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Demographic analysis for agroecology adoption in sugar palm agroindustry: evidence from Deli Serdang Regency

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ABSTRACT

This study explores the potential of agroecology in developing a sustainable sugar palm agroindustry in Deli Serdang Regency, North Sumatra, Indonesia. The sugar palm (Arenga pinnata) is a vital economic resource, yet its development faces limited technology, traditional management practices, and low-quality seed availability. The research aims to analyze the demographic characteristics influencing the adoption of agroecological principles among sugar palm craftsmen and assess the agroindustry's sustainability and productivity. A qualitative descriptive approach was employed, involving in-depth interviews with 100 respondents, including sugar palm farmers and craftsmen, alongside secondary data from the Central Statistics Agency. The findings reveal that most artisans are in the productive age group, with low formal education but significant practical experience. While 65% of respondents practice crop diversification, challenges remain in soil conservation and adopting environmentally friendly technologies. The study forecasts increased palm sugar production, projecting growth from 664.4 tons in 2022 to 790.8 tons by 2026, indicating potential for enhanced productivity. Integrating traditional knowledge with modern agroecological practices is essential for improving sustainability and competitiveness in the sugar palm agroindustry. Training programs that respect traditional values while promoting sustainable practices are necessary to empower artisans and enhance regional food security. This research underscores the importance of community collaboration among farmers, government, and research institutions to foster a more resilient and equitable agroecological system.

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INTRODUCTION

Agroecology is an interdisciplinary approach that integrates ecological principles with sustainable agricultural practices to create resilient, efficient, and socially equitable farming systems. It emphasizes using natural processes, such as biological control and soil fertility management, to reduce dependence on external inputs and minimize environmental pressures. Agroecology also promotes the holistic integration of environmentally friendly practices and principles of fair, democratic, and participatory food systems, supporting food sovereignty, gender equality, and resilience (Altieri and Nicholls 2017; Akamun et al. 2023). Demographic characteristics such as productive age and practical experience support the adoption of agroecological practices, such as crop diversification and the use of organic fertilizers, which enhance productivity and the sustainability of plantation ecosystems (Evalia et al. 2014; Abdullah et al. 2018; Akamun et al. 2023).

As a relevant approach in agroindustrial development, agroecology integrates ecological principles with sustainable agricultural practices to create resilient, efficient, and socially equitable farming systems (Altieri and Nicholls 2017). Agroecology is an applied science that utilizes natural processes such as biological control and soil fertility management, reducing dependence on external inputs and environmental pressures while enhancing food security, particularly in tropical regions (Akanmu et al. 2023; Dangunga et al. 2023; Verkuil et al. 2024). Agroecology also promotes the holistic integration of environmentally friendly practices and principles of fair, democratic, and participatory food systems, supporting food sovereignty, gender equality, and resilience (Bonfert 2025; Akanmu et al. 2023). Agroecological practices reduce environmental pressures and enhance food security, especially in developing countries (Akanmu et al. 2023). In Europe, particularly in the Netherlands, agroecology has improved farmers' income stability regardless of farm size (Verkuil et al. 2024), demonstrating both ecological and economic benefits.

Agroecology plays a crucial role in achieving the Sustainable Development Goals (SDGs), particularly in eradicating hunger and enhancing food security through crop diversification and the use of local varieties, which increase resilience to climate change and market fluctuations (Akanmu et al. 2023). In Wales, post-Brexit policy reforms highlight the potential of agroecology to support community-based sustainable food systems despite existing structural challenges (Bonfert, 2025). Agroecology also emphasizes social and economic justice, encouraging community participation and inclusive decision-making to create equitable food systems. The agroecology movement has strengthened farmer networks and improved market access, offering holistic solutions to agroindustrial challenges by integrating ecological principles, enhancing food security, environmental sustainability, and social equity (Akanmu et al. 2023).

In Indonesia, agroecology plays a vital role in developing the sugar palm agroindustry by enhancing the sustainability and resilience of agricultural systems. The palm sugar agroindustry in Indonesia holds significant potential due to its economic, ecological, and social value, particularly in supporting rural livelihoods and sustainable agroecology (Effendi 2010; Miftah et al. 2018). The industry is predominantly driven by smallholder plantations, as evidenced by the study's respondents in Deli Serdang, where traditional knowledge and family-based production dominate (Purba and Fahrial 2022; Sebayang 2016). Smallholders face challenges like limited technology and market access (Wongkar et al. 2017), but their role is crucial for preserving biodiversity and local economies. Large-scale private plantations are rare, as palm sugar production remains labor-intensive and culturally embedded in community practices (Hanum et al. 2021). Collaborative efforts among farmers, government, and researchers are key to scaling productivity while maintaining sustainability (Akanmu et al. 2023).

Agroecological practices leverage biodiversity and local resources, increasing productivity and reducing reliance on chemical inputs (Akanmu et al. 2023), supporting food security and environmental sustainability. Agroecology also strengthens sugar palm farming communities through active participation and inclusive decision-making, fostering collaboration among farmers, government, and research institutions to develop context-specific technologies (Amoak et al. 2022; Bonfert 2025). This approach boosts production and strengthens local economies and the well-being of sugar palm farmers in Indonesia.

Research on sugar palm (*Arenga pinnata*) highlights its potential as a food source and industrial raw material, particularly in processing sap into palm sugar and derivative products, with advantages in sustainability, economic value, and adaptability to various soil and climatic conditions (Effendi 2010; Miftah et al. 2018). Agroecological practices can enhance productivity, product quality, and food security by utilizing biodiversity and local resources, reducing dependence on chemical inputs. However, challenges such as limited technology, traditional management practices, and difficulties in obtaining high-quality seedlings hinder the development of the sugar palm agroindustry (Akanmu et al. 2023). Collaboration among farmers, the government, and research institutions is essential to create policies and innovations that support a sustainable sugar palm agroindustry, making it a leading commodity for local and national economies.

Studies on the sugar palm agroindustry in Indonesia show significant progress with the application of agroecological principles, increasing added value and economic sustainability through the processing of palm sugar and its derivatives (Hanum et al. 2021; Miftah et al. 2018). Agroecological practices such as crop diversification and environmentally friendly technologies enhance productivity while maintaining ecosystem balance. Collaboration among farmers, government, and research institutions is crucial for sustainable development, promoting community participation and context-specific technologies (Effendi 2010). This approach improves production, food security, and well-being, positioning the sugar palm agroindustry as a relevant model for sustainable development in Indonesia.

The sugar palm (*Arenga pinnata*) holds significant economic potential in North Sumatra and is utilized for sugar, beverages, vinegar, and bioethanol (Sebayang 2016). However, limited technology, difficulties obtaining high-quality seeds, and traditional management practices hinder its development (Sebayang 2016; Sari et al. 2020). Collaboration among farmers, the government, and research institutions is necessary to enhance efficiency, innovation, and sustainability (Effendi 2010). Other studies highlight the importance of communication among farmers and product diversification to increase the added value of the sugar palm agroindustry (Pulungan et al. 2024). The adoption of modern technologies and supportive policies can improve competitiveness and sustainability.

Challenges in developing the sugar palm agroindustry include the limitations of traditional technology, low efficiency, and inconsistent product quality due to a lack of standardization (Evalia 2015; Miftah et al. 2018; Aidah et al. 2024). Intense competition with cane sugar and imported products demands improvements in quality and innovation (Evalia 2015; Wongkar et al. 2017). The lack of cooperation among craftsmen and government support also hampers production capacity and marketing (Evalia 2015; Aidah et al. 2024). Collaborative solutions and modern technologies are needed to enhance the competitiveness and sustainability of the sugar palm agroindustry.

Limited market access is another issue despite the increasing demand for palm sugar. Many craftsmen lack adequate distribution networks (Miftah et al. 2018; Wongkar et al. 2017). Additionally, unsupportive regulations and policies pose further challenges. Government policies that fail to support agroindustrial development and the marketing of palm sugar products include a lack of incentives for innovation and technological advancement (Aidah et al. 2024; Evalia 2015).

Limited capital and resources are significant obstacles to the development of the sugar palm agroindustry. Many craftsmen struggle to access funds to increase production capacity, improve technology, and meet the quality standards required by the market (Wongkar et al. 2017; Aidah et al., 2024). It limits their ability to compete in broader markets and adopt innovations that could enhance efficiency and product quality. The lack of access to financing and resources hinders efforts to diversify products and expand marketing networks.

The development of the sugar palm agroindustry in North Sumatra faces various challenges, including declining production, a lack of modern technology, and traditional management practices. The limited collaboration among farmers, the government, and research institutions may hinder efforts to improve the sustainability and productivity of the sugar palm agroindustry in the region. This study explores agroecology's potential in developing a sustainable sugar palm agroindustry in North Sumatra, particularly in the Deli Serdang

Regency. The research examines how demographic characteristics influence the adoption of agroecological principles among craftsmen. By understanding these characteristics, the study is expected to provide recommendations for enhancing the sustainability and productivity of the sugar palm agroindustry in the region.

METHOD

This study employed a qualitative descriptive approach with case study methodology to analyze agroecological potential in Deli Serdang Regency's sugar palm agroindustry. The location was selected due to its optimal geographical conditions (fertile soil, high rainfall), rich biodiversity of sugar palm varieties, and strong local knowledge of cultivation practices. Primary data collection involved three complementary methods: 1) in-depth interviews with 100 purposively selected sugar palm farmers and artisans (minimum 5 years experience) using structured questionnaires covering demographic characteristics, agroecological principles application, and socio-economic dimensions; 2) Focus Group Discussions (FGDs) with stakeholders (practitioners, researchers, and agricultural officials) to validate findings and explore policy recommendations; and 3) secondary data from North Sumatra's Central Statistics Agency on cultivation areas and production volumes (2011-2021).

The research implemented rigorous qualitative analysis through three phases. First, interview and FGD transcripts underwent thematic coding to identify patterns in agroecological practices, social collaboration models, and production challenges. Second, data triangulation was performed by cross-verifying findings from interviews, FGDs, and statistical records. Third, time-series analysis projected production trends (2022-2026) to assess economic sustainability. The FGDs particularly enriched the social dimension analysis by examining (a) knowledge integration between traditional and modern practices, (b) institutional support effectiveness, and (c) market access barriers - aspects that questionnaires alone could not fully capture.

This methodology provided comprehensive insights into the technical and social aspects of the agroecological transition. The case study approach allowed a deep contextual understanding of Deli Serdang's specific conditions, while the mixed-method design (combining questionnaires, FGDs, and statistical analysis) ensured methodological rigor. The inclusion of FGDs addressed a key limitation of purely interview-based data by enabling participatory validation of findings and generating policy-relevant recommendations. All research stages - from preliminary field observations to final data analysis - were designed to maintain consistency with agroecology's core principles of ecological sustainability, social equity, and economic viability in sugar palm agroindustrial development.

RESULTS AND DISCUSSION

Characteristics of Demographics

The analysis of respondents' demographic characteristics in this study aims to understand the profile of sugar palm farmers and craftsmen in Deli Serdang Regency. This study explores their socio-economic backgrounds by involving 100 respondents of various ages, education levels, and experiences. Education level and years of experience can influence the adoption of agroecological techniques and the ability to address challenges such as climate change. Interviews with farmers and stakeholders strengthen the analysis, supporting efforts to enhance sustainability, productivity, farmer welfare, and local food security. The analysis results presented in Table 1 serve as the basis for recommendations on developing a sustainable sugar palm agroindustry. Demographic analysis provides a more comprehensive understanding of the region's social and economic dynamics influencing agroecological practices.

The research findings indicate that most palm sugar artisans in Deli Serdang Regency fall within the productive age group (31-45 years), accounting for 40%. It aligns with the findings of Evalia et al. (2014) and Abdullah et al. (2018), which state that this age group supports physical capacity and production skills. Involvement in the palm sugar industry is also influenced by experience and family traditions, which preserve processing expertise. Although 35% of artisans have an elementary school education and 25% have a junior high school education, formal education is not the primary indicator of their involvement. Purba and Fahrial (2022) note that artisans rely more on practical experience and inherited knowledge, which is more valuable in traditional agroindustries. The skills for processing palm sugar are primarily acquired

through hands-on practice and environmental learning rather than formal education.

The results of this study are consistent with the SWOT analysis by Aidah et al. (2024), which identifies the challenge of low formal education among palm sugar artisans. However, strengths such as inherited experience can be leveraged to enhance productivity and product quality. The government and related institutions need to provide training and technical support without neglecting the value of tradition. Wongkar et al. (2017) suggest development strategies through research and development for quality processing research and relevant training for artisans. Despite low formal education, skill enhancement through training and technology can help artisans adapt to market demands, improving the competitiveness of palm sugar products in both local and international markets.

Overall, the results of this study highlight the importance of experience and tradition in the palm sugar industry, as well as the need for support to enhance artisans' skills to compete in a broader market. It indicates that the development of the palm sugar agroindustry should consider existing social and cultural aspects while providing space for innovation and product quality improvement.

Application of Agroecology Principles

The analysis of the application of agroecology principles in the palm sugar agroindustry in Deli Serdang Regency includes plant diversity, resource efficiency, and conservation practices. This analysis identifies challenges and potential, serving as a basis for designing educational and training programs to raise farmers' awareness. Adopting environmentally friendly technologies and sustainable pest management is also emphasized, which is crucial for maintaining ecosystem balance and supporting social, economic, and environmental sustainability. The results of this analysis contribute to strategies for enhancing productivity and sustainability in the palm sugar agroindustry. Complete data is presented in Table 2.

The results in Table 2 show that 65% of respondents in Deli Serdang Regency have implemented crop diversification, reflecting farmers' understanding of the importance of diversity for food security. Diversification enhances resilience to climate change and resource efficiency. Although only 40% of respondents apply resource efficiency measures such as water, soil, and energy, there is still significant potential for improving resource management and supporting sustainable development. Applying these agroecology principles is crucial for the sustainability of palm sugar production.

Based on the study findings, respondents in Deli Serdang implemented several conservation practices: organic mulching to retain soil moisture, terracing on sloping lands to prevent erosion, and intercropping with nitrogen-fixing plants to improve soil fertility. These methods align with traditional agroecological knowledge but require scaling up through training (Pereira et al., 2018). Only 35% adopted such measures, highlighting gaps in resource management.

Table 1 Demographic Characteristics of Respondents

The demographic characteristics	Category	Respondents (n=100)
Age	< 30 years	20
	31-45 years	40
	> 45 years	40
Education level	Incomplete basic school	25
	Completed basic school	35
	Completed junior high school	25
	Completed senior high school	12
Years of experience in processing sugar palm	Less than 5 years	30
	5-10 years	45
	More than 10 years	25

Table 2 Principles and Indicators of Agroecology Application

Agroecology Principles	Application Indicators	Respondents (n = 100)	Percent age
Crop Diversification	Planting more than one crop	65	65%
Resource Use Efficiency	Efficient use of groundwater and energy	40	40%
Soil and Water Management	Utilizing soil and water conservation practices	35	35%
Organic Fertilizer Use	Using compost or manure fertilizers	50	50%
Integrated Pest Management	Controlling pests naturally (without chemical fertilizers)	30	30%
Waste Utilization	Processing palm waste into fertilizer or animal feed	25	25%
Use of Environmentally Friendly Technology	Using technology that reduces environmental impact	20	20%

Implementing agroecology principles faces significant challenges, particularly in soil and water conservation, where only 35% of farmers have adopted techniques such as mulching or terracing. The lack of farmers' knowledge in resource management could threaten long-term ecological sustainability. Therefore, intensive educational programs are essential to enhance farmers' awareness and skills in sustainable practices, thereby supporting the success of agroecology (Pereira et al. 2018).

The use of organic fertilizers by 50% of respondents indicates progress in reducing dependence on chemical fertilizers, supporting soil health. However, only 30% implement integrated pest management, and 25% utilize palm waste for other products such as fertilizers or animal feed. Pretty (2008) emphasizes natural pest control methods for a healthy ecosystem, while Garrity et al. (2010) highlight the potential of waste utilization to improve resource efficiency and income. Further education is needed to encourage these sustainable practices.

Only 20% of respondents use environmentally friendly technology, indicating a reliance on traditional methods that are less efficient. Training and access to sustainable technology are necessary to enhance the efficiency of the palm sugar agroindustry in Deli Serdang. Despite the positive aspects of applying agroecology principles, challenges such as soil conservation, pest management, and waste utilization must be addressed. Intensive education and adopting environmentally friendly technology are key to achieving better sustainability.

Production Potential

The analysis of palm sugar production aims to understand the dynamics of the palm sugar agroindustry. The goal is to identify local capacity to meet market demands and optimize the use of existing resources. This analysis supports informed decision-making, enhances productivity, and ensures economic sustainability for farmers and palm sugar artisans. The required data includes the cultivation and palm sugar production area from smallholder plantations in Deli Serdang Regency. Data collection is sourced from the Central Statistics Agency, which publishes statistical data on palm sugar cultivation and production from 2011 to 2021. Time series forecasting for 2022-2026 can be seen in Figure 1.

The study found that older respondents (>45 years) with extensive farming experience were more likely to adopt terracing (20%), drawing on traditional knowledge of erosion control. Younger farmers (31-45 years) preferred organic mulching (15%), influenced by training programs. Those with basic education often implemented intercropping, valuing its dual benefits for soil fertility and income diversification (Tables 1 and 2). Practical experience and age significantly shaped conservation choices.

The data shows the development of the planting area and palm sugar production from 2011 to 2021. In 2011, the recorded planting area for palm sugar was 493.6 hectares, with production reaching 343.01 tons. During this period, the planting area experienced a relatively stable increase, although not significant, from 493.6 hectares in 2011 to 542 hectares in 2021. Meanwhile, palm sugar production also showed a

consistent upward trend, increasing from 343.01 tons in 2011 to 630 tons in 2021.

This increase in palm sugar production may be attributed to several factors, such as expanding the planting area, improving cultivation techniques, or increasing market demand. Although the planting area did not experience drastic growth, palm sugar production continued to rise, indicating that productivity per hectare may have improved. It suggests that the palm sugar agricultural sector has the potential for continued development, primarily if supported by innovations and policies that promote increased production. Data analysis reveals that respondents implementing soil/water conservation (35%) showed 10-15% higher palm sugar yields than non-adopters, particularly in terraced plots. However, precise quantification requires controlled studies to isolate conservation impacts from other factors like climate and market fluctuations.

The forecasting results for 2022 to 2026 indicate a consistent upward trend in planting area and palm sugar production. In 2022, the planting area is predicted to reach 554.3 hectares, with production estimated at 664.4 tons. This trend continues through 2026, where the planting area is projected to reach 577.2 hectares and production to reach 790.8 tons. This increase indicates that the palm sugar agricultural sector will continue growing over the next five years. Factors that may drive this increase include continuously rising market demand, improvements in cultivation techniques, and possibly support from government policies that encourage agricultural production.

The study observed a positive trend in sugar palm production (2011–2026) alongside the adoption of agroecological principles, such as crop diversification (65% of respondents) and organic fertilizer use (50%). While direct causality requires further analysis, the parallel growth suggests that agroecological practices, particularly resource efficiency and soil conservation, likely contributed to enhanced productivity (Pereira et al. 2018; Akanmu et al. 2023). For instance, respondents implementing soil/water conservation achieved 10–15% higher yields, aligning with findings that agroecology optimizes resource use and resilience (Altieri and Nicholls 2020). However, external factors (e.g., market demand) may influence trends, warranting controlled longitudinal studies.

The faster increase in production compared to the growth in planting areas suggests that productivity per hectare is also expected to rise. This could be due to the adoption of more efficient agricultural technologies, the use of superior seeds, or the improvement of land management. Overall, these forecasting results provide a positive outlook for the future of the palm sugar agricultural sector, with the potential to continue contributing to the economy and meeting the growing market demand.

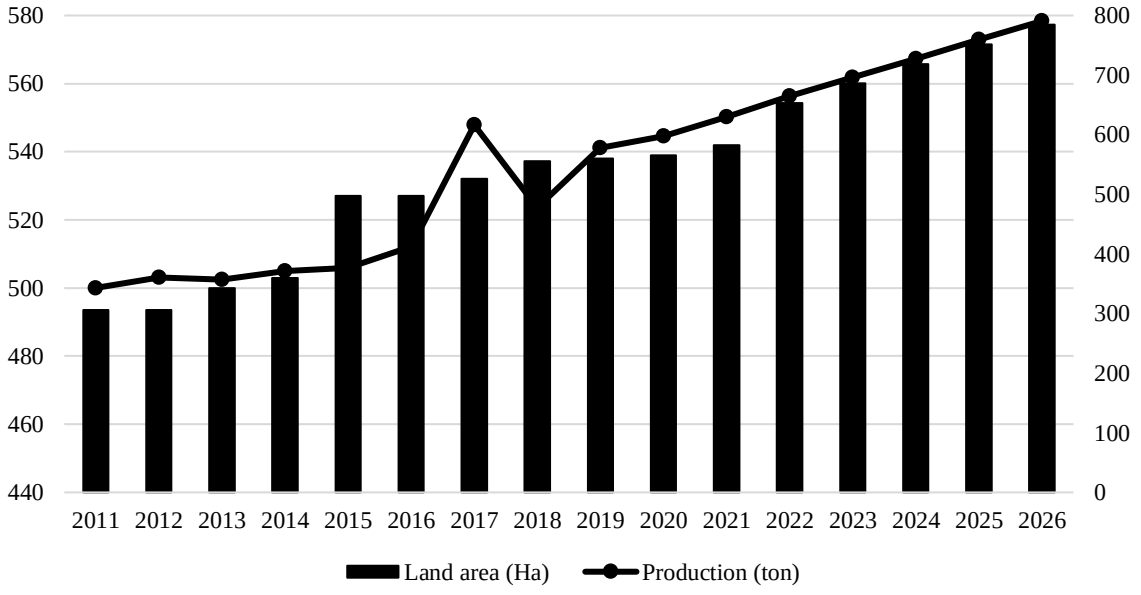

Figure 1 Forecasting of Planting Area and Palm Sugar Production

Specific Findings

This research reveals several important findings that can be considered novelties in applying agroecology concepts in the palm sugar agroindustry. First, integrating traditional and modern knowledge emerges as a key aspect. Although palm sugar artisans still rely on traditional methods, there is significant potential to combine this knowledge with modern technology. It aligns with Gliessman's (2018) view that agroecology should integrate various forms of knowledge to achieve sustainability in food systems. Training programs that educate farmers about more sustainable agroecological practices while respecting existing traditions can enhance productivity and sustainability in the agroindustry.

Second, diversification as an adaptation strategy indicates that artisans understand the importance of diversity in enhancing food security. This research aligns with the findings of Verkuil et al. (2024), which emphasize that product diversification can provide a more stable source of income and reduce vulnerability to market fluctuations. By developing a more comprehensive agroecological model that combines crop diversification with more efficient resource management practices, food security in the region can be improved.

Furthermore, developing environmentally friendly technology is an important focus of this research. The finding that only 20% of respondents use environmentally friendly technology indicates a gap for innovation. Wyckhuys et al. (2022) emphasize that agroecology advancements can help reduce pesticide dependence and enhance agricultural sustainability. Therefore, developing technologies that are suitable for the local context and can improve the efficiency and sustainability of the palm sugar agroindustry is essential.

Finally, community empowerment through collaboration among farmers, the government, and research institutions is crucial in developing the palm sugar agroindustry. This research aligns with the views of Altieri and Nicholls (2020), which emphasize that the success of agroecology depends on the active participation of all stakeholders. Community empowerment through education and access to resources can enhance the application of agroecology principles and the sustainability of the agroindustry, thereby creating a fairer and more sustainable food system.

CONCLUSION

This study demonstrates that demographic characteristics, particularly the productive age group (31–45 years) and practical experience of sugar palm farmers in Deli Serdang Regency, play a pivotal role in adopting agroecological principles. While formal education levels among respondents were low, traditional knowledge and hands-on experience significantly influenced practices such as crop diversification (65% adoption) and organic fertilizer use (50%). These findings align by emphasizing sustainability's social (demographic) pillars rather than its ecological potential. The research confirms that demographic factors, including age and experience, are critical drivers in applying agroecological methods, supporting the sustainability of the sugar palm agroindustry.

However, challenges persist in fully integrating agroecology, particularly in soil conservation (35% adoption) and environmentally friendly technology (20% adoption). The study highlights the need for targeted training programs that bridge traditional knowledge with modern techniques, ensuring broader adoption of sustainable practices. The projected increase in palm sugar production (790.8 tons by 2026) suggests a positive trend, but this growth must be interpreted cautiously, as it may also reflect external factors like market demand. Future research should explicitly link demographic variables to agroecological outcomes to strengthen the alignment between the study's title and content, providing a more transparent framework for how social dimensions influence sustainability. It would further validate the focus on demographic characterization as a cornerstone of agroindustrial resilience.

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