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Research article

Plant species diversity, plant use, and classification of agroforestry homegardens in southern and southwestern Ethiopia

Gezahegn Kassa [a,b,*], Tamrat Bekele [b], Sebsebe Demissew [b], Tesfaye Abebe [c]

[a] *Department of Natural Resource Management, Arba Minch University, Arba Minch, Ethiopia*
[b] *Department of Plant Biology and Biodiversity Management, Addis Ababa University, Ethiopia*
[c] *School of Plant and Horticultural Sciences, College of Agriculture, Hawassa University, Hawassa, Ethiopia*

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ABSTRACT

The attainment of ever more sustainable agricultural production and reconciling agriculture with conservation are the main challenges that human beings are confronted with head-on in the future. Through expanding and enhancing agroforestry homegardens at the agricultural landscape level, biodiversity can be increased and maintained while addressing several utility values, ensuring both ecological and socioeconomic sustainability. This study was conducted in agroforestry homegardens of southern and southwestern Ethiopia, to examine plant species richness and other diversity indices, plant use, and classify and identify different types of homegardens based on their species composition and abundance. In total, 93 homegarden owners participated in the study. Two hundred and six (mean 15.44 per homegarden) different plant species (excluding weeds) that belonged to 161 genera and 66 plant families were identified across the studied sites. Fifteen species (about 7.28% of all species recorded) are endemic and threatened to Ethiopia. The overall mean plant species richness per agroforestry homegardens, mean individual density and other diversity parameters varied strongly among sites ($P < 0.05$). In all of the agroforestry homegardens, roots, and tubers food producing plant species tended to be more dominant (based on summed dominance ratio, SDR) than other species, except the cereal crops barley and maize. Based on cluster analysis, four groups of agroforestry homegardens were identified including, 'small-sized, low plant diversity, barley-potato-enset-apple homegardens (Cluster-1)'; 'intermediate-sized, taro-enset-coffee homegardens (Cluster-2)'; 'large-sized, maize-taro-sweet potato-teff-enset homegardens (Cluster-3)'; and 'small-sized, high plant diversity with mixed-use category homegardens (Cluster-4)'. The results also indicate that agroforestry homegardens as ecological niches are valuable for the conservation and maintenance of biological diversity both for crop genetic as well as forest tree resources, including harboring of endemic and threatened species in those human-dominated landscapes.

1. Introduction

The attainment of ever more sustainable agricultural production, and reconciling agriculture with conservation are the main challenges that human beings are confronted with head-on in the future [1,2]. It was considered wrong, however, to capture

* Corresponding author. Department of Natural Resource Management, Arba Minch University, Arba Minch, Ethiopia.
E-mail addresses: gezahegn_k19@yahoo.com (G. Kassa), tambek07@gmail.com (T. Bekele), sebsebe.demissew@aau.edu.et (S. Demissew), tesfayea@hu.edu.et (T. Abebe).

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conventional intensive agriculture as the only best option rather than looking into a more ecologically sound form of agriculture [3,4]. Because reports indicate that farmers have been adversely impacted by the simplification of agroecosystems and the associated loss of biodiversity, the loss of productive capacity through soil erosion, the heavy dependence on external inputs, and the vulnerability of large-scale monocultures to climate change and pest-disease outbreaks [5–7]. But others argue that food production is reoriented towards organic agriculture as organically produced food is becoming increasingly mainstreamed around the developed world and that there emerged burgeoning popularity for organic products together with the policy support for the development of international export markets for these products [8].

As there exist links between nature conservation and agroecology [9], it is possible to maintain optimal sustainability outcomes by promoting diversity per se in tandem with the assembly of functional groups in biodiversity-friendly practices [6], and/or a set of ecologically benign innovations [7]. As maintenance of the sustainability of agricultural landscapes increases with their plant diversity and livestock included [10,11], research undertakings targeting the understanding of tropical biodiversity is unquestionable because of the on-going danger of local disappearance and dynamics of species composition [6,10,12], and due to the continued uncertainties in environmental conditions in future changes of the climate system [13,14]. Even analysis of the extent to which biodiversity can be supported in human-modified agroecosystems was given less emphasis or yet remains poorly understood [15–17], including the understanding of the relationship between biodiversity and ecosystem functioning [6].

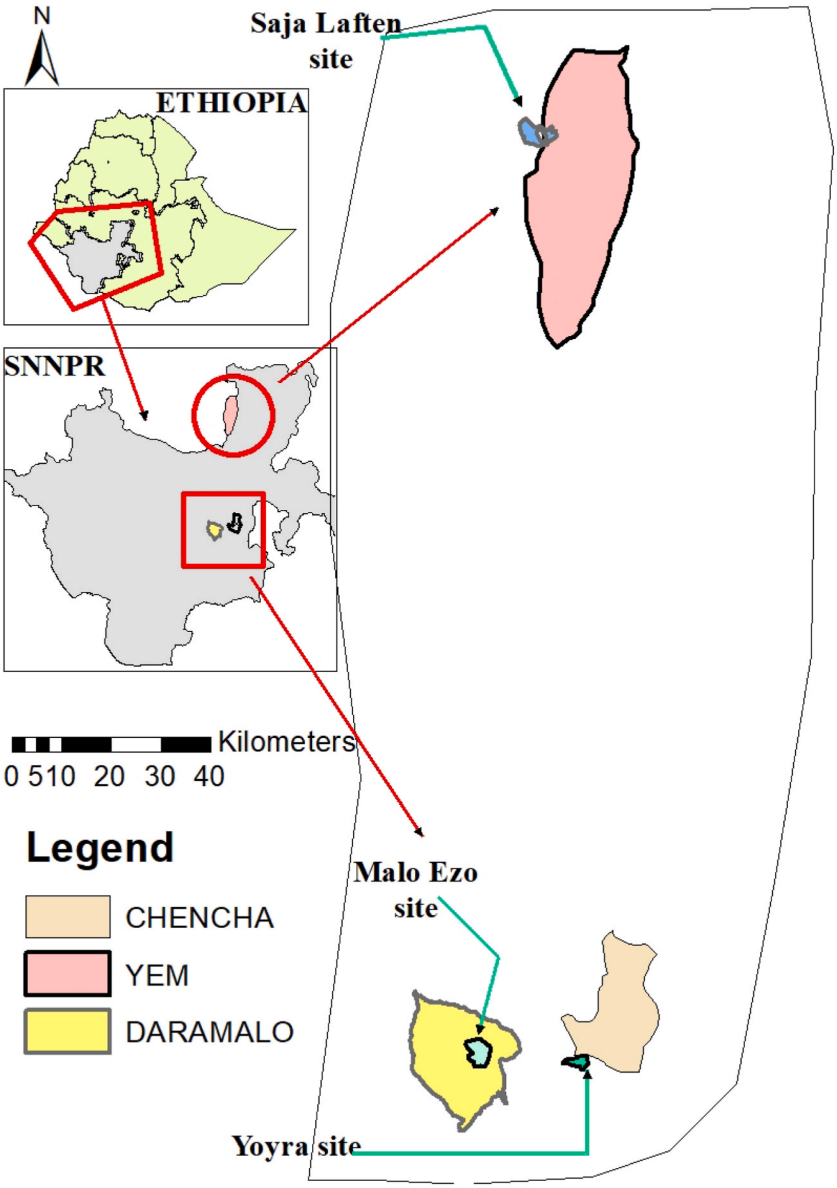

Fig. 1. A map showing the study sites in southern and southwestern Ethiopia.

Several studies have demonstrated that human-modified agroecosystems such as agroforestry homegardens [18,19] can be seen as a viable land use option to help reduce the loss of biodiversity [16,20] and avoid loss of ecosystem services [11,18,21], while simultaneously improving local livelihoods [19,22,23]. As diversified ecological niches [24], they often assist biodiversity conservation to be put on hold outside protected areas [25], preserving traditional crop varieties and landraces [24], serving as an alternative habitat for native trees [16], and fighting food insecurity and remedy nutritional requirements [26]. Moreover, maintenance and integration of forest tree species in these agroforestry systems address multifunctional roles such as carbon sequestration, soil fertility improvement, shade to crops and people, attracting birds and other frugivorous animals, and in diversifying farm products by producing timber, fruits, and non-timber forest products [18,22,27,28].

Despite these beneficial effects, more recent literature also indicates that the traditional agroforestry homegardens were declining and more endangered by the growing threats of homogenization of these systems [11,29–31] and changing socioeconomic situations [18,32–34]. As these agricultural intensification practices reduce the ecological resilience of these land use systems [27] (Tscharntke et al., 2011), it is therefore increasingly important to give due emphasis on their contribution to preserving ecological diversity [16,35] as explained in terms of the most commonly used plant species diversity [35]. Furthermore, most of the previous studies were location-specific involving long lists of plant species and evaluation of systems [36–40]. But those involving more analytical methods accompanied by multivariate statistical methods that systematically classify different homegarden types are recently used [10,33,34,38,41,42].

As plant diversity data are of utmost invaluable for decisions on design and location, management, monitoring order of magnitude of plant diversity changes, and the assessment of long-term sustainability of these land use systems [43], biodiversity can be evaluated and quantified as part of sustainability features of agroforestry homegardens in southern and southwestern Ethiopia. Therefore, the objectives of this paper were: (1) to investigate the level of plant species richness and other diversity indices, and the similarity of species composition between agroforestry homegardens across sites; (2) to identify the different plant use categories based on summed dominance ratio (SDR) across sites and cluster groups; and, (3) to classify and identify different types of agroforestry homegardens groups based on species abundance data.

2. Materials and methods

2.1. Study areas

Two woredas from the Gamo zone, namely, Chencha (6°05′–6°15′N, 37°34′–37°45′E) and Daramalo (6°15′–6°28′N, 37°14′E) from southern Ethiopia, and the other special woreda, Yem (7°37′–8°02′N, 37°40′–37°61′E) from southwestern Ethiopia were selected for this study, all situated in Southern Nation Nationality and Peoples Region (SNNPR) of Ethiopia (Fig. 1). Yoyra is the study site located in Chencha, Malo Ezo in Daramalo, and Saja Laften in Yem (Table 1). The study sites were selected for the study based on the presence and extensive abundance of enset-based agroforestry homegardens, and distance/travel time to major roads, and being disaggregated by major traditional agroecologic subdivisions, namely, Dega (cool and humid highland), Weyna Dega (cool sub-humid midland/

Table 1
Main characteristic of sampled agroforestry homegardens sites in southern and southwestern Ethiopia.

Characteristic	Sites		
	Yoyra/Chencha woreda	Malo Ezo/Dara Malo woreda	Saja Laftern/Yem woreda
Biophysical	2695		
Altitude (m asl.)		1744	1964
Annual rainfall (mm)	1263	1031	1365
Slope (%)	9.32	18.82	9.82
Geographic location			
Easting	37.5307	37.3520	37.4682
Northing	6.2832	6.3195	7.9993
Socioeconomic			
Woreda population by 2021 (projected based on 2007 census and 2.9% rate of growth for SNNPR)	166,644	120,864	120,338
Population density (Km^{-2})	445.57	326.66	166.1
Mean farm sizes (ha)	0.27	0.56	1.35
Homegarden size (m^2)	2374.88	3455.61	2748.64
Livelihood zone	*Enset* and barley are complemented by wheat, sweet or Irish potatoes, horse beans, and field-peas	Maize and root crop	A cereal and enset
Distance to major markets (hr)	0.6	1.12	1.24
Production system			
Major food crops	Enset and barley	Enset and root crops	Enset and maize
Major cash crops	Wheat, sweet or Irish potatoes,	Maize, teff	Teff, maize, sorghum, wheat
Livestock types	Cow, oxen, sheep, horses, mule	Cow, oxen, sheep, horses, goats	Cow, oxen, sheep, goats
Dominant ethnic group	Gamo	Gamo	Yem

midhighland) and Kolla (warm semiarid lowland). The elevation of Chencha is around 2378 m above sea level (m a.s.l.), while that for Daramalo and Yem ranges from 1217 to 2700 and 920–2939 m a.s.l., respectively.

2.2. Climatic and soil condition

Based on ten years of data (2007–2016) obtained from the National Meteorological Service Agency (NMSA), the climate diagrams of Chencha, Daramalo, and Saja Laften (represented by Sokoru the nearest recording station) woredas (Figs. 2–4) were computed using R version 4.0.1 [44]. The diagram depicts that Chencha and Daramalo woredas receive a bimodal rainfall pattern from the beginning of mid-March to May and September to October. While a unimodal rainfall pattern extending from March to October was recorded for Saja Laften (Fig. 4). The mean annual temperature was 15.3 °C for Chencha, 24.9 °C for Daramalo, and 20 °C for Saja Laften. And, the mean annual rainfall recorded for Chencha, Daramalo, and Saja Laften were 1263, 1031, and 1365 mm, respectively. The major soil types observed in the Chencha area include Immature Cambisols, Nitisols, Luvisols, Leptosols, Cambisols, and Andosols [45,46], but that observed in the Daramalo area are Andosols, Cambisols, and Luvisols [45], while that of Yem include Nitisols, Acrisols, Ferralsols, Vertisols, and Planosols [47].

The human population density of Chencha, Daramalo, and Yem woredas in 2021 was 445.57, 326.66, and 166.1 persons/km^2, respectively [48]. Taking into account the method developed by Ref. [49] and adopted by Ref. [50], the native vegetations of Chencha are characterized by dry Afromontane forests in the highlands where there appeared to be serious deforestation, with extensive areas being changed into bushlands [51–53]. Belonging to the Afromontane vegetation of certain high mountains, the area has been identified as part of the Somalia-Masai Regional Centre of Endemism [54]. The ubiquitous existence of individual forest trees such as *Juniperus procera* Hochst. ex Endl., *Olea europaea* subsp. c*uspidata* (Wall. ex G.Don) Cif., and *Croton macrostachyus* Del., a scattered relict, and few remnant forest patches in most highlands of Yem are indicative of a long history of forest exploitation [50,55,56], and deforestation for thousands of years [57] which can be outcomes of socioeconomic [56], and sociocultural activities of the local people [55]. In the lowlands of Yem, the part of the basin where the Ghibe-Omo lies, wooded grasslands, and bushland of Somalia-Masai type are found [50,58].

2.3. Sampling and data collection

The study was undertaken in three study sites (kebeles, the lowest Ethiopian administrative unit) selected from three woredas based on a stratified sampling strategy, where enset-based agroforestry homegardens are practiced and have similar livelihood patterns (Table 1). A stratified sampling strategy that involves first, a purposive sampling technique was applied to select woredas and sites. Secondly, the selection of farm households was made using systematic random sampling in probability proportionate to size (PPS) [59]. Next, based on the socioeconomic variability, and gender ratio of inhabitants, a total of 93 households were selected randomly out of the total 1878 heads by using the formula defined by Ref. [60],

$$n = \frac{z^2 \cdot p \cdot q \cdot N}{d^2(N-1) + z^2 \cdot p \cdot q} \quad (1)$$

where, n = sample size in the study site; N = number of households; z = the value of the normal variable ($z_{0.25}$ = 1.96) for a reliability

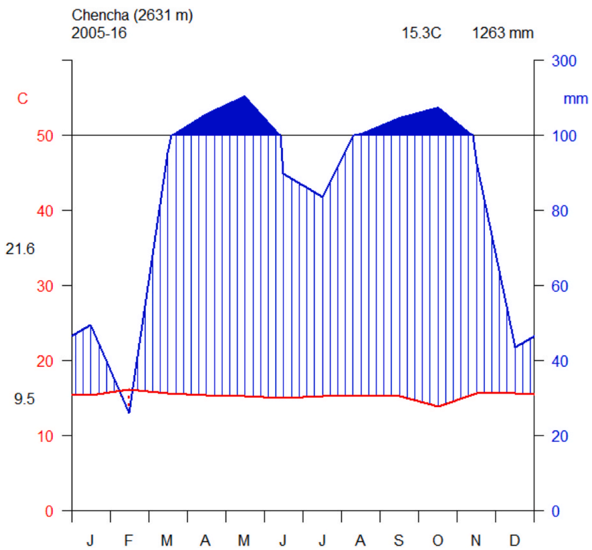

Fig. 2. Climate diagram showing the mean monthly rainfall and temperature distribution records of Chencha taking 10 years (2007–2016) (Source: NMSA).

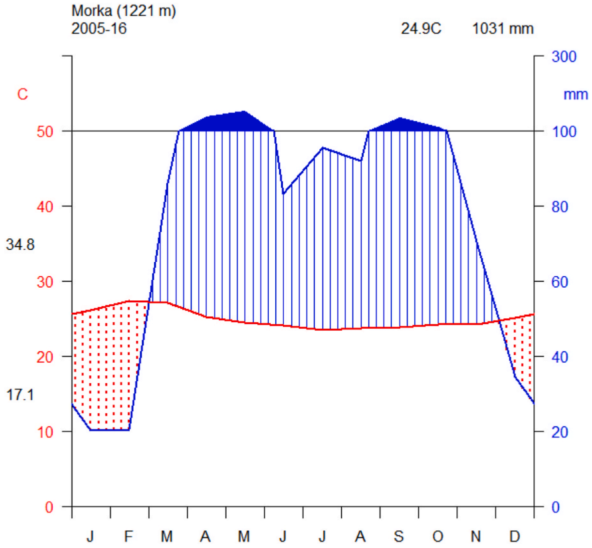

Fig. 3. Climate diagram showing the mean monthly rainfall and temperature distribution records of Daramalo taking 10 years (2007–2016) (Source: Unpublished Ethiopian National Meteorological Services Agency NMSA).

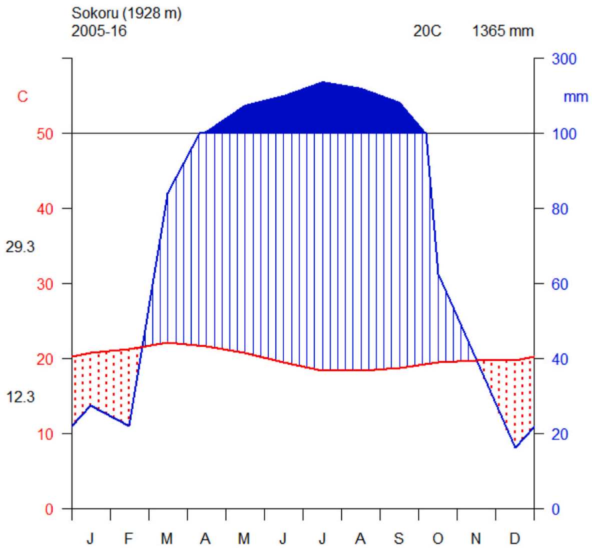

Fig. 4. Climate diagram showing the mean monthly rainfall and temperature distribution records of Saja Laften taking 10 years (2007–2016) (Source: Unpublished Ethiopian National Meteorological Services Agency NMSA).

level of 0.95; q = probability of failure (0.5); d = margin error (0.1), and p = probability of success (0.5). Among the 93 households, 22 households participated in the study in Yoyra, 49 households in Malo Ezo, and 22 households in Saja Laften.

2.4. Key informants' interview

To gain an understanding of the nature of homegardens and its species composition as well as the overall benefits that it provides towards meeting homegardeners' needs, interviews were held with key informants. Key informants were selected in each site through a snowball sampling approach [61] because they had lived long enough in the locality and had extensive knowledge of each household's socioeconomic status and overall homegardens management. Using key informants, a few individuals in each site were selected and they are then asked to identify other people in the sites, and those individuals selected by them become a part of the sample. Instead of asking separately, the authors waited for the maximum number of informants to be decided. But at this moment, from the list of possible nominees, some elderly individuals were asked to rank among those informants who had better experiences based on the criteria set for this purpose, and the list was narrowed to six informants at each site, totaling 18 key informants.

Information was later gathered from these informants.

2.5. Household survey

Following wealth ranking, a random sample of mixed-gender household-level data was collected using a structured questionnaire [62] in the three sites in southern and southwestern Ethiopia. Even though proportional gender allocation was made during the initial sampling process; the relative share of these female-headed households was obscured because most female-headed households were nominated and represented by matured sons on behalf of them in every aspect of community engagement. The questionnaire was initially prepared in the English language, but later on, translated into Amharic. The researcher together with the help of recruited translators conducted face-to-face surveys using local languages. The questionnaire included questions about household identity and socio-demography, landholding size, livestock ownership, and plant utilization.

2.6. Plant species survey

To assess the plant species composition, similarity, and characteristics of each homegarden, a plant species survey was conducted in each of the 93 households in the study area. During the survey, the area of homegarden micro-zones and total landholdings including their geographic locations and altitudinal variations were measured using a handheld Garmin GPS (Geographical Position System) and measuring tapes. Micro-zones represent spatial areas deliberately allocated to particular species and management [63].

Following the method adopted by Ref. [64], a complete enumeration of individuals of species was carried out in the agroforestry homegardens to get a broad view of the wide range of species and categories of plants. By dividing the homegarden into two roughly equal parts using s north-south baseline, sample centers were demarcated on this line at 10 m intervals until the boundary was reached. From the center points, additional lines perpendicular to the baseline were demarcated towards the east and west as far as the homegarden limit. By creating further points at 10 m intervals on these east-west lines, a 10 × 10 m sample grid was generated. Within each grid, the individuals of all perennial species mentioned above were documented. For each herbaceous component available on homogenous subplots of the homegarden, abundance was calculated using sample quadrats having sizes of 1 m × 1 m [23] but later extrapolated from densities in the subplot area [19].

2.7. Data analysis

Conventional and commonly used biodiversity indices were used to assess the status of biodiversity in agroforestry homegardens. Species richness indices (that is the number of species) were collected in total across sites. Furthermore, data on other diversity indices, namely, Shannon's diversity and species evenness indices [65] were also computed in this study. The Shannon index assumes that individuals are randomly sampled from an infinitely large population and that all the species are represented in the sample, where the values of the index usually lie between 1.5 and 3.5 [66,67]. Evenness represents how equally abundant the species (Magurran, 1988) were calculated in the agroforestry homegardens. Shannon diversity index (H′) was calculated with

$$H^{'} = -\sum(p_i \ln p_i) \ldots\ldots \quad (2)$$

where p_i is the proportion of individuals found in the *i*th species in the collection and the summation is over all of the species. The proportions p_i is given by n_i/N, where there are n_i individuals of the *i*th species. From that the Equitability or species evenness index (E) was calculated by Ref. [65],

$$E = H^{'}/H_{\max} = H^{'}/\ln S \ldots\ldots \quad (3)$$

where E is contained between 0 and 1, with 1 representing a situation in which all species are equally abundant; H_{max} is the maximum diversity and S species number. The degree of similarity of homegardens plant species composition across sites/habitats was calculated using Jaccard's coefficient (S_J) of similarity [67], given by Ref. [65],

$$S_J = a / (a + b + c) \ldots\ldots \quad (4)$$

where *a* is the number of species common to both sites, *b* is the number of species in site A only, and *c* is the number of species in site B only.

Based on similar cases done elsewhere [10,19,42], the main use category for each species was recorded based on homegarden owner's cited primary use (with single use for each species). To identify the importance of species in different plant use categories, the summed dominance ratio (SDR) was estimated following [68], as the averages of at least two of the parameters, namely, the sum of relative density, and relative frequency of species per site and per cluster. Then, the single SDR value of all species per use category and the site was summed up [10,19]. Plant species identification was carried out at the National Herbarium of Addis Ababa University (AAU).

To characterize homegardens based on species combinations a hierarchical cluster analysis involving ln-transformed plant species abundance data [68] (number of individual plants per 1000 m^2) with the squared Euclidean distances as a dissimilarity measure and Ward's (minimum variance) method clustering was performed using software package R (R version 4.0.1). As outliers need to be identified before looking for actual cluster analysis [69], single linkage clustering works well to carefully detect and evaluate the presence of those outlying data points [70]. Hence, to avoid problems associated with outliers, discarding them from the data set was considered a routine solution [69,70]. To decide on the appropriate number of clusters to be considered as a cutoff point on the produced dendrogram, the 'elbow' criterion [70] was used (see appendix A). The dendrogram was constructed based on species composition and abundance values. Discriminant analysis was employed to discriminate the existence of significant differences among cluster groups, and based on the defined standardized canonical discriminant function coefficients species that contribute to cluster separation were identified [68,71]. To test the significance of the discriminant model, Wilk's lambda (λ) statistic was considered.

Using Statistical Package for Social Sciences (SPSS, Version 16), data were subjected to ANOVA, and discriminant analysis. ANOVA was used to test characteristics of sample homegardens and household, plant species diversity, and agroecologic and plant diversity parameters among sites and across cluster groups. Canonical discriminant analysis was run to test the goodness of clustering and to check whether the original grouped cases were correctly classified. Assumptions of normal distribution and homogeneity of variances were checked by using Kolmogorov-Smirnov and Levene tests [72]. Appropriate *posthoc* pairwise comparisons were made with Fisher's Least Significance Difference (LSD) tests at $\alpha = 0.05$ to isolate group means that show significant differences. Where necessary, quantitative data were log-transformed to meet assumptions of normality and homogeneity of variance, otherwise non-parametric Kruskal–Wallis and Mann-Whitney tests were followed.

3. Results

3.1. Characteristics of agroforestry homegardens and households

The overall average size of agroforestry homegardens ranged between 165.18 and 12957.25 m^2, with an average of 3032.71 m^2. Although homegarden sizes did show no significant difference among sites ($p = 0.177$), the average size at Malo Ezo was roughly 1.5 times larger than that at Yoyra (Table 1). At Yoyra, sizes of homegardens were four-fold more than those of the cultivated fields situated far away from homegarden holdings, but the opposite holds for Saja Laften, where the cultivated fields found far away from homegardens were four-fold higher than that of homegardens.

The median age of agroforestry homegarden managers (40, range 37.0–53.0) did show significant differences among sites ($p = 0.003$), reflecting the fact that managers at Yoyra were older than the other sites (Table 2). Homegarden managers on average owned 2.31 (range from 2.26 to 2.45) livestock species. These animals are kept inside the homestead but are usually freely-roaming around the homegardens and beyond whenever micro-zones or crop fields were not covered with crops.

3.2. Plant species diversity and similarity of homegardens

Two hundred and six different plant species that belonged to 161 genera and 66 plant families were identified across the 93 homegardens surveyed (see Appendix B), out of which Asteraceae was the dominant family with 13 genera and 20 species. The other families that demonstrate the floristic importance of agroforestry homegardens included Fabaceae, Euphorbiaceae, Poaceae, and Lamiaceae, with 13, 13, 12, and 10 species, respectively. Of the total plant species registered, about 65.05% were native, while 34.95% were considered exotic species. When considering woody plants, constitute about 50.97% (105 species) of the total species, out of which 69.52% (73 species) were native woody plants while 30.48% (32 species) were considered exotic ones. Based on Flora of Ethiopia and Eritrea, and IUCN (The World Conservation Union) Red List, altogether 15 plant species (7.28%) are listed as endemic and threatened species to Ethiopia, except *Bidens macroptera* (Sch. Bip. ex Chiov.) Mesfin occurs as a weed in agroecosystems (see Appendix C). Some of the plant species such as enset (*Ensete ventricosum* (Welw.) Cheesman), amoch (*Arisaema schimperanum* Schott), dinich (*Solanum tuberosum* L.), boye (*Dioscorea* sp.), boyna (*Colocasia esculenta* (L.) Schott.), and others were also represented by several different landraces, including improved ones (see Appendix D).

The overall mean plant species richness ($p = 0.001$) per homegarden, mean Shannon diversity index ($p = 0.001$), mean individual density ($p = 0.001$), and evenness index ($p = 0.001$) varied strongly between sites (Table 3). Differences in mean species richness per homegarden at Saja Laften showed a markedly higher value than at Malo Ezo and Yoyra (Table 3). It implies that mean species richness at Saja Laften was about two-fold higher than that of Yoyra. Mean individual density per 1000 m^2 was relatively higher at Yoyra than at

Table 2
Characteristics of sample homegardens and households across study sites in southern and southwestern Ethiopia.

	Yoyra		Malo Ezo		Saja Laften	
	Mean	Range	Mean	Range	Mean	Range
Household age (years)*	53.00^a	23–97	41.50^b	26–96	37.00^c	24–58
Age of homegarden (years)	30.45	2–82	30.98	9–85	27.23	8–55
Family members (no.)	5.41^b	1–11	7.64^a	3–12	6.45^{ab}	3–10
Size of homegarden agroforestry (m^2)	2374.88	165.18–12014.93	3455.61	397.53–12957.25	2748.64	698.86–5049.68
Total landholding (ha)	0.27^b	0.01–2.00	0.56^a	0.13–2.00	1.35^c	0.07–3.50
Number of livestock species	2.27	0–5	2.27	1–5	2.46	0–4
Tropical Livestock Unit (TLU)	2.49^b	0–9.45	5.41^a	1.20–29.70	3.81^{ab}	0–10

Means in a row followed by different superscript letters are significantly different at $P \leq 0.05$ (Mann-Whitney or Kruskal-Wallis tests, depending on the data structure); Source: Survey data. The symbol * denotes median age.

Saja Laften and Malo Ezo, with a strongly significant difference (Table 3).

Regarding the occurrence of species, the most frequent plant species were *E. ventricosum*, *Cordia africana* Lam., *Coffea arabica* L., *Musa x-paradisiaca* L., *Zea mays* L., and *C. esculenta*. But the species that occurred most dominantly in the homegardens include *Hordeum vulgare* L., *A. schimperanum* Schott, *Z. mays* L., *C. esculenta, E. ventricosum,* and *Solanum tuberosum* L. (Table 4).

Apparent dissimilarity in species composition of agroforestry homegardens was encountered between sites. This is reflected by the calculated Beta (β) diversity which shows a very high dissimilarity between Yoyra and Saja Laften ($\beta = 0.73$), and between Yoyra and Malo Ezo ($\beta = 0.75$). However, a very low dissimilarity was found between Saja Laften and Malo Ezo ($\beta = 0.35$). The number of common plant species that were encountered in the homegardens in any of the sites varied from 26 to 47%. Considering all three sites, those species that were unique to any one of the sites constitute 67%.

3.3. *Major plant use categories in agroforestry homegardens*

Of those recorded species, the homegarden owners cited most species as useful for wood/multipurpose use plants (MPU) (21%), followed by ornamentals (12%), medicinals (10%), fruits (9%), vegetables (6%), and roots and tubers (6%), but except for others use category (24.27%, of which that of live fencing/boundary marking constitute 14%, the rest by others) (Table 5). Concerning specific sites, there were differences in the total number of species composition across sites and use categories (Table 5). Malo Ezo site had the highest total species number, followed by Saja Laften and Yoyra.

In respect to the total surface area allocated in homegardens, on average roots and tubers (41.65%) were the major component of the homegardens, followed by cereals (30.81%), and stimulants (6.92%), leaving the alone house and front spaces (10.15%) (Table 6). The dominant crops grown inside the roots and tubers micro-zone were enset, followed by *I. batatas* and, *Dioscorea* sp., and *C. esculenta* area shares within this division. Similarly, maize accounted for the largest surface share of cereals production micro-zone (Table 6). Beyond the homegarden which was found in the immediate residential center, farmers also maintained arable agricultural plots that were often very small in two sites, except that found at Saja Laften.

Summed dominance ratios (SDRs) per use category reflected differences in plant importance between sites (Fig. 5). Groups of homegardens at Yoyra had greater dominance of roots and tubers use group (36.52%) than the other sites, followed by the Malo Ezo site (32.12%). Agroforestry homegarden groups across the three sites did reflect a relatively equal distribution for each respective wood/MPU and cereals use category. Homegardens at Saja Laften had also higher dominance of fruits (16.37%) and ornamentals (13.37%) groups than the other sites (Fig. 5).

3.4. *Classification of agroforestry homegardens*

The hierarchical cluster analysis that was conducted based on species composition and abundance indicated that there were four different groups of agroforestry homegardens (Fig. 6). Three of them (no. 18, 23, and 33) were detected as outliers and were excluded from further analysis.

The first three canonical discriminant functions explained 100% of the variations observed in the dataset. Wilk's λ reflected the goodness of clustering and the independence between each cluster ($p < 0.001$). Fourteen species (in decreasing order of importance) that contributed most in defining the underlying construct to the discriminant function include *Hagenia abyssinica* (Brace) J.F. Gmel., *S. tuberosum*, *Daucus carota* L., *Brassica oleracea* L., *Discopodium penninervium* Hochst., *Sida rhombifolia* L., *Euphorbia abyssinica* Gmel., *Dianthus caryophyllus* L., *Capsella bursa-pastoris* (L.) Medic., *Allium sativum* L., *Nicotiana tabacum* L., *Calpurnia aurea* (Ait.) Benth., *Ehretia cymosa* Thonn. and *Passiflora caerulea* L. Fig. 7 shows the goodness fit of the separation of the groups of homegardens using canonical discriminant analysis. The discriminant analysis also showed that 100% of the original grouped cases were correctly classified (Appendix E).

In addition to the differences in species composition, various household- and farm-specific characteristics were found to distinguish the four clusters (Table 7), including SDRs. Cluster one had rather small-sized homegardens, and the lowest total landholdings, but had a significantly older homegarden manager's age, all located at the Yoyra site (Table 7). These groups of homegardens were exclusively distributed at higher elevations. Homegardens grouped in clusters 1 and 2 showed significantly lower species richness and Shannon diversity. The most dominant use category in the homegardens of cluster 1, together with those of cluster 2, was roots and tubers (at a mean SDR of 34%). The category of roots and tubers was dominated by *A. schimperanum, S. tuberosum,* and *E. ventricosum*, while the cereals group (at a mean SDR of 17%, Fig. 8) was the next important use category in cluster 1 and was dominated by *H. vulgare* L. The most dominant plant species in this cluster included *A. schimperanum*, *H.vulgare*, *S. tuberosum*, *E.ventricosum*, and *M. sylvestris* Mill. The

Table 3
Plant species diversity of sample agroforestry homegardens in three sites in southern and southwestern Ethiopia.

	Yoyra		Malo Ezo		Saja Laften	
	Mean	Range	Mean	Range	Mean	Range
Species richness	11.09^{c}	2–18	14.02^{b}	3–27	22.96^{a}	14–38
Individual density per 1000 m^2	9068.80^{a}	225–44088	1755.34^{b}	49–4344	1682.68^{b}	231–7741
Shannon diversity index	1.04^{b}	0.34–1.78	1.55^{a}	0.18–2.43	1.52^{a}	0.70–2.47
Species evenness index	0.47^{b}	0.13–0.99	0.60^{a}	0.16–0.88	0.48^{b}	0.24–0.76

Means in a row followed by different superscript letters are significantly different at $P \leq 0.05$; Source: Survey data.

Table 4
The 20 most dominant and frequent species out of the 206 plant species encountered in 93 agroforestry homegardens in three study sites of southern and southwestern Ethiopia from highest to lowest summed dominance ratio (SDR) ranking.

Species name	Occurrence[a]		SDR	
	Total	Rank	Total	Rank
Hordeum vulgare L.	5	64	8.793	1
Arisaema schimperanum Schott	14	30	8.149	2
Zea mays L.	48	5	6.493	3
Colocasia esculenta (L.) Schott.	47	6	5.440	4
Ensete ventricosum (Welw.) Cheesman	89	1	4.637	5
Solanum tuberosum L.	10	41	4.168	6
Ipomoea batatas (L.) Lam.	29	10	2.925	7
Brassica nigra (L.) Koch	23	15	2.665	8
Coffea arabica L.	63	3	2.405	9
Cordia africana Lam.	63	2	2.278	10
Musa x-paradisiaca L.	49	4	1.901	11
Manihot esculenta Crantz.	20	19	1.644	12
Persea americana Mill.	46	7	1.642	13
Eragrostis tef (Zucc.) Trotter	2	114	1.612	14
Mangifera indica L.	45	8	1.594	15
Daucus carota L.	5	69	1.446	16
Brassica carinata A. Br.	12	37	1.248	17
Saccharum officinarum L.	12	34	1.172	18
Capsicum annum L.	18	23	1.160	19
Catha edulis (Vahl.) Forssk. ex Endl.	26	11	1.087	20

[a] Number of homegardens where the plant species was recorded.
Source: Survey data.

Table 5
Total number of plant species per use category in the agroforestry homegardens in three sites in southern and southwestern Ethiopia.

Use category	Yoyra	Malo Ezo	Saja Laften	All sites
Fruits	2	8	16	19
Vegetables	6	9	4	12
Roots and tubers	5	8	7	12
Cereals	2	2	5	5
Medicinals	10	11	4	21
Spices	3	6	4	7
Stimulants	1	3	3	4
Wood/MPU	14	34	19	44
Ornamentals	8	6	17	25
Pulses/oil seeds	3	6	2	7
Others[a]	21	23	11	50
Total	75	116	99	206

[a] Others use categories include live fencing/boundary marking, fodder, fastening, implements, and fragrance. Source: Survey data.

exotic fruit shrub apple (*M. sylvestris*) was the most frequent species next to *E. ventricosum,* but was exclusively cultivated to generate cash income as part of their homegarden production. Based on the above-stated characteristics these groups of homegardens can be characterized as small-sized, older farmers, low plant diversity, barley-potato-enset-apple dominated agroforestry homegardens.

In cluster two, a large number of homegardens (13 out of 18) were located at Malo Ezo, while the rest were located at Saja Laften (4 out of 18) and Yoyra (only one out of 18) sites and they were all situated at an intermediate elevation. Clusters 2 and 4 were headed by nearly intermediate-age and young women and men, respectively. Although the mean size of homegardens was not significantly different among clusters ($F_{3, 86} = 1.40$, $p = 0.248$), they were of intermediate size in relative terms in this cluster (Table 7). Similarly, total landholding did seem to have intermediate size along with cluster 3 though, in contrast, statistically significantly different ($F_{3, 86} = 9.13$, $p < 0.000$). Clusters 2 and 3 had relatively intermediate species richness, Shannon diversity, and species evenness indices. Though exceptionally roots and tubers (33%) use category had higher mean values, homegardens grouped in cluster 2 had comparatively higher dominance of wood/MPU (15%) species than the other clusters (Fig. 8). The category of roots and tubers was dominated by *C. esculenta*, *E. ventricosum,* and *D. alata* while that of wood/MPU was dominated by *C. africana*, *Juniperus procera* Hochst. ex Endl., and *Croton macrostachyus* Del. The most dominant plant species include *C. esculenta*, *E. ventricosum*, *Saccharum spontaneum* subsp. *spontaneum* (Willd.), *C. africana*, and *C. arabica*. Based on the observed features, homegardens in cluster two can be distinguished by intermediate-sized, younger farmers, taro-enset-coffee dominated agroforestry homegardens.

Homegardens grouped in cluster three comprised the large majority (36 out of 44) from Malo Ezo and 8 out of those 44 from Saja Laften (Table 7). Although not significantly different, homegarden sizes in this cluster did show higher mean values than the others. Homegardens of this cluster had intermediate diversity parameters, except for the evenness index. Based on the SDRs per use category,

Table 6
Overall mean area share (%) of major crop categories grown in the homegardens.

Major micro-zone categories	% major micro-zone area share	% area contribution of main crop components in each major micro-zone
House and front space (including grazing land)	10.15	
Fallow	**3.23**	
Roots & tubers	**41.65**	
E.ventricosum		16.74
I. batatas		8.55
Dioscorea sp./*C. esculenta*		7.78
S. tuberosum		4.06
Others (qey sir, enchet boye, amoch, …)		4.52
Vegetables	**1.19**	
B. carinata		0.56
C. pepo		0.41
Others (tiqil gomen, nech/key shinkurt)		0.22
Stimulants	**6.92**	
C. arabica		3.46
C. edulis		3.46
Fruits	**2.18**	
Malus sylvestris		1.29
Musa x-paradisiaca		0.80
Others (aleko, birtukan, …)		0.09
Cereals	**30.81**	
Zea mays		27.78
Eragrostis tef		1.46
Hordeum vulgare		0.95
Sorghum bicolor		0.39
Triticum aestivum		0.23
Spices & condiments	**0.35**	
Woodlots	**2.81**	
Others[a]	**0.71**	

[a] Others micro-zone represents haphazard arrangement of plant components that are appearing as more mixed ones.
Source: Survey data.

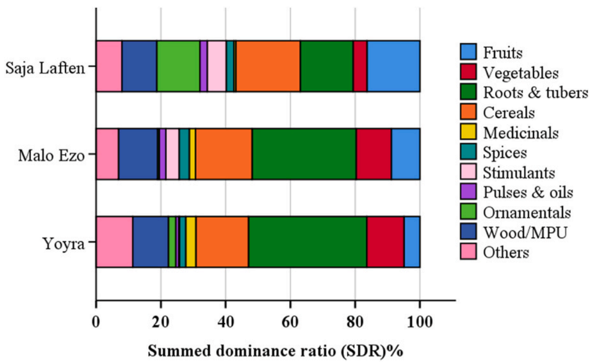

Fig. 5. Summed dominance ratios (SDR) for 206 plant species classified in different use categories found in agroforestry homegardens in the three sites in southern and southwestern Ethiopia. Source: Field Survey.

roots and tubers (27%), and cereals (25%) revealed more equally distributed use categories in this cluster, followed by a balanced distribution of Wood/MPU (11%), vegetables (10%) and fruits (9%) use categories (Fig. 8). The most dominant plant species in the homegardens grouped in this cluster include *Z. mays*, *C. esculenta*, *I. batatas*, *E. tef*, and *E. ventricosum*. Based on the observed features, homegardens of this cluster were considered to be large-sized, corn-taro-sweet potato-teff-enset dominated agroforestry homegardens.

For cluster four, which included only 8 homegardens (8.9% of the total sampled respondents) from the Saja Laften site, the main features include young homegarden owners with relatively low homegardens sizes, but with rather significantly larger total land-holding sizes being distributed at intermediate elevations. These groups of homegardens did show a significantly higher species richness and Shannon diversity index as compared to homegardens in the other clusters, except for the species evenness index which did reflect relatively equal values for clusters 2, 3 & 4 (Table 7). The mean SDRs value for this cluster revealed a mixed distribution for different use categories (Fig. 8). As compared to other clusters, the importance of fruits and ornamentals use groups was relatively higher, each with mean SDRs of 18%. The fruit use group was dominated by *Ananas comosus* (L.) Merr., *M. x-paradisiaca*, and *P. americana*. On the other hand, the dominance of *Dianthus longiglumis* Del., *Sagina apetala* Ard., and *D. caryophyllus* tend to explain their utilization tendencies for ornamental purposes. The homegardens grouped in cluster 4 were represented by high dominance

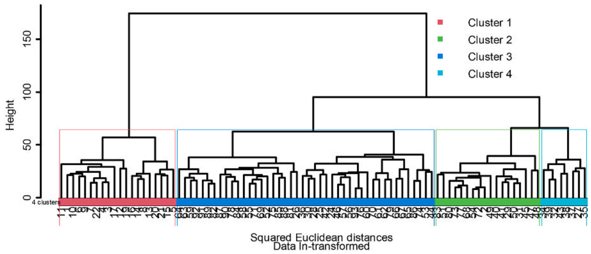

Fig. 6. Dendrogram as result of hierarchical cluster analysis for ln transformed abundance data of 90 agroforestry homegardens in three study sites of Gamo zone and Yem special woreda, southern and southwestern Ethiopia. Clusters in different bar colors define the correct number of clusters according to the elbow method. Source: Survey data. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

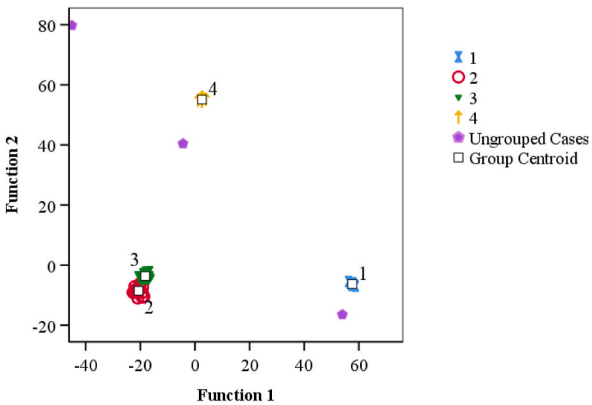

Fig. 7. Scatter diagram of stepwise canonical discriminant analysis for ln transformed abundance data of agroforestry homegardens in southern and southwestern Ethiopia. Source: Survey data.

Table 7
Household-, farm-specific and plant diversity parameters of 90 homegardens grouped into four clusters surveyed in southern and sothwestern Ethiopia.

	Cluster 1 (n = 20)		Cluster 2 (n = 18)		Cluster 3 (n = 44)		Cluster 4 (n = 8)	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Median household head age (years)††	53.50^{a}	23–97	40^{b}	24–56	42^{b}	26–96	33.50^{b}	29–45
Age of homegarden (years)	29.00	2–82	28.35	10–85	30.98	9–83	26.63	10–40
Family size (no.)	5.35^{a}	1–11	7.12^{b}	4–11	7.35^{b}	3–12	7.25^{b}	5–10
Size of homegarden (m^2)	2405.05	506–12014	2789.19	165–12957	3542.12	398–10544	2324.97	732–4726
Total landholding (ha)	0.28^{a}	0.01–1.50	0.61^{b}	0.02–2.0	0.67^{b}	0.13–3.00	1.59^{c}	0.50–3.50
Tropical Livestock Unit (TLU)	2.63^{a}	0.20–9.45	4.10^{ab}	0.0–8.70	5.40^{b}	0.65–29.70	3.34^{ab}	0.15–8.95
Species richness	11.35^{a}	6–18	11.44^{a}	2–22	16.16^{b}	6–27	26.63^{c}	16–37
Median individual density per 1000 m^2 ††	7016.5^{a}	518–44087	989.48^{b}	49–3711	1698.91^{c}	776–7741	1373.5^{bc}	287–2966
Shannon diversity	1.04^{a}	0.35–1.78	1.25^{a}	0.18–2.26	1.55^{b}	0.70–2.43	1.86^{b}	1.37–2.44
Median species evenness index ††	0.45^{a}	0.13–0.78	0.53^{ab}	0.16–0.99	0.61^{b}	0.27–0.84	0.59^{b}	0.44–0.74

Means in a row followed by different letters are significantly different at $P < 0.05$ (one-way ANOVA followed by LSD test). The symbol †† signifies Kruskal–Wallis test. Source: Survey data.

values of *C. esculenta*, *Triticum aestivum* L., *Saccharum officinarum* L., *D. longiglumis*, and *S. apetala*. Based on the observed features, homegardens of cluster four were considered as small-sized homegardens but with large landholdings, and high plant diversity with a mixed distribution of different use categories.

4. Discussion

4.1. Characteristics of sample homegardens and households

The average landholding size of the respondents varies from one geographic location to the other depending upon how big or small

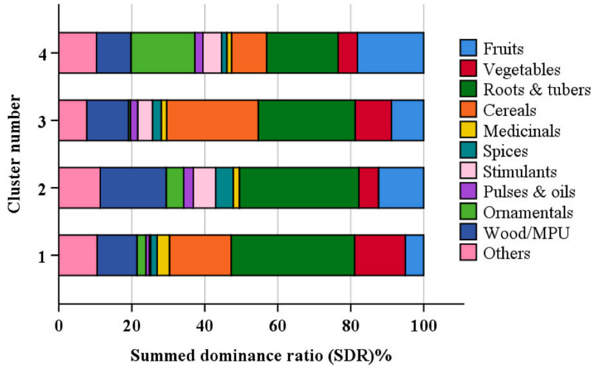

Fig. 8. Summed dominance ratios (SDR) for 206 plant species classified in different use categories found in 90 agroforestry homegardens in southern and sothwestern Ethiopia. Source: Survey data.

size the land resource is endowed and inherited from ancestral parents. In the present study, the average total landholding size recorded for Yoyra represents 55% of the SNNPR average, and 28% of the national average value [73]. Similarly, the mean total landholding recorded at Saja Laften in the present finding was found to be 2.75 times greater than the regional and 1.4 times greater than the national average [73]. In addition, the diminishing size of farmlands in some sites as compared to others might be attributed to the prevailing differences in agroecological conditions, and population densities as they are high in mountainous areas [74], or to wealth status [75].

As there were numeric differences in sizes of homegardens between sites, the average values in this study were comparable within the ranges reported to the humid lowland and tropical homegardens of Africa and the American tropics [63,76,77], but larger than that reported in some sites in Indonesia [29,38], Vietnam [78], and India [33]. The fact that agroforestry homegardens took up an overwhelming majority surface from the available total landholding in Yoyra and Malo Ezo sites indicates their relative importance in the farming system, particularly in addressing most of the family consumption needs, local food culture, and cash supplement [78,79]. This may reflect the fact that the size of homegardens is context-specific and variability among each other did occur depending upon agroecological and socioeconomic situations [24].

The increasing integration of livestock into the homegardens, as manifested by the presence of a higher Tropical Livestock Units (TLUs) value could indicate the addition of more sources of manure to the system which in turn reduces the need for chemical fertilizer [26,80]. However, a negative nutrient balance was reported in homegardens where there was no inclusion of cattle or in situations where there was a decline in herd size and sparse manure application [26,80].

4.2. Plant species diversity and similarity of homegardens

The total plant species richness (206, Table 5; Appendix B) observed in the surveyed homegardens in southern and southwestern Ethiopia was comparable to what was reported in eastern Africa, and elsewhere in the world (209 by Ref. [19] in Uganda; 198 by Refs. [75,81] in southern Ethiopia), but were much higher than that reported elsewhere in Ethiopia and other ecological regions (153 by Ref. [39] in Kerala State, India; 127 by Ref. [79] in southwestern Ethiopia; 110 by Ref. [42] in Sudan; and 81 by Ref. [82] in western Kenya). Mohan's et al. [39] report of the above-mentioned total species, together with the same diversity values as related to the present study confirms that ecological diversity emerging from their study establishes the similarity between homegardens and natural ecosystems in their geographical region.

The relatively higher number of species in the study area may be associated with the predominance of complementary agroforestry homegardens as compared to integral homegardens where farmers may possess multipurpose farm fields around homes that form the principal means of livelihood for the households with no or little additional land allocated to specialized production systems such as cereals in the latter case [75]. While complementary homegardens typically represent small-scale supplementary food production systems around houses in areas where the livelihood of the owners is based on other land use or other activities [41]. Furthermore, the lower diversity of the integral agroforestry homegardens may be attributed to the incorporation of light-demanding staple food crops and a relatively large number of cash crops [75] that might be associated with the management of varying niches meant for addressing different socioeconomic needs within the homegardens [63,83]. The relatively higher plant richness, paired with the harboring of endemic and threatened species, in the present study is indicative of what those human-dominated landscapes are valuable for the conservation and maintenance of biological diversity both for crop genetic as well as forest tree resources [38]. With the inventory record of fifteen endemic and threatened species in Ethiopia, the present study revealed a relatively similar number compared to, for instance, coffee landscapes in southwest Ethiopia with sixteen endemic and threatened species [84], but higher than the agroforestry systems in Kachabira district, Southern Ethiopia, which showed only two species [85], reflecting the fact that more threatened species were supported in the present study [84].

When considering the mean species richness (11–23) per agroforestry homegardens in the present study, a comparable mean value of 15.71, which fell within these ranges was registered for homegardens in the upper Citarum watershed, Indonesia [29]. Similar results were also documented from the Nuba Mountains, Sudan with a mean of 23 species [42]; and 17–28 species from Kerala, India [33]. However, a lower extreme mean richness value of 4 was also reported from Sudan [86] (Thompson et al., 2010). Contrary to the present study, a slightly higher mean value of 37 species per homegarden was noted in Sidama, Ethiopia [75]. These all may imply that variation in plant species richness may be observed in different geographical areas owing to the prevailing differences in altitude, amount of rainfall, type of soil, and other socioeconomic and environmental variables [87].

The Shannon diversity index (H′) in the studied homegardens varied from 1.04 to 1.55 which was comparably matching to the values ranging from 1.10 to 1.46 in the eastern region of Ghana, where it was located in the semi-deciduous forest zone of the region [88]. In the Nuba mountains, Sudan, the mean H′ was ranging from 1.43 to 1.56 [42], and similarly, the mean H' (1.61) was recorded in southwest Uganda [19]. Other studies conducted in homegardens of Sidama region, southern Ethiopia, and multistrata agroforestry systems of the humid tropics yielded mean diversity values (H′, 1.57 [82]; and H′, 1.45; [18]), respectively, close to the present study. When considering south Asia, a remarkably comparable mean range of Shannon diversity index (H′, 1.15–1.42) was noted in Thrissur district, Kerala, India [39]. However, a rather low range of Shannon diversity index (H′, 0.53–1.13) was documented in Niger [10]. In this study, a decreasing gradient of the mean Shannon diversity index was observed as one moves from one geographical region to the other. For instance, a relatively lower diversity value was noticed in Yoyra (H′, 1.04) as compared to Malo Ezo (H′, 1.55) and Saja Laften (H′, 1.52), which may be because of the dominance of few species [89] and prevailing altitudinal differences of the homegardens as reflected by contrasting agroclimatic condition where therein cool temperate climate (Dega) is being experienced at Yoyra [41,90], as depicted by the mean altitude of 2695 m a.s.l. In general, although there were variations in diversity patterns across different geographical areas, the mean Shannon values in the present study did imply that the homegardens were not very diverse or can be considered moderate as suggested by Ref. [42], who rated H′ values of >2 as high. A similar medium diversity index (H', 1.80) was also reported in the homegardens of eastern Amazon, Brazil [28]. The mean species evenness index (0.47–0.60) recorded in the present homegardens was comparably somewhat similar in magnitude to those homegardens in the Sidama region, southern Ethiopia [81], and rural Ghana [88], where they documented a mean evenness index of 0.53 and 0.42–0.57, respectively. The fact that evenness values became not very high means that the distribution of plants among agroforestry homegardens may explain the varying relative abundance of each species [81,91]. In the present study, the mean individual density per 1000 m^2 was comparably equal to the one recorded in the Nuba Mountains, Sudan [42], where they reported mean values that lay between 1851 and 8552 plants per 1000 m^2. Similarly, a recent study in homegardens of southwest Uganda also confirmed the same range of individual density per 1000 m^2 [19]. A rather low range value of individual density between 70 and 3940 plants per 1000 m^2 was documented in Central Sulawesi, Indonesia [38]. In the present finding, the highest individual plant density per 1000 m^2 was recorded in the Yoyra site. In this site, smaller-sized agroforestry homegardens were observed, which is indicative of the fact that the density of individual plants has increased with decreasing farmland because farmers are highly in need of satisfying their consumption as well as income incentives within these small pieces of land or to adapt to their land constraints [38,75,90].

In these homegardens, the most frequently occurring typical tropical homegarden plants include enset (*E. ventricosum*) as reported by several others in Ethiopia [11,31,92], followed by *C. africana* and species of the same genus were also mentioned as the most frequent timber species in homegardens elsewhere in other studies [16,41,63]. The other more frequently encountered species, as was also demonstrated in other geographical areas, including coffee (*C. Arabica*), banana (*M. x-paradisiaca*), corn (*Z. mays*), and taro (*C. esculenta*) [38]. Enset is a herbaceous multipurpose crop that serves as a staple food for an estimated 20 million people, mainly in southwestern and southern Ethiopia [81].

Although there exist differences in species composition among homegardens across sites as revealed by the high Beta (β) diversity between Yoyra and Saja Laften, and also between Yoyra and Malo Ezo, all the sites shared some common species that frequently occurred in each, implying that they similarly valued these common plants [41,93], as mentioned above.

4.3. Plant use category in agroforestry homegardens

In the studied agroforestry homegardens, wood/MPU (representing 21% of total species) use category was found to be the most species-rich similar to the homegardens in Tanzania and southwest Uganda [19,94]. Although the staple crops represented by roots and tubers, and cereals use categories were found to have few species (Table 5), they had the highest micro-zone area share (41.65% and 30.81%, respectively; Table 6) in the studied homegardens. This implies that each use category that contains fewer species may not undermine the extent to which they were cultivated and their relevance to the farm family requirement. This corroborates with the observation by Ref. [81] who did show a higher proportional area share of root and tuber crops (29.6%), followed by cereals (17%) than the rest in the homegardens of Sidama, southern Ethiopia. Furthermore, the observed variation in use categories across sites may reflect differences in farm family's needs and interests sought to exploit different utility values, where some utility values did show the richest families while some others low families exemplifying varying floristic significance in the agroecosystems [95].

Homegardens aside from capturing diverse plant species, also tend to reflect different uses as explained by key elements of agroecosystem structure resulting from a mosaic of micro-zones interplanted with different species each being designated by a use category or functional use group [81,82]. Based on the SDR values per use category as assessed at a site level, the present finding revealed the dominance of starchy roots and tubers use group as staple food crops in Yoyra and Malo Ezo as compared to that of Saja Laften, as demonstrated in recent studies in Kenya [82]. Following the roots and tubers, the cereals use group in the present finding was recognized to be another dominant group that could also serve as a staple and co-staple food in all three sites, as revealed by Refs. [82,96] in the homegardens of Kenya and Benin, respectively, where they reported as main food groups. Similar to what was noted in the findings of [82], a relatively lower dominance of pulses and oils was reported in the present study homegardens. As per SDR at a site level, groups of homegardens at Saja Laften which had a relatively equal distribution of different use categories, except that of a slightly dominant cereal reveal a more efficient and balanced supply of diversity of nutritious foods all over the year-round [19].

4.4. Classification of the agroforestry homegardens

Although cluster analysis was most commonly applied to vegetation science, recently it was frequently used and applied to differentiate agroforestry homegardens [18,19,28,33,34,38,41,42]. The method is used to evaluate the overall plant species composition and structure, and eventually recommend their relevance in conservation and management strategies [10,33,42].

The results of cluster analysis were important not only because they illustrate the variation in diversity, but also dictate some similarity in the floristic composition among the agroforestry homegardens in different sites. This can be further supported by the calculated Beta (β) diversity. Besides the distinctness in the floristic composition of groups of homegardens in Yoyra where they were exclusively found in cluster 1, there were also slight overlappings across clusters for some groups of homegardens in Saja Laften and Malo Ezo sites, e.g. clusters 2 and 3. Although Saja Laften and Malo Ezo sites are geographically distant, their similarities in species composition may be attributed to the prevailing similar environmental conditions [93]. The common species in clusters 2 and 3 may also indicate characteristics of homegarden floras shared and culturally important species by groups of people living in different areas [93,97], e.g. roots and tubers such as potato, sweet potato, taro, yam, and enset being used as staple foods in southern Ethiopia, as mentioned by Ref. [41].

The most notable result of the cluster analysis among the studied homegardens in the present work was the marked isolation of the high-altitude Yoyra site from the other two sites. The homegardens in Yoyra site ("cluster 1") were separated from others may be due to the effect of higher elevation on plant species richness which could be reflected to dropping in mean temperature [41]. This, in turn, dictates that there exists a set of different climatic characteristics that impose limitations on the adaptation of some species that can be grown in the homegardens [38,41,93].

Moreover, the cluster analysis in the present work helps to differentiate homegarden types that did vary both in the household- (household head age, family size) and farm-specific (total landholding) characteristics, and socioeconomic (TLUs variables) (Table 7). Our results of cluster analysis agree with the works of other researchers elsewhere in Niger [10], who did indicate that high species diversity can be maintained and conserved in those households having a higher family size, small-sized homegarden but larger landholdings (a proxy for wealth), and whose income source is not restricted only to homegardens. Similar to the present study, researchers found that higher species richness, diversity index, and individual density per 1000 m^2 were also noted in small-sized groups of homegardens among clusters in Indonesia [38,90]. In western Kenya, Ng'endo et al. [82] also confirmed that higher species diversity values were recorded in small-sized farms as compared to larger ones except that of the individual density of plants per 1000 m^2. Wiehle et al. [42] also reported a higher Shannon diversity index among clustered groups of homegardens having relatively small-sized homegardens. But, in contrast to Ref. [10], high species diversity among clusters in the present study was not found in groups of elderly households. Similar to the present work, sweet potato, and coffee were mentioned as they characterized groups of homegardens in different clusters in southern Ethiopia [11,81] and Central Sulawesi, Indonesia [38].

In contrast to the findings of [19] who discussed no more significantly different TLUs among homegarden clusters, the present work tended to differ indicating the importance of livestock rearing as potential sources of animal-based protein supplement, income, and provision of manure for soil fertility enhancement or nutrient cycling [23]. Several studies undertaken elsewhere [10,19,42,81] indicate that staple food plants with different sets of species were dominating among homegarden clusters similar to groups of homegardens that emerged from clusters 1, 2, and 3 of the present study. Similar to what was reported by Refs. [10,19], fruits and coffee were also reported to be dominant in groups of homegardens from clusters 1 and 2, respectively. As observed in cluster group 2 of the present study, native woody species were also reported as they were prevalent in groups of homegardens identified as cluster 2 in Niger [10]. Based upon the calculated mean SDR value in the present work, groups of homegardens from cluster 4 did reveal a mixed distribution for different use categories similar to the findings of [19] who reported a balanced dominance of a variety of crops. A balanced distribution of functional use groups for groups of homegardens within a cluster may dictate the continued contribution of diverse foods to farm families throughout the year [11,19,41,82]. In summary, the four groups of agroforestry homegardens identified include, 'small-sized, low plant diversity, barley-potato-enset-apple homegardens (Cluster 1)'; 'intermediate-sized, taro-enset-coffee homegardens (Cluster 2)'; 'large-sized, maize-taro-sweet potato-teff-enset homegardens (Cluster 3)'; and 'small-sized, high plant diversity with mixed-use category homegardens (Cluster 4)'. These identified groups of homegardens may reveal the varying potentials each group of homegardens had under the prevailing socioeconomic and sociocultural settings where the farm households meet their livelihood, and food and nutrition requirements [19]. Aside from its role in conservation strategies, pattern analysis of species composition [98,99] may be relevant in sufficiently separating homegardens into identifiable groups that are different in the household- [10,19] and farm specific [10,42,98], socioeconomic characteristics [42], and diversity parameters [10,19,42,98]. This, in turn, may be valuable in identifying homegarden groups that are the most suitable ones and those that need some kind of improvements [10,19,98], and to be extensively practiced in the different studies sites. However, one-time studies [10], and the lack of consistent research methodology of previous studies make precise comparisons difficult [99].

4.5. The implication of agroforestry homegardens plant species diversity, and use groups for sustainable agriculture

Compared to other land uses like monoculture, structurally more complex and multistoried agroecosystems that support higher species richness like the present agroforestry homegardens (comprising 206 species) did reflect the multifunctional roles of these niches of agroecosystems. Besides the diverse species, assemblages that this homegardens exhibit, the presence of different species use categories may also indicate that each farm household had a built-in experience for placing haphazardly each of these species on their homesteads in due course of their farming systems management. Homegardens are important niches in agroecosystems where the core principles of sustainable agriculture and agroecology can be addressed through the maintenance of plant diversity because of the wide range of goods and services that they provide in supporting ecosystem functioning, resilience, and productivity [24].

Today a fundamental issue in all land use practices is sustainability, meeting today's needs without compromising the ability of future generations to satisfy their needs [100]. As part of social sustainability, agroforestry homegardens attempt to meet the livelihood needs by harboring a varying mix of valued species with different life cycles, and the functional groups (use groups) being manifested as mosaics of heterogeneous landscape in which they form part of it [32,101]. The varying life cycles of diverse homegarden plant species exemplify a sustained year-round supply of goods for farm households [24]. It is not only the livelihood condition [32] but also the social dynamics that were relevant in judging social sustainability [32,33], implying that homegardens are important social places for the integration of agricultural practices through domestication and maintenance of the plant world [24,102]. Wider utilization of homegardens in different parts of the world, including Ethiopia [81,100] may have proven to be a resilient agricultural system that co-existed and stood the test of time against the social and cultural changes [103,104]. As there is an enormous need to meet food production through agricultural intensification, maintaining and enhancing such diverse species mix landscapes can be appropriately addressed if strategically managed to maximize the benefits of both sustainable agricultural production and conservation of plant diversity [11,101].

As domestic animals are a basic attribute of agricultural sustainability [11,105], they are reared either for direct home consumption to obtain a sustained protein supply or for sale, and to enhance soil fertility through the use of animal manure although its availability to cover large areas of croplands may be questionable [104]. Even if it was neglected in some studies as a system component within homegardens, it had a resultant positive effect towards achieving both ecological and economic roles [81]. Beyond the role it played as a staple food, enset was also reported to spread the risk of total crop failure [81]. Enset also renders environmental roles as it prevents soil erosion; it maintains microclimate for the undergrowth through the provision of shade and improves soil fertility through litter addition from leaves and pseudostems [11]. Integrated farming systems characterized by a simultaneous combination of micro-zones or different functional use groups (such as cereals, fruits, vegetables, fodder, animal products, etc.) could result in more diverse farms which are more sustainable and resilient than species-poor farms [106]. As demonstrated by Refs. [38,82], a well-balanced mix of varying functional use groups might lead to higher plant diversity, as it can be evidenced by a more balanced proportion of SDR values and diversity indices.

Furthermore, according to Refs. [24,32] the multispecies composition and presence of trees in homegardens enable for continued synergetic ecological processes such as (a) efficient utilization of aboveground and belowground space; (b) efficient circulation of nutrients and reduced risks for the depletion of nutrients as the result of the presence of filters against such losses is key to the ecological sustainability of homegardens [32,104]; (c) enhanced control of soil erosion and soil fertility through fallen leaves and the accumulation of humus; (d) plant protection as a result of the presence of buffers against damaging agents such as pests and diseases; and (e) protection against potentially degrading forces such as torrential rainfall, surface run-off or strong winds as a result of the presence of vegetative barriers. Understanding agroforestry systems may open up new opportunities for developing new unifying concepts for agroforestry research as well as further development of 'nature-analogous' agroforestry systems [32]. In particular, a well-thought-out concept for enhancing the productivity of agroforestry homegardens while concomitantly addressing ecological and socioeconomic functions may likely be devised to reduce the negative impacts of agricultural intensification [38]. In this regard, as there were no resolved concepts of sustainable intensification and ecological intensification, continued debate on these issues is still open for the scientific community [107–109] (Bommarco et al., 2013; Garnett et al., 2013; Zimmerer et al., 2015).

5. Conclusion

In the studied agroforestry homegardens a relatively larger total plant species richness was reported quite comparable to that retained in western and eastern Africa, and elsewhere in the world. Endemic and threatened species were also harbored in this system. These all are reflecting the fact that these systems are valuable for biodiversity conservation and maintenance in human-dominated landscapes, which in turn fosters the ecological sustainability of the systems. The reason for this relatively high diversity in the present study may be attributed to the integrative management of varying niches/micro-zones meant for addressing different socioeconomic needs and the predominance of complementary homegardens. The fact that a large majority of surface area was allocated for homegardens in most sites as compared to the total landholding, among which roots and tubers cover a significant portion, and followed by cereals and others, may reflect the multiple production functions associated with increased diversity of plants and functional groups. This, in turn, may reflect the fact that agroforestry homegardens beyond serving as reservoirs of biodiversity, their associated production functions do reveal socioeconomic benefits, let alone ecological ones. While addressing sustainability concerns, increasing the dual advantages of enhancing food supply and more diverse diets through sustainable intensification should take into account the advantages of ecological processes. Following the application of cluster analysis, it was possible to classify the present agroforestry homegardens into distinct groups being significantly differentiated by various household- and farm-specific, and socioeconomic variables. Those groups of agroforestry homegardens identified include, 'small-sized, low plant diversity, barley-potato-enset-apple homegardens'; 'intermediate-sized, taro-enset-coffee homegardens'; 'large-sized, maize-taro-sweet potato-teff-enset homegardens'; and 'small-sized, high plant diversity with mixed-use category homegardens'. The identified groups of homegardens may reveal the varying potentials each group of homegardens had under the prevailing socioeconomic and sociocultural settings where the farm households meet their livelihood, and food and nutrition requirements. Further research may be required to employ different factors to classify homegarden groups that seem to involve development interventions, and for enhancing the role of agroforestry homegardens in different socioeconomic and agroecologic situations. In addition, both temporal and spatial analyses of the structural dynamics of these systems need to be further considered to ascertain the magnitude of plant diversity changes, and the assessment of long-term sustainability.

Author contribution statement

Gezahegn Kassa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Tamrat Bekele, Sebsebe Demissew, and Tesfaye Abebe: Analyzed and interpreted the data; contributed materials, analysis tools or data; wrote the paper.

Data availability statement

Data will be made available on request.

Additional information

No additional information is available for this paper.

Declaration of competing interest

The authors report that there are no competing interests to declare.

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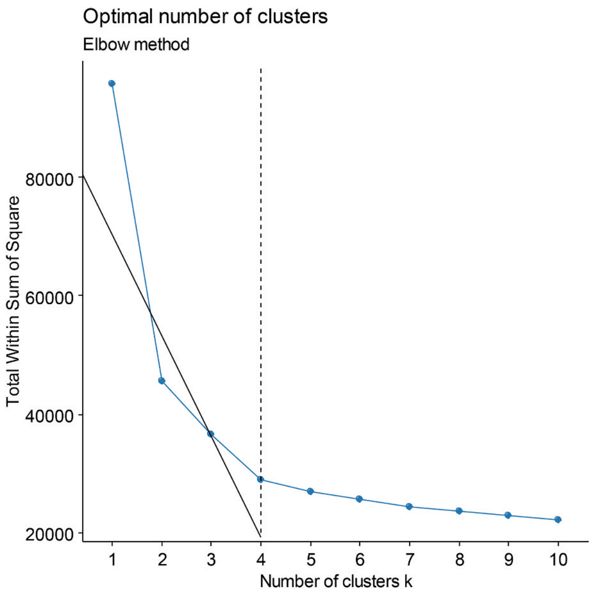
Appendix A. Schematic representation indicating the number of clusters determined using 'elbow' criterion, carried out on the basis of ln-transformed plant species abundance data of 90 agroforestry homegardens in southern and southwestern Ethiopia



Appendix B. Plant species found in 93 agroforestry homegardens surveyed in three sites in southern and southwestern Ethiopia

No.	Overall species	Family name	Habit	Native/Exotic
1.	*Acacia melanoxylon* R. Br.	Fabaceae	Tree	Ex
2.	*Achyrospermum schimperi* (Hochst. ex Briq.) Perkins	Lamiaceae	Herb	N
3.	*Aframomum corrorima* (Braun) Jansen	Zingiberaceae	Herb	N
4.	*Agapanthus praecox* Willd.	Alliaceae	Herb	N
5.	*Ajuga alba* (Gürke) Robyns	Lamiaceae	Herb	N
6.	*Albizia schimperiana* Oliv.	Fabaceae	Tree	N
7.	*Allium cepa* L.	Alliaceae	Herb	Ex
8.	*Allium sativum* L.	Alliaceae	Herb	Ex
9.	*Alternanthera sessilis* (L.) DC.	Amaranthaceae	Herb	N
10.	*Amaranthus hybridus* L.	Amaranthaceae	Herb	N
11.	*Ananas comosus* (L.) Merr.	Bromeliaceae	Herb	Ex
12.	*Annona senegalensis* Pers.	Annonaceae	Tree	N
13.	*Annona squamosa* L.	Annonaceae	Shrub	Ex
14.	*Arachis hypogaea* L.	Fabaceae	Herb	Ex
15.	*Argemone mexicana* L.	Papaeraceae	Herb	N
16.	*Arisaema schimperanum* Schott	Araceae	Herb	N
17.	*Artemisia annua* L.	Asteraceae	Herb	Ex
18.	*Artemisia absinthium* L.	Asteraceae	Herb	Ex
19.	*Artemisia afra* Jacq. ex Willd.	Asteraceae	Herb	N
20.	*Artocarpus heterophyllus* Lam.	Moraceae	Tree	Ex
21.	*Arundinaria alpina* K. Schum.	Poaceae	Tree	N
22.	*Arundo donax* L.	Poaceae	Herb	N
23.	*Bersama abyssinica* Fresen.	Meliaceae	Tree	N
24.	*Beta vulgaris* L.	Chenopodiaceae	Herb	Ex
25.	*Beta vulgaris* L.	Chenopodiaceae	Herb	Ex
26.	*Bothriocline schimperi* Oliv. & Hiern ex Benth.	Asteraceae	Herb	N
27.	*Brassica carinata* A. Br.	Brassicaceae	Herb	Ex
28.	*Brassica nigra* (L.) Koch	Brassicaceae	Herb	N
29.	*Brassica oleracea* L.	Brassicaceae	Herb	Ex
30.	*Bridelia micrantha* (Hochst.) Baill.	Euphorbiaceae	Tree	N
31.	*Brucea antidysenterica* J. F. Mill.	Simaroubaceae	Tree	N
32.	*Buddleja polystachya* Fresen.	Laganiaceae	Shrub	N
33.	*Calpurnia aurea* (Ait.) Benth.	Fabaceae	Shrub	N
34.	*Canna indica* L.	Cannaceae	Herb	Ex
35.	*Canna* × *generalis* L.H. Bailey	Cannaceae	Herb	Ex
36.	*Capsella bursa-pastoris* (L.) Medic.	Brassicaceae	Herb	Ex
37.	*Capsicum annum* L.	Solanaceae	Herb	Ex
38.	*Carica papaya* L.	Caricaceae	Tree	Ex
39.	*Carthamus lanatus* L.	Asteraceae	Herb	N
40.	*Casimiroa edulis* La Llave	Rutaceae	Tree	Ex
41.	*Cassipourea malosana* (Baker) Alston	Rhizophoraceae	Shrub	N
42.	*Catha edulis* (Vahl.) Forssk. ex Endl.	Celastraceae	Shrub	N
43.	*Celtis africana* Burm.f.	Ulmaceae	Tree	N
44.	*Chaemaecytisus proliferus* L.f.	Fabaceae	Shrub	Ex
45.	*Cirsium vulgare* (Savi.) Ten.	Asteraceae	Herb	N
46.	*Citrus aurantifolia* (Christm.) Swingle	Rutaceae	Tree	Ex
47.	*Citrus aurantium* L.	Rutaceae	Tree	Ex
48.	*Citrus medica* L.	Rutaceae	Tree	Ex
49.	*Citrus sinensis* (L.) Osb.	Rutaceae	Tree	Ex
50.	*Clematis hirsuta* Perr. & Guill (leaf tri-lobed)	Ranunculaceae	Climber	N
51.	*Clematis simensis* Fresen.	Ranunculaceae	Climber	N
52.	*Clerodendrum myricoides* (Hochst.) Vatke	Lamiaceae	Shrub	N
53.	*Coffea arabica* L.	Rubiaceae	Shrub	N
54.	*Colocasia esculenta* (L.) Schott.	Araceae	Herb	Ex
55.	*Combretum molle* R. Br. ex G. Don	Combretaceae	Tree	N
56.	*Combretum adenogonium* Steud. ex A. Rich.	Combretaceae	Tree	N
57.	*Combretum rochetianum* A. Rich ex A. Juss.	Combretaceae	Tree	N
58.	*Commelina diffusa* Burm f.	Commelinaceae	Herb	N
59.	*Conyza hypoleuca* A. Rich.	Asteraceae	Shrub	N
60.	*Cordia africana* Lam.	Boraginaceae	Tree	N
61.	*Coriandrum sativum* L.	Apiaceae	Herb	Ex
62.	*Croton macrostachyus* Del.	Euphorbiaceae	Tree	N
63.	*Cucurbita pepo* L.	Cucurbitaceae	Herb	Ex
64.	*Cupressus lusitanica* Mill.	Cupressaceae	Tree	Ex
65.	*Curcuma domestica* Valeton	Zingiberaceae	Herb	Ex
66.	Cyphomandra betacea (Cav.) Sendtner	Solanaceae	Shrub	Ex
67.	*Cyphostemma adenocaule* (Steud. ex A. Rich.) Desc. ex Wild & Drummond	Vitaceae	Climber	N

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No.	Overall species	Family name	Habit	Native/Exotic
68.	*Daucus carota* L.	Apiaceae	Herb	Ex
69.	*Dianthus caryophyllus* L.	Caryophyllaceae	Herb	Ex
70.	*Dianthus longiglumis* Del.	Caryophyllaceae	Herb	Ex
71.	*Dioscorea alata* L.	Dioscoreaceae	Herb	Ex
72.	*Dioscorea bulbifera* L.	Dioscoreaceae	Herb	N
73.	*Dioscorea praehensilis* Benth.	Dioscoreaceae	Herb	N
74.	*Diospyros abyssinica* (Hiern) F. White	Ebenaceae	Tree	N
75.	*Discopodium penninervium* Hochst.	Solanaceae	Shrub	N
76.	*Dodonaea angustifolia* L. f.	Sapindaceae	Shrub	N
77.	*Dombeya torrida* (G. F. Gmel.) P. Bamps	Sterculiaceae	Tree	N
78.	*Dracaena afromontana* Mildbr.	Dracaenaceae	Tree	N
79.	*Dracaena steudneri* Engl.	Dracaenaceae	Tree	N
80.	*Echinops kebericho* Mesfin	Asteraceae	Herb	N
81.	*Echinocloa haploclade* (Stapf) Stapf	Poaceae	Herb	N
82.	*Ehretia cymosa* Thonn.	Boraginaceae	Tree	N
83.	*Ekebergia capensis* Sparrm.	Meliaceae	Tree	N
84.	*Ensete ventricosum* (Welw.) Cheesman	Musaceae	Herb	N
85.	*Eragrostis tef* (Zucc.) Trotter	Poaceae	Herb	N
86.	*Erythrina brucei* Schweinf.	Fabaceae	Tree	N
87.	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	Tree	Ex
88.	*Eucalyptus globules* Labill	Myrtaceae	Tree	Ex
89.	*Euphorbia abyssinica* Gmel.	Euphorbiaceae	Tree	N
90.	*Euphorbia ampliphylla* Pax	Euphorbiaceae	Tree	N
91.	*Euphorbia cotinifolia* L.	Euphorbiaceae	Tree	Ex
92.	*Euphorbia pulcherrima* Klotzsch.	Euphorbiaceae	Shrub	Ex
93.	*Euphorbia tirucalli* L.	Euphorbiaceae	Shrub	N
94.	*Faurea speciosa* Welw.	Proteaceae	Tree	N
95.	*Ficus ingens* (Miq.) Miq.	Moraceae	Tree	N
96.	*Ficus lutea* Vahl	Moraceae	Tree	N
97.	*Ficus thonningi* Blume	Moraceae	Tree	N
98.	*Ficus sur* Forssk.	Moraceae	Tree	N
99.	*Ficus sycomorus* L.	Moraceae	Tree	N
100.	*Ficus vasta* Forssk.	Moraceae	Tree	N
101.	*Foeniculum vulgare* Miller	Apiaceae	Herb	Ex
102.	*Gardenia ternifolia* (Schumach.) & Thonn.	Rubiaceae	Tree	N
103.	*Gossypium barbadense* L.	Malvaceae	Herb	Ex
104.	*Gouania longispicata* Engl.	Rhamnaceae	Climber	N
105.	*Grevillea robusta* R. Br.	Proteaceae	Tree	Ex
106.	*Hagenia abyssinica* (Brace) J.F. Gmel.	Rosaceae	Tree	N
107.	*Haplocarpha schimperi* (Sch. Bip.) Beauv.	Asteraceae	Herb	N
108.	*Hibiscus acetosella* Welw. ex Hiern	Rosaceae	Climber	Ex
109.	*Hibiscus rosa-sinensis* L.	Malvaceae	Shrub	Ex
110.	*Hordeum vulgare* L.	Poaceae	Herb	N
111.	*Hypoestes forskaolii* (Vahl) R. Br.	Acanthaceae	Herb	N
112.	*Hypoestes triflora* (Forssk.) Roem & Schult.	Acanthaceae	Herb	N
113.	*Impatiens ethiopica* Grey-Wilson	Balsaminaceae	Herb	N
114.	*Impatiens rothi* Hook. f.	Balsaminaceae	Herb	N
115.	*Ipomoea batatas* (L.) Lam.	Convolvulaceae	Herb	Ex
116.	*Iresine herbstii* Lindl.	Amaranthaceae	Herb	N
117.	*Iris germanica* L.	Iridaceae	Herb	N
118.	*Jacaranda mimosifolia* D. Don	Bignoniaceae	Tree	Ex
119.	*Jasminum grandiflorum* L.	Oleaceae	Climber	N
120.	*Jatropha curcas* L.	Euphorbiaceae	Shrub	Ex
121.	*Juniperus procera* Hochst. ex Endl.	Cupressaceae	Tree	N
122.	*Justicia schimperiana* (Hochst. ex Nees) T. Anders.	*Acanthaceae*	Shrub	N
123.	*Kalanchoe lanceolata* (Forssk.) Pers.	*Crassulaceae*	Herb	N
124.	*Kalanchoe petitiana* A. Rich.	*Crassulaceae*	Herb	N
125.	*Kniphofia foliosa* Hochst.	Asphodelaceae	Herb	N
126.	*Lagenaria siceraria* (Molina) Standl.	Cucurbitaceae	Herb	N
127.	*Landolphia buchananii* (Hall.f.) Stapf	Apocynaceae	Climber	N
128.	*Lantana ukambensis* (Vatke) Verdc.	Verbenaceae	Herb	N
129.	*Lepidium sativum* L.	Brassicaceae	Herb	N
130.	*Linum usitatissimum* L.	Linaceae	Herb	N
131.	*Lippia adoensis* Hochst. ex Walp.	Verbenaceae	Shrub	N
132.	*Lycopersicon esculentum* Mill.	Solanaceae	Herb	Ex
133.	*Maesa lanceolata* Forssk.	Myrsinaceae	Shrub	N
134.	*Malus sylvestris* Mill.	Rosaceae	Shrub	Ex
135.	*Mangifera indica* L.	Anacardiaceae	Tree	Ex
136.	*Manihot esculenta* Crantz.	Euphorbiaceae	Shrub	Ex
137.	*Melia azedarach* L.	Meliaceae	Tree	Ex

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No.	Overall species	Family name	Habit	Native/Exotic
138.	*Mentha x-piperata* L.	Lamiaceae	Herb	N
139.	*Mikaniopsis clematoides* (Sch. Bip. ex A. Rich.) Milne-Redh.	Asteraceae	Herb	N
140.	*Milletia ferruginea* (Hochst.) Bak.	Fabaceae	Tree	N
141.	*Momordica feotida* Schumach.	Cucurbitaceae	Herb	N
142.	*Moringa oleifera* Lam.	Moringaceae	Tree	Ex
143.	*Moringa stenopetala* (Bak.f.) Cufod.	Moringaceae	Tree	N
144.	*Musa x-paradisiaca* L.	Musaceae	Herb	N
145.	*Nicotiana tabacum* L.	Solanaceae	Herb	Ex
146.	*Ocimum basilicum* L.	Lamiaceae	Herb	N
147.	*Ocimum lamiifolium* Hochst. ex Benth.	Lamiaceae	Shrub	N
148.	*Ocimum urticifolium* Roth	Lamiaceae	Shrub	N
149.	*Olea europaea* subsp. *cuspidata* (Wall. ex G.Don) Cif.	Oleaceae	Tree	N
150.	*Passiflora caerulea* L	Passifloraceae	Climber	N
151.	*Passiflora edulis* Sims	Passifloraceae	Climber	Ex
152.	*Pelargonium zonaale* (L.) L'Hér.	Geraniaceae	Herb	Ex
153.	*Pennisetum pedicellatum* Trin	Poaceae	Herb	N
154.	*Persea americana* Mill.	Lauraceae	Tree	Ex
155.	*Phaseolus vulgaris* L.	Fabaceae	Herb	Ex
156.	*Phoenix reclinata* Jacq.	Arecaceae	Tree	N
157.	*Piliostigma thonningii* (Schumach.) Milne-Redh.	Fabaceae	Tree	N
158.	*Pisum sativum* L.	Fabaceae	Herb	N
159.	*Plantago palmata* Hook.f.	Plantaginaceae	Herb	N
160.	*Plectranthus caninus* Roth	Lamiaceae	Herb	N
161.	*Plectranthus edulis (*Vatke) Agnew	Lamiaceae	Herb	N
162.	*Premna schimperi* Engl.	Lamiaceae	Shrub	N
163.	*Prunus africana* (Hook. f.) Kalkm.	Rosaceae	Tree	N
164.	*Prunus persica* (L.) Batsch	Rosaceae	Tree	Ex
165.	*Psidium guajava* L.	Myrtaceae	Tree	Ex
166.	*Ranunculus multifidus* Forssk.	Ranunculaceae	Herb	N
167.	*Rhamnus prinoides* L′ Herit.	Rhamnaceae	Shrub	N
168.	*Rhoicissus tridentata* (L.f.) Wild & Drummond	Vitaceae	Climber	N
169.	*Rhus natalensis* Krauss	Anacardiaceae	Tree	N
170.	*Ricinus communis* L.	Euphorbiaceae	Shrub	N
171.	*Rosa x richardii* Rehd.	Rosaceae	Shrub	Ex
172.	*Rubus niveus* Thunb	Rosaceae	Shrub	N
173.	*Rubus apetalus* Poir.	Rosaceae	Shrub	N
174.	*Rumex abyssinicus* Jacq.	Polygonaceae	Herb	N
175.	*Rumex nepalensis* Spreng.	Polygonaceae	Herb	N
176.	*Ruta chalepensis* L.	Rutaceae	Shrub	Ex
177.	*Saccharum officinarum* L.	Poaceae	Herb	Ex
178.	*Saccharum spontaneum* subsp. *spontaneum* (Willd.) Hack.	Poaceae	Herb	N
179.	*Sagina apetala* Ard.	Caryophyllaceae	Herb	Ex
180.	*Sansevieria nilotica* Baker	Dracaenaceae	Herb	N
181.	*Schrebera alata* (Hochst.) Welw.	Oleaceae	Tree	N
182.	*Sesbania sesban* (L.) Merr.	Fabaceae	Shrub	Ex
183.	*Sida rhombifolia* L.	Malvaceae	Herb	N
184.	*Solanecio angulatus* (Vahl) C. Jeffrey	Asteraceae	Herb	N
185.	*Solanecio gigas* (Vatke) C. Jeffrey	Asteraceae	Shrub	N
186.	*Solanum dasyphyllum* Schumach.	Solanaceae	Herb	N
187.	*Solanum macrocarpon* L.	Solanaceae	Shrub	N
188.	*Solanum tuberosum* L.	Solanaceae	Herb	Ex
189.	*Sonchus gigas* Boulos ex Humbert	Asteraceae	Herb	N
190.	*Sorghum bicolor* (L.) Moench	Poaceae	Herb	N
191.	*Spathodea campanulata* P. Beauv.	Bignoniaceae	Tree	Ex
192.	*Sporobolus africanus* (Poir.) Robyns & Tournay	Poaceae	Herb	N
193.	*Syzygium guineense* (Willd.) DC.subsp. *macrocarpum* (Engl.) F. White	Myrtaceae	Tree	N
194.	*Tagetes minuta* L	Asteraceae	Herb	Ex
195.	*Terminalia brownii* Fresen.	Combretaceae	Tree	N
196.	*Terminalia shimperiana* Hochst.	Combretaceae	Tree	N
197.	*Triticum aestivum* L.	Poaceae	Herb	N
198.	*Vernonia amygdalina* Del.	Asteraceae	Shrub	N
199.	*Vernonia rueppellii* Sch. Bip. ex Walp.	Asteraceae	Shrub	N
200.	*Vicia faba* L.	Fabaceae	Herb	Ex
201.	*Vigna unguiculata* (L.) Walp.	Fabaceae	Herb	N
202.	*Vinca rosea* L.	Apocynaceae	Herb	Ex
203.	*Zantedeschia ethiopica* (L.) K.P.J. Sprengel.	Araceae	Herb	Ex
204.	*Zea mays* L.	Poaceae	Herb	Ex
205.	*Zingiber offjicinale* Roscoe	Zingiberaceae	Herb	Ex
206.	*Ziziphus mucronata* Willd.	Rhamnaceae	Tree	N

Native species are denoted with 'N' and exotic species with 'Ex.'

Appendix C. Endemic and threatened plant species found in agroforestry homegardens in three sites in southern and southwestern Ethiopia [110–117]

Species	Endemicity	IUCN category	Remark
Aframomum corrorima		ND	
Eragrostic tef	Yes	ND	
Bothriocline schimperi	Yes	LC	
Combretum rochetianum	Yes	ND	
Echinops kebericho	Yes	VU	
Erythrina brucei	Yes	LC	
Impatiens rothi	Yes	LC	
Kalanchoe petitiana	Yes	ND	
Kniphofia foliosa	Yes	ND	
Lippia adoensis	Yes	LC	
Mikaniopsis clematoides	Yes	ND	
Milletia ferruginea	Yes	LC	
Prunus africana		VU	
Solanecio gigas	Yes	LC	
Vernonia rueppellii	Yes	NE	
Bidens macroptera	Yes	ND	Though a weed species in agroecosystems

ND=Not yet decided against the IUCN criteria; LC = Least concern; NE = near endemic; VU=Vulnerable.

Appendix D. Plant species represented by several different landraces in 93 agroforestry homegardens surveyed in three sites in southern and southwestern Ethiopia

Plant species	Names of landraces	Number of landraces
Barley (*Hordeum vulgare* L.)	Feleqe, bote, sentela, solk, ocho, daro, hunche, gecheta, giso, welete	10
Apple (*Malus sylvestris* Mill.)	Grany, krispy, BR4, peer, Ana, plum (peach)	6
Potato (*Solanum tuberosum* L.)	Nechu (dagmegna), qeyu (tolcha), gudene, wechecha, jalani/yalan, yalan, belete	7
Enset(Ensete ventricosum (Welw.) Cheesman),	Meze, beshira, sorge, katis, chemo, gena, orgozo, kunka, cheche, lobe, pelo, feleqe	12
Amoch (*Arisaema schimperanum* Schott)	kalezo, feleqe, meze, uucha, dashere, bondere, quliqolto	7
Banana(Muz)	Habesha muz, kenya muz	2
Yehareg boye (*Dioscorea* sp.)	Ayno boye; tetsiye boye; tolo boye	3
Godere (boyna) (*Colocasia esculenta* (L.) Schott)	Molo, gursheme, kone, pille, chula, bereket	6

Appendix E. Number and percentage of cases correctly classified as result of discriminant analysis, carried out on the basis of ln-transformed plant species abundance data of 90 agroforestry homegardens in southern and southwestern Ethiopia

Classification Results[a]							
		Cluster groups	Predicted Group Membership				Total
			1	2	3	4	
Original	Count	1	20	0	0	0	20
		2	0	18	0	0	18
		3	0	0	44	0	44
		4	0	0	0	8	8
		Ungrouped cases	1	0	0	2	3
	%	1	100.0	.0	.0	.0	100.0
		2	.0	100.0	.0	.0	100.0
		3	.0	.0	100.0	.0	100.0
		4	.0	.0	.0	100.0	100.0
		Ungrouped cases	33.3	.0	.0	66.7	100.0

[a] 100.0% of original grouped cases correctly classified.

References

[1] P.A. Matson, P.M. Vitousek, Agricultural intensification: will land spared from farming be land spared for nature? Conserv. Biol. 20 (3) (2006) 709–710.
[2] B. Phalan, R.E. Green, L.V. Dicks, G. Dotta, C. Feniuk, A. Lamb, B.B.N. Strassburg, D.R. Williams, E.K.H.J. zu Ermgassen, A. Balmford, How can higher yield farming help to spare nature? Mechanisms to link yield increases with conservation, Science 351 (6272) (2016) 450–451.
[3] J. Vandermeer, I. Perfecto, The agricultural matrix and a future paradigm for conservation, Conserv. Biol. 21 (1) (2007) 274–277.

[4] IPES-Food, From Uniformity to Diversity: A Paradigm Shift from Inductrial Agriculture to Diversified Agroecological Systems. Ingternational Panel of Experts on Sustainable Food Systems, 2016. www.ipes-food.org.
[5] M.A. Altieri, P. Rogé, The Ecological role and enhancement of biodiversity in agriculture, in: S. Lockie, D. Carpenter (Eds.), Agriculture, Biodiversity and Markets Livelihoods and Agroecology in Comparative Perspective, Earthscan Ltd, London, UK, 2010, pp. 15–32.
[6] S. Lockie, D. Carpenter, Agriculture, biodiversity and markets, in: S. Lockie, D. Carpenter (Eds.), Agriculture, Biodiversity and Markets Livelihoods and Agroecology in Comparative Perspective, Earthscan Ltd, London, UK, 2010, pp. 1–14.
[7] M.A. Altieri, Convergence or divide in the movement for sustainable and just agriculture, in: E. Lichtfouse (Ed.), Organic Fertilisation, Soil Quality and Human Health, Springer Science+Business Media B.V., Dordrecht, 2012, pp. 1–9.
[8] S.R. Gliessman, Transforming the global food system, in: S.R. Gliessman, M. Rosemeyer (Eds.), The Conversion to Sustainable Agriculture Principles, Processes, and Practices, CRC Press, Boca Raton, FL, USA, 2010, pp. 345–352.
[9] A. Wezel, J.-C. Jauneau, Agroecology – interpretations, approaches and their links to nature conservation, rural development and ecotourism, in: W. B. Campbell, L. Ortíz (Eds.), Integrating Agriculture, Conservation and Ecotourism: Examples from the Field, Springer Science, Dordrecht, 2011, pp. 1–25.
[10] H. Bernholt, K. Kehlenbeck, J. Gebauer, A. Buerkert, Plant species richness and diversity in urban and peri-urban gardens of Niamey, Niger, Agrofor. Syst. 77 (2009) 159–179, https://doi.org/10.1007/s10457-009-9236-8.
[11] T. Abebe, F. Bongers, Land-use dynamics in enset-based agroforestry homegardens in Ethiopia, in: B. Arts, S. van Bommel, M. Ros-Tonen, G. Verschoor (Eds.), Forest-People Interfaces: Understanding Community Forestry and Biocultural Diversity, Wageningen Academic Publishers, 2012, pp. 69–85.
[12] N.S. Sodhi, Tropical biodiversity loss and people: a brief review, Basic Appl. Ecol. 9 (2008) 93–99, https://doi.org/10.1016/j.baae.2007.11.001.
[13] S. Rajput, D.R. Bhardwaj, N.A. Pala, Factors influencing biomass and carbon storage potential of different land use systems along an elevational gradient in temperate northwestern Himalaya, Agrofor. Syst. 91 (2017) 479–486, https://doi.org/10.1007/s10457-016-9948-5.
[14] G. Abebe, A. Tsunekawa, N. Haregeweyn, T. Takeshi, M. Wondie, E. Adgo, T. Masunaga, M. Tsubo, K. Ebabu, M. Liyew, A. Tassew, Effects of land use and topographic position on soil organic carbon and total nitrogen stocks in different agro-ecosystems of the upper Blue Nile Basin, Sustainability12 2425 (2020), https://doi.org/10.3390/su12062425.
[15] S.A. Bhagwat, K.J. Willis, H.J.B. Birks, R.J. Whittaker, Agroforestry: a refuge for tropical biodiversity? Trends Ecol. Evol. 23 (5) (2008) 261–267.
[16] K. Hylander, S. Nemomissa, Complementary roles of home gardens and exotic tree plantations as alternative habitats for plants of the Ethiopian montane rainforest, Conserv. Biol. 23 (2) (2009) 400–409.
[17] L. Kumsa, K. Hylander, D. Gurmessa, S. Nemomissa, Patch area and current coffee management determine woody plant diversity in patches of semi-forest coffee embedded in an agricultural matrix, Glob. Ecol. Conserv. 8 (2016) 230–240.
[18] B.M. Kumar, P.K.R. Nair, The enigma of tropical homegardens, Agrofor. Syst. 61 (2004) 135–152.
[19] C.W. Whitney, E. Luedeling, J.R.S. Tabuti, A. Nyamukuru, O. Hensel, J. Gebauer, K. Kehlenbeck, Crop diversity in homegardens of southwest Uganda and its importance for rural livelihoods, Agric. Hum. Val. 35 (2018) 399–424, https://doi.org/10.1007/s10460-017-9835-3.
[20] D.K.N.G. Pushpakumara, B. Marambe, G.L.L.P. Silva, J. Weerahewa, B.V.R. Punyawardena, A review of research on homegardens in Sri Lanka. The status, importance and future perspective, Trop. Agric. 160 (2012) 55–125.
[21] I. Perfecto, J. Vandermeer, The agroecological matrix as alternative to the land-sparing/agriculture intensification model, Proc. Natl. Acad. Sci. USA 107 (13) (2010) 5786–5791.
[22] J.R.S. Tabuti, V.B. Muwanika, M.Z. Arinaitwe, T. Ticktin, Conservation of priority woody species on farmlands: a case study from Nawaikoke sub-county, Uganda, Appl. Geogr. 31 (2011) 456–462, https://doi.org/10.1016/j.apgeog.2010.10.006.
[23] T. Abebe, Determinants of crop diversity and composition in Enset-coffee agroforestry homegardens of Southern Ethiopia, J. Agric. Rural Dev. Tropics Subtropics 114 (1) (2013) 29–38.
[24] G. Galluzzi, P. Eyzaguirre, V. Negri, Home gardens: neglected hotspots of agro-biodiversity and cultural diversity, Biodivers. Conserv. 19 (13) (2010) 3635–3654, https://doi.org/10.1007/s10531-010-9919-5.
[25] L.P. Koh, T.A. Gardner, Conservation in human-modified landscapes, in: N.S. Sodhi, P.R. Ehrlich (Eds.), Conservation Biology for All, Oxford University Press, Oxford, 2010, pp. 236–261.
[26] D.H. Galhena, Home Gardens for Improved Food Security and Enhanced Livelihoods in Northern Sri Lanka, Michigan State University, 2012.
[27] T. Tscharntke, Y. Clough, S.H. Bhagwat, D. Buchori, H. Faust, D. Hertel, D. Hölscher, J. Juhrbandt, M. Kessler, I. Perfecto, C. Scherber, G. Schroth, E. Veldkamp, T. Wanger, Multifunctional shade-tree management in tropical agroforestry landscapes: a review, J. Appl. Ecol. 48 (2011) 619–629, https://doi.org/10.1111/j.1365-2664.2010.01939.x.
[28] B.N.R. Garcia, T.A. Vieira, F.D.-A. Oliveira, Tree and shrub diversity in agroforestry homegardens in rural community in eastern Amazon, Floresta 47 (4) (2017) 543–552, https://doi.org/10.5380/rf.v47i4.48196.
[29] O.S. Abdoellah, H.Y. Hadikusumah, K. Takeuchi, S. Okubo, Parikesit, Commercialization of homegardens in an Indonesian village: vegetation composition and functional changes, Agrofor. Syst. 68 (2006) 1–13, https://doi.org/10.1007/s10457-005-7475-x.
[30] M. Gebrehiwot, M. Elbakidze, G. Lidestav, Gender relations in changing agroforestry homegardens in rural Ethiopia, J. Rural Stud. 61 (2018) 197–205, https://doi.org/10.1016/j.jrurstud.2018.05.009.
[31] B.T. Mellisse, G.W.J. van de Ven, K. Giller, K. Descheemaeker, Home garden system dynamics in southern Ethiopia, Agrofor. Syst. 92 (2018) 1579–1595, https://doi.org/10.1007/s10457-017-0106-5.
[32] K.F. Wiersum, Forest gardens as an intermediate land-usesystem in the nature-culture continuum: characteristics and future potential, Agrofor. Syst. 61 (2004) 123–134.
[33] A. Peyre, A. Guidal, K.F. Wiersum, F. Bongers, Homegarden dynamics in Kerala, India, in: B.M. Kumar, P.K.R. Nair (Eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, Springer Science, Dordrecht, 2006, pp. 87–103.
[34] D.W.D.-S. Santos, T.A. Vieira, Plant diversity of tree and shrub strata of agroforestry homegardens in an agro-extractive settlement, Monte Alegre, Pará, Brazil, Cienc. Nat. 43 (e1) (2021) 1–17, https://doi.org/10.5902/2179460X40633.
[35] A.J. Hamilton, Species diversity or biodiversity? J. Environ. Manag. 75 (2005) 89–92, https://doi.org/10.1016/j.jenvman.2004.11.012.
[36] V. Rico-Gray, J.G. Garcia-Franco, A. Chemas, A. Puch, P. Sima, Species composition, similarity, and structure of mayan homegardens in tixpeual and tixcacaltnyub, Yucatan, Mexico, Econ. Bot. 44 (1990) 470–487.
[37] P.K.R. Nair, Do tropical homegardens elude science, or is it the other way around? Agrofor. Syst. 53 (2001) 239–245.
[38] K. Kehlenbeck, Rural Homegardens in Central Sulawesi, Indonesia: an Example for a Sustainable Agro-Ecosystem? Georg-August-Universität, Göttingen, 2007.
[39] S. Mohan, P.K.R. Nair, A.J. Long, An Assessment of ecological diversity in homegardens: a case study from Kerala State, India, J. Sustain. Agric. 29 (4) (2007) 135–153, https://doi.org/10.1300/J064v29n04_10.
[40] F. Woldeyes, Z. Asfaw, S. Demissew, B. Roussel, Homegardens (Aal-oos-gad) of the basket people of southwestern Ethiopia: sustainable agro-ecosystems characterizing a traditional landscape, Ethnobot. Res. Appl. 14 (2016) 549–563, https://doi.org/10.17348/era.14.0.549-563.
[41] T. Abebe, Diversity in Homegardens Agroforestry Systems of Southern Ethiopia, Wageningen University, The Netherlands, 2005.
[42] M. Wiehle, S. Goenster, J. Gebauer, S.A. Mohamed, B. Andreas, K. Katja, Effects of transformation processes on plant species richness and diversity in homegardens of the Nuba Mountains, Sudan, Agrofor. Syst. 88 (2014) 539–562.
[43] M. Kessler, S. Abrahamczyk, B. Bos, D. Buchori, D.W. Putra, S.R. Gradstein, P. Höhn, J. Kluge, F. Orend, R. Pitopang, S. Saleh, C.H. Schulze, S.G. Sporn, I. S. Dewenter, S.S. Tjitrosoedirdjo, T. Tscharntke, Cost-effectiveness of plant and animal biodiversity indicators in tropical forest and agroforest habitats, J. Appl. Ecol. 48 (2011) 330–339.
[44] R Development Core Team, R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, 2020.
[45] B. Berhanu, A.M. Melesse, Y. Seleshi, GIS-based hydrological zones and soil geo-database of Ethiopia, Catena 104 (2013) 21–31, https://doi.org/10.1016/j.catena.2012.12.007.

[46] M. Coltorti, P. Pieruccini, K.J.W. Arthur, J. Arthur, M. Curtis, Geomorphology, soils and palaeosols of the Chencha area (Gamo Gofa, south western Ethiopian Highlands), J. Afr. Earth Sci. 151 (2019) 225–240.

[47] E. van Ranst, M. Dumon, A.R. Tolossa, J.-T. Cornelis, G. Stoops, R.E. Vandenberghe, J. Deckers, Revisiting ferrolysis processes in the formation of Planosols for rationalizing the soils with stagnic properties in WRB, Geoderma 163 (2011) 265–274, https://doi.org/10.1016/j.geoderma.2011.05.002.

[48] G. Kassa, T. Bekele, S. Demissew, T. Abebe, Above- and belowground biomass and biomass carbon stocks in homegarden agroforestry systems of different age groups at three sites of southern and southwestern Ethiopia, Carbon Manag. 13 (1) (2022) 531–549, https://doi.org/10.1080/17583004.2022.2133743.

[49] K. Gerhardt, H. Hytteborn, Natural dynamics and regeneration methods in tropical dry forests: an introduction, J. Veg. Sci. 3 (1992) 361–364.

[50] T. Bekele, Vegetation Ecology of Remnant Afromontane Forests on the Central Plateau of Shewa, Ethiopia. Acta Phytogeogr, vol. 79, Suec., Uppsala, 1993.

[51] I. Friis, S. Demissew, P. van Breugel, Atlas of the Potential Vegetation of Ethiopia, The Royal Danish Academy of Sciences and Letters, 2010.

[52] L.H. Samberg, C. Shennan, E.S. Zavaleta, Human and environmental factors afect patterns of crop diversity in an Ethiopian highland agroecosystem, Prof. Geogr. 62 (3) (2010) 395–408.

[53] S. Demissew, I. Nordal, Aloes and Lilies of Ethiopia and Eritrea, Shama Books, Addis Ababa, Ethiopia, 2010, p. 351.

[54] F. White, The Vegetation of Africa: A Descriptive Memoir to Accompany the UNESCO/AETFAT/UNESCO Vegetation Map of Africa. Natural Resource Research 20, UNESCO, Paris, 1983, p. 354.

[55] F. Senbeta, M. Denich, Efects of wild cofee management on species diversity in the Afromontane rainforests of Ethiopia, For. Ecol. Manage. 232 (2006) 68–74.

[56] G. Kassa, T. Abebe, Z. Ewnetu, Diversity, density and management of trees in different agroforestry practices of Yem special district, southern Ethiopia, SINET Ethiop. J. Sci. 38 (1) (2015) 1–16.

[57] T. Bekele, Phytosociology and ecology of a humid Afromontane forest on the central plateau of Ethiopia, J. Veg. Sci. 5 (1994) 87–98.

[58] I. Friis, Forests and Forest Trees of Northeast Tropical Africa: Their Natural Habitats and Distribution Patterns in Ethiopia, Djibouti and Somalia, Royal Botanical Gardens, Kew Bulletin, Additional Series XV, Her Majesty's Stationery Ofce (HMSO), London, 1992, p. 396.

[59] M. Krause, H. Uibrig, B. Kodane, Decision modeling for the integration of woody plants in smallholder farms in the central highlands of Ethiopia, J. Agric. Rural Dev. Tropics Subtropics 108 (2007) 1–17.

[60] C.R. Kothari, Research Methodology: Methods and Techniques, New Age International (P) Limited, Publishers, New Delhi, 2004.

[61] H.R. Bernard, Research Methods in Anthropology: Qualitative and Quantitative Approaches, AltaMira Press, 2006.

[62] A. Bryman, Social Research Methods, Oxford University Press Inc., New York, 2012.

[63] V.E. Méndez, R. Lok, E. Somarriba, Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance, Agrofor. Syst. 51 (2001) 85–96.

[64] M. Millat-e-Mustafa, A.K.O. Haruni, Vegetation characteristics of Bangladesh homegardens, Schweiz. Z. Forstwes. 153 (12) (2002) 454–461.

[65] A.E. Magurran, Ecological Diversity and its Measurement, Princeton University Press, Princeton, 1988.

[66] A.E. Magurran, Measuring Biological Diversity, Blackwell Science Ltd, Malden, 2004.

[67] M. Kent, Vegetation Description and Analysis: a Practical Approach, John Wiley & Sons, Ltd, Chichester, West Sussex, UK, 2012.

[68] B. McCune, J.B. Grace, Analysis of Ecological Communities, MjM Software Design, Gleneden Beach, Oregon, USA, 2002.

[69] L. Kaufman, P.J. Rousseeuw, Finding Groups in Data: an Introduction to Cluster Analysis, John Wiley & Sons, Inc., Hoboken, New Jersey, 2005.

[70] E. Mooi, M. Sarstedt, A Concise Guide to Market Research: the Process, Data, and Methods Using Ibm Spss Statistics, Springer-Verlag, Berlin Heidelberg, 2011.

[71] B.G. Tabachnick, L.S. Fidell, Using Multivariate Statistics, Pearson Education. Inc., Boston, 2007.

[72] A. Field, Discovering Statistics Using SPSS, SAGE Publications Ltd, London, 2009.

[73] D. Headey, M. Dereje, A.S. Taffesse, Land constraints and agricultural intensification in Ethiopia: a village-level analysis of high-potential areas, Food Pol. 48 (2014) 129–141, https://doi.org/10.1016/j.foodpol.2014.01.008.

[74] N. Sakané, Analysing and Exploring Land Use Decisions by Smallholder Agrowetland Households in Rural Areas of East Africa, Wageningen University, Wageningen, NL, 2011.

[75] T. Abebe, K.F. Wiersum, F. Bongers, F. Sterck, Diversity and dynamics in homegardens of Southern Ethiopia, in: B.M. Kumar, P.K.R. Nair (Eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, Springer Science, Dordrecht, The Netherlands, 2006, pp. 33–64.

[76] G.H. Rugalema, F.H. Johnsen, J. Rugambisa, The homegarden agroforestry system of Bukoba district, North-Western Tanzania. 2. Constraints to farm productivity, Agrofor. Syst. 26 (1994) 205–214.

[77] T.A. Vieira, L.D.-S. Rosa, M.M.D.-L.S. Santos, Agrobiodiversity of homegardens in Bonito, state of Para, Brazil, Rev. Cienc. Agrar. 55 (3) (2012) 159–166, https://doi.org/10.5902/2179460x40633.

[78] L.N. Trinh, J.W. Watson, N.N. Hue, N.N. De, N.V. Minh, P. Chu, B.R. Sthapit, P.B. Eyzaguirre, Agrobiodiversity conservation and development in Vietnamese home gardens, Agric. Ecosyst. Environ. 97 (2003) 317–344.

[79] O. Mohammed, The Role of Local Agroforestry Practices for Enhancing Food and Nutrition Security of Smallholding Farming Households: the Case of Yayu Area, South-Western Ethiopia, Bonn University, 2018.

[80] B.T. Mellisse, Trends and Prospects for the Productivity and Sustainability of Home Garden Systems in Southern Ethiopia, Wageningen University, Wageningen, the Netherlands, 2017.

[81] T. Abebe, K.F. Wiersum, F. Bongers, Spatial and temporal variation in crop diversity in agroforestry homegardens of southern Ethiopia, Agrofor. Syst. 78 (2010) 309–322.

[82] M. Ng'endo, G.B. Keding, S. Bhagwat, K. Kehlenbeck, Variability of on-farm food plant diversity and its contribution to food security: a Case study of smallholder farming households in western Kenya, Agroecol. Sustain. Food Syst. 39 (10) (2015) 1071–1103, https://doi.org/10.1080/21683565.2015.1073206.

[83] M. Aguilar-Støen, S.R. Moe, S.L. Camargo-Ricalde, Home gardens sustain crop diversity and improve farm resilience in Candelaria Loxicha, Oaxaca, Mexico, Hum. Ecol. 37 (2009) 55–77, https://doi.org/10.1007/s10745-008-9197-y.

[84] G. Tadesse, E. Zavaleta, C. Shennan, Coffee landscapes as refugia for native woody biodiversity as forest loss continues in southwest Ethiopia, Biol. Conserv. 169 (2014) 384–391, https://doi.org/10.1016/j.biocon.2013.11.034.

[85] A. Legesse, M. Negash, Species diversity, composition, structure and management in agroforestry systems: the case of Kachabira district, Southern Ethiopia, Heliyon 7 (2021), e06477, https://doi.org/10.1016/j.heliyon.2021.e06477.

[86] J.L. Thompson, J. Gebauer, K. Hammer, A. Buerkert, The structure of urban and peri-urban gardens in Khartoum, Sudan, Genet. Resour. Crop Evol. 57 (4) (2010) 487–500, https://doi.org/10.1007/s10722-009-9485-4.

[87] E. Tadesse, A. Abdulkedir, A. Khamzina, Y. Son, F. Noulèkoun, Contrasting species diversity and values in home gardens and traditional Parkland agroforestry systems in Ethiopian sub-humid lowlands, Forests 10 (266) (2019) 1–22, https://doi.org/10.3390/f10030266.

[88] S. Akrofi, P.C. Struik, L.L. Price, HIV and orientation of subsistence and commercial home gardens in rural Ghana: crop composition, crop diversity and food security, Afr. J. Agric. Res. 5 (18) (2010) 2593–2607.

[89] L. Zapfack, S. Engwald, B. Sonke, G. Achoundong, M. Birang, The impact of land conversion on plant biodiversity in the forest zone of Cameroon, Biodivers. Conserv. 11 (2002) 2047–2061.

[90] F. Pinard, E. Joetzjer, R. Kindt, K. Kehlenbeck, Are coffee agroforestry systems suitable for circa situm conservation of indigenous trees? A case study from Central Kenya, Biodivers. Conserv. 23 (2) (2014) 467–495, https://doi.org/10.1007/s10531-013-0615-0.

[91] C.J. Krebs, Ecology: the Experimental Analysis of Distribution and Abundance, sixth ed., Pearson Education, Inc, Eugene Hecht, 2014.

[92] Z. Asfaw, Z. Woldu, Crop associations of home-gardens in Welayta and Gurage in southern Ethiopia, Sinet: Ethiop. J. Sci. 20 (1) (1997) 73–90.

[93] K. Srithi, C. Trisonthi, P. Wangpakapattanawong, P. Srisanga, H. Balslev, Plant diversity in Hmong and mien homegardens in northern Thailand, Econ. Bot. 66 (2) (2012) 192–206, https://doi.org/10.1007/s12231-012-9199-y.

[94] A. Hemp, The banana forests of Kilimanjaro: biodiversity and conservation of the Chagga homegardens, Biodivers. Conserv. 15 (4) (2006) 1193–1217.

[95] M. Asigbaase, E. Dawoe, B.H. Lomax, S. Sjogersten, Temporal changes in litterfall and potential nutrient return in cocoa agroforestry systems under organic and conventional management, Ghana, Heliyon 7 (2021), e08051, https://doi.org/10.1016/j.heliyon.2021.e08051.
[96] R.C. Gbedomon, V.K. Salako, A.B. Fandohan, A.F.R. Idohou, R.G. Kakaï, A.E. Assogbadjo, Functional diversity of home gardens and their agrobiodiversity conservation benefits in Benin, West Africa, J. Ethnobiol. Ethnomed. 13 (66) (2017) 1–15, https://doi.org/10.1186/s13002-017-0192-5.
[97] D.H. Galhena, R. Freed, K.M. Maredia, Home gardens: a promising approach to enhance household food security and wellbeing, Agric. Food Secur. 2 (8) (2013) 1–13, https://doi.org/10.1186/2048-7010-2-8.
[98] K. Kehlenbeck, B.L. Maass, Crop diversity and classification of homegardens in Central Sulawesi, Indonesia, Agrofor. Syst. 63 (2004) 53–62.
[99] U.P. Albuquerque, L.H.C. Andrade, J. Andrade, Structure and floristics of homegardens in Northeastern Brazil, J. Arid Environ. 62 (2005) 491–506, https://doi.org/10.1016/j.jaridenv.2005.01.003.
[100] P.K.R. Nair, B.M. Kumar, Introduction, in: B.M. Kumar, P.K.R. Nair (Eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, Springer Science, Dordrecht, 2006, pp. 1–10.
[101] A. Asase, D.A. Tetteh, The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana, Agrofor. Syst. 79 (2010) 355–368, https://doi.org/10.1007/s10457-010-9311-1.
[102] P.L. Howard, Gender and social dynamics in swidden and homegardens in Latin America, in: B.M. Kumar, P.K.R. Nair (Eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, Springer Science, Dordrecht, 2006, pp. 159–182.
[103] R.P. Miller, J.W. Penn Jr., J. van Leeuwen, Amazonian homegardens: their ethnohistory and potential contribution to agroforestry development, in: B. M. Kumar, P.K.R. Nair (Eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, Springer Science, Dordrecht, 2006, pp. 43–60.
[104] F. Montagnini, Homegardens of Mesoamerica: biodiversity, food security, and nutrient management, in: B.M. Kumar, P.K.R. Nair (Eds.), Tropical Homegardens: A Time-Tested Example of Sustainable Agroforestry, Springer Science, Dordrecht, 2006, pp. 61–84.
[105] E. Torquebiau, Are tropical agroforestry homegardens sustainable? Agric. Ecosyst. Environ. 41 (1992) 189–207.
[106] M.A. Altieri, F.R. Funes-Monzote, P. Petersen, Agroecologically efficient agricultural systems for smallholder farmers: contributions to food sovereignty, Agron. Sustain. Dev. 32 (2012) 1–13, https://doi.org/10.1007/s13593-011-0065-6.
[107] R. Bommarco, D. Kleijn, S.G. Potts, Ecological intensification: harnessing ecosystem services for food security, Trends Ecol. Evol. 28 (2013) 230–238, https://doi.org/10.1016/j.tree.2012.10.012.
[108] T. Garnett, M.C. Appleby, A. Balmford, I.J. Bateman, T.G. Benton, P. Bloomer, B. Burlingame, M. Dawkins, L. Dolan, D. Fraser, M. Herrero, M. Hoffmann, P. Smith, P.K. Thornton, C. Toulmin, S.J. Vermeulen, H.C.J. Godfray, Sustainable intensification in agriculture: premises and policies, Science 341 (2013) 33–34, https://doi.org/10.1126/science.1234485.
[109] K.S. Zimmerer, J.A. Carney, S.J. Vanek, Sustainable smallholder intensification in global change? Pivotal spatial interactions, gendered livelihoods, and agrobiodiversity, Curr. Opin. Environ. Sustain. 14 (2015) 49–60, https://doi.org/10.1016/j.cosust.2015.03.004.
[110] S. Edwards, S. Demissew, I. Hedberg (Eds.), Flora of Ethiopia and Eritrea. Hydrocharitaceae to Arecaceae, vol. 6, Addis Ababa: The National Herbarium, Addis Ababa University and Uppsala University, Sweden, 1997.
[111] Flora of Ethiopia and Eritrea, in: S. Edwards, M. Tadesse, S. Demissew, I. Hedberg (Eds.), Part 1: Magnoliaceae to Flacourtiaceae, ume 2, Addis Ababa, Ethiopia and Uppsala, Sweden, 2000, p. 532.
[112] S. Edwards, M. Tadesse, I. Hedberg (Eds.), Flora of Ethiopia and Eritrea, Volume 2, Part 2: Canellaceae to Euphorbiaceae, Addis Ababa, Ethiopia and Uppsala, Sweden, 1995, p. 456.
[113] Flora of Ethiopia, in: I. Hedberg, S. Edwards (Eds.), Pittosporaceae to Araliaceae. Addis Ababa, Ethiopia, ume 3, 1989.
[114] I. Hedberg, I. Friis, S. Edwards, Flora of Ethiopia and Eritrea, Vol 4, Issue 2, Addis Ababa: The National Herbarium, Addis Ababa University and Uppsala University, Sweden, 2004.
[115] N.I. Vavilov, The Origin, Variation, Immunity, and Breeding of Cultivated Plants, Chronica Botanica, New York, Stechert Hafner, 1951.
[116] J.L. Vivero, E. Kelbessa, S. Demissew, The Red List of Endemic Trees & Shrubs of Ethiopia and Eritrea, Fauna and Flora International, United Kingdom, 2005, p. 28.
[117] J.L. Vivero, E. Kelbessa, S. Demissew, Progress on the Red List of plants of Ethiopia and Eritrea: conservation and biogeography of endemic flowering taxa, in: S.A. Ghazanfar, H.J. Beentje (Eds.), Taxonomy and Ecology of African Plants, Their Conservation and Sustainable Use, Royal Botanic Gardens, Kew, 2006, pp. 761–778.