Research Article

Ethnobotanical Values in Ecosystem Conservation of Coffee-Based Agroforestry System on the Slope of Mt. Semeru, East Java

Luchman Hakim[1]*, Jehan Ramdani Hariyati[2] and Erona Wafaretta[3]

[1]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia; [2]Graduate School, Universitas Brawijaya, Jl. MT. Haryono No. 169, Malang 65145, East Java, Indonesia; [3]Department of Biology, Faculty of Mathematics and Natural Sciences, State University of Makassar. Jl. Mallengkeri Raya, Makassar, 90224, South Sulawesi, Indonesia.

Abstract | Planting coffee farms using agroforestry practices is one strategy to create an important ecosystem to assist numerous rural development programs and supported biodiversity conservation in Mt. Semeru National Park, Poncokusumo, East Java. The aim of this research is to describe the plant species diversity in a local preserved coffee-based agroforestry system on the slope of Mt. Semeru. A field survey was conducted at four preserved coffee-based agroforestry orchards in Poncokusumo. Data were taken qualitative by interview to find out the ethnobotanical function of plants, and quantitative data were collected using plotting at each location (individual number, frequency, and dominance relatives) to be analyzed to find out the important value index and diversity index. There are 61 plant tree species found in coffee-based agroforestry orchards, which have numerous benefits in supporting the basic needs of the local community. The dominant species differed each plot, with the highest IVI in *Hibiscus macrophyllus* (151.52), *Erythrina subumbrans* (148.48), and *Paraserianthes falcataria* (110.38). The H' values ranged from 0.69 to 2.63, indicating that high dominance of one species tends to reduce vegetation diversity. These findings confirm that coffee agroforestry in Poncokusumo is a multifunctional system that integrates ecological and economic functions, and has the potential as a nature-based solution for food security and sustainable landscape management in the buffer zone of the national park.

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***Correspondence** | Luchman Hakim, Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia; **Email:** luchman@ub.ac.id
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Introduction

Agroforestry is one of the sustainable agricultural practices that takes advantage of the indigenous knowledge of the local community. In Indonesia, rural residents have adopted agroforestry as a crucial strategy to ensure family subsistence and food resilience. This sustainable agricultural practice receives appreciation as a traditional ecological farming system providing social, economic, and ecological benefits. Agroforestry practices are highly suggested as a strategy to reduce global warming and avoid the phenomenon of land degradation. In many agroforestry systems, indigenous knowledge of the local community contributes to the vegetation structure of the agroforestry (Michon and De Foresta, 1991; Rajasekaran *et al*., 1991; Schroth *et al*., 2004; Lin 2007; Rahu *et al*., 2013; Thaman *et al*., 2017). Besides being ecologically sustainable, many agroforestry systems have recently decreased both in terms of quality and quantity. Many agroforestry systems with a high number of plant species have been replaced by the monoculture plantation system (Liu *et al*., 2018).

The growing population in rural areas causes a decrease in agricultural lands with a high number of plant species as the lands are transformed into human-dominated ones (e.g., settlements) (Verma and Raghubanshi, 2019). These phenomena are crucial, especially for areas located adjacent to national parks. Transformation of agricultural land systems with a high number of plant species into land systems with a low number of plant species impacts the national park system (Elmqvist *et al*., 2005; Hakim *et al*., 2019). Coffee-based agroforestry is one of the most interesting agroforestry systems in Indonesia. Smallholder coffee farmers in Indonesia cultivated coffee under the shade of trees, mixing with various plantations, from herbs to trees. The structure of coffee-based agroforestry in many areas of Indonesia is rich in biodiversity and might contribute directly to biodiversity conservation (Michon and De Foresta, 1991; Toledo and Moguel, 2012; Ruslim *et al*., 2017). Diverse plant species in the agroforestry system provide significant contributions to community food resilience, which is also a crucial contribution to home gardens in global food resilience programs (Duffy *et al*., 2021).

Many countries, especially in developing countries, have recently been interested in developing a strategy for improving home garden systems, which further contributes to a resilient food program implementation (Maredia *et al*., 2023). Researchers stated that agroforestry with a high abundance of food resources represents the knowledge and capacity of local people to sustain and improve their livelihood and well-being despite environmental and economic disturbances (Mulugeta, 2014; Pancholi *et al*., 2023). In developing countries with an abundance of flora in home gardens, exploring diverse types, vegetation diversity, composition, and structure was important to support food resilience programs. Local community knowledge is key to describing the various benefits of flora among the locals, especially edible flora as a food resource. Therefore, conducting an ethnobotanical study in the less-studied agroforestry area was crucial for supporting the programs' implementation of food security and resilience (Michon and De Foresta, 1991; Rahu *et al*., 2013; Thaman *et al*., 2017).

Agroforestry not only promotes greater coffee plant development, but it also benefits the social and economic well-being of rural people, making it a sustainable farming practice (Santoro *et al*., 2023). The rural area in the western part of Mt. Semeru plays an important role in supporting the Bromo Tengger Semeru National Park (East Java) ecosystem through the conservation of rural landscapes, including coffee-based agroforestry as one of its components. With the abundance of farmlands, those with an agroforestry system are potential sites of buffer areas for biodiversity conservation inside the national park ecosystem. Evaluating and strengthening farmlands in the periphery of the conservation area were important (Lynagh and Urich, 2002; Mayele and Bongo, 2023). Few studies have been done to evaluate the diversity of plant species in agroforestry in the rural areas of the western area of Mt. Semeru. The aim of this present study is to describe the plant species diversity in a locally preserved coffee-based agroforestry system on the slope of Mt. Semeru in Poncokusumo, East Java. It is important to determine the potential of a coffee-agroforestry system in supporting numerous rural development programs and biodiversity conservation in Bromo Tengger Semeru National Park.

Materials and Methods

Study area

A field survey was conducted at Pandansari Village in Poncokusumo sub-district, Malang (8.0717° S, 112.808° E), shown in Figure 1. Coffee-agroforestry orchards were distributed at elevations ranging from 700 to 1000 m a.s.l. in the western area of Mt. Semeru. Located at the periphery of Bromo Tengger Semeru National Park, this village plays an important role as a buffer area in the regional conservation system. It means the quality of the environment in the villages contributes to the success and sustainability of biodiversity conservation programs. Many areas located on the slope of Mt. Semeru are considered the center of coffee production areas, as coffee-based agroforestry systems are applied. Initiated in the past decades, the recent center of the coffee plantation covered a wide area in sub-regencies of Dampit, Tirtoyudo, Ampel Gading, and Poncokusumo. Recent coffee orchards in Poncokusumo, however, have decreased significantly in their cultivation area (Hakim, 2021). The introduction of citrus (*Citrus L.*), apple (*Malus sylvestris*), and sugarcane (*Saccharum officinarum*) has recently transformed many coffee-based agroforestry systems into monoculture-based farmlands. Even so, some paths of coffee-agroforestry orchards still exist under the traditional management approach.

Figure 1: *Sampling area in Pandansari village, East Java. The dot area in East Java indicates the Poncokusumo sub-district, Malang.*

Methods

A field survey was performed by exploring the Pandansari Village in Poncokusumo sub-district area to identify the existence of the agroforestry system. Data collected in January-August 2021. An interview with a chief leader was conducted to collect comprehensive information and obtain permission to conduct the field survey before finally deciding on the selected study area. Interviews with informants were conducted to describe the traditional names of species in coffee plantations, as well as their cultivation status and functions. Informants consisted of representative coffee-farming families, including men and women responsible for the coffee cultivation. The local names collected in this research are the names used by residents to refer to types of plants and species for identification. Tree species were identified and counted to collect data related to individual number, frequency, and dominance relatives.

Result of a preliminary survey, four coffee-based agroforestry plots were selected as a representative coffee-based agroforestry system. The distribution of the sampling area can be seen in Figure 1. A quadrat plot of 20x20 m was set in each plot for vegetation survey and analysis. Each plot has specific characteristics, as shown in Table 1. In each plot, plants have previously been identified according to their morphological traits. An important value index (IVI) of plants composing agroforestry was analyzed to provide information on the ecological importance of species in coffee-based agroforestry following the standard methods (Kent, 2011).

Table 1: *Description of the observed plot area*

Plot	Codes	Description
1	MHN	Agroforestry with newly planted *Coffea arabica* in 2018.
2	SNW1	Agroforestry was established in 2010 with numerous plant tree species and planted with *Coffea liberica* in 2011-2013.
3	SNW2	Agroforestry was established in 2010 with numerous plant tree species and planted with *Coffea liberica* in 2011-2013.
4	JN	Agroforestry with *C. arabica* and *C. canephora.* No information regarding the year of its establishment
5	PON	Agroforestry with a mixture of *C. arabica* and *C. canephora* populations, established in 2010

The IVI formula (Aminatun *et al.*, 2021):

$$IVI = RD + RF + RDm$$

With Density (D) and Relative Density (RD)

$$D = \frac{Total\ number\ of\ individual}{Total\ Plot\ area}$$

$$RD = \frac{D\ of\ a\ species}{D\ of\ all\ species} \times 100\%$$

Frequency (F%) and Relative Frequency (RF)

$$F = \frac{\Sigma sub\ plot\ observed\ species}{\Sigma All\ sub\ plot\ sampled}$$

$$RF = \frac{F\ of\ a\ species}{F\ of\ all\ species} \times 100\%$$

Dominance (Dm) and Relative Dominance (RDm) formula (Aminatun *et al.*, 2021):

$$Dm = \frac{Size\ of\ the\ plot\ of\ species}{Size\ of\ the\ plot\ sampled}$$

$$RDm = \frac{Dm\ of\ a\ species}{Dm\ of\ all\ species} \times 100\%$$

Table 2: *Some important herbs and shrubs found in the coffee-based agroforestry system of the study areas*

No	Local name	Species name	Function
1	Gamal	*Gliricidia sepium*	Animal feed, shading trees, bio-fences
2	Calliandra	*Calliandra calothyrsus*	Animal feeds, soil conditioners, soil protections against erosion
3	Pepaya	*Carica papaya*	Consumption (fruits, young leaves), shading plants, fruit sold as additional income
4	Pisang	*Musa* spp.	Consumption, shading plants, fruit, and leaf sold as additional income
5	Labu siam	*Sechium edule*	Consumption, fruit sold as additional income
6	Puring	*Codiaeum variegatum*	Ornamental plants, bio-fences
7	Pandan betawi	*Dracaena angustifolia*	Food ingredients, natural dye, bio-fences
8	Teh-tehan	*Acalypha siamensis*	Bio-fences, grow wild
9	Jarak pagar	*Jatropha curcas*	Bio-fences, marks of land border
10	Bentoel	*Colocasia* sp.	Food, sold as additional income
11	Mbote	*Colocasia esculenta*	Food, sold as additional income
12	Delekan	*Cestrum nocturnum*	Fences, grow wild
13	Lombok	*Capsicum annum*	Consumption, spices, sold as additional income
14	Jagung	*Zea mays*	Food, sold as additional income, animal feeds
15	Kacang kapri	*Pisum sativum*	Vegetables, cultivated for income
16	Benguk	*Mucuna pruriens*	Food, vegetables
17	Serut/garut	*Maranta arundinacea*	Food, starch sources
18	Terong pokak	*Solanum torvum*	Vegetables, grow wild as weed
19	Paku tiang	*Cyathea contaminans*	Grow wild, as ornamental plants

Data analysis was carried out using diversity indices of Shannon-Wiener (H') to show species richness in the plot using the total number of species in the sample and the total number of individuals (Abedi and Pourbabaei, 2010). The diversity index is analyzed based on 3 stages of categories, namely trees, poles, saplings, and ground covers category. The Shannon-Wiener Diversity Index formula (Abedi and Pourbabaei, 2010):

$$H' = -\sum_{i=1}^{n}\left[\left(\frac{ni}{N}\right) ln \left(\frac{ni}{N}\right)\right]$$

Where: H' : Diversity Index
ni : Number of individuals of each species
N: Total number of individuals

Results

Plant species found in agroforestry plots vary from trees, shrubs, and herb types. These plants were previously cultivated and grew together in a single patch called an agroforestry system, locally called *kebon* (English: garden). Plants can be classified as species introduced and cultivated in agroforestry systems due to their specific values or properties, and as plant species that grow wild through the natural dispersal and seedling mechanism. Three species of coffee were cultivated under the agroforestry system, including *Coffea arabica*, *Coffea canephora*, and *Coffea liberica*. According to respondents, *Coffea arabica* was cultivated a long time ago as the main coffee species in rural communities. The result of species identification shows that *Coffea arabica var. typica* is the dominant arabica species in the local agroforestry garden. A good flavor of this coffee species has often been said to be the main consideration in making *Coffea arabica var. typica* the main coffee cultivation.

Coffea canephora is the most common coffee species cultivated under the agroforestry system in Pandasari. The local community recognized the species as robusta or besta. Robusta is a commonly consumed coffee bean, especially by people in East Java. The robusta consumer recently increased significantly, following the trend of recent coffee consumption in East Java. There are various cultivars of robusta coffee, including the BP series and Tugusari. Only a few populations of *Coffea liberica* were cultivated in the agroforestry system due to the lower productivity of liberica coffee (Davis *et al*., 2020). Coffee-based agroforestry systems consist of diverse plant species

Table 3: *Plant tree species found in the coffee-based agroforestry system of the study areas*

No	Local name	Species name	Cultivation status	Functions
1	Angrung	*Trema orientalis*	Gw.	Allowed growing as timber
2	Alpukat	*Persea amaericana*	Cu.	Wild variety with less productivity, fruit is often eaten by bats
3	Awar awar	*Ficus septica*	Gw.	Periodically cleared
4	Bambu Ampel	*Bambusa vulgaris*	Cu.	Civil construction, sold as income
5	Bambu Kuning	*Bambusa vulgaris* var. Striata	Cu.	Ornamental plants
6	Bambu Apus	*Gigantochloa apus*	Cu.	Civil construction, sold as income
7	Bambu Jabal	*Schizostachyum brachycladum*	Cu	Sold as income
8	Bambu Jajang	*Giganthocloa nigrocillata*	Cu.	Civil construction, sold as income
9	Bambu Ori	*Bambusa bambos*	Cu.	Civil construction, sold as income
10	Bambu petung	*Dendrocalamus asper*	Cu.	Civil construction, sold as income
11	Bambu Jawa	*Gigantochloa atter*	Cu.	Civil construction, sold as income
12	Bambu Rampal	*Schizostachyum zollingeri*	Cu.	Sold as family income
13	Bendo	*Artocarpus elasticus*	Cu.	Allowed growing as timber
14	Beringin	*Ficus benjamina*	Gw.	Preserved in the sacred area
15	Cempaka	*Magnolia champaca*	Cu	Allowed growing as timber
16	Cengkeh	*Syzigium aromaticum*	Cu	Flower harvested and sold as income
17	Dandanggulo	-	Gw.	Allowed growing as timber
18	Durian	*Durio zibethinus*	Cu.	Allowed growing as timber, and fruit sold as income
19	Genitu/kenitu	*Chrysophyllum cainito*	Cu.	Fruit sold as income
20	Gmelina	*Gmelina arborea*	Cu.	Sources of timber, shading trees
21	Dadap	*Erythrina subumbrans*	Gw.	Allowed growing as shading trees
22	Jabon	*Neolamarckia cadamba*	Cu.	Sources of timber, shading trees
23	Jati	*Tectona grandis*	Cu.	Sources of timber, shading trees
24	Jambu air	*Syzygium aqueum*	Gw.	Fruit consumed, ornamental plants, fruit is often eaten by bats
25	Jambu biji	*Psidium guajava*	Gw.	Fruit consumed, ornamental plants; fruit is often eaten by bats
26	Jarak Pagar	*Jatropha curcas*	Gw.	Periodically cleared
27	Jeruk sitrun	*Citrus* sp.	Gw	
28	Jeruk Bali	*Citrus* sp	Cu.	Ornamental plant, fruit consumed
29	Kayu manis/ keningar	*Cinnamomum verum,* sin. *C. zeylanicum)*	Cu.	Ornamental plant shading trees, spices
30	Kedoyo	*Dysoxylum amooroides*	Cu.	Shading trees
31	Kelapa	*Cocos nucifera*	Cu.	Multipurpose tree species
32	Kelengkeng	*Dimocarpus longan*	Cu.	Fruit consumed by family alone; fruit is often eaten by bats
33	Kelor	*Moringa oleifera*	Cu.	Shading trees, vegetables
34	Kemlandingan	*Paraserianthes lophantha*	Gw.	Sources of timber, shading trees
35	Kersen	*Muntingia calabura*	Gw	
36	Lamtoro	*Leucaena leucocephala*	Cu, Gw.	Animal feed., shading trees
37	Lansat	*Lansium domesticum*	Cu.	Fruit consumed
38	Marsusi	*Maesopsis eminii*	Cu.	Animal's feeds, shading trees
39	Mahoni	*Swietenia macrophylla*	Cu.	sources of timber, shading trees
40	Mangga	*Mangifera indica*	Cu.	Fruit consumed by family alone
41	Mindi	*Melia azedarach*	Cu.	Sources of timber, shading trees
42	Nangka	*Artocarpus heterophyllus*	Cu.	Sources of timber, animal feed., shading trees

43	Pasang (Pasang sungu)	*Lithocarpus* sp.	Cu.	Sources of timber, shading trees
44	Petai	*Parkia speciosa*	Cu.	Shading trees, fruits sold as additional income
45	Poh Ketek	-	Gw	
46	Pinus	*Pinus merkusii*	Cu.	Sources of timber, shading trees
47	Randu	*Ceiba pentandra*	Gw.	Sources of timber, shading trees
48	Sapen	*Aglaia palembanica*	Gw.	Sources of timber, shading trees
49	Sengon	*Paraserianthes falcataria*	Cu.	Sources of timber, shading trees, animal feeds
50	Sengon pekik	*Paraserianthes* sp.	Gw.	Sources of timber, shading trees
51	Sirsat	*Anona muricata*	Cu.	Fruit consumed
52	Senu	*Hibiscus* sp.	Gw.	Periodically cleared
53	Sono	*Dalbergia latifolia*	Cu.	Sources of timber
54	Sukun	*Artocarpus communis*	Cu.	Shading trees, fruits sold as additional income
55	Suren	*Toona sureni*	Cu.	Sources of timber, shading trees, animal feeds
56	Trembesi	*Samanea saman*	Cu.	Sources of timber, shading trees
57	Tritis/trete	*Microcos tomentosa*	Gw.	None
58	Tutup awu	*Macaranga rhizinoides*	Gw.	None
59	Waru	*Hibiscus tiliaceus*	Cu.	Shading trees
60	Waru gunung	*Hibiscus macrophyllus*	Cu.	Sources of timber, shading trees
61	Waru		Cu.	

that cultivated and grew wild, with numerous contributions to both ecological and economic functions. The understory vegetation, which includes herbs and shrubs, is listed in Table 2, with primary functions as a source of food, fodder, soil protection, and medicinal properties. Most species have multiple uses, such as *Gliricidia sepium*, which serves as forage, shade trees, and hedges. The multifunctional role of this understory underscores the importance of the understory vegetation layer in supporting community food security while maintaining the ecological function of coffee agroforestry.

Table 3 lists 61 tree species found across all study plots, comprising both cultivated and wild species. This diversity encompasses a wide range of ecosystem functions, from food providers (*Durio zibethinus, Artocarpus communis*), timber sources (*Tectona grandis, Swietenia macrophylla*), livestock feed (*Leucaena leucocephala*), to soil protection (*Calliandra calothyrsus*). The presence of wild species such as *Trema orientalis* and *Ficus benjamina* reflects the role of coffee agroforestry as a secondary habitat and important germplasm reserve in the national park buffer zone.

Gw=grows wild, Cu=cultivated

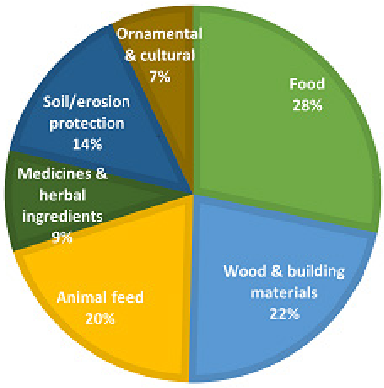

Figure 2: *Function of each species in the coffee-based agroforestry system of the study areas.*

Analysis of species contributions to ecosystem services in Figure 2 shows that coffee agroforestry in Poncokusumo serves multiple functions that are significant for the food security, economy, and ecology of local communities. Twenty-eight percent of species serve as food sources, followed by timber and building materials (22%). The high proportions in the food and timber categories reflect the strategic role of this system in supporting basic needs while contributing to the economy. This functional diversity confirms that coffee agroforestry not only maintains biodiversity but also provides a range of ecosystem services relevant to sustainable development in the national park buffer zone.

Table 4: *Comparison of important value index of coffee-based agroforestry orchards.*

No.	Species	Important value index				
		MHN	SNW 1	SNW 2	JN	PON
1	*Paraserianthes falcataria*	110.38	-	-	-	-
2	*Artocarpus communis*	68.32	-	-	-	-
3	*Hibiscus* Sp.	60.87	27.16	-	-	-
4	*Leucaena leucocephala*	-	87.72	-	63.46	41.01
5	*Magnolia champaca*	-	56.56	-	52.78	-
6	*Ceiba pentandara*	-	50.24	-	-	-
7	*Senna siamea*	-	28.1	-	-	-
8	*Pinus merkusii*	-	25.39	-	-	-
9	*Persea americana*	-	24.82	-	-	-
10	*Hibiscus macrophyllus*	-	-	151.52	-	-
11	*Erythrina subumbrans*	-	-	148.48	-	-
12	*Artocarpus altilis*	-	-	-	129.57	-
13	*Musa paradisiaca*	-	-	-	54.19	-
14	*Melia azedarach*	-	-	-	-	86.75
15	*Maesopsis emenii*	-	-	-	-	83.66
16	*Trema orientalis*	-	-	-	-	47.16

The comparison of the important value index (IVI) in Table 4 confirms the dominant role of several species in the structure of the agroforestry ecosystem. For example, *Paraserianthes falcataria* in the MHN plot achieved the highest IVI value (110.38), while *Hibiscus macrophyllus* (151.52) and *Erythrina subumbrans* (148.48) dominated the SNW2 plot. These high IVI values indicate the contribution of certain species as shade, wood producers, and structural elements that determine the stability of the agroforestry system.

Each agroforestry plot observed in this research shows different shading, plant tree structure, and composition. It is shown by the number of plant species and the important value index of each species in each agroforestry system (Table 4).

Table 5: *Diversity of trees, poles, saplings, and ground covers categories in each observed area*

Plot codes	Diversity indices (H')			
	trees	poles	saplings	ground covers
MHN	1.33	1.25	2.63	2.38
JN	1.77	1.85	2.45	2.21
SNW1	0.69	1.58	2.17	2.00
SNW2	1.24	1.84	2.38	2.46
PON	1.55	1.99	2.24	2.61

Table 5 indicates that diversity varies from low to moderate throughout all vegetative strata, as measured by the Shannon-Wiener (H') index. Overall, the diversity index value is below 2.49 scale in all plots in trees and poles, except the sapling in MHN and ground cover in PON. The highest values were found in the sampling category in MHN (H'=2.63) and ground cover in PON (H'=2.61), indicating relatively good vegetation regeneration conditions at these categories.

Discussion

In the case of the community in Poncokusumo, the option to cultivate *Coffeea arabica* seems to be related to the culture and natural wild seedlings. There are no records of a new cultivar of *Coffeea arabica* introduction reported. Physical factors of Poncokusumo, such as altitude and local climates, allowed *Coffeea arabica* species to grow optimally in this area, as the *Coffeea arabica* has been reported to be a highland coffee species (Wellman, 1961). In East Java, the center for *Coffeea arabica* cultivation is located in the highlands, with the center of cultivation in the Ijen mountains area (Bondowoso), the area around Mt. Iyang, and Bromo-Tengger Semeru. In addition, there are no reports on the cultivation.

Therefore, the diverse plants cultivated in agroforestry are crucial to supporting the daily community needs in remote areas (livelihood benefits). The diverse plant species in agroforestry also have the potential to contribute to various ecological services, such as carbon sequestration (Muthuri *et al*., 2023). Interestingly, located at the periphery area of Mt. Semeru, some tree species are known as mountain origins, including *Trema orientalis*, *Artocarpus elasticus*, *Paraserianthes lompatha*, *Ficus benjamina*, and *Lithocarpus sp*. There is also a population of fern trees, such as *Cyathea contaminans* which is commonly found in secondary mountain forest areas with high humidity (Praptosuwiryo and Usmadi, 2023). The existence of an individual and small population of fern trees in coffee-based agroforestry shows that such an ecosystem can be a potential refuge for wild forest plant species. Natural dispersal seems to be the main mechanism of such species entering the agroforestry system, e.g., by wind-flow dynamics and spore-like particle dispersal (Michon and de Foresta, 1991; Dupont *et al*., 2022). It allows opportunities to increase the contribution of coffee agroforestry in Poncokusumo as a potential spot for forest tree seedling banks.

In agroforestry with less management, weeds grow significantly and disturb the coffee plantations. Some plants ecologically support wildlife conservation, as shown by fruit consumption by bats and frugivorous animals, functioning in seed dispersal (Bodmer and Ward, 2006; Jordano, 2014; Corlett, 2017). Some plant fruits were consumed, including *Persea americana*, *Dimocarpus longan*, *Psidium guajava*, and *Syzygium aqueum*. According to respondents, the local species of guava (*Psidium guajava*) and watery rose apple (*Syzygium aqueum*) grow wild and experience a species of seedling in the coffee garden facilitated by the animal dispersal of those frugivorous species, including birds and bats. Previous researchers have reported the uses of agroforestry as a frugivore habitat, and it is crucial information or finding for biodiversity conservation in the area beyond the conservation area (Udawatta *et al*, 2019).

Plants with the highest IVI are *Paraserianthes falcataria* in MHN, *Leucaena leucocephala* in SNW 1, *Hibiscus macrophyllus* in SNW 2, *Artocarpus altilis* in JN, and *Melia azedarach* in PON. *Paraserianthes falcataria* is a timber plant that serves as animal feed, but it can also be a valuable shade tree that benefits commercial agroforestry operations in Southeast Asia (Ehrenbergerová *et al*., 2019). Shading trees is an important component in agroforestry. Timber tree species are important, as shown by the existence of *Paraserianthes falcataria*, *Magnolia champaca*, and *Melia azedarach*. The existence and distribution of timber species in each observed area, however, vary according to farmer preference when selecting cultivated trees.

Leucaena leucocephala is one of the important shading tree species in SNW 1, especially in coffee-based agroforestry systems. The use of *Leucaena leucocephala* has been reported to be common in coffee agroforestry. *L. leucocephala* is known as a multipurpose species that provides effective fodder, firewood, and ground cover, while improving soil fertility through nitrogen fixation (Brewbaker, 1987; Bageel *et al*., 2020). *Artocarpus altilis,* which is found in abundance in the JN plot, not only provides optimal shade for coffee, but also serves as an additional food source that contributes to household food security (Maredia *et al*., 2023). This confirms that combining ecological and economic functions in shade species selection is a key factor in the sustainability of coffee agroforestry in the national park buffer zone.

The biodiversity index (H') is high in value, more than 3, moderate with an H' value between 2-3, whereas at other growth stages, it is low with an H' value between 0 and 2 (Aminatun *et al*., 2021). MHN and ground cover in PON has a high diversity index value more than 2.49, but other plot suggesting has a low diversity index (Baliton *et al*., 2020). The low plant diversity index seems to be related to complicated causes, as reported by informants. The low plant diversity index is a result of garden management, and the low category of index was also related to the farmer's contributions to maintaining the sunlight penetration to the coffee plantations. Sunlight can penetrate sufficiently for photosynthesis, but it is not too intense to prevent the coffee plants from being stressed or sunburned (Fernandez *et al*., 2024).

The food-producing category (36%) was dominated by species with high IVI values in several plots, such as *Artocarpus communis* in MHN and *Artocarpus altilis* in JN. These species not only contribute to food diversification but also increase H' in the tree strata due to their coexistence with other shade species (Franzel *et al*., 2014). The wood and building materials category (28%), which includes dominant species such as *Paraserianthes falcataria* (IVI 110.38 in MHN) and *Melia azedarach* (IVI 86.75 in PON), generally correlated with a decrease in H' in monodominant plots, as seen in SNW2 with the dominance of *Hibiscus macrophyllus* (IVI 151.52) and a low H' (1.24).

The forage function (25%) is supported by multipurpose species such as *Leucaena leucocephala* and *Gliricidia sepium*, which contribute to the diversity of ecosystem functions and sustain stable vegetative structure in some plots, albeit not necessarily with the maximum IVI (Méndez *et al*., 2010). The soil protection function (18%) and medicinal plants (11%) are largely derived from species with moderate IVI, whose role in maintaining ecosystem health is enhanced when extreme dominance is absent. This aligns with findings that agroforests with a balanced IVI distribution tend to have higher H', which in turn increases ecosystem resilience (Jose, 2009). The integration of the findings, suggests that coffee agroforestry management that balances dominant, high-value species with a diversity of species with multiple functions will result in a more sustainable system. This approach not only maintains coffee productivity but also optimizes ecosystem services, supports food security, and maintains ecological sustainability in the buffer zone of the conservation area.

Respondents have different opinions on plant cultivation depend on their needs, both in terms of species selection, planting system, and management, which contributes to the diversity index profiles of each plot (Ndihokubwayo *et al*., 2021). The vegetation structure in the different type of coffee in Poncokusomo shows a different structure and seems related to the coffee farmer's decision to cultivate plant species in the coffee garden. For example, Robusta and Arabica coffees have major ecological variations that necessitate different shade management approaches (Piato *et al*., 2020), but liberica coffee responds better to shade with a tall, mature habitus. The garden is a site to generate income, and therefore, species inside the garden should be able to provide economic benefits that are different from other agroforestry systems in Indonesia. As a result, the composition of gardens is rich in species with potential economic worth (Mulugeta, 2014; Hakim *et al*., 2018). Langellotto (2014) also mentioned that garden crops, such as fruits and vegetables, helped cut grocery costs. Interestingly, some plants originated from the national park through the occurrence of natural dispersal and grow as a component of the agroforestry system.

Local farmers allow such species to be members of coffee-based agroforestry systems as the species have economic properties, such as shading trees and timber plants (Ehrenbergerová *et al*., 2019). The existence of forest tree species in the agroforestry system provides significant opportunities for coffee-based agroforestry, as agroforestry is a spot for a wild flora reserve in the periphery of Bromo Tengger Semeru National Park. This data shows that coffee-based agroforestry not only has economic benefits but also supports wild forest flora's natural growth beyond the conservation area. Coffee shading needs to consider the income and positive effects on the ecosystem, thus highlighting the role of native species that are suitable for both functions. These agroforestry models have become the key role of community participation in forest biodiversity conservation through coffee-based agroforestry in the periphery zones of conservation areas.

Conclusions and Recommendations

The locally preserved coffee-based agroforestry system in Poncokusumo is home to numerous plant species. Three species of coffee were cultivated under the agroforestry system, namely *Coffea arabica*, *Coffea canephora*, and *Coffea liberica*, which are economically important crops. Plants cultivated in the agroforestry system provide numerous benefits to support conservation programs, with their environmental, economic, and cultural values. The dominance of certain species plays an important role, but has the potential to reduce diversity. This system combines ecological and economic benefits and has the potential to be a nature-based solution for food security and conservation. This situation offers opportunities for the contribution of agroforestry as a spot for wild flora reserves in the periphery of the conservation area. The preservation of coffee agroforestry in the Poncokusumo area is one of the answers to the forest re-vegetation and restoration program for degraded forests, so that the community is not only able to carry out reforestation but also obtain long-term benefits from coffee agroforestry in the buffer area.

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Novelty Statement

This fieldwork demonstrates that growing coffee agroforestry can help to protect Bromo Tengger Semeru National Park in East Java.

Authors' Contribution

Luchman Hakim: Substantial contributions to the conception or design of the work, methodology design, writing draft, final approval of the version to be published, and funding Acquisition.
Jehan Ramdani Hariyati: Data collection, data analysis and interpretation, writing and editing.
Erona Wafaretta: Data analysis and interpretation, drafting the work and reviewing it critically for important intellectual content.

Generative AI or AI assisted technology statement
The authors used AI-assisted language editing tools only for grammar and readability improvements. All content, data analysis, and interpretations were performed by the authors.

Conflict of interest
The authors declare that there is no conflict of interest among the authors of the manuscript.

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