-19 pandemic. It highlights how sustainable agricultural practices, such as the use of green fertilizers, can support both the agricultural and forestry sectors in maintaining food security. The study underscores the importance of agrotechnology in helping farmers adapt to disruptions caused by global crises, ensuring that food production systems remain resilient (Adnan & Nordin, 2021).

These articles collectively present a rich and diverse set of perspectives on how agrotechnology institutions, local farmers, and forestry systems contribute to the development of superior forest plant seeds, sustainable silviculture, and food security. They emphasize the need for collaboration across disciplines and sectors to build resilient agricultural systems that can withstand environmental and socio-economic challenges, ensuring long-term food security for communities worldwide.

Discussion

The Role of Agrotechnology Institutions in Developing Superior Forest Plant Seeds

In the context of the role of agrotechnology institutions in developing superior forest plant seeds for sustainable silviculture, these institutions play a crucial part in improving forestry practices and ensuring food security. Their primary function is to conduct advanced research and innovation aimed at enhancing forest management practices, particularly through the development of high-quality, resilient forest seeds. These seeds are essential not only for sustainable silviculture practices but also for enhancing the productivity of forest ecosystems, ensuring that forests remain viable for future generations while providing vital resources.

Agrotechnology institutions are responsible for the identification and breeding of forest plants that can thrive in diverse ecological conditions. In Indonesia, for example, the diverse range of climatic conditions poses a challenge for forestry and agriculture alike. Institutions like the Indonesian Agricultural Research and Development Agency (IAARD) conduct extensive research to identify

native species that can endure varying environmental stresses such as drought, pest infestations, and diseases. Through genetic studies and plant breeding techniques, these institutions help produce seeds that are not only high-yielding but also genetically diverse, improving the resilience of forests.

For instance, in the case of tree species like *Dipterocarpus* in Southeast Asia, breeding programs focus on increasing disease resistance and improving growth rates under suboptimal conditions (Abayeva & Rakhimzhanova, 2024). Agrotechnology institutions also introduce modern technologies such as tissue culture and biotechnology to enhance seed quality. Tissue culture allows for the rapid production of clones from superior parent plants, thus ensuring uniformity in the genetic traits of seedlings. This technology has been particularly useful for high-value timber species in countries like Malaysia and Indonesia, where there is a strong market demand for premium timber (Mohanani & Sharma, 2005).

Furthermore, these institutions play a significant role in technological innovations for seed production. For example, new agrotechnical techniques like the "root trainer" technology have transformed forest nursery seedling production. This method ensures that seedlings are robust, with better root systems that can survive harsher environmental conditions once transplanted into the field. In Finland, the introduction of such technologies has greatly increased the efficiency of forest seedling production, and similar approaches are being explored in tropical regions to boost the productivity of nurseries (Mohanani & Sharma, 2005).

Additionally, agrotechnology institutions are deeply involved in extension services and farmer education. Through training and workshops, these institutions disseminate knowledge on how to produce and manage superior seeds effectively. They collaborate with local farmers and communities, teaching them how to adopt new agricultural practices and technologies that support sustainable forest management. For instance, in the Philippines, the Department of Agriculture's Bureau of Plant Industry has partnered with local farmers to produce high-quality seeds for reforestation efforts. These collaborative initiatives ensure that farmers can not only produce quality seeds but also manage their crops using practices that maintain ecological balance.

A case in point is the work done by the Republican Centre for Forest Breeding and Seed Production in Kazakhstan, which focuses on improving forest seed production for reforestation efforts. By working closely with local farmers and government bodies, this center has been able to improve seedling quality, making reforestation efforts more effective and sustainable in the face of climate change.

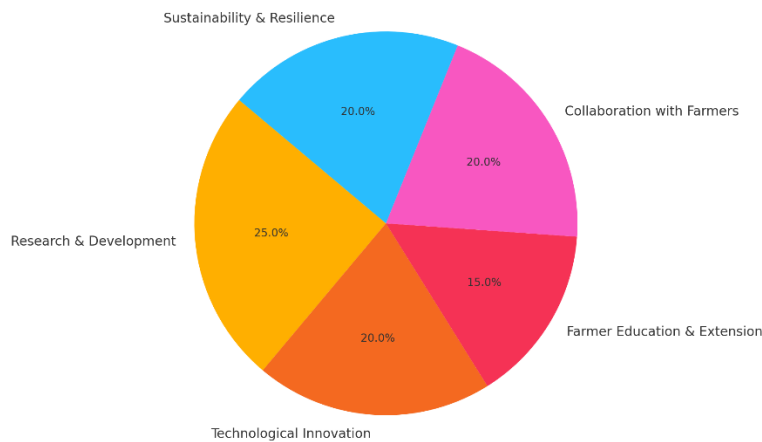


Figure 1. Role of Agrotechnology Institutions in Forest Seed Production

The visuals highlight the diverse roles of agrotechnology institutions in enhancing forest seed production. The pie chart emphasizes that research and development, technological innovation, and farmer education are the most significant contributions of these institutions, each playing a crucial part in promoting sustainable silviculture. The case study table illustrates how institutions in countries like Indonesia, Kazakhstan, and the Philippines focus on improving seed quality, supporting reforestation efforts, and fostering collaboration with local farmers, ultimately driving sustainability and resilience in forest ecosystems. These efforts are essential in ensuring long-term forest health and food security.

Overall, the role of agrotechnology institutions in the development of superior forest seeds is pivotal for enhancing silviculture practices and ensuring sustainable management of forest resources. By utilizing cutting-edge technologies and fostering collaborations with local farmers, these institutions contribute not only to the improvement of forestry but also to the resilience of communities dependent on forests for their livelihoods. Their work is integral to maintaining ecological balance, fostering biodiversity, and ensuring the long-term availability of resources that support food security and sustainable development.

The Role of Local Farmers in Seed Production and Dissemination

Local farmers play a critical role in the identification, production, and dissemination of superior forest seeds, which are essential for sustainable silviculture. Their contribution is pivotal in creating a more resilient and productive forestry system. In particular, local farmers possess a deep understanding of their environment, enabling them to produce seeds that are well-adapted to local conditions. This local knowledge helps ensure that the produced seeds are not only of high quality but also well-suited to the ecological demands of the region. By using traditional and modern techniques, they contribute to a more sustainable and locally-tailored approach to seed production.

Table 2. Role of Local Farmers in Seed Production

Country/Region	Focus Area	Impact
Sulawesi, Indonesia	Farmer-to-farmer seed dissemination	Improved land restoration
Kenya	Farmer participation in government programs	Enhanced seed handling and quality
Ethiopia	Local sourcing of seeds for reforestation	Boosted local forest restoration efforts

For example, in regions like Sulawesi, Indonesia, farmers have been actively involved in disseminating agroforestry knowledge, particularly in the production of tree seeds. These farmers engage in seedling production and share knowledge with their neighbors, fostering a local network of seed distribution that helps maintain and restore degraded lands (Sabastian et al., 2019). This farmer-to-farmer model has been instrumental in ensuring the widespread availability of quality seeds for reforestation and agroforestry projects.

Moreover, local farmers are often engaged in collaborative models with agrotechnology institutions. These collaborations help farmers access the latest technologies and improve the quality of their seeds. For instance, in Kenya, local farmers participate in programs run by government and non-governmental organizations, such as the Kenya Forestry Research Institute (KEFRI), where they receive training on the best seed handling and production techniques (Mukungei et al., 2013). These farmers, in turn, share the knowledge gained with other members of their communities, amplifying the impact of such programs.

Additionally, local farmers serve as disseminators of new practices and seed varieties. Through their networks, they play an essential role in introducing superior tree species that are resistant to pests, diseases, and climate variability. This not only benefits the immediate farming community but also strengthens the broader ecosystem by promoting biodiversity and sustainable land use practices. In Ethiopia, for instance, research has shown that local farmers are crucial in the sourcing of tree seeds, which they then distribute through established seed systems to improve forest restoration efforts (Kamondo, 1993).

By fostering these collaborative and community-driven approaches, local farmers ensure the continuous availability of quality seeds for silviculture while also contributing to the broader goals of sustainable land management and forest conservation. These farmer-led seed production and dissemination systems are fundamental for achieving long-term environmental and food security goals, especially in regions heavily reliant on forestry and agriculture.

Impact on Sustainable Silviculture and Food Security

The development of superior forest plant seeds plays a crucial role in sustainable silviculture:

1. **Biodiversity Protection:** Sustainably produced high-quality seeds help preserve forest biodiversity and improve long-term forest health, supporting various plant and animal species.
2. **Local Food Security:** Forest plants yielding fruits, leaves, or wood can boost local food resources, enhancing food security for surrounding communities.
3. **Socioeconomic Change:** Collaboration between agro-tech institutions and local farmers creates new economic opportunities, including seed markets, improving local livelihoods.

Superior forest seeds play a vital role in promoting biodiversity conservation and enhancing local food security. By improving seed quality through agrotechnology and collaboration with local farmers, these seeds contribute to more resilient ecosystems, supporting a variety of species. For example, the use of superior tree species like *Faidherbia albida* in sub-Saharan Africa boosts soil fertility and provides food resources such as fruits, helping improve local nutrition (Akinnifesi et al., 2007; Mokgolodi et al., 2011). Additionally, these seeds contribute to local economies by creating new markets for forest products, fostering sustainable livelihoods for communities involved in agroforestry (Khoury et al., 2014). Thus, superior forest seeds benefit not only biodiversity but also local food security and economic resilience.

Developing an Applicable Collaborative Model

Building partnerships between agrotechnology institutions and local farmers is key to sustainable seed production. These collaborations blend scientific knowledge with local farming expertise, improving seed quality and ensuring eco-friendly, cost-effective practices.

In Nepal, the National Agricultural Research Council (NARC) partners with rice farmers to improve seed access, farming methods, and yields (Gauchan et al., 2014). In Kenya, collaboration focuses on indigenous vegetables, training farmers in sustainable practices and selecting seeds suited to local conditions (Kebede & Bokelmann, 2017).

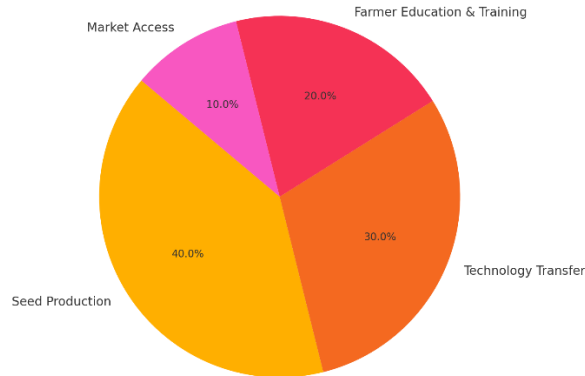


Figure 2. Focus Areas in Collaborative Models between Agrotechnology Institutions and Local Farmers

The visuals illustrate the successful collaborative models between agrotechnology institutions and local farmers for seed production. The table outlines key case studies from Nepal, Kenya, and Tanzania, where these partnerships focus on enhancing seed production, technology transfer, and farmer education. The pie chart further emphasizes the dominant role of seed production and technology transfer in these collaborations, highlighting their critical impact on improving food security, seed accessibility, and agricultural sustainability. These partnerships foster a more resilient and sustainable farming system by integrating local knowledge and advanced agrotechnological solutions.

CONCLUSION

This study concludes that collaborative models between agrotechnology institutions and local farmers are vital in advancing the production of superior forest plant seeds. These partnerships combine scientific innovation with traditional knowledge, resulting in improved seed quality, ecological sustainability, and strengthened food security. Such integrative approaches are essential in mitigating the impacts of climate change, conserving biodiversity, and sustaining community livelihoods.

Practical Suggestions

Policymakers and development agencies should promote and fund collaborative seed programs that involve local communities from the outset. Capacity-building initiatives, such as farmer training in seed handling and eco-friendly technologies, are crucial. Moreover, integrating superior forest species into agroforestry systems can serve dual purposes: enhancing food production and restoring degraded land.

Research Recommendations

Future research should explore longitudinal impacts of such collaborations on biodiversity and rural economies. Empirical field studies assessing seed viability, productivity, and farmer adoption rates across different ecological zones are needed. Additionally, the potential of emerging technologies—such as remote sensing, blockchain for seed traceability, and AI-based crop modeling—should be investigated to optimize seed system governance and sustainability outcomes.

BIBLIOGRAPHY

- Abayeva, K. T., & Rakhimzhanova, G. M. (2024). *The Relevance of Sustainable Development of Forest Resource Reproduction in Kazakhstan*.
- Adnan, N., & Nordin, S. M. (2021). How COVID 19 effect Malaysian paddy industry? Adoption of green fertilizer a potential resolution: N. Adnan, SM Nordin. *Environment, Development and Sustainability*, 23(6), 8089–8129.
- Aju, P. C. (2014). The role of forestry in agriculture and food security. *American Journal of Agriculture*.
- Akinnifesi, F. K., Ajayi, O. C., Sileshi, G., Kadzere, I., & Akinnifesi, A. I. (2007). *Domesticating and commercializing indigenous fruit and nut tree crops for food security and income generation in Sub-Saharan Africa*.
- Akinola, R., Pereira, L. M., Mabhaudhi, T., De Bruin, F.-M., & Rusch, L. (2020). A review of indigenous food crops in Africa and the implications for more sustainable and healthy food systems. *Sustainability*, 12(8), 3493.
- Boell, S. K., & Cecez-Kecmanovic, D. (2014). A hermeneutic approach for conducting literature reviews and literature searches. *Communications of the Association for Information Systems*, 34(1), 12.
- Budiawan, A. (2023). Harvesting Systems of Private Forests in Indonesia: A Review. *Jurnal Manajemen Hutan Tropika*, 29(3), 219.
- Chakravarty, S., Puri, A., Subba, M., Dey, T., Rai, P., Shukla, G., & Pala, N. A. (2015). Value addition of non-timber forest products: prospects, constraints, and mitigation. In *Value Addition of Horticultural Crops: Recent Trends and Future Directions* (pp. 213–244). Springer.
- FAO. (2022). *State of the World's Forests 2022*. Rome: FAO. <https://www.fao.org/publications/sofo/2022/en/>
- Fauziyah, E., & Sanudin, S. (2022). Review on Adoption of Agroforestry Innovation by Farmers' Social Forestry Program. *Jurnal Penelitian Sosial Dan Ekonomi Kehutanan*, 4(1), 51–60.
- Frianto, D., Sutrisno, E., Wahyudi, A., Novriyanti, E., Adinugroho, W. C., Yuniyanto, A. S., Kurniawan, H., Khotimah, H., Windyoningrum, A., & Dharmawan, I. W. S. (2024). Carbon stock dynamics of forest to oil palm plantation conversion for ecosystem rehabilitation planning. *Global Journal of Environmental Science & Management (GJESM)*, 10(4).
- Garrity, D. P., Akinnifesi, F. K., Ajayi, O. C., Weldesemayat, S. G., Mowo, J. G., Kalinganire, A., Larwanou, M., & Bayala, J. (2010). Evergreen Agriculture: a robust approach to sustainable food security in Africa. *Food Security*, 2(3), 197–214.
- Gauchan, D., Thapa Magar, D. B., Gautam, S., Singh, S., & Singh, U. S. (2014). Strengthening seed system for rice seed production

- and supply in Nepal. *IRRI-NARC Collaborative EC-IFAD Funded Project on Seed Net Development. Socioeconomics and Agricultural Research Policy Division, Nepal Agricultural Research Council, Nepal*. 40p.
- Hadianto. (2024). *Silvikultur, Agroforestri, dan Ekologi Manusia untuk Kelestarian Hutan dan Kesejahteraan Masyarakat*. <https://fkt.ugm.ac.id/2024/02/21/silvikultur-agroforestri-dan-ekologi-manusia-untuk-kelestarian-hutan-dan-kesejahteraan-masyarakat/>
- Hakim, A., Jamaluddin, J., Al Idrus, S. W., Jufri, A. W., & Ningsih, B. N. S. (2022). Ethnopharmacology, phytochemistry, and biological activity review of *Aleurites moluccana*. *Journal of Applied Pharmaceutical Science*, 12(4), 170–178.
- Indriyanto, N. H. (2023). The Existence of Undergrowth at Forest Garden Stands in Grand Forest Park, Lampung Province. *Jurnal Biodjati*, 8(2), 335–346.
- Jihad, A. N., & Lestari, L. D. (2021). An overview and future outlook of Indonesian agroforestry: A bibliographic and literature review. *E3S Web of Conferences*, 305, 7002.
- Kamondo, B. M. (1993). *Farmers' practices in tree seed handling and their future role in tree seed supply: an exploratory survey carried out in the Kakamega-Kisii, Siaya-S. Nyanza, Kitale and Nakuru regions, Kenya*. Wageningen University.
- Kaul, S., Singh, A., Biradar, C., & Kumar, S. (2024). *Food Legumes for Sustainable Crop Intensification of Rice-Based Cropping Systems: Bolstering Food and Nutritional Security in South Asia*.
- Kebede, S. W., & Bokelmann, W. (2017). African indigenous vegetables and their production practices: evidence from the HORTINLEA survey in Kenya. *Agrotechnology*, 6(170), 2.
- Khoury, C. K., Bjorkman, A. D., Dempewolf, H., Ramirez-Villegas, J., Guarino, L., Jarvis, A., Rieseberg, L. H., & Striuk, P. C. (2014). Increasing homogeneity in global food supplies and the implications for food security. *Proceedings of the National Academy of Sciences*, 111(11), 4001–4006.
- Kinho, J., Tuheteru, F. D., Arini, D. I. D., Lawasi, M. A., Ura', R., Prayudyaningsih, R., Abdulah, L., Susanti, R., Waluyo, T. K., & Suhartana, S. (2023). Conserving potential and endangered species of *Pericopsis mooniana* Thwaites in Indonesia. *Forests*, 14(2), 437.
- Krippendorff, K. (2018). *Content analysis: An introduction to its methodology*. Sage publications.
- Maponya, P., Nkuna, T., Mongwaketsi, K., Tahulela, T., Makgwale, R., Selepe, T., Olivier, N., & Banda, H. (2023). *FOOD SECURITY STATUS AND INCOME GENERATION: A CASE STUDY OF THE AGRI-SILVICULTURE IN SOUTH AFRICA*.
- Maryawan, I., & Rochsas, A. (2022). Pendidikan dan Penelitian Kehutanan di Berbagai Belahan Dunia: Sebuah Tinjauan Literatur. *Journal of Science and Applicative Technology*, 6(1), 22–31.
- Mazid, M., Khan, T. A., & Mohammad, F. (2012). Medicinal plants of rural India: a review of use by Indian folks. *Indo Global Journal of Pharmaceutical Sciences*, 2(3), 286–304.
- Mohanani, C., & Sharma, J. K. (2005). Improvement of seedling production system in forestry sector and its impact on seedling health. *Kerala for Research Institute*, 11, 77–82.
- Mokgolodi, N. C., Setshogo, M. P., Shi, L., Liu, Y., & Ma, C. (2011). Achieving food and nutritional security through agroforestry: a case of *Faidherbia albida* in sub-Saharan Africa. *Forestry Studies in China*, 13(2), 123–131.
- Mukungei, P. K., Cheserek, G. J., Arusei, E. J., Chedotum, K., & Mining, P. J. (2013). Socio-economic factors affecting farmers' decisions to adopt agro-silviculture in Turbo Division, Uasin Gishu County, Kenya. *Journal of Emerging Trends in Economics and Management Sciences*, 4(1), 8–14.
- Nahiyoon, S. A., Ren, Z., Wei, P., Li, X., Li, X., Xu, J., Yan, X., & Yuan, H. (2024). Recent development trends in plant protection UAVs: a journey from conventional practices to cutting-edge technologies—a comprehensive review. *Drones*, 8(9), 457.
- Nalefo, L., Jusoff, K., Ali, M. S. S., Salman, D., & Demalino, E. B. (2013). Towards an Institutional Sustainable Agriculture in Parabela. *World Applied Sciences Journal*, 26(26), 55–59.
- Nurlia, A., Widarti, A., & Mindawati, N. (2024). The Flexibility of Sengon Agroforestry in Small-Scale Forest Development in Indonesia. *IOP Conference Series: Earth and Environmental Science*, 1315(1), 12010.
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., & Brennan, S. E. (2021). The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Systematic*

Reviews, 10(1), 1–11. <https://doi.org/10.1186/s13643-021-01626-4>

- Sabastian, G. E., Yumn, A., Roshetko, J. M., Manalu, P., Martini, E., & Perdana, A. (2019). Adoption of silvicultural practices in smallholder timber and NTFPs production systems in Indonesia. *Agroforestry Systems*, 93(2), 607–620.
- Sari, M. K., Wijayanto, N., & Hartoyo, A. P. P. (2025). Application of seedball materials compositions on swamp jelutung (*Dyera polyphylla* (miq) Stennis) growth for peatland rehabilitation. *IOP Conference Series: Earth and Environmental Science*, 1506(1), 12009.
- Sasmito, S. D., Basyuni, M., Kridalaksana, A., Saragi-Sasmito, M. F., Lovelock, C. E., & Murdiyarso, D. (2023a). Challenges and opportunities for achieving Sustainable Development Goals through restoration of Indonesia's mangroves. *Nature Ecology & Evolution*, 7(1), 62–70.
- Sasmito, S. D., Basyuni, M., Kridalaksana, A., Saragi-Sasmito, M. F., Lovelock, C. E., & Murdiyarso, D. (2023b). Merestorasi hutan mangrove Indonesia dengan benar dapat membantu pencapaian Sustainable Development Goals (SDGs). *Researchgate. Net*, No.
- Sharma, V., Goyal, S., & Ramawat, K. G. (2011). Biotechnology and agroforestry in Indian arid regions. In *Genetics, Biofuels and Local Farming Systems* (pp. 309–345). Springer.
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333–339.
- Suryanto, P. (2014). Traditional silviculture and its opportunity in privately owned forest Menoreh Mountain-Kulonprogo. *Jurnal Kawistara*, 4(1).
- Turjaman, M. (2018). Pemanfaatan Fungi Ektomikoriza di Hutan Tropis Indonesia. *Prosiding Seminar Nasional Mikoriza*, 17–32.