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Agrobiodiversity and plant use categories in coffee-based agroforestry in East Java, Indonesia

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Abstract. *Kusumawati IA, Mardiani MO, Purnamasari E, Batoro J, van Noordwijk M, Hairiah K. 2022. Agrobiodiversity and plant use categories in coffee-based agroforestry in East Java, Indonesia. Biodiversitas 23: 5412-5422.* Beyond documenting the ethnobotanical knowledge by managers of complex agroforestry systems, the actual use of such knowledge in adapting to new circumstances and adopting new practices in dynamic farming systems has been described as ecological wisdom. Our study in the Kali Konto catchment of East Java (Indonesia) focused on an inventory of plants that are part of coffee-based agroforestry, their various types of use, and the role they play in the further integration of livestock into the local farming system. The 48 respondents mentioned, on average, 105 combinations of plant species and use categories for their coffee agroforestry plots. Across nine use categories (food, with spices and food wrapping as subcategories, animal fodder, medicine, construction, hedge/ornamentals, handicrafts, ritual uses), a total of 83 plant species (in 36 botanical plant families) were mentioned, with on average 2.18 reported uses per species. A small majority (56%) of the plant species was actively managed (and often planted); the rest were spontaneously established species.

Keywords: Biodiversity conservation, coffee-based agroforestry, ethnobotany, farmer's preference, fodder

INTRODUCTION

Local knowledge of farmers has accumulated across generations from interactions between humans and the environment; its use can help to conserve living natural resources through the tradition of sustainable stewardship (Krell and Treakle 2014), allowing farmers to respond to new challenges. In a recent literature review, Manningtyas and Furuya (2022) distinguished descriptive studies of traditional knowledge (Berkes et al. 2000) from discussions of how farmers use it as part of Ecological Wisdom (EW) in their existing land use practices and resilience to climate change (Ford et al. 2020). Agroforestry as a land-use system has been a major part of such ecological wisdom (van Noordwijk et al. 2018) as it allows farmers to use agrobiodiversity and adapt to climate change, provides diverse yields and reduces the risk of damage to the environment. However, recalling that production is not the only priority has led farmers and various stakeholders to investigate and explore agroforestry. The risks are managed by maintaining multiple options open as part of functional diversity (Jackson et al. 2010). Yet, documenting the knowledge is more straightforward than evaluating farmer actions as a representation of 'wisdom' in new circumstances.

Farmers on the volcanic slopes of densely populated Java (Indonesia) benefit from fertile soils and high rainfall. Still, they have to face the specific challenges of high tectonic activity, volcanic eruptions, and ash deposition events (Saputra et al. 2022), on top of the challenges of high-intensity rainfall events and landslides (Hairiah et al. 2020). They have responded by combining paddy rice cultivation in the valleys and mixed agroforestry on the lower slopes, while on the upper slopes remaining forests are protected, and a zone of active reforestation by the state forest agency now supports the production of fodder grasses that allowed a substantial increase of dairy production (Lusiana et al. 2012). In addition to fodder grasses, nitrogen-fixing and forage-producing species such as *Gliricidia sepium* and *Calliandra calothyrsus* (Seruni et al. 2020) have been successfully adopted.

Indonesia ranked 4th, respectively, with 7% of global production of coffee (van Noordwijk et al. 2021) planted in agroforestry systems. Companion crops below the coffee tree have to deal with lower light intensities and are selected for direct local use, with some opportunities for market-based production. The agroforestry system offers flexibility in labor use for maintenance relative to the peak demands in paddy rice or vegetable cultivation while providing stable income streams across the various components (de Foresta et al. 2000). Initially considered as an 'ancillary work' for farmers, keeping dairy cattle that added value to available fodder resources in the landscape developed into a major source of income; but also to challenges with dry season fodder availability (Maleko et al. 2018; Boote et al. 2021). Diversification of the use of plants that develop into fodder sources can impact soil biophysical conditions because biomass transport out of the land reduces carbon storage and soil fertility level. Farmers add livestock manure to coffee agroforestry lands to anticipate lower soil quality after using it for biogas energy. The waste produced by cattle farming, particularly solid, can be used directly as organic fertilizer and recycling waste of biogas as fertilizer for coffee plants (Wang et al. 2021).

Identifying the understory and tree composition in coffee agroforestry is essential to understanding the species and their benefits required to enhance biodiversity conservation in this dynamic concept of changing land use. While Krishidaya et al. (2022) observed wild understory in coffee agroforestry gardens and their use for food and organic fertilizers, and Mardiani et al. (2022) documented farmer knowledge of earthworms as keystone soil biota, not much information is available about the economic value and ecological impact of implementing local animal feed crops in Ngantang Sub-district, Sub-district, Malang District, East Java, Indonesia. Our research questions regarding agrobiodiversity use in the study area were (i) Which companion plants (herbs, thickets, shrubs, trees) for coffee are currently used in agroforestry practices?; (ii) What types of use do farmers report for the species present in their plots and how consistent is informant knowledge?; (iii) How does agrobiodiversity contribute to the farming systems, resilience to shocks and a shift towards integrated livestock?

MATERIALS AND METHODS

Study area

This study was conducted from March to May 2022 at the foot of Mount Kelud, Ngantang Sub-district, Malang District, East Java, Indonesia (112°22'86″ East Longitude and 7°49'45″LS)(Figure 1), located at an elevation between 500-700 m above sea level. Daily average temperature ranges from 23 to 32ºC, annual rainfall varies from 2900 to 4400 mm, and air humidity averages 70% (BMKG Malang District, 2019). In the hilly topography, Ngantang Sub-district is bordered by Jombang District in the north, Pujon Sub-district (Malang District) in the east, Blitar District in the south, and Kasembon Sub-district (Malang District) in the west. In the southwest of the research, the location of the land was strongly influenced by ash deposits from Mount Kelud in 2014.

In-depth interview

The process for collecting information is done through in-depth interviews. However, the number of key informants by in-depth interview as part of the qualitative research is not greater than 50 (Patilima 2011). Therefore, in this study, the number of primary informants was 48 persons, and the key informants were 3 persons consisting of elders, also known as '*Kamituwo*.'

In the interview process, the use of plants in the coffee-based agroforestry system was divided into two blocks based on the understanding of each gender. First, interviews initially took place in the field, in conjunction with the farmer exploring the plants present in the coffee agroforestry plots and recording the types of use. Then, where local plant names could not be directly related to scientific names, follow-up investigations were conducted at the Plant Taxonomy Laboratory, Department of Biology, the Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. As a next step, the male informant has a holistic understanding related to the uses of plant species; meanwhile, female informants were interviewed especially sharing knowledge on the use of plants for food, medicine, spices, and flavors.

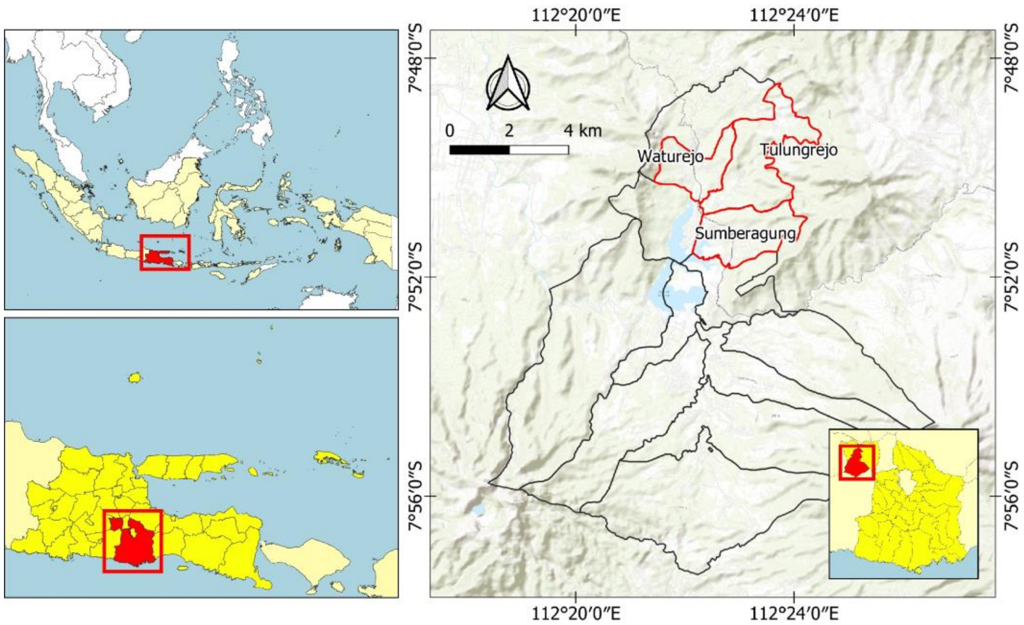

Figure 1. Research location in three villages (i.e. Waturejo, Sumberagung, and Tulungrejo) in Ngantang Sub-district, Malang District, East Java, Indonesia

Informants were also questioned about how agroforestry can survive and continue to produce yield when extreme events occur, such as crop failures caused by climate fluctuation and the constrained market access due to COVID-19 influencing farmgate prices.

Data analysis

Data generated from the informants' inventory process were processed several ways to explore patterns and present output in specific formats.

Ethnobotany quantification

Two indicators were used: the Informant Consensus Factor (ICF) and Fidelity Level (FL). ICF, this quantitative method investigates the effectiveness of plants on particular ailments using the formula (Belgica et al. 2021):

$$ICF = \frac{nur - nt}{nur - 1}$$

Where:

'n_{ur}' is the number of informants who know and use plant species for specific purposes, while

'n_t' is the number of species in each category of objectives.

FL, the percentage of informants, claiming the use of plants for similar major purposes was calculated for the most frequently reported uses or ailments as follows (Belgica et al. 2021):

$$FL = \frac{Np}{n} \times 100\%$$

Where:

'Np' is the number of informants who claim specific uses of the plant, and 'n' is the number of informants who know or use the plant for any purpose.

RESULTS AND DISCUSSION

Demographic analysis of informants

Our interviews with farmers were held in three villages (Tulungrejo, Waturejo, and Sumberagung), selecting more experienced farmers and household heads as informants (Table 1). The informant's age was average above 40 years, and most had between 15 and 25 years of experience managing coffee-based agroforestry systems through at least one volcanic ash deposition cycle (Saputra et al. 2022). In addition, men and women informants had the same level of education (primary school = SD, junior high school = SMP, and senior high school = SMA/SMK).

Ethnobotany

Across nine use categories (food, with spices and food wrapping as subcategories, animal fodder, medicine, construction, hedge/ornamentals, handicrafts, and ritual uses), a total of 83 plant species (Table 2) was mentioned, with an average 2.18 reported uses per species and involving 35 botanical plant families (Figure 2).

The most common plant species were found within the Zingiberaceae family, with 11 species, and the Asteraceae family, with 10 species. The Zingiberaceae family included *Curcuma aeruginosa ('temu ireng'*), *Curcuma heyneana* (*'temu glenyeh'*), *Curcuma longa* (*'kunir'*), *Curcuma xanthorrhiza ('temu lawak'*), *Zingiber officinale* var. Amarum (*'jahe emprit'*), a raw material for medicine, spices, and flavors, has been carried out for generations. Zingiberaceae is most commonly found in humid tropical to sub-tropical areas and is well known in everyday life (Saensouk et al. 2017). The Asteraceae family has therapeutic applications and a long history in traditional medicine: they have been cultivated for many years for edible and medical purposes (Rolnik and Olas 2021). Several types of Asteraceae family plants can be used as traditional medicines, such as *Blumea balsamifera ('sambung guntur'*), *Elephantopus scaber* (*'tapak liman'*), *Tridax procumbens ('cemondelan'*); this is due to essential oils, lignans, saponins, polyphenolic compounds, phenolic acids, sterols, polysaccharides (Koc et al. 2015), and rich in flavonoids (Shukurlu et al. 2021).

Consistency of species uses

The 48 respondents mentioned, on average, 105 combinations of plant species and use categories for their coffee agroforestry plots. The informant consensus indicator (Table 3) was high, showing a low disagreement level between informants on the types of use for a specific plant species. The highest result of ICF value (1) on the food category showed that coffee-based agroforestry systems are traditional food systems adapted over generations to fit local cultural and ecological conditions. Agroforestry systems, also known as homegardens in Uganda, provide a year-round diversity of nutritious foods for smallholder farming communities in many regions of the tropics and subtropics (Whitney et al. 2017).

Table 1. Demographic characteristics of informants

Variable	Category	Number	%
Gender	Men	31	64.6
	Women	17	35.4
Age	40-50	14	29.2
	51-60	17	35.4
	61-70	16	33.3
	>70	1	2.1
Education level	6 (Primary school)	18	37.5
	9 (Junior high school)	13	27.1
	12 (Senior high school)	17	35.4
Farm area (ha)	1-2	39	81.3
	2-3	4	8.3
	3-4	3	6.3
	4-5	1	2.1
	> 5	1	2.1
Years of experience with agroforestry practices	<15	3	6.3
	15-25	35	72.9
	25-35	10	20.8

Table 2. Botanical species identified in agroforestry plots and their reported uses

Species	Family name	Local name	No. of reported uses	Use categories (relative weights)
Achyranthes aspera	Amaranthaceae	Rendetan	1	Animal fodder (1)
Gomphrena serrata	Amaranthaceae	Remejun putih	1	Animal fodder (1)
Mangifera foetida	Anacardiaceae	Mangga kweni/ pakel	2	Food (0.98), building material (0.02)
Mangifera indica	Anacardiaceae	Mangga	2	Food (0.98), animal fodder (0.02)
Amorphophallus muelleri	Arecaceae	Walur/ iles-iles/ porang	2	Food (0.979), medicine (0.021)
Amorphophallus paeoniifolius	Arecaceae	Suweg	1	Food (1)
Cocos nucifera	Arecaceae	Kelapa	7	Building material (0.199), ritual uses (0.199), medicine (0.199), food (0.199), handicrafts (0.195), animal fodder (0.01), hedge/ornamental (0.004)
Colocasia esculenta	Arecaceae	Talas	1	Food (1)
Salacca zalacca	Arecaceae	Salak	2	Food (0.96), food (packing material) (0.04)
Xanthosoma sagittifolium	Arecaceae	Bentul	1	Food (1)
Cordyline fruticosa	Asparagaceae	Andong	3	Hedge/ornamental (0.585), animal fodder (0.354), medicine (0.062)
Ageratum conyzoides	Asteraceae	Wedusan	1	Animal fodder (1)
Bidens pilosa	Asteraceae	Ketul	2	Food (0.75), animal fodder (0.25)
Blumea balsamifera	Asteraceae	Sambung guntur/ menyeng	2	Animal fodder (0.717), food (0.283)
Elephantopus scaber	Asteraceae	Tapak liman	3	Medicine (0.675), animal fodder (0.3), food (spices, flavours) (0.025)
Mikania micrantha	Asteraceae	Rayutan	1	Animal fodder (1)
Pluchea indica	Asteraceae	Luntas	3	Food (0.716), medicine (0.269), hedge/ornamental (0.015)
Sonchus arvensis	Asteraceae	Tempuyung	1	Food (1)
Sphagneticola trilobata	Asteraceae	Ririan/ suket kuningan	1	Animal fodder (1)
Tithonia diversifolia	Asteraceae	Paitan/ plolong	1	Animal fodder (1)
Tridax procumbens	Asteraceae	Cemondelan	3	Food (0.828), animal fodder (0.103), medicine (0.069)
Impatiens balsamina	Balsaminaceae	Pacar banyu	4	Animal fodder (0.467), handicrafts (0.333), ritual uses (0.1), hedge/ornamental (0.1)
Spathodea campanulata	Bignoniaceae	Kecrutan	3	Animal fodder (0.536), building material (0.429), medicine (0.036)
Ananas comosus	Bromeliaceae	Nanas	3	Food (0.857), medicine (0.071), handicrafts (0.071)
Hippobroma longiflora	Campanulaceae	Kleciran	3	Animal fodder (0.878), medicine (0.049), food (0.049)
Trema orientalis	Cannabaceae	Anggrung	3	Building material (0.686), animal fodder (0.3), handicrafts (0.014)
Drymaria cordata	Caryophyllaceae	Cemplonan	2	Animal fodder (0.848), food (0.091)
Amischotolype mollissima	Commelinaceae	Kerok bathok	1	Animal fodder (1)
Commelina nudiflora	Commelinaceae	Bedesan	1	Animal fodder (1)
Acalypha siamensis	Euphorbiaceae	Cemitian/ penitian	3	Hedge/ornamental (0.547), animal fodder (0.34), medicine (0.113)
Euphorbia hirta	Euphorbiaceae	Patikan	3	Animal fodder (0.867), hedge/ornamental (0.089), medicine (0.044)
Manihot esculenta	Euphorbiaceae	Ketela pohong	3	Food (0.906), animal fodder (0.075), medicine (0.019)
Calliandra houstoniana var. calothyrsus	Fabaceae	Anjrah merah	1	Animal fodder (1)
Calliandra tetragona	Fabaceae	Anjrah putih	1	Animal fodder (1)
Falcataria moluccana	Fabaceae	Sengon	2	Building material (0.558), animal fodder (0.442)
Gliricidia sepium	Fabaceae	Gamal/ teresede	1	Animal fodder (1)
Leucaena leucocephala	Fabaceae	Petai cina/lamtoro	2	Food (0.623), animal fodder (0.377)
Hyptis brevipes	Lamiaceae	Plompongan	1	Animal fodder (1)
Tectona grandis	Lamiaceae	Jati	2	Building material (0.571), food (packing material) (0.429)
Litsea glutinosa	Lauraceae	Nyampoh	2	Building material (0.696), animal fodder (0.304)
Persea americana	Lauraceae	Alpukat	4	Food (0.407), building material (0.273), animal fodder (0.24), medicine (0.083)
Magnolia champaca	Magnoliaceae	Kembang gading/ kantil	4	Ritual uses (0.783), building material (0.15), animal fodder (0.05), handicrafts (0.017)
Durio zibethinus	Malvaceae	Durian	3	Food (0.485), building material (0.354), animal fodder (0.162)
Hibiscus tiliaceus	Malvaceae	Waru	2	Building material (0.716), food (packing material) (0.284)

Lansium domesticum	Meliaceae	Duku	2	Food (0.906), building material (0.094)
Lansium parasiticum	Meliaceae	Langsep	3	Food (0.762), building material (0.222), animal fodder (0.016)
Toona sureni	Meliaceae	Suren	2	Building material (0.658), animal fodder (0.342)
Cyclea barbata	Menispermaceae	Cincau	2	Food (0.973), medicine (0.027)
Artocarpus heterophyllus	Moraceae	Nangka	4	Building material (0.343), food (0.343), animal fodder (0.307), medicine (0.007)
Ficus variegata	Moraceae	Gondang merah	4	Animal fodder (0.489), building material (0.4), food (0.089), food (spices, flavours) (0.022)
Musa textilia	Musaceae	Pisang raja	5	Ritual uses (0.262), food (packing material) (0.262), food (0.262), animal fodder (0.202), handicrafts (0.011)
Syzygium aromaticum	Myrtaceae	Cengkeh	3	Food (spices, flavors) (0.571), medicine (0.417), building material (0.012)
Oxalis corniculate	Oxalidaceae	Rempi	2	Medicine (0.96), animal fodder (0.04)
Phyllanthus urinaria	Phyllanthaceae	Meniran	2	Food (0.814), animal fodder (0.186)
Peperomia pellucida	Piperaceae	Sirih cina	4	Medicine (0.629), food (0.171), animal fodder (0.143), hedge/ornamental (0.057)
Piper nigrum	Piperaceae	Lada	1	Food (spices, flavors) (1)
Dendrocalamus asper	Poaceae	Pring petung	4	Building material (0.511), food (0.404), handicrafts (0.064), animal fodder (0.021)
Gigantochloa apus	Poaceae	Pring apus	2	Building material (0.716), handicrafts (0.284)
Gigantochloa atter	Poaceae	Pring jowo	4	Building material (0.857), handicrafts (0.089), food (0.036), medicine (0.018)
Imperata cylindrica	Poaceae	Alang-alang	2	Medicine (0.629), animal fodder (0.371)
Pennisetum purpureum Schum. cv. Mott	Poaceae	Odot	1	Animal fodder (1)
Pennisetum purpureum Schum. cv King	Poaceae	Kalanjana/ rumput gajah	1	Animal fodder (1)
Pyrrosia piloselloides	Polypodiaceae	Sisik boyo	1	Hedge/ornamental (1)
Adiantum peruvianum	Pteridaceae	Pakis suplir	1	Hedge/ornamental (1)
Maesopsis eminii	Rhamnaceae	Masusi	2	Building material (0.615), animal fodder (0.385)
Coffea canephora	Rubiaceae	Kopi robusta	1	Food (1)
Coffea liberica	Rubiaceae	Kopi asisa	1	Food (1)
Paederia foetida	Rubiaceae	Simbukan	3	Medicine (0.489), food (0.489), animal fodder (0.021)
Capsicum frutescens	Solanaceae	Cabai	3	Food (0.475), food (spices, flavours) (0.475), medicine (0.05)
Solanum nigrum	Solanaceae	Ranti	4	Food (0.868), medicine (0.053), hedge/ornamental (0.053), animal fodder (0.026)
Parasponia rigida	Ulmaceae	Anggrung hijau	1	Animal fodder (1)
Stachytarpheta jamaicensis	Verbenaceae	Pecut kuda	2	Animal fodder (0.724), medicine (0.276)
Achasma walang	Zingiberaceae	Walang sangitan	1	Medicine (1)
Alpinia galanga	Zingiberaceae	Laos putih	2	Food (spices, flavors) (0.734), medicine (0.266)
Alpinia purpurata	Zingiberaceae	Laos merah	2	Food (spices, flavours) (0.676), medicine (0.324)
Boesenbergia rotunda	Zingiberaceae	Kunci	2	Food (spices, flavors) (0.535), medicine (0.465)
Curcuma aeruginosa	Zingiberaceae	Temu ireng	1	Medicine (1)
Curcuma heyneana	Zingiberaceae	Temu glenyeh	1	Medicine (1)
Curcuma longa	Zingiberaceae	Kunir	2	Medicine (0.5), food (spices, flavours) (0.5)
Curcuma xanthorrhiza	Zingiberaceae	Temu lawak	1	Medicine (1)
Zingiber officinale var. Amarum	Zingiberaceae	Jahe emprit	2	Medicine (0.615), food (spices, flavours) (0.385)
Zingiber officinale var. Rubrum	Zingiberaceae	Jahe merah	3	Medicine (0.623), food (spices, flavours) (0.351), food (0.026)
Zingiber zerumbet	Zingiberaceae	Rempuyang	2	Ritual uses (0.5), medicine (0.5)

The high consistency indicated by the ICF value is also supported by the FL value, which is the percentage of the number of informants who report the utility of the species for a specified purpose. A percentage of 100 indicates that one such species is entirely used for the same specific purpose. In contrast, a percentage of < 100 indicates that the use of one species is divided into several categories and purposes. The FL quantification results indicate a range between 0.4 to 100%. The highest FL values (100%) consisted of *Achyranthes aspera, Ageratum conyzoides, Mikania micrantha, Sphagneticola trilobata, Tithonia diversifolia, Amischotolype mollissima, Commelina nudiflora, Calliandra calothyrsus, Calliandra tetragona, Gliricidia sepium, Gomphrena serrata, Pennisetum purpureum, Urtica pilulifera,* and *Parasponia rigida*, as animal fodder. Other species include *Achasma walang, Curcuma aeruginosa, Curcuma heyneana,* and *Curcuma xanthorrhiza* as medicine. Fully used as an ornamental plant was found in *Pyrrosia piloselloides* dan *Adiantum peruvianum*. Other species used as food ingredients consist of *Amorphophallus paeoniifolius, Colocasia esculenta, Xanthosoma sagittifolium, Sonchus arvensis, Coffea canephora*, and *Coffea liberica*. For species fully used as spices and flavorings found in *Piper nigrum.*

Table 3. Use categories and Informant Consensus Factor (ICF) for reported uses

Use category	Reported uses (N_{ur})	Species involved (N_t)	ICF
Food	1366	36	**1**
Food (spices, flavors)	385	11	0.97
Food (packing material)	106	4	0.97
Animal fodder	1310	50	0.96
Medicine	727	35	0.95
Building material	706	21	0.97
Hedge/ornamental	129	10	0.93
Handicrafts	93	9	0.91
Ritual uses	195	5	0.98
Totals	5017	181	
Records/informant	104.5		
Uses/species		2.18	
Average ICF			0.964

Sources of farmer knowledge

Farmers cultivate coffee in an agroforestry system based on the knowledge which has been passed on from generation to generation from the family (79%), hereditary knowledge is combined with learning and exchanging experiences with fellow farmers (10.5%) and hereditary knowledge combined with personal experience (10.5%). Coffee farmers in Ngantang Sub-district (100%) never attended the socialization of coffee cultivation in the agroforestry system either from the local government or other institutions. Only some were active (60.5%) in coffee agroforestry farmer groups.

Types of use

The use of the plant is accomplished by taking parts of the plant such as leaves, twigs, fruits, seeds, roots, and stems (Figure 2). Leaves (83%) were the most frequently used part of the plant for all categories except building materials. Leaves are easy to obtain and the quickest to regenerate. Local people assume that using leaves will not cause the death of the plant; moreover, the leaves are the part that regenerates quickly and is easy to get. Leaves and fruits are the most preferred parts for sustainable plant use since they are the least destructive to the plant (Mukungu et al. 2016); the concentrations of nutrients were high in general (de Santos et al. 2021) so that the greater part may be consumed.

Overall, 52% of plant parts were used in a fresh state and 48% after processing (including drying, sieving, cooking, frying, and/or cutting). The major part (56%) of plants considered to be useful were actively managed as part of the agroforestry land use, with the remaining (44%) growing and spreading spontaneously (Figure 3).

The plants found and used included all habitus, namely herbs, trees, thickets, lianas, and shrubs (Figure 4). Herbs, shrubs, vines, and thickets are included in the plant understory communities (Cutway 2017), while trees are cambium plants with four size classes of trees, namely seedlings (diameter <5 cm and height at least 0.5 m), saplings (diameter between 5 and 10 cm), poles (dbh between 10 and 20 cm) and "mature" trees (dbh >20 cm) were considered when determining the density (Worku et al. 2015).

Ash-related species

Among the 83 species found, 2 plant species spontaneously grew after the eruption of Mount Kelud, namely *P. rigida* (Ishaq et al. 2020) and *G. serrata*, which are used as animal fodder (Figure 5).

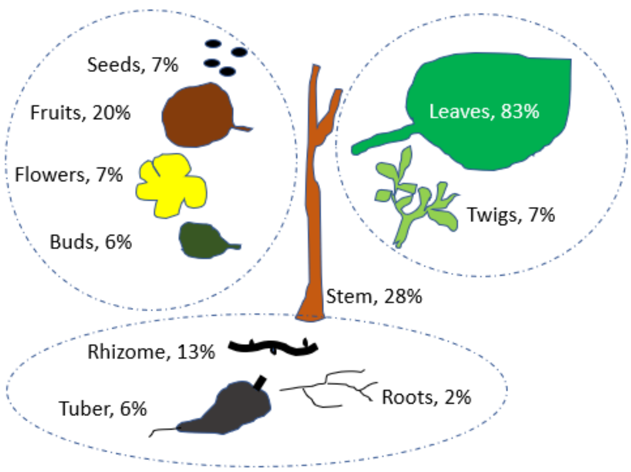

Figure 2. Plant parts mentioned as the basis for human use

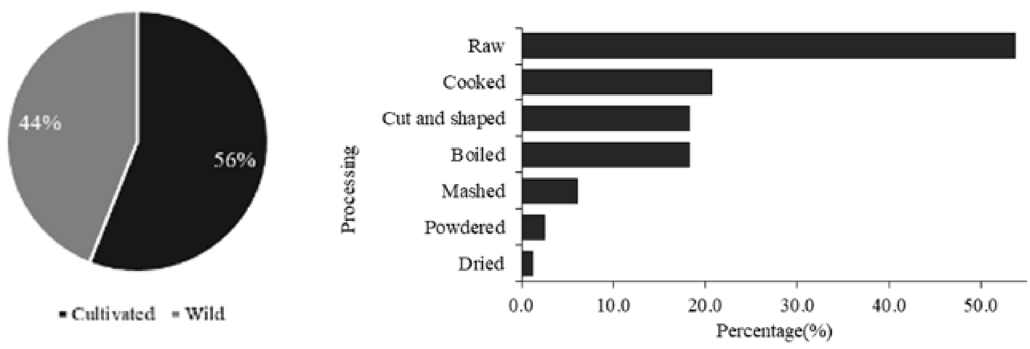

Figure 3. Processing before use

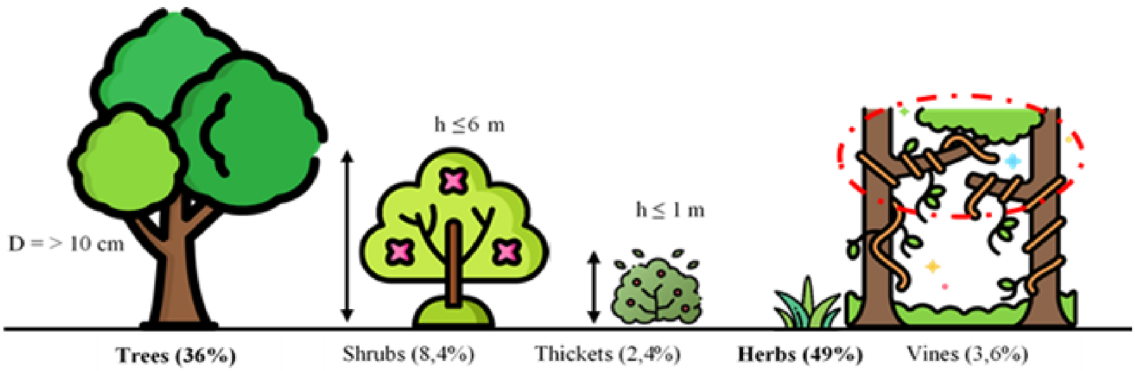

Figure 4. Management status per plant growth form (D =trees diameter; h= plants height)

A B C D

Figure 5. Plants found after the eruption of Mount Kelud (A) *Parasponia rigida* (http://www.phytoimages.siu.edu//users/pelserpb/721111/21Jul11a/ Parasponiarugosa1.jpg); (B) *Parasponia rigida* personal documentation; (C) *Gomphrena serrata* (https://mrec.ifas.ufl.edu/research/weedsbyflowercolor/white/gomphrenaserrata/); (D) *Gomphrena serrata* personal documentation

Farming system change with the integration of livestock

According to them, farmers' decisions in selecting and combining shade tree species and understorey crops in coffee agroforestry are based on meeting their daily needs. The ICF value illustrates this for using plants for food, which is 1, and the ICF value for animal feed is 0.96. In the FL value, which describes the level of community trust in the use of plants, there are 15 species found in coffee agroforestry land that are trusted and used entirely for animal feed (100%) and 6 species for food ingredients (100%). Selecting plants to produce feed triggers the process of transporting biomass from coffee agroforestry lands. On average, 35 farmers carry 30 kg/ha of feed per day on coffee agroforestry farms (Figure 6), while the need for animal feed is 20 to 60 kg/day. To meet food requirements, farmers typically purchase food from other farmers or regions (48.5%), while other farmers grow their own elephant grass meadow (51.5%). The fodder harvest uses a sickle to cut the plants above the ground, hoping that the roots will remain in the soil so that the parts of the plant can regrow.

While the cattle are stable, the forage is harvested and transported from the field to the stable (Figure 7). All 35 farmers in this study who own cattle and operate a biogas digester stated that they use the remaining cattle manure used as biogas. The average remaining waste from the biogas treatment process returned as manure to the field is 7-10 kg/day. Farmers who process cattle droppings directly into manure add materials such as husks, plant biomass, and microbial starters such as EM4. The ratio of manure to the additives used is 1:1, with a 30% reduction compared to the original weight. On average, farmers can obtain 15 to 18 kg of manure daily. Manure treatment activities around the farmer's house, including cage cleaning until returning manure to a coffee-based agroforestry system (Figure 7).

Forest dependence vs. agroforestry as a substitute

In-depth interviews in the three village communities clarified that forests higher up in the landscape continue to be important for local livelihoods (100% agreement). Forests can meet the requirements of daily life (100%), but they also impact other land uses such as rice fields, agroforestry, and settlements (100%). Conserving forests can directly maintain water quantity and quality (100%), microclimate (62.5%), maintain soil fertility inside and outside forest areas (100%), and reduce the potential for flooding and erosion (100%). The survival of local communities is inextricably linked to the role of forestry and cultural resources, which are still rooted, particularly in agricultural activities.

Figure 6. Cut and carry system

Figure 7. Process of processing cow dung into biogas and applying biogas waste to agroforestry system as manure

Most locals have a livelihood with coffee, durian, and dairy as important components. Coffee is cultivated in an agroforestry system with several shaded trees, such as durian and avocado. So far, the community still maintains its jobs as coffee and durian farmers (47.9%), but some have become cattle and goat farmers (39.6%) due to several factors. Time flexibility and ease of maintenance of coffee agroforestry lands trigger farmers to use their time to work as part-time farmers (64.6%). Recent fluctuations in time and climate (18.8%) have influenced the flowering process of coffee and durian. Fallen flowers cause fruit and seed formation failure, leading to lower coffee and durian yields (16.7%).

Discussion

Agroforestry is reported to be an interesting and effective option to decrease the loss of forests, conserve biodiversity, and provide important sources of income for the local population (Mbow et al. 2014; Reed et al. 2017). Meeting household needs is the main reason farmers manage agro-biodiversity in their coffee agroforestry lands. Information regarding the choice and combination of plant species was obtained from generation to generation (64.5%), personal experience (10.5%), and exchanged experiences with fellow farmers (25%). Arsyad et al. (2018) said that farmer groups are one of the essential factors in supporting farming activities, especially in the cultivation and procurement of production facilities. Communities who live and manage agroforestry lands around forest areas have for generations studied the problems they faced, linked them back to local wisdom, and integrated them with new knowledge so that interactions between individuals became closer and participatory communication was formed (Meyfroidt et al. 2022).

The 'cut and carry' system has been used for hundreds of years, especially in Asia (Youkhana and Idol 2017). This cut-and-carry system triggers a loss of biomass and nutrients in the land from the harvesting process if it is not balanced with the return of livestock manure to the land (Munroe and Isaac 2014). Our results agree with other studies that tree diversity and care flexibility in agroforestry systems is essential to adapt to economic needs and social conditions (Fujisawa et al. 2012). The flexibility of the design and maintenance of agroforestry systems in providing various environmental services has the opportunity to solve various challenges, such as bioenergy production, urban food security, and floodplain management (Patel-Weynand et al. 2017).

Various vegetative growth processes, such as flowering, fruit formation, and quality, are susceptible to climate change (Haokip et al. 2020). Seasonal uncertainties, such as heavy rains and long dry seasons, may influence coffee flowering and production (Kath et al. 2021). Climate change and erratic weather, such as rain throughout the year, can cause coffee to continue to flower, so the harvesting mechanism is irregular in small quantities and impacts the workforce (WeldeMichael and Teferi 2019). Cultivated plant types that are more resilient to fluctuations in climate change are the driving forces that lead to changes in the livelihoods of local communities. Reliance on global markets has gradually diminished, and in the context of the COVID-19 pandemic, pressure on global exports can at least be partially offset by domestic markets (van Noordwijk et al. 2021). As a selected land use that has been able to adapt to climate change and the COVID-19 pandemic, the capacity of coffee-based agroforestry is reliable in terms of sustaining environmental services by providing products to local communities and regulating water and resource cycles. The strong demand for dairy products for health issues has led to an increased need for fodder, making them a secondary employment opportunity for coffee farmers.

In low-income countries, livestock products are becoming a fast-growing subsector (Alexandratos and Bruinsma 2012). Therefore, livestock feed species are widely selected as shaded coffee plants and understory in the agroforestry system. Among the forage species favored by farmers in this study were *G. sepium* and *Leucaena leucocephala*, the animal feed within tree growth form; *C. calothyrsus*, *C. tetragona*, *T. diversifolia* and *A. aspera* within shrubs growth form; and also *P. purpureum* Mott, *P. purpureum* Schumach and Thonn, *A. conyzoides*, *A. aspera*, *T. diversifolia* within herbs growth form. Animal feed can be in the form of herbs and trees; in general, leaves and other non-woody parts are taken (Youkhana dan Idol 2017). Nitrogen-fixing such as *L. leucocephala* plants which are widely growing on the earth, particularly in tropical regions such as Indonesia, are generally classified as the preferred animal feed (Youkhana and Idol 2017) and to improve soil quality (Ngongo et al. 2021). By incorporating food crops and multipurpose trees into their coffee plots, farmers were ensuring alternative livelihood strategies in the face of market fluctuations (Lamond et al. 2019).

Much has changed in Kali Konto since studying socio-economic conditions and developments in the Kali Konto upper watershed in 1980 (Nibbering 1986). When our informants were just born or young children, that study assessed the general level of development and possible constraints for future development, serving as background for planning and implementing one of the first integrated watershed development projects in Indonesia activities. The subsequent project aimed at (a) improving the living conditions of the local people, encouraging self-reliance and maintaining and increasing their standard of living; (b) creating sound and stable ecological systems; (c) creating a forest system based upon multipurpose management fitting into the national forest policy. In hindsight, these objectives were mostly achieved. However, at the same time, local livelihoods emerged from the risks of over-intensification of food-crop-based systems (Nibbering 1993) evolved by building on local knowledge and fitting in the specific opportunities and constraints of the landscape, demonstrating that hydrological recovery of past conditions was not feasible (Nibbering and de Graaf 1998).

In conclusion, we found that herbs and trees are the most found growth form in coffee-based agroforestry. Farmers widely use those species for food, cultural needs, packing material, building material, fodder, spices, and flavors. The use of plants based on the farmers' local knowledge represents the contribution of agrobiodiversity through provisioning services. According to in-depth interviews, farmers think coffee-based agroforestry systems can be resilient to changes in species composition while continuing to produce coffee as a main marketable product and fodder as a potential additional income, despite the effects of climate change and market fluctuations as observed during the COVID-19 pandemic. That matches resilience concepts explored in the emerging COVID literature (Duguma et al. 2021).

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