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Alternative crops for climate adaptation in low-lying regions: The case of lotus farming in Thua Thien Hue Province, Central Vietnam

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ABSTRACT
Crop conversion from rice to alternative crops has gained momentum in many Southeast Asian countries as a strategy to adapt to climate change and strengthen rural livelihoods. This research examines lotus farming in Thua Thien Hue Province, one of the nation's most climate-vulnerable regions. We used a mixed-methods approach that included key informant interviews, focus group discussions, and a household survey with 95 lotus farmers. The shift to lotus cultivation was driven by the poor performance of rice in low-lying areas and farmers' expectations of higher returns. Crop conversion policies also improved land access for many households. Although lotus is considered a high-value crop and plays an important role in land-use strategies for flood-prone areas, benefit–cost analysis showed it was economically unviable for most households in 2024. Smallholders relying on family labor tended to earn higher returns, creating a paradox where larger-scale operations did not improve profitability. Repeated crop failures from nematode infestations and extreme weather, combined with high production costs, created significant constraints, particularly for larger farms. Improving the sustainability of lotus and other alternative crops will require promoting indigenous lotus varieties, expanding mechanization, and strengthening post-harvest practices to increase efficiency and resilience.

Contribution/Originality: This study contributes to the literature on crop diversification and climate change adaptation by presenting empirical evidence from lotus farming in Central Vietnam. It is among the few to investigate the economic efficiency, policy support, and constraints of lotus cultivation through a mixed-methods approach in a climate-vulnerable region.

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1. INTRODUCTION
Agriculture is a key sector of Vietnam's economy, accounting for 12% of the country's GDP and employing 27% of the labor force (General Statistics Office of Vietnam, 2024). Rice, Vietnam's primary crop, occupies over 54% of the agricultural land, ensures food security for more than 90% of the population, and accounts for 30% of the country's

agricultural production value (World Bank, 2022). Despite this central role in food security and exports, rice production in Vietnam is increasingly facing critical challenges. For example, rice farming yields relatively low profits for many farmers (Nguyen, Do, & Kompas, 2021). Furthermore, long-term reliance on rice monoculture has prevented farmers from diversifying their income, thereby increasing their vulnerability to market fluctuations. In addition, declining rice consumption rates in both rural and urban areas are undermining the economic viability of rice production (Nguyen, Nguyen, & Grote, 2023). Given these challenges, promoting high-value alternatives to rice will be essential for improving farmers' incomes and livelihoods in Vietnam.

Lotus (*Nelumbo nucifera*) is a horticultural crop widely cultivated in Southeast Asia, particularly in China, Thailand, and Vietnam (Lin, Zhang, Cao, Damaris, & Yang, 2019). In Vietnam, the lotus has been promoted as a resilient alternative to rice in wetland areas and is considered a specialty crop due to its economic value and numerous by-products. In the Mekong Delta region, commonly referred to as the rice bowl of Vietnam, lotus cultivation is an essential part of climate change adaptation strategies due to its economic advantages in flood-based farming systems (Tran, Van Halsema, Hellegers, Ludwig, & Seijger, 2018; Vo, Van Halsema, Hellegers, Wyatt, & Nguyen, 2021). For example, lotus cultivation has been shown to be more profitable than rice during the third season of triple-cropping systems in high-dyke zones (Tran, Van Halsema, Hellegers, Ludwig, & Wyatt, 2018). Other studies have found that integrated rice–lotus systems generate higher returns than conventional double rice cropping (Vo et al., 2021). In addition to increasing farmer income, lotus cultivation during the flood season supports sustainable livelihoods because it improves soil quality more effectively than intensified rice production (Tran et al., 2024).

Despite these promising early findings, the long-term potential of lotus as an alternative to rice across Vietnam's agricultural sector is not fully understood. To date, most research has been conducted in the Mekong Delta, where favorable conditions such as dyke systems and predictable flooding support lotus cultivation as part of flood-based farming systems. In these areas, lotus is promoted primarily for its economic viability rather than as a direct response to the challenges of rice cultivation. In contrast, Central Vietnam is more vulnerable to extreme weather events, including floods, storms, and droughts, making it difficult to adopt the same farming strategies. These distinct agroecological conditions raise important questions about the potential for lotus cultivation in Central Vietnam, where lotus has recently been promoted as a climate-resilient crop.

This study addresses this research gap by presenting a case study of lotus cultivation in Thua Thien Hue Province, the largest lotus cultivation region in Central Vietnam and one of the most climate-sensitive areas in the country. The province's high reliance on agricultural production, particularly rice, exacerbates its susceptibility to future climate change. While lotus has already been farmed in this region for many years, it is being increasingly promoted as a promising crop with high economic potential. Lotus production areas in the province, reaching 633 hectares in 2023, have primarily been sourced from abandoned wetlands and inefficient rice fields, especially in lowland flood-affected areas (Thua Thien Hue Department of Agriculture and Rural Development, 2023). The crop has been officially recognized as a local specialty, and its production is strongly supported by provincial authorities. These provincial efforts reflect the potential of lotus cultivation as an adaptive solution for low-lying areas in danger of being abandoned. However, lotus production in the province remains small-scale, fragmented, and highly vulnerable to external risks.

This research evaluates the performance and contribution of lotus farming and explores the opportunities and challenges of growing lotus as an alternative to rice in a provincial context. It specifically addresses the following research questions: (i) How has lotus cultivation expanded in low-lying areas in Thua Thien Hue Province? (ii) What are the key characteristics of lotus cultivation and its contribution to household income? and (iii) What are the opportunities and challenges associated with the transition from rice to lotus farming systems?

2. MATERIALS AND METHODS

2.1. Research Background And Conceptual Framework

2.1.1. Opportunities and Challenges of Alternative Crops

Alternative crops, also known as underutilized, neglected, traditional, or niche species, have promising economic potential and high nutritional value but have received limited attention from policymakers, researchers, and breeders (Pradhan, Rane, & Pathak, 2021). They also include reintroduced species that were previously abandoned due to low yields, declining quality, or changing technologies and consumer preferences (Konvalina, 2016). Alternative crop species are often adopted when staple crops underperform due to biotic or abiotic stresses or in areas unsuitable for conventional agriculture (Hirich, Choukr-Allah, & Ragab, 2020). Some farmers may select these crops for their market potential or their complementary role in mixed farming systems, even if the crops are not traditionally cultivated in their region (Isleib, 2012).

In recent years, alternative crops have gained renewed interest due to their suitability for marginal environments and degraded soils, which allows them to enhance food and nutritional security (Elouafi, Shahid, Begmuratov, & Hirich, 2020) and improve farm productivity through cropping system diversification (Mavroeidis, Roussis, & Kakabouki, 2022) while supporting smallholders and indigenous livelihoods (Hirich et al., 2020). Cultivating these crops can also empower women, particularly through the revival of traditional species and knowledge. Changing consumer preferences have further driven the growth of markets for alternative products. Alternative crops should therefore be actively promoted to enhance agricultural profitability, support diversified food systems, respond to emerging dietary trends, and strengthen rural economies (Karelakis & Tsantopoulos, 2017).

Despite their potential, these crops have not been widely adopted due to their limited competitiveness against staple crops and their more niche markets (Kumar & Bhalothia, 2020). In many developing countries, non-staple crop markets are underdeveloped at all levels due to a historical, long-term policy emphasis on staple crops. However,

growing concerns over biodiversity loss, food security, and malnutrition have generated renewed interest in alternative crop species, and several countries in Europe and Africa have launched research and development efforts to explore their potential (Pradhan et al., 2021).

2.1.2. The Role of Lotus as An Alternative to Rice in Southeast Asia

One of the most promising alternative crops in Asia is lotus, which has expanded significantly across several Asian countries over the past two decades and offers attractive economic opportunities for farmers. In Southeast China, over 600,000 hectares were under lotus cultivation in 2021, particularly in reclaimed wetlands and lowland areas (Guo, 2009; Zhu et al., 2023). Originally grown in the Yangtze and Yellow River basins, lotus has become a key part of regional agricultural systems. For example, in the Pearl River Estuary, three lotus farming models have all demonstrated strong financial performance, competing successfully with other local industries such as orchards, aquaculture, and ecotourism (Lu et al., 2017). Lotus cultivation has similarly been shown to be highly profitable in the wetlands of Chhattisgarh, India (Sahu & Chandravanshi, 2018).

As a flood-resilient plant, the lotus can be cultivated in areas that are otherwise unsuitable for conventional crops. It adapts to long-term submergence through microRNA-regulated responses that enhance its tolerance to waterlogging (Jin et al., 2017). This resilience makes the lotus a viable agricultural option in wetland areas, which are increasingly affected by erratic rainfall and flooding that can threaten less tolerant crops (Jain, Singh, & Singh, 2004). As a result, lotus has become an integral part of flood-based farming systems and wetland conservation efforts in China, India, and the Mekong Delta region of Vietnam (Lu et al., 2017; Vo et al., 2021).

Rising demand for healthy food has also generated increased interest in lotus, particularly for its seeds. Recent studies have highlighted the nutritional value of lotus seeds, whether consumed fresh (Shad, Nawaz, Siddique, Zahra, & Mushtaq, 2013) or as processed flour (Sopawong, Warodomwichit, Srichamnong, Methacanon, & Tangsuphoom, 2022). For example, lotus seeds contain significantly more protein than major staples such as wheat, rice, and corn. Their rich profile of high-quality proteins, polysaccharides, lipids, and bioactive compounds also supports their use in functional foods and nutraceuticals (Bangar, Dunno, Kumar, Mostafa, & Maqsood, 2022). Overall, lotus is a resilient, high-value crop that provides both economic and ecological benefits, making it a promising alternative to rice for improving farmer livelihoods and supporting rural development in climate-vulnerable, low-lying areas.

Although lotus has been promoted as a high-value alternative crop in flood-based agricultural systems throughout Asia, previous research on lotus cultivation has focused primarily on regions with favorable hydrological infrastructure, such as the Mekong Delta and the river basins of Southern China. In contrast, few studies have considered the performance of lotus cultivation and its contribution to climate adaptation and farmer livelihoods in more marginal environments. In Vietnam, declining returns from rice production have prompted many farmers to diversify their cropping systems by integrating short-season crops or transitioning to more profitable alternatives (Le, Mao, Kristiansen, & Coleman, 2025). However, studies on substitute crops for rice remain limited, especially in Central Vietnam, a climate-sensitive region where household incomes and livelihoods are heavily dependent on agriculture, particularly rice production (General Statistics Office of Vietnam, 2024).

2.2. Study Site

This study examines lotus farming in Thua Thien Hue, a coastal province in north-central Vietnam where adaptive farming strategies are still underexplored in research and policy. Thua Thien Hue is bordered by Laos to the west and the East Sea to the east. It lies within the tropical monsoon zone and is frequently affected by extreme weather events such as floods and typhoons.

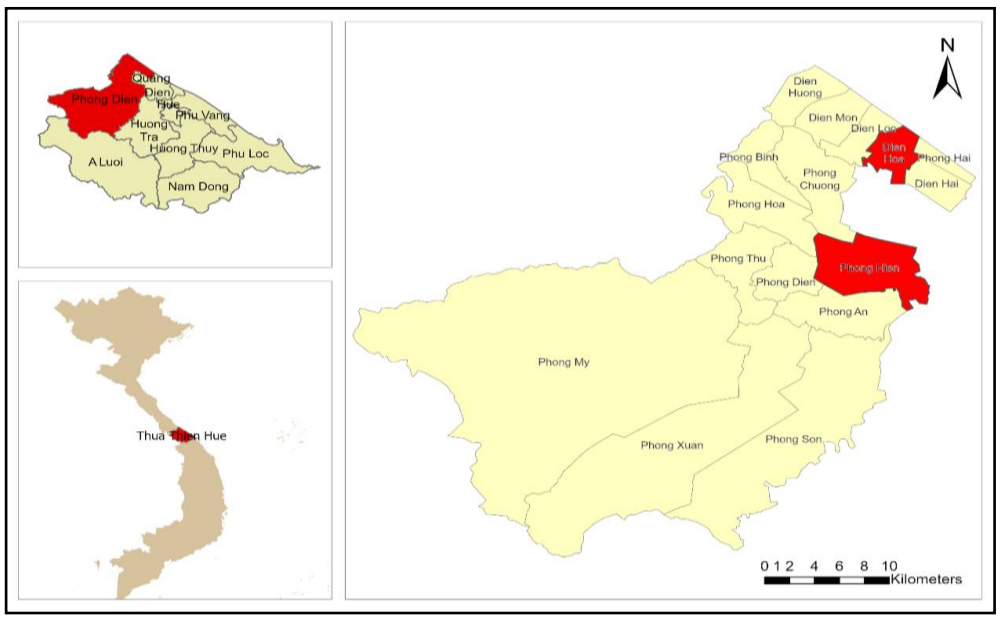
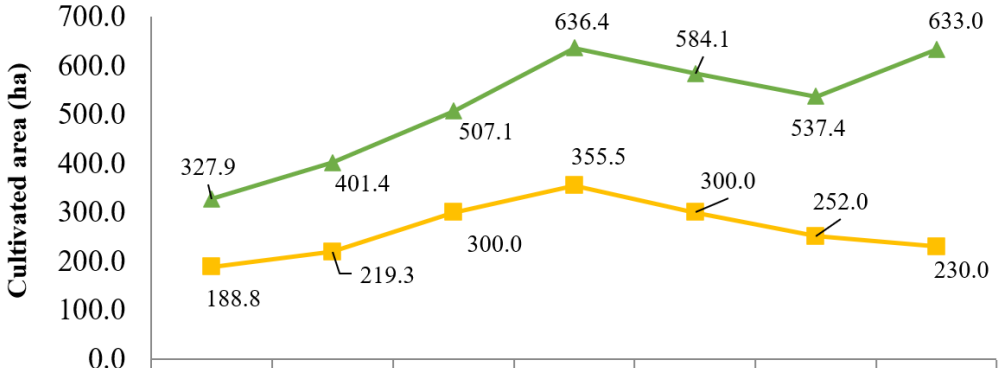


Figure 1. Location of study sites.

Figure 1 illustrates the location of the study areas in Thua Thien Hue Province, Central Vietnam. The province's largest coastal district, Phong Dien, is a major agricultural zone with 12,581 hectares of farmland representing 18.55% of the provincial total (Department of Agriculture and Rural Development, 2023). Because of its suitable climate, Phong Dien became the province's largest lotus cultivation area: lotus cultivation expanded rapidly from 2017 to a peak of 355.5 hectares in 2020, when Phong Dien accounted for over half of the province's total lotus-growing area. However, the area under cultivation has since declined by more than 35% (Figure 2), making Phong Dien a relevant study site to investigate the underlying drivers of lotus farming.



	2017	2018	2019	2020	2021	2022	2023
Phong Dien District	188.8	219.3	300.0	355.5	300.0	252.0	230.0
Thua Thien Hue Province	327.9	401.4	507.1	636.4	584.1	537.4	633.0

Figure 2. Change in lotus cultivated area in the study site.

Source: Reports of Phong Dien District Department of Agriculture and Rural Development in 2021, 2022 and 2023.

Although lotus is cultivated across all communes in the Phong Dien District, two communes were selected for this study based on their production area, number of lotus-growing households, and representation of distinct agroecological zones. The first commune, Dien Hoa, is in the coastal lagoon region and has the largest lotus cultivation area converted from low-efficiency rice fields. The second commune, Phong Hien, is in the inland plain and has long been recognized as a major lotus-producing area with widespread household participation (Phong Điền District Department of Agriculture and Rural Development, 2023).

2.2.1. Data Collection and Analysis

2.2.1.1. Data Collection

This study used a mixed-methods approach that combined quantitative and qualitative techniques, including key informant interviews, focus group discussions, and household surveys (Hesse-Biber, 2010). A pilot survey was conducted in July 2023 to test the questionnaire and refine the study design, including site selection and sample size. The main fieldwork took place from August to October 2024 through face-to-face interviews with local authorities, experts, lotus farmers, and traders.

Twelve key informants were interviewed for this study, including lotus traders, university experts, and local government officials at both the district and commune levels. These interviews explored the characteristics and historical development of lotus farming in the region and collected secondary data from annual reports. Additional insights into market access, price fluctuations, and vertical coordination were obtained through direct interviews with traders in local and wholesale markets.

Two focus group discussions were subsequently conducted with five and eight farmer representatives from the Dien Hoa and Phong Hien communes, respectively, to capture farmers' perspectives, their motivations for crop switching, and adaptive strategies. Key points of consensus and disagreement were documented, transcribed, and thematically analyzed to identify patterns across locations and production scales. Focus group participants were selected for their direct involvement and long-term experience with lotus farming. To validate the focus group findings, triangulation was used to compare perspectives across different stakeholder groups (Carter, Bryant-Lukosius, DiCenso, Blythe, & Neville, 2014).

Although official statistics are unavailable, estimates from provincial and district agricultural officers suggest that approximately 300 households across Thua Thien Hue Province cultivate lotus, with over 200 located in Phong Dien District (Table 1). Because the scattered distribution of lotus cultivation across multiple communes makes it difficult to identify and monitor individual farming households, purposive and quota sampling methods were used to select participants that fit the study's objectives and varied in their farming experience and production scale. This sampling framework led to the purposive selection of the Dien Hoa and Phong Hien communes due to their large lotus-growing areas and high concentration of growers.

Within each commune, quota sampling was used to target farmers with at least two years of lotus farming experience and varying landholding sizes to explore variation across production scales and strategies. A total of 95 lotus farmers were surveyed using a semi-structured questionnaire. The survey collected data on socio-demographic

characteristics, farming practices, and changes in lotus cultivation, including cultivation area, yield, and selling price, from 2019 to 2024. The year 2019 was selected as the baseline, as commercial lotus farming expanded rapidly from that time onward due to strong support from local authorities. To assess differences across production scales, farmers were classified into three groups based on their cultivation area: small (<1 ha), medium (1–2 ha), and large (>2 ha).

Table 1. Number and structure of household survey.

Administrative unit	Lotus-growing households	Surveyed households	Surveyed households by landholding size		
			Small (<1ha)	Medium (1-2ha)	Large (>2ha)
Phong Hien commune	80*	55	42 (76.36)	11 (20.00)	2 (3.64)
Dien Hoa commune	55*	40	19 (47.50)	13 (32.50)	8 (20.00)
Phong Dien district	200*	95	NA	NA	NA
Thua Thien Hue Province	300*	95	NA	NA	NA

Note: The percentages are in parentheses; NA: not available data; *: Estimated by agricultural officers at the provincial and district levels

2.2.1.2. Data Analysis

A one-way ANOVA was applied to test differences in farm characteristics and production costs across farm size groups. Descriptive statistics were used to summarize key features of lotus farming and farmers' perceptions of crop failure and coping strategies. Benefit-cost analysis was conducted using the following formula:

$$B/C\ ratio = \frac{Profit}{Total\ costs} \quad (1)$$

Financial indicators, including cost, gross output, and profit, were used to assess the economic efficiency of lotus farming. Profit was calculated as:

Profit = Gross output – Total costs

with

Gross output = Price of lotus grain × Yield of lotus grain.

Total costs include rental fees, seedling or cutting costs, fertilizers (both chemical and organic), pesticides, mechanization, irrigation, loans, and labor.

3. RESULTS

3.1. Weather Conditions and Cultivation Period of Rice and Lotus Crop

Figure 3 illustrates how seasonal weather patterns in Vietnam affect crop choices and cultivation timing. During the rainy and flood season, from September to December, monthly precipitation can reach up to 1,600 mm, often forcing farmers to leave fields fallow. Lotus is cultivated once a year, typically from January to August, with the harvest occurring in July and August. This schedule excludes a second rice crop, requiring farmers to choose between growing either two rice crops or one lotus crop in a year. The lack of crop rotation reflects local climatic constraints. In the Mekong Delta region, dyke systems allow year-round lotus cultivation or rotation with rice, whereas in Central Vietnam, lotus is not part of a flood-adaptive farming system but is instead restricted to a short planting window during the dry season.

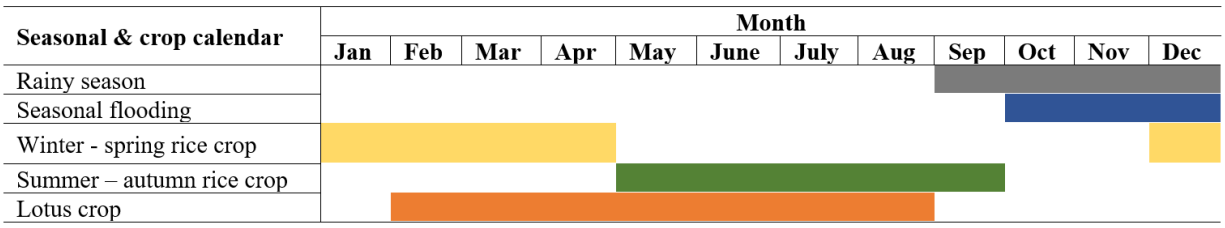


Figure 3. Seasonal and crop calendar.

Source: Reports of Thua Thien Hue Plant Protection Department in 2023.

3.2. Land Sources and Tenure for Lotus Farming

Lotus farming initially emerged as a land-use solution for low-lying areas such as ponds, lakes, and fallow wetlands that were otherwise at risk of abandonment. Poor drainage, thick mud, and frequent flooding have reduced the viability of rice cultivation in these areas because these conditions hinder mechanization and force farmers to rely on costly manual labor. As a result, many farmers in low-lying areas have lost interest in rice cultivation and have begun seeking alternative crops. Lotus is increasingly viewed as a viable alternative due to its tolerance for flooded soils, high market value, and growing consumer demand. These factors have driven the recent expansion of lotus cultivation across vulnerable lowland areas of Thua Thien Hue. However, its adoption remains limited, particularly among smallholders, due to their reliance on leased land and the high initial investment required.

Our findings indicate that land access and the expansion of lotus cultivation are closely linked to crop restructuring policies that allow farmers to convert inefficient rice fields into high-value alternatives. Since 2013, a national strategy

(Decision No. 899/QD-TTg) has promoted agricultural restructuring toward high-value crops. In line with this national initiative, the provincial government introduced measures in 2016 (Decision No. 32/QD-UBND) to encourage and support rice-to-lotus conversion. Further efforts were outlined in Plan No. 65 (2020), which set a target of expanding lotus cultivation to 745 hectares by 2025, primarily through the conversion of inefficient rice fields and unused low-lying wetlands.

According to our findings, lotus land tenure comprises three forms: owned, leased, and mixed ownership. Figure 4 presents differences in land tenure by farm size. Small-scale farmers primarily convert their own rice fields for lotus production, while medium- and large-scale producers rely more heavily on leased land. Specifically, 90% of large-scale and 54.17% of medium-scale lotus farms are fully leased, with an additional 10% and 20.83%, respectively, combining leased and owned land.

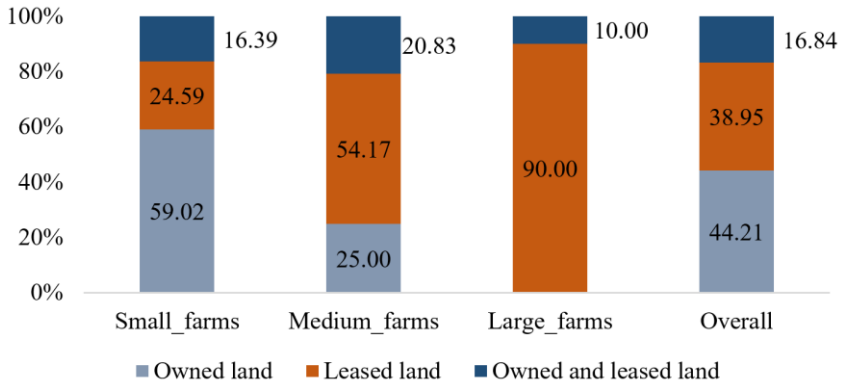


Figure 4. Land tenure based on farm size production.

3.3. Farming Systems, Lotus Varieties, and Planting Techniques

3.3.1. Farming Systems

Figure 5 shows the distribution of lotus farming systems by farm size in Phong Dien District, highlighting differences in adoption and associated production benefits. Three lotus-based farming systems are practiced in Phong Dien District: lotus monoculture, lotus–fish, and lotus–fish–duck systems. The integrated lotus–fish model is the most widely adopted of these systems, practiced by 52.63% of surveyed households and up to 70.83% of those with medium-sized farms. This model generates additional income from fish with minimal additional labor or technical input, as most farmers do not need to purchase juvenile fish or supply extra feed. Although fish are typically raised on a small scale for home consumption, the lotus–fish system still allows households to diversify their outputs from lotus fields without significant investment.

The lotus–fish–duck system was recently introduced in Dien Hoa and offers the highest income potential due to its diversified outputs. However, it requires more labor and infrastructure to manage both ducks and fish effectively, which makes it more challenging for smallholder farmers to adopt.

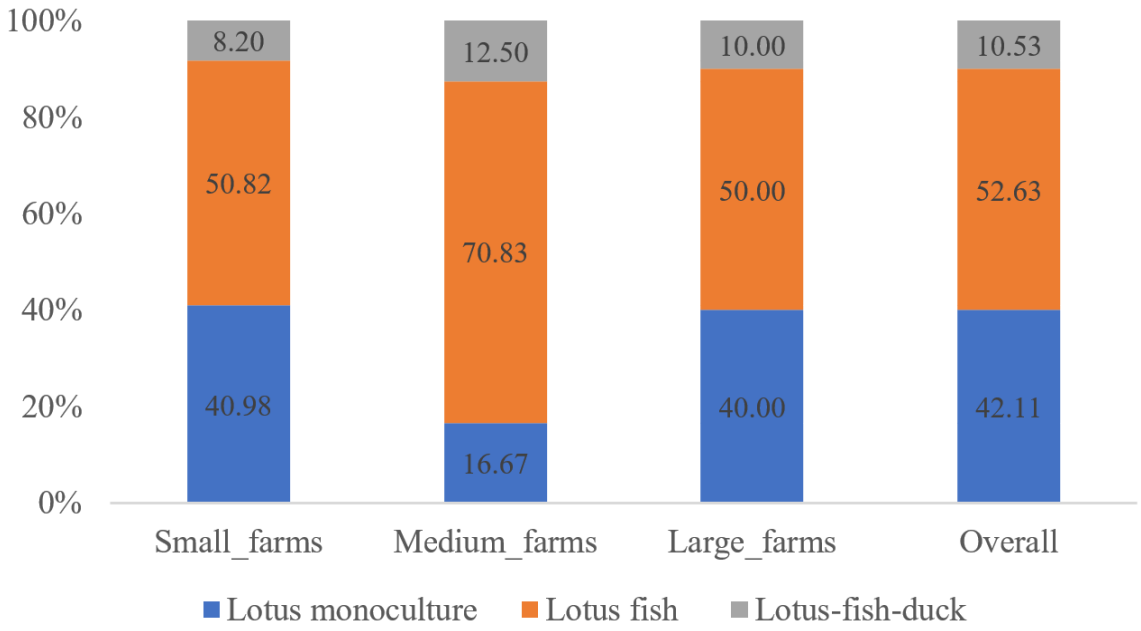


Figure 5. Lotus farming systems based on farm-size production.

3.3.2. Lotus Varieties and Planting Techniques

There are many lotus varieties, each cultivated for different purposes or products such as seeds, roots, or flowers. Although Thua Thien Hue province is renowned for its high-quality local lotus varieties and the "Tinh Tam" brand, these local varieties have become less common as more farmers have shifted to a higher-yield lotus variety from Dong Thap Province that is primarily cultivated for its seeds. This variety is preferred for its productivity, yielding twice as much as local varieties at an average of two tons of lotus grain per hectare.

In addition to the different varieties of lotus, lotus farmers currently use two planting techniques: transplanting new seedlings or reusing lotus roots from the previous season. We found that 68.42% of farmers reuse existing roots to reduce seedling costs. This method is most common among large-scale producers, followed by medium- and small-scale farms (Figure 6). In the absence of disease outbreaks, farmers often continue to re-use existing roots for three to five years. However, prolonged reliance on old roots increases the risk of soil-borne diseases and may lead to reduced yields over time.

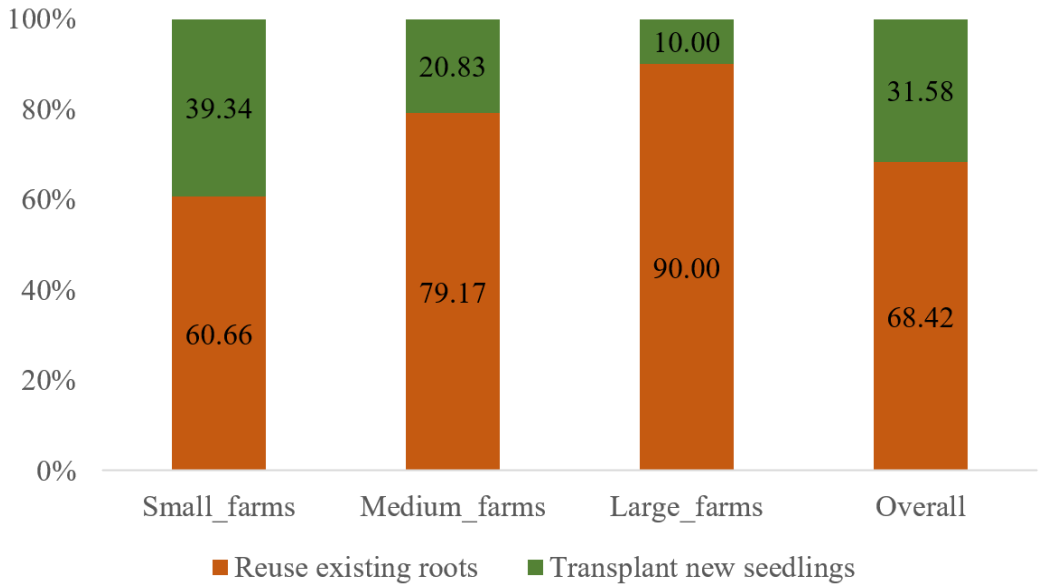


Figure 6. Planting technique based on farm-size production.

3.3.3. Market Access and Product Diversification

Although all parts of the lotus plant are edible, product diversification remains limited, with most farmers prioritizing seed production. Lotus seeds have long been used in traditional cuisine in Thua Thien Hue Province, particularly in soups and specialty desserts. They are primarily consumed fresh or dried and are distributed domestically through traders, wholesale markets, and small retail outlets. Processed lotus seeds can sell for two to three times the price of unpeeled seeds, but most farmers sell them fresh immediately after harvesting due to their perishability. Limited labor, lack of processing equipment, and restricted market access hinder their ability to add value through post-harvest processing.

3.4. Characteristics of Lotus Farming in Thua Thien Hue Province

To examine the landscape of lotus farming in the two studied communes, we compared small-, medium-, and large-scale households based on their demographics, cost structure, and production efficiency per hectare (Table 2). There were no significant differences in family labor, regular labor, off-farm income, or access to training across household sizes. Although labor demand in the early stages of cultivation is relatively low, harvesting is labor-intensive, requiring an average of 2.5 workers per household. Most small-scale farmers rely on family labor due to high hiring costs and labor shortages, while larger farms depend more heavily on seasonal labor and therefore incur higher labor costs. Lotus is harvested every two days over a period of one to three months, with seeds manually extracted and sold on the same day. Transport costs are minimal, as traders often collect seeds directly at the field or household.

Most farmers reported having access to training on lotus farming techniques provided by the local government. However, there were significant differences in age, education, and farming experience across households. Larger-scale producers tend to be younger, better educated, and more experienced, characteristics that enhance their adaptability to crop conversion and modern farming practices. Higher income levels among large-scale households additionally reflect their stronger financial capacity, which enables further investments to expand production.

Total farmland, rice-cultivated land, and lotus acreage also vary across the three production scales. Small-scale producers, who represent 64% of surveyed households, cultivate an average of 0.36 hectares of lotus. In contrast, medium- and large-scale producers, comprising 25% and 11% of the sample, manage significantly larger areas, averaging 1.21 and 3.97 hectares, respectively. Overall, the share of farmland dedicated to lotus, as well as to rice and other crops, increases with production scale, reflecting the broader resource advantages of larger producers. Moreover,

larger-scale farmers are more likely to access credit, enabling both initial investments and continued expansion of lotus cultivation.

Table 2. Farm characteristics.

Indicator	Farm size group			Overall	P_value[1]
	Small	Medium	Large		
Age (Years)	57.48	53.13	45.40	55.11	0.00*
Education (Years)	7.31[a]	8.13	9.60[b]	7.76	0.03*
Farming experience (Years)	5.82[a]	8.04	10.30[b]	6.85	0.00*
Family labors (Laborers)	2.57	2.33	2.50	2.51	0.67
Regular labors (Laborers)	1.77	1.58	1.70	1.72	0.23
Seasonal labors (Laborers)	0.26[a]	0.67[a]	1.70[b]	0.52	0.00*
Agricultural farmland (Hectare)	1.03[a]	2.09[b]	6.04[c]	1.82	0.00*
Rice production area (Hectare)	0.36[a]	0.84[b]	2.08[c]	0.66	0.00*
Lotus production area (Hectare)	0.36[a]	1.21[b]	3.97[c]	0.96	0.00*
Farmland under lotus cultivation (%)	39.41[a]	63.70[b]	70.97[b]	48.87	0.00*
Income (Million VND)	82.54[a]	138.69[b]	191.00[b]	108.14	0.00*
Off farm income (=1 if yes)	0.75	0.63	0.40	0.68	0.06
Credit access (=1 if yes)	0.03[a]	0.13[a]	0.50[b]	0.11	0.00*
Training access (=1 if yes)	0.87	0.88	0.90	0.87	0.96
Cooperative member (=1 if yes)	0.75[a]	1.00[b]	1.00	0.84	0.01*
No. of observations	**61**	**24**	**10**	**95**	

Note: [1] p-value of one-way ANOVA tests on the equality of means; * significantly different at 5%.
Different superscript letters [a, b, c] indicate significant differences between groups ($p < 0.05$).
Vietnam Dong; USD 1.00 = VND 25,488.00 (2024) (https://www.gso.gov.vn/)

3.5. Production Costs and Economic Efficiency

3.5.1. Production Costs Based on Farm Size

Table 3 presents the production costs per hectare of lotus across different farm-size groups. In general, the cost of lotus cultivation per hectare is relatively high, averaging 40 million VND per hectare. This cost gradually increases with production scale, from an average of 34 million VND per hectare for small-scale households to 45 million VND for medium-scale households and 65 million VND for large-scale households.

Our surveys identified four primary cost components in lotus farming: family labor, seedlings, chemical fertilizer, and land rental. Family labor accounts for a significant portion of total costs across all production scales, reflecting the high labor demands of lotus cultivation, especially during the extended harvest season. This labor demand makes the lotus cultivation model more suitable for households with idle labor, especially male household members. Overall labor costs, including both family and hired labor, increase noticeably with farm size.

In contrast, there are no significant differences in seedling and chemical fertilizer costs across household groups. Seedlings cost an average of 6 million VND per hectare, which covers 400 cuttings, transportation, and planting labor. Most farmers purchase cuttings from wholesalers. However, due to the high cost of seedlings, especially as a proportion of total expenses, many households reuse lotus roots from the previous season (Figure 6). Fertilizer expenditures average 8 million VND per hectare, primarily for NPK (nitrogen, phosphorus, and potassium) fertilizer, which is typically applied three times per season at 450 kg per hectare.

Finally, land rental costs vary significantly across household groups. While small-scale farmers primarily convert their existing rice fields for lotus cultivation, large-scale farmers expand their farmland by leasing. As a result, rental expenses increase with production scale. Other costs, such as organic fertilizer, machinery rental, pesticides, irrigation, and interest payments, represent a small portion of total expenses and show little variation among groups.

Table 3. Production costs per hectare of lotus unit: Million VND/hectare.

Indicators	Farm size group			Overall	P_value[1]
	Small	Medium	Large		
Rental	2.54[a] (7.47)	6.46[b] (14.16)	12.39[c] (19.10)	4.57 (11.36)	0.00*
Seedlings	6.00 (17.65)	6.00 (13.15)	5.38 (8.30)	5.94 (14.77)	0.12
Chemical fertilizers	7.62 (22.41)	8.29 (18.17)	7.97 (12.29)	7.83 (19.48)	0.62
Organic fertilizers	0.07 (0.21)	0.02 (0.05)	0.20 (0.31)	0.07 (0.18)	0.21
Pesticides	1.23 (3.62)	0.82 (1.80)	1.56 (2.40)	1.16 (2.89)	0.27
Mechanization	3.29 (9.66)	1.75 (3.84)	0.44 (0.68)	2.60 (6.46)	0.08

Indicators	Farm size group			Overall	P_value[1]
	Small	Medium	Large		
Irrigation	1.68 (4.93)	1.07 (2.35)	1.41 (2.17)	1.50 (3.72)	0.75
Loan	0.13 (0.39)	0.52 (1.14)	0.55 (0.84)	0.27 (0.68)	0.21
Family labor	10.14[a] (29.80)	18.43[b] (40.37)	26.62[c] (41.05)	13.97 (34.74)	0.00*
Hired labor	1.32[a] (3.87)	2.27[a] (4.98)	8.33[b] (12.85)	2.30 (5.71)	0.00*
Total costs	34.02[a]	45.65[b]	64.83[c]	40.20	0.00*
No. of observations	61	24	10	95	

Note: The percentages are in parentheses.
[1] p-value of one-way ANOVA tests on the equality of means; * significantly different at 5%.
Different superscript letters [a, b, c] indicate significant differences between groups ($p < 0.05$).
Vietnam Dong; USD 1.00 = VND 25,488.00 (2024) (https://www.gso.gov.vn/)

3.5.2. Economic Analysis of Lotus Production

Table 4 summarizes the average selling prices for unpeeled lotus seeds and rice grains from 2019 to 2024, based on household survey data collected in Phong Dien. This five-year period was chosen to capture recent price changes and assess the relative competitiveness of lotus seeds compared to rice. Prices are expressed as means with standard deviations (± SD) to reflect the variability in farmer-reported prices. As shown in the table, lotus is more competitive than rice in terms of both market access and selling price. Although the selling prices of both crops have increased over time, the price gap has persisted, with fresh, unpeeled lotus seeds selling at prices up to five times higher than rice. Lotus seed prices also fluctuate significantly across the early, mid, and late harvest seasons, but the average price during the harvest period is consistently high.

Table 4. Change in selling price of lotus and rice grain.

Year	Unpeeled lotus seed (Thousand VND/kg)	Rice grain (Thousand VND/kg)	Lotus/Rice ratio
2019	31.53 ± 2.67	5.74 ± 0.53	5.49
2020	34.52 ± 8.60	5.93 ± 0.54	5.82
2021	34.32 ± 3.14	6.22 ± 0.67	5.51
2022	37.31 ± 5.67	6.77 ± 0.53	5.52
2023	40.94 ± 4.09	7.55 ± 0.53	5.43
2024	48.73 ± 3.58	8.48 ± 0.40	5.75

Note: Values are presented as Mean ± SD; Vietnam Dong; USD 1.00 = VND 25,488.00 (2024) (https://www.gso.gov.vn/).

Table 5 summarizes the economic efficiency of lotus farming by farm-size groups. Our data also show that large-scale farms have the highest average yield and gross production, while medium-scale farms have the lowest, though these differences are not statistically significant. Due to their lower production costs, small-scale farms achieve greater economic efficiency than larger-scale farms, as reflected in their significantly higher net income and benefit-cost ratios. In contrast, higher labor and rental expenses result in negative profitability for medium- and large-scale households.

These findings suggest that reducing production costs, particularly labor expenses, is essential for improving the profitability of medium- and large-scale lotus farms. Enhancing labor efficiency and minimizing inputs could further support the financial viability of these larger operations. In contrast, low net profits among small-scale farmers are primarily linked to limited yields. Addressing these yield constraints through targeted interventions is therefore crucial to strengthening the economic viability of smaller-scale lotus farms.

Table 5. Economic efficiency of lotus farming by farm size groups.

Variable	Farm size group			Overall	P_value[1]
	Small	Medium	Large		
Yield (Ton/Hectare)	0.89	0.75	1.03	0.87	0.44
Selling Price (thousand VND/kg)	49.41	47.71	47.00	48.73	0.04*
Gross Production (million VND/hectare)	43.63	35.74	47.63	42.06	0.46
Total costs (Million VND/Hectare)	34.02[a]	45.65[b]	64.83[c]	40.20	0.00*
Net Income (Million VND/Hectare)	9.61[a]	-9.91[b]	-17.20[b]	1.86	0.00*
Cost-benefit ratio	0.28[a]	-0.22[b]	-0.27	0.05	0.01*
No. of observations	**61**	**24**	**10**	**95**	

Note: [1] p-value of one-way ANOVA tests on the equality of means; * significantly different at 5%.
Different superscript letters [a, b, c] indicate significant differences between groups ($p < 0.05$).
Vietnam Dong; USD 1.00 = VND 25,488.00 (2024) (https://www.gso.gov.vn/).

3.6. Crop Failure and Farmer's Perspective

3.6.1. Cultivation Acreage and Yield From 2019-2024

Table 6 shows the total acreage under lotus cultivation and associated yields from 2019 to 2024, revealing contrasting trends between the expansion of lotus cultivation and declining productivity. While the number of farmers and the average area under cultivation have steadily increased, yields have remained low and continued to decline over the same five-year period. This persistent underperformance raises concerns about the suitability of the high-yield variety, which has been adopted primarily because of its perceived yield potential.

Table 6. Change in acreage and yield of lotus crop.

Year	No. of observations	Acreage (Hectare)	Yield (Ton/Hectare)
2019	61	0.64 ± 0.94	1.17 ± 0.70
2020	64	0.66 ± 0.94	0.86 ± 0.65
2021	69	0.72 ± 1.05	0.89 ± 0.71
2022	85	0.84 ± 1.08	0.90 ± 0.69
2023	95	0.90 ± 1.06	0.81 ± 0.57
2024	95	0.96 ± 1.29	0.87 ± 0.62

Note: Values are presented as Mean ± SD.

Table 7 presents farmers' opinions on the main causes of crop failure. Several environmental and agronomic factors have contributed to the recent decline in lotus productivity and farm income. Most respondents in our surveys and interviews identified extreme weather events, including heavy rainfall, unseasonal flooding, prolonged drought, and high temperatures, as the primary causes of crop failure. Prolonged heat stress was reported to reduce yields, while excessive rainfall and flooding during the harvest period resulted in substantial crop losses. In addition to climatic challenges, soilborne diseases have become a major constraint in recent years, with over 90% of farmers reporting nematode infestations as the greatest threat to their lotus fields.

"Once nematode disease breaks out, I generally accept the loss of the entire crop. Even when I replant, the lotus crop loss continues. We are just hoping for a cure for this disease" (farmer, Phong Hien commune, Phong Dien district).

"Nematode disease is the main cause of crop failure and the reduction in lotus cultivation in our commune. Despite numerous visits from university research teams, the agricultural department, and the provincial agriculture office to seek solutions, no effective method has been found to manage and control this disease in lotus plants" (agricultural officer, Phong Hien commune, Phong Dien district).

Table 7. Farmer's opinion on main causes of crop failure.

Factors	Yes		No	
	No. of farmer	Percentage	No. of farmer	Percentage
Heavy rains	61	64.21	34	35.79
Droughts and prolonged heat waves	46	48.42	49	51.58
Off-season floods*	26	27.37	69	72.63
Floods	1	1.05	94	98.95
Diseases	86	90.53	9	9.47

Note: * Floods are unseasonal and unpredictable, especially in March and April.

3.6.2. Motivations to Continue Lotus Farming

Although farmers typically abandon crops after repeated failures, most farmers who experienced at least one failed lotus crop in the past five years still intend to continue cultivation. This decision is driven by two main reasons. First, all respondents identified profit expectations as their main motivation for switching to lotus farming. Despite its production risks, lotus is still perceived to offer significantly higher returns than rice, making its income potential a key factor sustaining farmers' commitment to the crop.

"Agricultural production mainly depends on the weather; no matter which crop you choose to cultivate, you have to accept the risk of crop failure. There is no crop that is more profitable than lotus; a successful crop can cover losses of three previous crops. As long as I continue to grow lotus, I still have a chance to recover the money I lost" (farmer, Phong Hien commune, Phong Dien district).

Second, the challenges that initially motivated farmers to switch from rice to lotus, such as limited mechanization in low-lying areas, have become barriers preventing them from returning to rice cultivation.

"My farmland is in a low-lying area, making rice cultivation very difficult because plows and harvesters can't be used. My spouse and I are also getting older; therefore, if we don't grow lotus, we will likely leave the land fallow rather than continue farming on it" (farmer, Dien Hoa commune, Phong Dien district).

4. DISCUSSION

Lotus is widely recognized as a flood-tolerant and climate-adaptive crop, a perception that has been supported by studies in flood-prone regions such as the Mekong Delta in Vietnam and the Yangtze River basin in China. However, our case study in Thua Thien Hue province, Vietnam, offers a contrasting perspective on its viability as an alternative to rice in regions that experience more extreme climate variability. Despite its flood tolerance, most lotus cultivars

cannot survive submergence beyond two to three meters or more than ten days, and prolonged inundation can lead to growth reduction, yield decline, physiological stress, and mortality (Deng et al., 2022; Nohara & Tsuchiya, 1990; Wang et al., 2018). At our study site, the erratic and intense rainy season restricts lotus cultivation to a single annual crop and eliminates the possibility for crop rotation. As a result, lotus cultivation in this region, particularly in low-lying areas, may heighten exposure to production risks and crop failure rather than support climate adaptation.

Nevertheless, farmers and local authorities in Thua Thien Hue continue to view lotus as a practical alternative to rice because it overcomes the structural limitations in lowland rice farming systems, where paddy land is increasingly at risk of abandonment. This favorable perception of lotus stems from the challenges of limited mechanization, high labor costs, and declining soil quality that have made rice cultivation increasingly unsustainable. Despite its agronomic limitations, lotus is therefore seen as more compatible with local conditions and a means of sustaining land use where rice farming is no longer viable. This finding reframes the role of alternative crops in extreme climate contexts, highlighting their value not as inherently climate-resilient solutions but as a practical response to production challenges in existing farming systems. In this context, and with appropriate governmental support, lotus cultivation has the potential to contribute both economically and ecologically to more sustainable land use in flood-prone areas.

Economic conditions also drive the transition from rice to lotus. Lotus seeds from Thua Thien Hue province command a price premium in local markets, despite the challenging growth conditions, due to their limited seasonal availability and single annual harvest. These favorable market conditions have strengthened farmers' interest in lotus cultivation as a viable alternative to rice in lowland areas. Although lotus farming did not generate positive returns in 2024 for most of the surveyed households, especially the medium- and large-scale producers, all farmers expressed an intention to continue lotus cultivation. Their continued engagement reflects not only the crop's potential to generate higher income under favorable conditions but also its compatibility with underutilized land. Additional factors, such as low labor requirements in the early stages of cultivation, the ability to continue using land no longer suitable for rice, and local policy incentives, further support farmers' choice to persist with lotus cultivation. These findings suggest that, when adopting alternative crops, farmers often prioritize long-term expectations and land-use sustainability over shorter-term profitability.

All households surveyed for this study cultivate the high-yield lotus variety from Dong Thap, based on the belief that it offers higher yields compared to indigenous varieties. However, repeated crop failures in recent years have raised concerns about this variety's adaptability and disease resistance under local weather and soil conditions. Nematode infestations have emerged as a major constraint to lotus cultivation, causing significant crop losses in Tokushima, Japan (Koyama et al., 2013) and widespread crop failure in Dong Thap Province in 2018 (Vo et al., 2021). No effective nematode control measures have been identified, leaving farmers highly vulnerable to future outbreaks. Current practices such as continuous monoculture and reusing lotus roots from previous seasons may further increase crop susceptibility to soilborne diseases and reduce yields. For example, Wu et al. (2022) found that repeated monoculture led to the accumulation of pathogenic plant viruses in the soil, thereby heightening the risk of soilborne disease outbreaks.

To address these challenges with the Dong Thap lotus variety, more research attention should be directed toward the potential of indigenous lotus varieties, which have been largely overlooked in recent years. In addition to being valuable genetic resources, many local cultivars have demonstrated superior nutritional quality. For example, lotus seeds from the indigenous Vinh Thanh, Phu Mong, and Gia Long varieties have higher nutritional value than the higher-yield Dong Thap variety (Trang, Hồng, Long, Loan, & 2019). However, these varieties account for less than 10% of the province's total lotus cultivation area (Thua Thien Hue Department of Agriculture and Rural Development, 2023). Further research will be needed to assess the agronomic performance, climate resilience, and disease resistance of indigenous lotus cultivars. Promoting indigenous varieties as specialty crops could also enhance product differentiation, strengthen Thua Thien Hue's lotus brand, and increase value across the supply chain. A focus on local cultivars could therefore represent a promising strategy for advancing sustainable alternative crops in environmentally vulnerable areas, beyond the case of lotus in Thua Thien Hue.

Finally, high labor costs continue to pose a major barrier to upscaling and improving the efficiency of lotus farming in Thua Thien Hue. Because harvesting is labor-intensive and cannot be mechanized, production costs increase with farm size, creating a paradox in which larger farms may be less cost-effective than smaller ones. Nguyen et al. (2023) similarly found that small-scale farmers, benefiting from lower labor costs, were better able to diversify and achieve higher economic efficiency. Although lotus cultivation has been promoted as a solution to labor shortages and the challenges of mechanization in lowland rice systems, the advantages of lotus cultivation are most apparent among smallholders who can rely on family labor for harvesting. These findings underscore the need for policies that promote context-appropriate mechanization, reduce production costs, and enhance efficiency. In addition, strengthening cooperation among farmers and investing in post-harvest innovations could further improve both the scalability and competitiveness of lotus farming.

5. CONCLUSIONS

This study offers insights into the transition from staple to alternative crops using the case of lotus cultivation in Thua Thien Hue Province, Central Vietnam. While converting inefficient rice fields into lotus farms has been promoted as a strategy to improve land-use efficiency in flood-prone areas, our findings reveal several limitations to the economic viability of lotus cultivation. High production costs, low yields, and recurrent crop failures due to harsh weather conditions and soil-borne diseases have posed significant challenges for lotus farmers. Our benefit-cost analysis also

highlights a paradox in which small-scale farms, despite having limited capital, achieve higher efficiency due to their lower input costs and reliance on family labor.

Based on this study's findings, the following recommendations can help improve the feasibility and sustainability of lotus cultivation in low-lying regions of Central Vietnam: (1) enhance lotus seedling quality and planting techniques through farmer training programs, extension services, and improved access to certified seedling resources; (2) promote the conservation and use of indigenous lotus varieties, which may be better suited to local agroecological conditions and possess both cultural and market value; (3) support mechanization in land preparation and harvesting, particularly for medium- and large-scale farms, to reduce reliance on manual labor and lower production costs; and (4) encourage innovations in post-harvest handling and processing, including drying, sorting, and storage, to minimize losses, diversify products, and enhance product value.

A key limitation of this study was the limited observation of farmers growing indigenous lotus varieties. In the two studied communes, the scattered distribution of farmers and the lack of data on those cultivating local varieties constrained our access to this group. Future studies should therefore explore the agronomic performance and economic benefits of indigenous lotus varieties to better understand their potential to improve the sustainability of climate-adaptive alternative crops.

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Institutional Review Board Statement: Ethical review and approval were waived for this study, as it involved only voluntary socio-economic data collection through interviews and group discussions, with no medical or health-related procedures. In accordance with Vietnamese national regulations (Circular No. 4/2020/TT-BYT issued by the Ministry of Health), ethical approval is not required for non-medical socio-economic research. Nevertheless, verbal informed consent was obtained from all participants prior to interviews and survey participation. The research design and data collection procedures adhered strictly to principles of confidentiality, voluntary participation, and data protection.
Transparency: The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.
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