Sustainability index analysis of traditional organic coffee agroforestry in Pati Regency, Central Java, Indonesia

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Research

Abstract

Background: Indonesia is one of the countries that contributes the most significantly to the global production of coffee. This study aims to determine organic farming practices and the diversity of plants in coffee agroforestry.

Method: This research was carried out in the organic coffee-growing region of Gunungsari Village, Pati Regency, Central Java, Indonesia. Data were collected through field observation and semi-structured interviews containing 47 attributes, such as ecological, economic, social, institutional, and technology dimensions. It was examined utilizing the Multidimensional Scaling (MDS) method using RAPFISH software and Monte Carlo analysis to demonstrate the sustainability status leverage attributes and discuss scoring errors and interpretations.

Results: Based on the analysis results of the sustainability status, the traditional organic coffee agroforestry system in Gunungsari Village was fairly sustainable, and the highest value was 74.25 social dimension. The attribute of social dimensions was education level, which had the highest RSM value of 8.62. The Monte Carlo analysis test results showed that the values for all sizes were almost the same as the MDS analysis results.

Conclusions: Therefore, increasing farmer education is very important to increase agricultural productivity, introduce technological innovations, and empower them with knowledge and skills that can increase crop yields and economic prosperity in the agricultural sector.

Keywords: Gunungsari Village, multi-dimensional scaling, organic coffee agroforestry, RAPFISH, sustainability

Abstrak

Latar belakang: Indonesia merupakan salah satu negara yang memberikan kontribusi besar terhadap produksi kopi dunia. Penelitian ini bertujuan untuk menganalisis praktik pertanian organik dan keanekaragaman tanaman di wanatani kopi. Penelitian ini dilakukan di daerah penghasil kopi organik di Desa Gunungsari, Kabupaten Pati, Jawa Tengah, Indonesia.

Metode: Data dikumpulkan melalui observasi lapangan dan wawancara semi-terstruktur yang terdiri dari 47 atribut, seperti dimensi ekologi, ekonomi, sosial, kelembagaan, dan teknologi. Penelitian ini menggunakan metode Multidimensional Scaling (MDS) dengan menggunakan perangkat lunak RAPFISH dan analisis Monte Carlo untuk menunjukkan atribut pengungkit status keberlanjutan serta membahas kesalahan skoring dan interpretasi.

Hasil: Berdasarkan hasil analisis status keberlanjutan, sistem wanatani kopi organik tradisional di Desa Gunungsari tergolong cukup berkelanjutan, dengan nilai tertinggi pada dimensi sosial sebesar 74,25. Atribut dari dimensi sosial yaitu tingkat pendidikan memiliki nilai RSM tertinggi yaitu 8,62. Hasil uji analisis Monte Carlo menunjukkan bahwa nilai untuk semua dimensi hampir sama dengan hasil analisis MDS.

Kesimpulan: Oleh karena itu, peningkatan pendidikan petani sangat penting untuk meningkatkan produktivitas pertanian, memperkenalkan inovasi teknologi, dan memberdayakan mereka dengan pengetahuan dan keterampilan yang dapat meningkatkan hasil panen dan kesejahteraan ekonomi di sektor pertanian.

Kata kunci: Desa Gunungsari, penskalaan multi-dimensi, wanatani kopi organik, RAPFISH, keberlanjutan

Background

Coffee is a profitable agricultural commodity in Indonesia. Indonesia is one of the countries with the world's most significant coffee production. With seven percent of the world's coffee production grown, Indonesia was fourth as the fourth coffee producer in the world (van Noordwijk *et al.* 2021). Indonesia exported 397,350 tons of coffee in 2018, reaching all regions worldwide (BPS, 2020). The types of coffee cultivated in Indonesia are Arabica, Robusta, Liberika, and Ekselsa. Coffee plantations in Indonesia are dominated by Robusta coffee. The coffee industry in Indonesia has experienced rapid development over the last few decades. The coffee bean production process (planting, picking, and processing) is increasingly modern and well-controlled.

Even though the coffee industry in Indonesia is well-developed, there are still several challenges that must be faced, such as price fluctuations, climate change, sustainability, and environmental preservation issues (Lechthaler & Vinogradova 2017, DaMatta *et al*. 2018, Ho *et al*. 2018, Pham *et al*. 2019). However, the Indonesian government continues to work to improve the sustainability and welfare of coffee farmers through programs that support environmentally friendly farming. The government conducted the 1000 Organic Villages program, where coffee was one of the commodities in the program. Through this program, the Indonesian Ministry of Agriculture planned to increase the production or availability of agricultural commodities, including plantations. Hence, the commodities have value-added qualities that allow them to compete in the world market. Although there are challenges to developing organic coffee, such as higher production costs and market uncertainty, organic coffee cultivation has become an increasingly popular choice for farmers and consumers who wish to support environmental sustainability and farmer welfare (Folch & Planas 2019).

The existence of trade barriers in the form of environmental and social issues in the coffee trade causes the need for standardization institutions to guarantee the coffee marketed. International and national must ensure that products are certified based on social, environmental, and economic aspects (Tscharntke *et al*. 2015). The existence of a coffee certification program for farmers can provide guarantees to complete specific environmental and social implementation standards (Ibanez & Blackman 2016). In addition, by organic certification, farmers can receive economic advantages, such as price premiums and enhanced market entrance (Dragusanu *et al*. 2014).

From the consumer's point of view, the world coffee trade is slowly shifting towards the trade-in of environmentally friendly. This increase in demand is due to changes in coffee consumers' lifestyles, who are becoming more aware of health and environmental sustainability (Yu *et al*. 2014). Sustainability certifications can inform consumers how goods and services have been guaranteed the quality of products (Hainmueller *et al*. 2015). For example, consumers know about synthetic chemicals' dangers (Gatti*et al*. 2022). Consumers aware of synthetic chemicals' impact on health will choose food that is safe for health and environmentally friendly, thereby encouraging increased demand for organic products.

Organic certification is a process that ensures that agricultural products are produced according to organic farming standards. It includes food, fibber, and raw materials made using environmentally friendly and sustainable methods (BSN 2016). Organic certification is issued by an independent and recognized institution. Some aspects that are parameters in organic certification are (1) soil and nutrient management, (2) pest and disease control, (3) seeds and planting materials, (4) animal welfare, (5) environmental management, (6) product handling and processing, and (7) recording and tracking. farmers or producers must undergo inspections from certification bodies to ensure all aspects meet organic standards in the organic certification process. If they pass the inspection, the product can be labelled organic, showing consumers that it has been produced according to organic principles and standards. Organic coffee in Pati Regency is officially certified by the ICERT and Inoffice. Organic coffee in Pati Regency is spread to several villages and sub-districts. Organic coffee certification can improve the quality of coffee, which will ultimately increase the competitiveness of coffee in the international market and benefit the sustainability of coffee farming for organic coffee farmers in Pati Regency economically, socially, and environmentally.

The coffee planting system used is a traditional or simple agroforestry system. Farmers usually combine coffee trees with other commercial gardens. Local people also know this system as *tumpang sari* (traditional agroforestry). The agroforestry system has a promising impact on society, especially for economic and conservation purposes. Making this organic certification will positively impact the management of existing traditional coffee agroforestry. Local conventional coffee knowledge agroforestry by Gunungsari Village also plays a role in supporting the certification program. Therefore, information is needed regarding the sustainability status of the Gunungsari Village's traditional coffee agroforestry system. This research aims to analyze the sustainability of conventional organic coffee agroforestry index based on ecological, economic, social, institutional, and management technology dimensions.

Materials and Methods

Study area

This study was conducted in the organic coffee cultivation area of Gunungsari Village, Pati Regency, Central Java, Indonesia (Figure 1). The case study was carried out on the land of 25 farmers who joined the coffee organic certification program, an inspector of organic certification, and a village staff. This village was included in the organic village program and given direct assistance from the Horticulture and Plantation Food Crops Protection Agency (BPTPHP) of Central Java to develop organic coffee. Pati Regency is one of the areas developed by the government as one area that produces organic coffee in Central Java. Some of the farmer's land is also on the land of Perum *Perhutani* (State-Owned Enterprise in the forest sector) under *Pinus merkusii*.

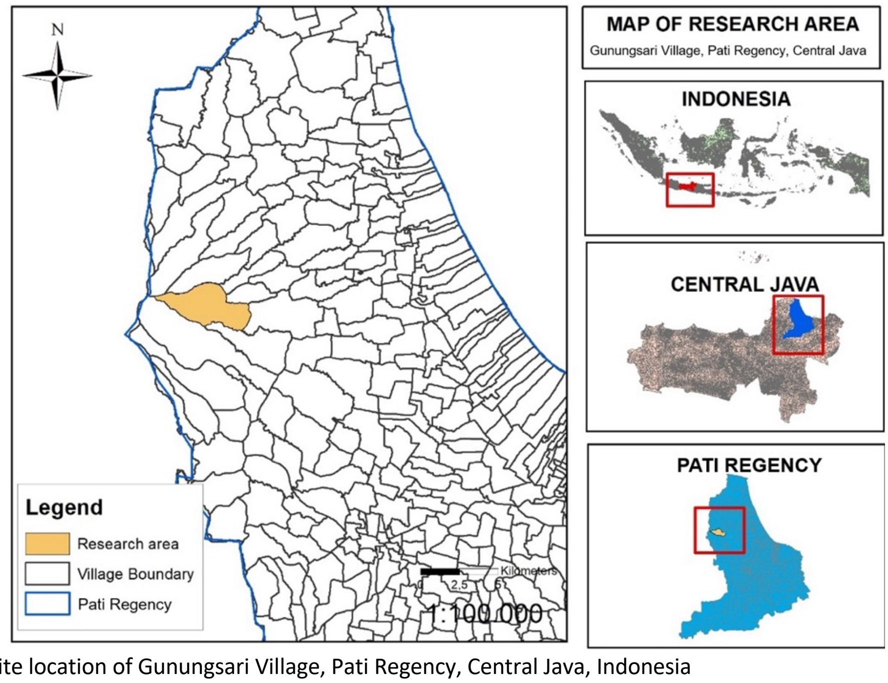

Figure 1. Study site location of Gunungsari Village, Pati Regency, Central Java, Indonesia

Javanese and Muslims dominate the Gunungsari community. The Gunungsari community manages their land by combining traditional ecological knowledge (TEK) and organic farming systems. The knowledge transfer process is carried out by the children of each farming family, where the children have been involved either by seeing practices or being included in the work their parents did was farming. Regarding formal education, the older generation is elementary school (SD) and junior high school (SMP) graduates. However, some younger generations continue to high school (SMA) or college today.

The coffee agroforestry system is still conducted traditionally. Organic coffee farming is an agriculture system that integrates the principles of sustainable management into coffee production, distribution, and use (Ayalew 2014). The general overview of organic coffee farming is about increasing coffee productivity, quality sustainably, and added value (Wahyudi *et al*. 2017). Coffee certification involves various aspects, including using sustainable resources, cultivation practices, environmentally friendly production, providing benefits to farmers and local communities, and proper product marketing (Ibanez & Blackman 2016). It can be done by increasing farmers knowledge about coffee cultivation and management techniques, enriching farmers ability to access market resources and technology, and providing access to funding sources to support their coffee farming. The organic coffee in Gunungsari Village was officially certified by OCI (Organic Certification Institute). The total organic coffee plantation had already a certificate of 15 ha. Pati Regency was selected to be assisted and funded for five years for the 1,000 organic village programs.

Data Collection

The research was done using a combination of qualitative and quantitative approaches. This research used a descriptive ethnobotany approach through field observation and semi-structured interviews (Albuquerque *et al*. 2014). The observation was conducted to survey the organic organization, farmer cultivation activities, coffee processing post-harvesting, and agrobiodiversity. Semi-structured interviews were done with purposefully chosen informers. We used some direction on particular topics, including coffee management, land establishment, land preparation, planting and maintenance, harvesting and post-harvesting, and marketing. The field observation surveyed the organic organization, farmer cultivation activities, coffee processing post-harvesting, and agrobiodiversity. Semi-structured interviews were done with purposefully chosen informers. The researchers also engaged in participant observation, closely observing the informants as they went about their daily business and discussing it during the interview. Additionally, researchers participated in diverse farmer activities being researched. In organic coffee plantations, this observation was mostly used to observe the overall conditions of settlements, agricultural regions, and the vegetation structure of systems. In contrast, participant observation involved researchers exploring with one or more farmers to see what they do and say and how they participate, to varied degrees, in the observed activities. Member of the farmer group was a member of the Internal Control System (ICS).

Data Analysis

This research used Multidimensional Scaling (MDS) analysis to identify sustainability indices in each dimension. The MDS analysis used was Rapid Appraisal for Fisheries (RAPFISH), a procedure designed by the University of British Columbia in 1999 to assess capture fisheries in a multidisciplinary form. The working principle used technique ordination with MDS. The dimensions and attributes used were determined through literature studies and adapted to the conditions of organic coffee agroforestry. Although RAPFISH was designed for fishery sustainability analysis, its sustainability principles can be applied to other sectors. Therefore, in this study, RAPFISH was used in the agroforestry sector. In this way, the dimensions and attributes used can describe the sustainability conditions of the certified coffee program run by the farmers of Gunungsari Village (Table 1). The attribute examination phase on the ordinal scale varies from 1-10, in which the change rate of probability is 5% (10-9), 6-20% (8-7), 21-50% (6-5), 51-99% (4-3), and 100% (2 -0). This analysis of sustainability index value was in the shape of a two-dimensional image with a rating scale from 0% to 100%, the R^2 value (coefficient of determination), and stress value. The higher the stress value, the worse the consequential MDS model and vice versa. If the S value <0.25% and the R^2 value was near one, the model was satisfactory (normally distributed). Leverage analysis to understand sensitive attributes related to the sustainability index value based on the highest Root Mean Square (RMS) value. The results of the leverage analysis were obtained from the influence of all attributes originating from changes in the RMS value. The selected sensitive attributes have the highest RMS values, up to half of each sustainability dimension (Suwarno2011).

Monte Carlo was carried out to evaluate the effect of errors on the process as a test of validity and accuracy. Monte Carlo analysis also determines how random variations or errors affect a system model's sensitivity, performance, and reliability (Mahida & Handayani 2019). The frequency index is a numerical declaration of informers' ratio frequency of references to each species (Mahwasane *et al*. 2013). The horizontal (x-axis) indicates bad (B) and good (G). In contrast, the Y-axis indicated from down (D) to up (U) only provides variation and is unrelated to the degree of sustainability. All dimensions ordinations were pictured on the horizontal and vertical axes with a rotation procedure. The point's position can be envisioned in the horizontal axis with range scores of 0% (bad) and 100% (good). The functions' sustainability index had a range from 1-100%. The values of the sustainability index are displayed in Table 2. The frequency index of plants represents the numerical measure of how often informants mention a particular plant species. The higher the stress value, the worse the consequential MDS model and vice versa.

Table 1 Dimensions and attributes of the RAPFISH method

Ecological	Economic	Social	Intuitional	Technology
1. Prohibit of land clearing	16. ICS one-stop sales system	24. Underage workers	29. Land legality status	40. Accessibility of facilities and infrastructure
2. Use of compost	17. Minimum living wage	25. Balanced working hours	30. Administrative activities	41. Technology knowledge level of land preparation
3. Source of seed	18. Income level	26. Inclusive	31. Intensity consultation	42. Technology knowledge level of seedling
4, Equipment cleanliness	19. Employment opportunity	27. Protection of workers' rights and security	32. Farmers' group activity level	43. Technology knowledge level of planting
5. Weed management	20. Coffee prices	28. Education level	33. Institutional partnerships	44. Technology knowledge level of maintaining
6. Biological control agency	21. Strategy market and sales		34. Deliberation frequency	45. Technology knowledge level of harvesting
7. Protect forests	22. Sustainability business		35. Women involved	46. Technology knowledge level of post-harvesting
8. Prohibit of illegal hunting	23. Business capital		36. Conflict frequency	47. Technology knowledge level of sales and marketing
9. Buffer zone			37. Decision-making process on ICS	
10. Shade plants			38. Knowledge of ICS rules	
11. Agrobiodiversity			39. Leadership on ICS	
12. Burning activities on land				
13. Soil conservation				
14. Water conservation				
15. Land productivity				

Table 2 Index value categories and sustainability status

Index value	Category
0 - 25.00	Bad: Unsustainable
25.01 - 50.00	Less: Less sustainable
50.01 - 75.00	Fill: Fairly sustainable
75.01 - 100.00	Good: Very Sustainable

Results

The sustainability analysis of traditional organic coffee agroforestry management assessed the five management dimensions: ecology, economy, social, institution, and management technology. Each dimension was evaluated regarding the indicator attributes of sustainability.

Ecology dimension

Based on the result of the sustainability status index of the traditional organic coffee agroforestry system in Gunungsari Village was 68.95 and classified as complete (fairly sustainable) (Figure 2a). A leverage analysis was used to identify sensitive attributes in each sustainability dimension. The leverage analysis was presented using a bar chart, where each attribute with the most outstanding value had the most significant influence on the sustainability status of a dimension. Figure 2b shows the results of the leverage analysis for each dimension. A sensitive attribute in the ecological dimension was the prohibition of illegal hunting, with an RMS value of 1.30. These sensitive attributes were nearly connected to environmental sustainability. The Monte Carlo analysis result showed 69.03, narrowly diverse from the MDS analysis results (Figure 2c).

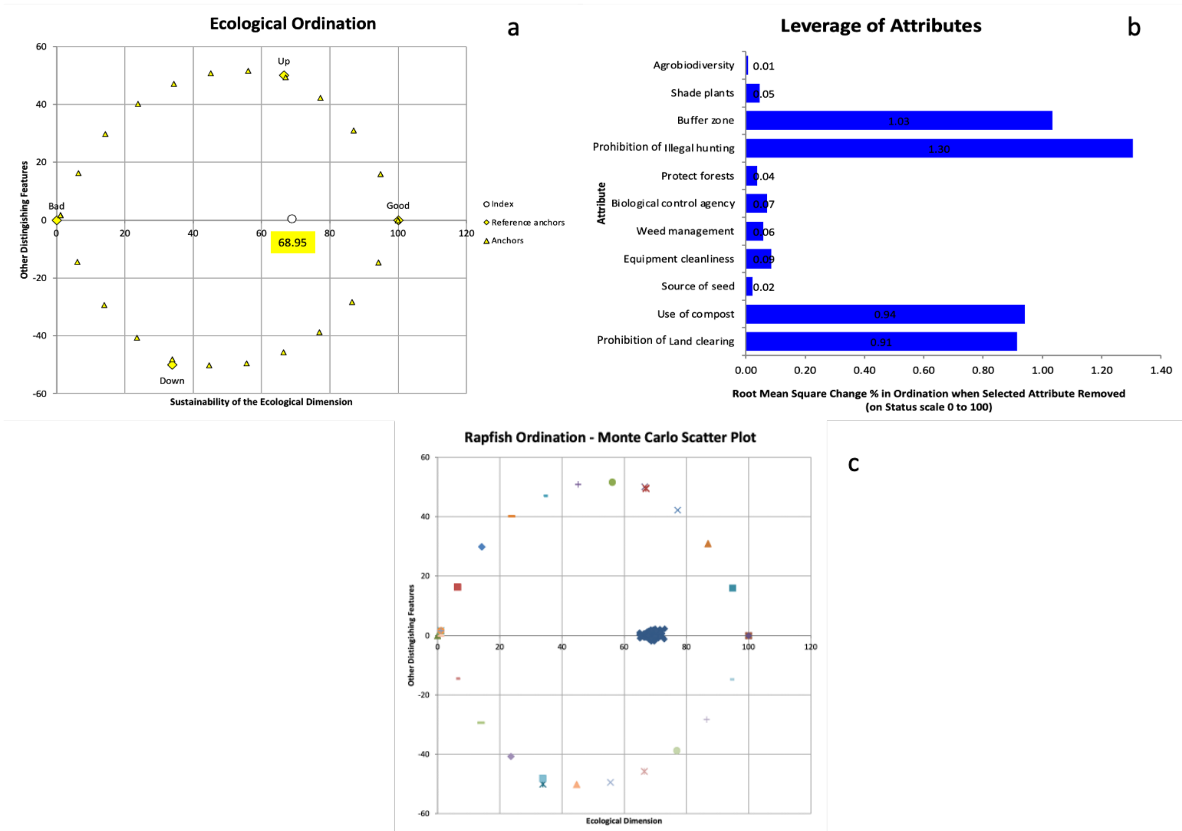

Figure 2. Sustainability ordination index values of ecological dimensions, (a) MDS analysis, (b) leverage analysis, and (c) Monte Carlo analysis

The land used to grow organic coffee had already a planting permit from the village government. Registered land must not within the scope of or adjacent to high conservation value (HCV) areas or protected areas. According to Takahashi and Todo (2013), coffee-certified forests have been proven to have a lower risk of deforestation compared to non-coffee-certified forests. Organic coffee cultivations have more excellent tree species based on the richness and diversity index and more tree layers and shade than conventional coffee cultivation (Haggar *et al*. 2015). Certified coffee cultivation also significantly improved the quantity of tree cover compared to non-certified coffee cultivation (Rueda *et al*. 2015). According to farmers, no illegal hunting had been carried out. Farmers did not hunt animals such as birds. In addition, there were no protected animals and plants in the coffee plantation area.

Several farmers used *Perhutani* land for coffee cultivations. In this case, *Perhutani* gave land use rights to farmers to manage under *P. merkusii* if they were not cultivated in a conservation zone or have damaged *P. merkusii*. The cooperative relationship between farmers and *Perhutani* has proven economic and conservation impacts (Iskandar *et al*. 2018). Planting coffee beneath *P. merkusii* can be used to regulate the sun intensity as required, absorb nutrients from the soil within, produce organic matter like leaves to fertilize the soil, break the wind, prevent soil erosion, hinder the development of some kinds of weeds, decrease the drought impact, serve as livestock feed, and reduce maintenance expenses (Natsir *et al*. 2017). From an economic perspective, farmers have economic benefits because the cost of renting land in state forests or *Perhutani* can be more affordable. (Gunawan *et al*. 2023).

Shade plants in coffee cultivation play a role in supporting the sustainability of coffee farming, namely maintaining production in the long term (over 20 years) and reducing excess production (overbearing) and branch death (DaMatta *et al*. 2018). Coffee agroforestry with woody plants such as *T. grandis*, *F. moluccana* affects the physical characteristics of Robusta coffee beans (Prawoto & Yuliasmara 2010). The higher the level of shade, the higher the percentage of single and empty beans increases. Total macronutrients (N, P, K, calcium (Ca), Mg and sulfate (SO4) that can potentially be returned to coffee-based agroforestry land derived from shade plants of *H. tiliaceus*, *L. leucocephala*, *F. moluccana*, and *T. grandis* (Prawoto 2008). On the other hand, the use of certain types of shade plants has negative impact on coffee production. Several research results show that exudates from the roots of *P. merkusii* can inhibit the growth of other species (Supartono *et al*. 2023).

For land adjacent to non-organic land, farmers were necessary to make sure that the land registered for organic can be protected from contamination. For coffee plants, barrier plants were to use a minimum of two rows of plants (minimum four meters) managed organically, considered a buffer zone, and cannot be claimed as organic. The minimum distance was at least three meters wide for buffer zones shaped like ditches and roads. If the source of contamination was a water source, filtering must be made with a size of 0.1% of the total land area to minimize contamination.

Farmers had a conversion period of three years from the last date they used agrochemicals. The coffee plant can be declared an organic product if the conversion period passes. However, non-organic trees or seedlings from vegetative propagation were planted on the land after the conversion period. In that case, the conversion period must be repeated unless it is confirmed that the trees or seedlings are grown organically. According to informants and verified evidence, the coffee fields in Gunungsari Village were residue-free based on a recommendation from the head of the village or local agriculture office. However, the conversion lands period was a significant challenge for farmers because, during the conversion period, farmers had to wait for three years. This condition caused coffee production to decline. As a result, coffee production needs to be improved.

"...Our initial challenge in starting organic farming was changing the converted land. Previously the land was synthetic which has now migrated to organic land." [Ngarjono, translate Indonesia to English].

Farmers stated they cultivated woody and ground cover plants on sloping land locations with potential erosion, especially for non-cultivation under *P. merkusii*. The land was cleared manually by removing or using a lawn mower. These actions reflected the coffee farmers' awareness of environmental sustainability and their efforts to maintain the ecosystem around their coffee cultivation land. In this way, they can balance economically profitable coffee farming and important long-term ecological sustainability. Outside of *P. merkusii* land, farmers planted coffee trees in a mixture of fruit and commercial wood trees and medicinal plants in their agroforestry system.

The results from informants showed that 27 plant species were used in the traditional organic coffee agroforestry of Gunungsari Village. Plant species found in this study were deliberately planted. Farmers cultivated coffee with an agroforestry system based on knowledge passed down from generation to generation from families, exchanging experiences with fellow farmers, personal experiences, and information from counseling from related agencies. The government is also essential in transferring knowledge and providing facilities and infrastructure (Afrianto *et al*. 2022).

Identification of understory and tree composition in coffee agroforestry helps to know the benefits that can be used to increase biodiversity conservation efforts and the socio-economic aspects. Several previous studies have been reported regarding the relationship between plant species diversity, both undergrowth and shade, in agroforestry (Fujisawa *et al*. 2012, Kusumawati *et al*. 2022). This research unearths valuable information on how local people use the various plants around their organic coffee plantations, which can provide unique insights into the cultural and environmental relationships in sustainable farming practices in the region, especially on certified organic coffee lands. The research on ethnobotany provides excellent benefits in uncovering local knowledge and wisdom regarding the traditional use of plants, which can be used to develop the potential of natural resources and conserve biodiversity (Afrianto *et al*. 2021, Metananda *et al*. 2023, Afrianto *et al*. 2023a-c).

The description and characteristics of the plants used are presented in Table 3. The dominant family was Fabaceae (five species), followed by Malvaceae and Zingiberaceae, with four species each. Research by Kusumawati *et al.* (2022) shows different results, in which the dominating plants were the Zingiberaceae family. The composition of life forms found was only two kinds, namely herbs and trees, with a proportion of 70% and 30%, respectively. Tree species are frequently employed in agroforestry systems as fuel, a source of food for wildlife, and shade for crops (da Cruz Silva *et al*. 2023).

Meanwhile, herb plants are grown because of their benefits nutritional and medicinal potential (Aragaw *et al*. 2021). Based on observations, the existing tree land is dominated by medium trees. It is the same as Hartoyo et al. (2018), who show that medium trees dominate agroforestry land in East Kalimantan.

Table 3. Plant diversity found and their reported uses in Gunungsari Village, Central Java, Indonesia

Local name	Scientific name	Life form	Part used	Utilization	Processing	FI (%)
Altingiaceae						
Rasamala	*Altingia excelsa* Noronha	Tree	Stems	Building materials	Cut and shaped	4
Arecaceae						
Talas	*Colocasia esculenta* (L.) Schott	Herb	Tubers, leaves	Food	Boiled	8
Clusiaceae						
Manggis	*Garcinia mangostana* L.	Tree	Fruits, leaves	Food	Raw	48
Fabaceae						
Sengon	*Falcataria moluccana* (Miq.) Barneby & J.W. Grimes	Tree	Leave, stems	Building material, animal fodder	Cut and shaped	68
Kleresede	*Gliricidia sepium* (Jacq.) Kunth	Tree	Leaves	Animal fodder	Raw	44
Petai	*Parkia speciosa* Hassk.	Tree	Seeds, leaves	Food, animal fodder	Raw, cooked, cut and shaped	32
Dadap	*Erythrina variegata* L.	Tree	Stems, leaves	Animal fodder	Raw, cut and shaped	8
Lamtoro	*Leucaena leucocephala* (Lam.) de Wit	Tree	Seeds, leaves, stems	Food, animal fodder	Raw, cooked, cut and shaped	4
Lamiaceae						
Jati	*Tectona grandis* L.f.	Tree	Stems, leaves	Building material	Cut and shaped	4
Lauraceae						
Alpukat	*Persea americana* Mill.	Tree	Fruits, leaves	Food	Raw	12
Malvaceae						
Kakao	*Theobroma cacao L.*	Tree	Fruits, leaves	Food	Powdered	4
Durian	*Durio zibethinus* Rumph. ex Murray	Tree	Fruits, leaves, stems	Food, building material, animal fodder	Raw, cooked	4
Randu	*Ceiba pentandra* (L.) Gaertn.	Tree	Leaves, stems	Animal fodder, building material	Raw, cut and shaped	4
Waru	*Hibiscus tiliaceus* L.	Tree	Leaves, stems	Building material	Cut and shaped	4
Meliaceae						
Mahoni	*Swietenia mahagoni* (L.) Lam.	Tree	Leaves, stems	Building material	Raw, cut and shaped	12
Duku	*Lansium parasiticum* (Osbeck) Sahni & Bennet	Tree	Fruits, leaves	Food	Raw	4

Local name	Scientific name	Life form	Part used	Utilization	Processing	FI (%)
Langsep	*Lansium domesticum* Corrêa	Tree	Fruit, leaves, stems	Food	Raw, cut and shaped	4
Musaceae						
Pisang	*Musa* x *paradisiaca* L.	Herb	Fruits	Foods	Raw, boiled, cooked	36
Myrtaceae						
Cengkeh	*Syzygium aromaticum* (L.) Merr. & Perry	Tree	Flowers, leaves	Food	Raw	4
Pinaceae						
Pinus	*Pinus merkusii* Jungh. & de Vriese	Tree	Leaves, stems	Building material	Raw	4
Piperaceae						
Lada	*Piper nigrum* L.	Herb	Seeds	Foods	Raw, powder, cooked	9
Poaceae						
Serei	*Cymbopogon nardus* (L.) Rendle	Herb	Leaves	Foods	Raw, cooked, boiled	4
Sapindaceae						
Rambutan	*Nephelium lappaceum* L.	Tree	Fruits, stems	Food	Raw, cut and shaped	4
Zingiberaceae						
Jahe	*Zingiber officinale* Roscoe	Herb	Rhizomes	Medicine	Powdered, boiled, cooked	32
Kunyit	*Curcuma longa* L.	Herb	Rhizomes	Foods, medicine	Powdered, boiled, cooked, mashed	16
Temukunci	*Curcuma aeruginosa* Roxb.	Herb	Rhizomes	Medicine	Powdered, boiled, cooked	16
Temulawak	*Curcuma zanthorrhiza* Roxb.	Herb	Rhizomes	Medicine	Powdered, boiled, cooked	4

The most widely used part of the plant was the leaves (19 species). Utilization of leaves is important because this part is easy to obtain and the fastest to regenerate (Kusumawati *et al*. 2022). In addition, according to Aragaw *et al*. (2021), vegetable leafy plants are grown in coffee agroforestry, such as *Amaranthus graecizans*, *Portulaca oleracea*, and *Solanum nigrum*, have shown to be reliable providers of minerals (Ca, Fe, and Zn) and protein. The consumption method of these plants was mostly raw (17 species).

F. moluccana was a tree with the highest FI value (68%). *F. moluccana* was used by the community as a building plant and animal feed. The combination of coffee and *F. moluccana* is medium-term but has high economic value because it is a shade-tolerant plant with high economic value (Widiyanto and Hani 2021). This species is fast-growing, nitrogen-fixing, effortlessly grown, and generating cash revenue (Iskandar et al. 2017). *F. moluccana* plants are used as long-term savings (Rojas-Sandoval 2023). Farmers usually sold timber when there was a significant need, such as children's education, celebration parties, or other things that required considerable funds. Coffee agroforestry with *empon-empon* (herbs) and fruit was a sustainable approach in an integrated ecosystem. This integration provides potential economic opportunities for non-timber forest products in agroforestry (Affandi *et al*. 2017). In addition to financial benefits, farmers can gain greater access to medicinal plants and food sources (Sari *et al*. 2023). An agroforestry system with high economic value can provide sustainable economic and ecological benefits (Herwanti *et al*. 2019).

Economic dimension

Figure 3a shows that the sustainability status index of the traditional organic coffee agroforestry system in Gunungsari Village, based on the economic dimension, was 54.48 and classified as complete (fairly sustainable). The leverage analysis for each dimension showed that two attributes have the highest sensitive attribute in the economic dimension: sustainability business market and sales and sustainability business with an RMS value of 1.05 (Figure 3b). The Monte Carlo analysis result showed 54.51, almost identical to the MDS analysis results (Figure 3c).

Sales used a one-door system through the ICS purchasing unit. Farmers ensured that the crops bought/sold were organically managed. There was a recording of the time of entry and exit of the product in the storage area as the traceability process. In addition, harvest documentation and purchase documentation were routinely checked. The facilities and infrastructure owned by the farmer groups in implementing farming community empowerment activities in developing organic coffee were complete. One of the obstacles for farmers was market access. This was because the price of organic coffee tended to be more expensive, and the market was narrow at the domestic level. The cost of coffee was IDR 150,000/kg in roasted beans and IDR 155,000/kg in powder. Organic coffee was 10-30% more expensive than non-organic coffee because it required additional costs, had more complex cultivation than conventional farming, and had lower yields because it did not use pesticides and chemical fertilizers. Organic and non-organic coffee are physically the same, but they taste different. In Indonesia, the customer persona for organic products is middle-class households with higher education or for export purposes (Wahyudi & Ardiansyah 2017). According to Saragih (2013), the price of certified coffee is higher, but coffee productivity is lower by up to 8% compared to conventional coffee.

"...The difference between organic and non-organic coffee lied in its taste. According to many who have consumed organic coffee, it was safe for the stomach and can even be used for therapy for stomach ulcers." [Ngarjono, translate Indonesia to English].

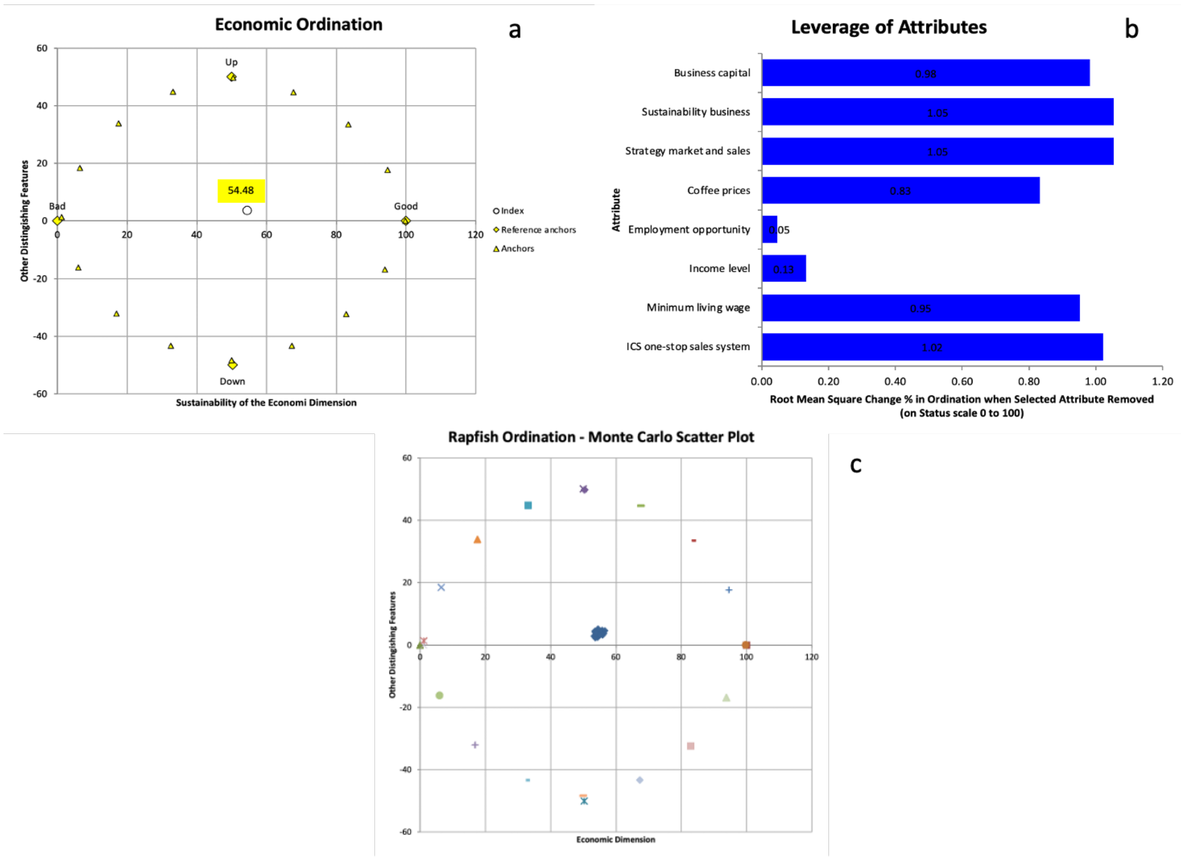

Figure 3. Sustainability ordination index values of economic dimensions, (a) MDS analysis, (b) leverage analysis, and (c) Monte Carlo analysis

Social dimension

Figure 4a shows that the sustainability status index of the traditional organic coffee agroforestry system in Gunungsari Village, based on the social dimension, was 74.25 and classified as complete (fairly sustainable). The leverage analysis for each dimension shows that an attribute with the highest sensitivity was education level, with an RMS value of 8.62 (Figure 4b). The Monte Carlo analysis result showed 73.67 (Figure 4c).

Low farmer education was a challenge that needed serious attention in efforts to improve the welfare of agricultural communities. Low-income farmers often required more access to formal education and skills training that could increase their agricultural productivity. Lack of knowledge about modern farming practices, natural resource management, and the latest agricultural technology hindered low-income farmers from optimizing their agricultural yields. Therefore, collaboration efforts were needed from the government, educational institutions, and non-governmental organizations to provide support through training, technical guidance, and access to information that can improve the quality and sustainability of low-income farmers' agriculture. Education focused on sustainability, application of appropriate technology, and strengthening managerial skills can help low-income farmers face the challenges of climate change and improve food security in their communities.

The importance of inclusiveness, safety protection, and workers' rights in the work environment was the main foundation for ensuring the sustainability and welfare of society as a whole. Inclusivity provides equal opportunities, regardless of background or identity. Protection of workers' security and rights was critical in ensuring workers had access to safe working conditions and rights and welfare guaranteed by law. A work time system that was balanced and not excessive was also an essential aspect of maintaining a balance between productivity and worker welfare.

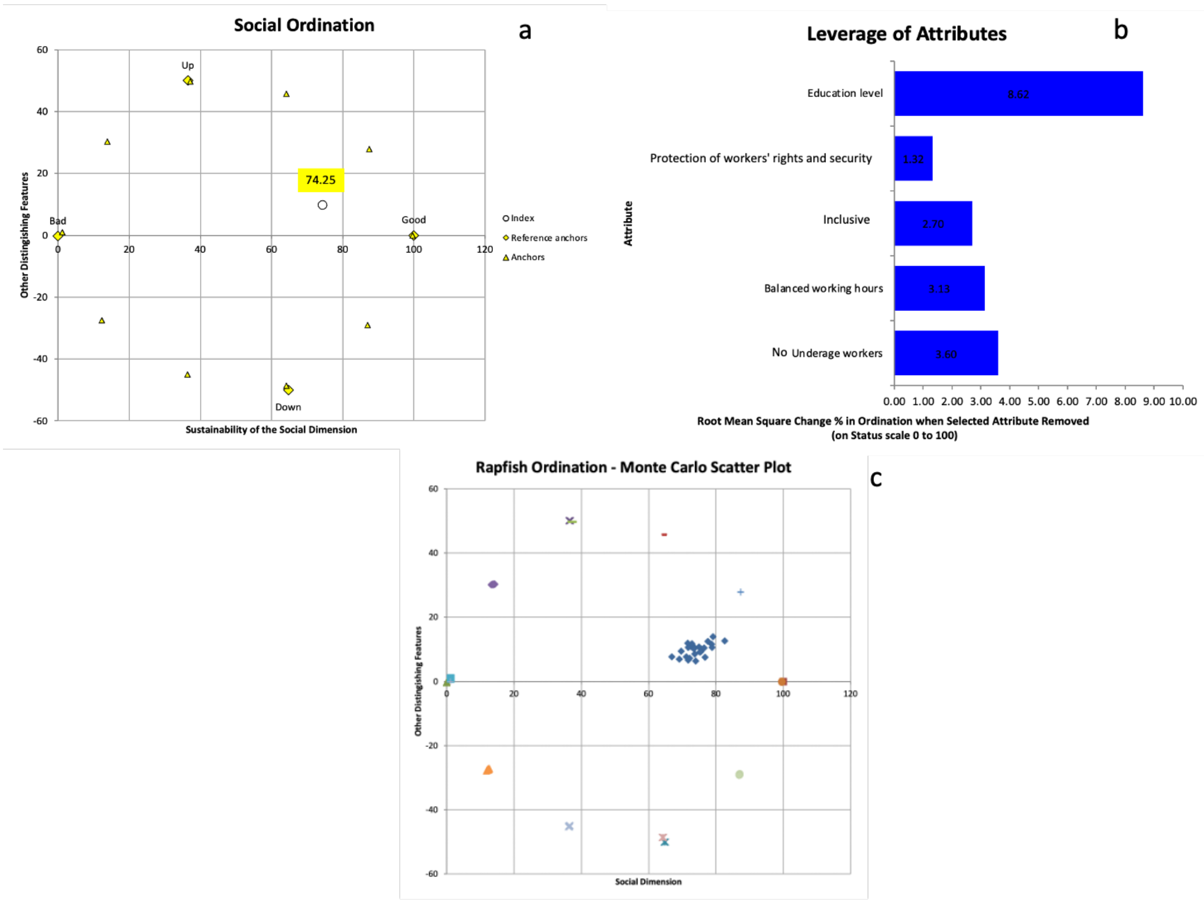

Figure 4. Sustainability ordination index values of social dimensions, (a) MDS analysis, (b) leverage analysis, and (c) Monte Carlo analysis

Institution dimension

Figure 5a shows that the result of the sustainability status index of the traditional organic coffee agroforestry system in Gunungsari Village based on institution dimension was 51.87 and classified as complete (fairly sustainable). The leverage analysis for each dimension showed that conflict frequency was the most sensitive attribute in the institution, with an RMS value of 1.66 (Figure 5b). These values indicated that the ICS system was deficient and could be handled. The Monte Carlo analysis result showed 51.61 (Figure 5c).

ICS was created to implement organic agriculture. ICS organized agricultural activities that adhered to organic farming principles and developed procedures and regulations. The objective of ICS was to control risks, adhere to rules, improve the effectiveness and sustainability of agricultural enterprises, and uphold the integrity and quality of organic products. The important elements of ICS were: (1) establishing procedures and standards for agricultural methods. (2) Recording and documenting all agricultural actions from seed selection through post-harvest procedures. (3) Educating and training on the fundamentals of organic farming and the significance of upholding internal standards. (4) Monitoring and evaluating each step of the agricultural process complies with the organic criteria. (5) Monitoring risk management to assess and control risks related to organic farming. (6) ICS guaranteed specified organic criteria for quality. (7) Communicating and collaborating with relevant parties, including consumers, retailers, and organic certification bodies.

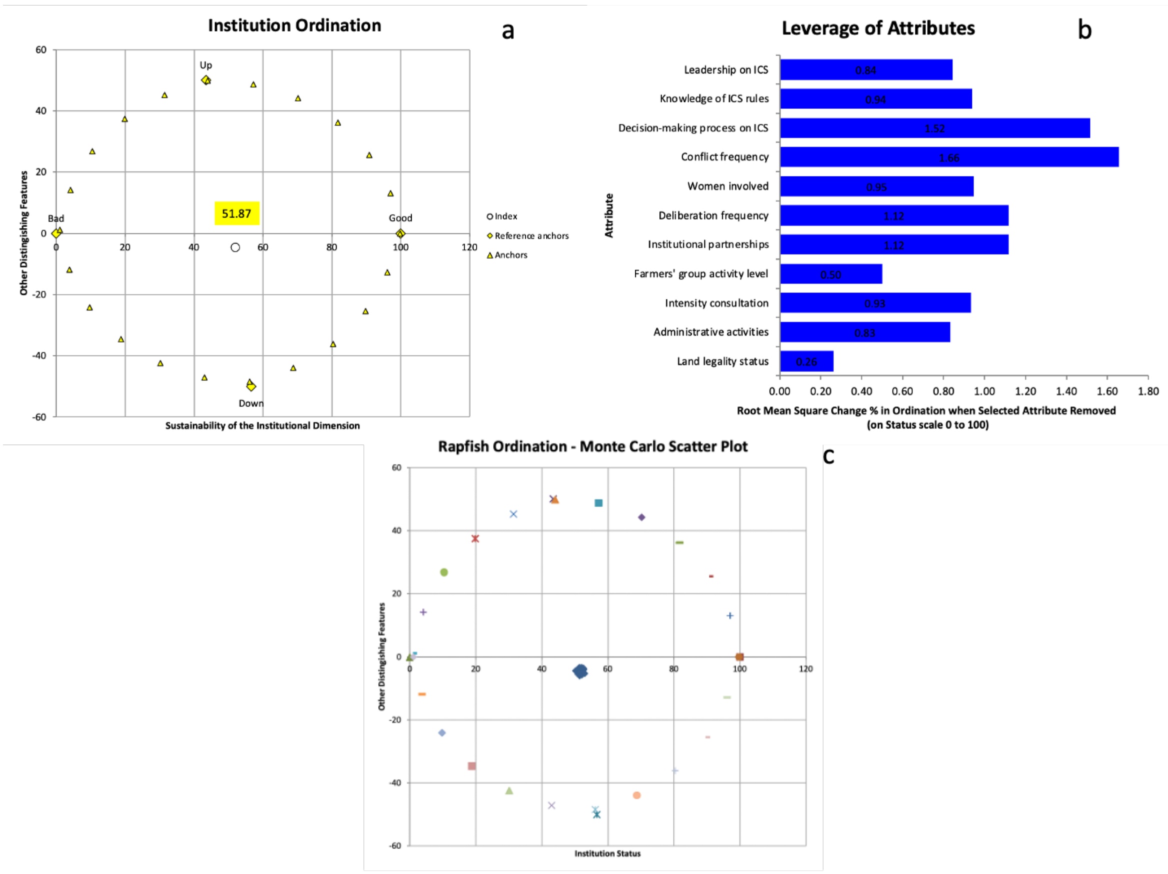

Figure 5. Sustainability ordination index values of institution dimensions, (a) MDS analysis, (b) leverage analysis, and (c) Monte Carlo analysis

The ICS in Gunungsari Village had a structure and desk, as shown in Table 4. The organizational structure included an ICS manager, an internal approval committee, registration and training officers, internal inspectors, purchasing units, and sectaries. The structure selection was carried out by deliberation. The appointment was made based on a direct commission based on an agreement. Even though there were no specific criteria, people with activeness and competence were chosen.

Table 4. ICS of the organic coffee in Gunungsari Village, Central Java, Indonesia

Position	Job description
Manager ICS	1. Supervise ICS
	2. Provide resources and hire member
Secretary ICS	1. Manage administration files in ICS
	2. Organize data and report to ICS manager
Internal approval committee	1. Supervise field

	2. Develop and conduct internal control
	3. Communicate with the manager
	4. Review and decide on the results of the internal inspection
	5. Decide sanction against farmers
Internal inspector	1. Conduct internal inspection to all member lands
	2. Conduct inspection to farmers document
Purchasing unit	1. Ensure the traceability of product
	2. Clean the storage area
	3. Sign the organic product receipt
Registration and training	1. Maintain map and note for producer
	2. Inform producer about the standard and the need for improvement
	3. Train member and producer in organic production
	4. Register and contract manufacture

Women's participation in ICS management was significantly lower or almost non-existent, but they were involved in nearly all stages of plant coffee cultivation. According to informants, women were involved in planting coffee seedlings, managing coffee plantations, and harvesting coffee cherries. They had an essential role in maintaining the coffee bean's quality. Women were also involved in processing coffee beans after harvest. They can carry out processes such as drying, sorting, and peeling coffee beans. Women were suitable for administrative activities that required neat, thorough, and structured record-keeping. However, according to Muhaimin *et al*. (2023), women are more likely to be aware of agricultural sustainability, for example, by adopting organic fertilizers and bio-pesticides.

Organic farming was a new method for Gunungsari Village farmers, but had several challenges and problems. Difficulties were encountered both in terms of certification administration and cultivation issues. Thus, ICS should train farmers to increase building capacity, commitment, production quality, and yields. It was also necessary to fulfil adequate infrastructure aspects because this would increase farmer involvement and produce optimal results.

The agent of change was crucial in the success or failure of the farming community empowerment program. Change agents were empowerment actors who had stages for carrying out empowerment. The Department of Agriculture (Extension Officers), ICS, OCI, and BPTPHP Central Java were agents of change or empowerment actors here (Figure 6). Based on the interview and previous research (Hidayati *et al*. 2020), we classified stakeholders into seven priorities.

Figure 6. Stakeholder analysis

In addition to the stakeholders above, internal village institutions were involved in the organic coffee program. For example, Forest Village Community Institution was involved in helping, especially with the legality and licensing aspects. On the other hand, other local institutions, such as the Youth Organization (*Karangtaruna*), Neighborhood Association (*RT*), and Community Association (*RW*), were not directly involved. Routine agendas were carried out by visiting the homes of the management of the farmer group once a month. It can also be done outside the schedule without an urgent agenda. In addition, consultations were carried out with an uncertain schedule and can be done informally.

Table 5. Topic of education training for ICS

Topic	Description
Quality system documents	1. Quality management
	2. Quality management requirements
	3. Basic documents of organic systems
Good agriculture practice	1. Introduction to the ICS quality system
	2. Terms and principles of quality control
	3. ICS and job description structure
	4. Conflict of interest
	5. Membership
	6. Making land maps
	7. Risk management
	8. Internal inspection
Institutions and market development	1. Strengthening institutions
	2. Market introduction
Sustainable practice	1. Control of plant pest organisms
	2. Soil fertility management

Farmers who previously cultivated non-organic coffee received education directly from OCI, agricultural extension workers, and related agencies. With the organic village program implemented in Gunungsari Village, the Wanna Lestari farmer group provided education regarding organic cultivation as applied to organic coffee. An educator had a person's ability to increase awareness through information and knowledge. Teaching was carried out by holding outreach activities and training for farmer groups. The material covered four main topics: quality system documents, good agricultural practice, institutions and market development, and sustainable practice (Table 5).

The role of a facilitator was to accompany and provide encouragement, knowledge, assistance, and advice to a group in solving problems so that the group can progress further. The facilities provided include socialization, allowing livestock to make vegetable fertilizer or bokashi, organic coffee processing equipment, and organic certificates. The assistance provided by the government was all to support the development of organic coffee in farmer groups. It took farmers four years to complete the assessment, which will then be submitted to OCI. After five years of running this program, a new organic certificate was issued.

Regarding empowerment, consultants provided management assistance in planning a program. Management of a program included planning, financing, supervision, monitoring, coordination, and control. The consultant had a role in helping run programs, such as socialization and training for the farming community members of the Wanna Lestari farming group. The consultation program was carried out regularly once a month with regular meetings. However, farmers can also consult with related parties regarding their obstacles outside the consultation program.

Companion was carried out from the program's start until after passing organic certification. At this time, assistance was provided to solve individual or group problems and achieve a goal. There were two types of companions: field assistance and regional assistance.

Supervision was carried out to ensure the program ran smoothly according to plan. It involved observing the implementation of all organizational activities based on predetermined procedures. It was done by coming directly to the farmer's house to see whether the storage was organic. For example, monitoring land planted with coffee must be free from residue and other chemicals. ICS had a role in this supervision through internal supervision.

The farmer group carried out the evaluation, which was conducted to determine organic coffee cultivation according to guidelines. Government stakeholders were involved during the evaluation process. So far, the program review had been running satisfactorily for five years until the issuance of an organic certificate for the Wanna Lestari farmer group.

The connector's role was to bridge information between one stakeholder and another. This connector was essential for empowerment in developing organic coffee. It was because information was shared more specifically by disseminating information.

Management technology dimension

Figure 7a shows that the result of the sustainability status index of the traditional organic coffee agroforestry system in Gunungsari Village based on the technology dimension was 59.07 and classified as complete (fairly sustainable). The leverage analysis for each dimension showed that technology knowledge of sales and marketing had the highest sensitive attribute with an RMS value of 1.25 (Figure 7b). The Monte Carlo analysis result showed 58.50 (Figure 7c).

Farmers used certified organic seeds or organically managed self-breeding results. Using radiation-treated and genetically modified organism (GMO) seeds was prohibited in organic farming. The seeds used by farmers also did not use chemical treatments. The water used in the nursery did not come from chemically contaminated sources. Seeds from the field can be used by sorting and soaking them in a water bath and selecting the coffee cherries that sink. Picked coffee cherries were peeled by hand or stepped on with feet. Peeling can also be done with a fruit skin peeler. The peeled coffee cherries (grain coffee) were fermented for 12 hours and washed to remove the mucilage. The grain coffee was air-dried in the shade for two to three days (about 30% moisture content). The last step was sorting by selecting pithy-grain coffee with a straight center line.

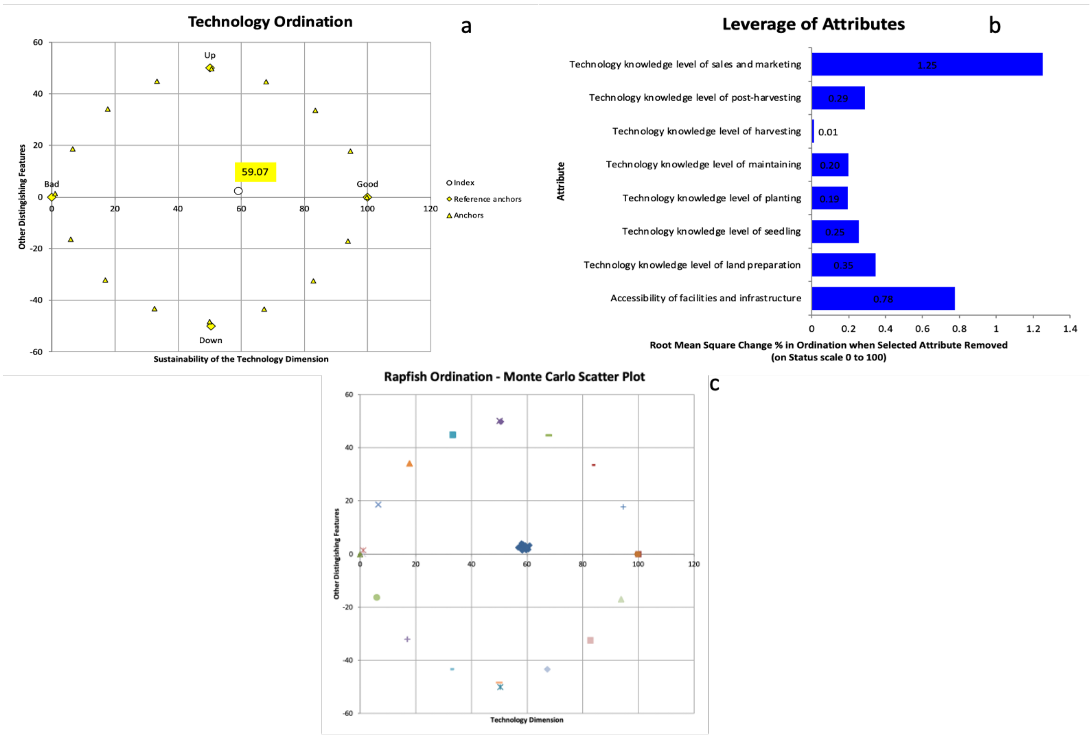

Figure 7. Sustainability ordination index values of institution dimensions, (a) MDS analysis, (b) leverage analysis, and (c) Monte Carlo analysis

According to the farmers, the vegetative rejuvenation method for transplanting coffee stems was done by grafting old coffee trees in the garden. Farmers generally used good-quality seeds to grow coffee as a generative rejuvenation method. Farmers selected the coffee seeds used for cultivation to ensure good quality. The success of farmers in coffee farming was due to their ability to integrate local knowledge with modern cultivation provided by the government through extension programs. According to Musa *et al*. (2019), rejuvenation trimming is one of the variables that significantly influences coffee productivity, especially the Arabica variety.

Farmers controlled weed by cutting or manually (physical and mechanical). For conditions where weeds are not dense in coffee plantations (no competition), farmers do not need to clean them (Ronchi et al. 2018). Farmers also operated cover crops (mulch) or green manure that can be intercropped with coffee. Residues from other agroforestry plants and coffee trees can be used as mulch (Fontes *et al*. 2022). Although manual weeding is slow and tiring, it is one of the most critical control methods on coffee plantations (Ronchi *et al*. 2018). The right time for weeding can be done at the growth stage and two years after planting the seeds in the field. According to Teferi (2017), manual treatments have more or less the same results as synthetic herbicides.

Figure 8. The concept of an integrated farming system of coffee plants and goats

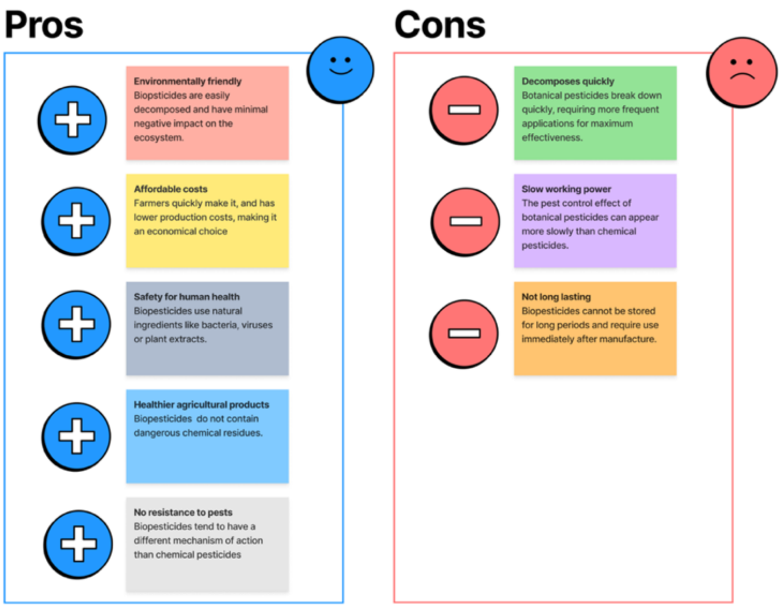

Figure 9. The advantages and disadvantages of using biopesticide according to the Wanna Lestari farmer group

Based on farmers' information, the coffee berry borer attack (*Hypothenemus hampei*) was the most common pest. This pest has been reported as a significant reason for harvest loss and deduction of fruit quality for coffee plants in many countries (Johnson *et al*. 2020). It can be managed for pest control by preserving and utilizing natural enemies of pests as natural pest control (Campera *et al*. 2021). For example, vertebrates and birds have multiple functions in coffee cultivation, such as seed dispersal, pollination, and pest control (Subrata & Syahbudin 2016; Ratto *et al*. 2018; Chain-Guadarrama *et al*. 2019). Farmers use repellent plants or living fences to repel pest attacks (Latifah *et al*. 2018; Latifah *et al*. 2019). Farmers can also apply *Trichoderma spp*. as a biological control because this filamentous fungus has a versatile mode of action (Lyubenova *et al*. 2023). Using biopesticides in organic systems has several disadvantages and advantages based on farmers' experiences (Figure 9).

Farmers ensured that the harvest area and equipment were always free from contaminants. The tools used had to be specific to organic products. If this was not possible, farmers usually washed the tools after use. Farmers also did not use chemical packaging residue. Farmers recorded yield estimates and harvest records to maintain a mix of organic and non-organic crops. The yield estimation method was calculated based on the number of coffee produced multiplied by the average coffee production per plant, considering the climatic/weather conditions per harvest season.

After the post-harvest process, farmers separated organic and non-organic coffee yields. The harvest was ensured from animal waste, oil, gasoline, or other contaminants. Processing was carried out using an exceptional or conventional organic coffee grinding machine, and the initial one-kilogram calibration was not considered organic coffee. Coffee was stored in harvested warehouses in clean conditions and separated between organic and non-organic. The harvest warehouse was cleaned for storage one week before the harvest season began, as evidenced by the warehouse cleaning records. Pest control in storage areas should not be carried out by spraying chemicals. The packaging site was given an organic label and farmer codes to avoid product mixing. There was a recording of the time of entry and exit of the product in the storage area. There were practical guidelines that farmers can refer to in carrying out the production process of organic coffee cultivation, including procedures for accepting members, imposing sanctions, purchasing and selling through ICS, internal inspections, internal approvals, filing appeals, handling complaints, issuing and revising documents, and document control.

Challenges

The Wanna Lestari farmer group in Gunungsari had established itself as a key social institution supporting organic coffee development. However, investigations revealed that not all aspects of the institution were functioning optimally. For instance, the training activities, which were currently organized monthly, needed to be expanded. The education level among farmer group members remained relatively low, with a predominance of elderly individuals. The age and educational background of the farming community affected their ability to receive and apply information and knowledge from community empowerment activities.

Research indicated that the facilities and infrastructure available to the farmer groups involved in organic coffee development were generally complete, enabling the smooth conduct of related activities. Proper facilities and infrastructure were crucial for effective community empowerment, and their availability enhances the community's willingness to engage in these activities. However, farmers reported several challenges, such as the need for a permanent location for roasting equipment and ongoing issues with administrative processes due to limited human resources. The central government funded the development of organic coffee through program-based financing. Despite this, farmer groups also managed their costs, which the farmers themselves primarily cover. The narrow market share limited the profitability of organic coffee cultivation, meaning that the economic impact on the farming community had been minimal.

Conclusions

The study on traditional organic coffee agroforestry in Pati Regency highlighted its multidimensional sustainability, and it was fairly sustainable across various dimensions: ecological, economic, social, institutional, and technological management. While the system excels in environmental practices such as prohibiting illegal hunting, it faced challenges in agrobiodiversity, which was identified as a weaker attribute. Economically, the system was strengthened by sustainable business practices and robust marketing strategies, but improvements were needed to create more employment opportunities. Socially, the focus on education enhanced sustainability, yet the lack of worker protection and security diminished these gains. Institutionally, the management of conflict frequency stood out, although land legality was seen as less crucial in this context.

Technologically, while sales and marketing knowledge was strong, improvements were necessary in planting techniques.

Integrating agroforestry with organic coffee plantations was highly beneficial across all these dimensions. Farmers minimized economic risks by diversifying income streams and not relying on a single commodity. Their collaboration with *Perhutani* ensured that economic benefits were not at the expense of environmental conservation. This balance between financial gain and forest preservation showed a sustainable model that other regions can adopt. The success of the organic coffee farming program was also attributed to the involvement of various stakeholders, such as educators, consultants, supervisors, and funders, who work together to support the program.

To further strengthen ecological resilience in the region, biodiversity must be bolstered through more varied plant species. Limited market access and the premium cost of organic coffee presented significant economic hurdles. Despite this, farmers managed to secure economic advantages by adopting sustainable business models and improving their marketing efforts. Organic certification added value to the coffee, appealing to domestic middle-class consumers and the export market due to its superior quality and safety. These factors positioned coffee as a competitive product in the global market, albeit with room for broader market penetration and employment generation.

Institutionally, the ICS played a critical role in maintaining the standards of organic coffee farming. The system effectively supervised and regulated farming practices, ensuring compliance from planting through post-harvest. While internal conflicts among farmers were minimal, indicating the robustness of the institutional framework, there remained an opportunity to increase women's participation in ICS management. This was especially important, considering their substantial contributions to coffee cultivation and processing.

The implications of this study indicated that with support from the government and related institutions in the form of education, infrastructure, and market access, the organic coffee agroforestry system can continue to develop sustainably. The combination of economic success, environmental conservation, and social empowerment suggested that this model can be replicated in other areas. Increasing farmers' capacity through training and access to modern agricultural technology will further strengthen their resilience in facing future agricultural challenges.

Declarations

List of abbreviations: BPTPHP - the Horticulture and Plantation Food Crops Protection Agency; GMO -genetically modified organism; HCV - high conservation value; ICS - Internal Control System; MDS - Multidimensional Scaling; OCI - Organic Certification Institute; RMS - Root Mean Square; TEK - traditional ecological knowledge; RAPFISH - Rapid Appraisal for Fisheries; SD - elementary school-; SMP - junior high school; SMA - senior high school.

Ethics approval and consent to participate: This study was conducted according to the ethics guidelines of the International Society for Ethnobiology Code of Ethics All the participants provided prior informed consent before the interviews.

Consent for publication: Not applicable

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Author contributions: WFA conducted the research idea, data collection, analyzed and interpreted the data, drafted the initial manuscript, revised and improved the manuscript. RJT, SWI, MIz, Z, and HPS analyzed and interpreted the data. MI and TH revised and improved the manuscript. All the authors read, reviewed, and approved the final version of the manuscript.

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