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Diversity and Composition of Plant Species in Home Gardens of Damot Gale Woreda in Wolaita Zone, SNNPRS, Ethiopia

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Abstract

Home gardens are the areas adjacent to households used for growing a diverse array of plant species in a spatially complex pattern that serve a multitude of functions. The objective of this study was to evaluate the diversity and composition of plant species within home-garden areas of Damot Gale Woreda, Wolaita Zone. The study period was from March to July 2020, and this study aimed to document home-garden plant species found in the area and also the knowledge regarding the uses, hazards, and management of those plants found in that area. Out of the total, 276 households were selected for this investigation. Semi-structured interviews, transect walks, and focus group discussions were employed as data collection methods. Plant species diversity was calculated using the Shannon-Wiener diversity index. A total of 57 plant species of 56 genera belonging to 30 families of beneficial plants have been identified from home-garden areas. The inventoried plant species were classified into 4 growth forms: 50.87% herbs, 24.56% shrubs, 19.29% trees, and 5.26% climbers. Most plants belonged to the family Solanaceae (5 species), followed by Rutaceae, Poaceae, and Lamiaceae.

Out of all the identified plant species, 59.6% were edible, 22.8% medicinal plants, 14% material culture used, 12.2% firewood, 7% ornamental plants, 5.3% live fencing, 3.5% stimulants, and 7% shading plants. The highest Shannon diversity index ($H' = 2.94$) was recorded in Gacheno Kebele, followed by Kebele Pulasa ($H' = 2.51$) and Woreda Gale ($H' = 2.34$) among the sampled kebeles. Several hazards were identified in home gardens to valuable plants. Those Hazards were cutting the stem for construction, improper land husbandry, and deforestation for making charcoal fuel. The study concludes home-garden to be a reservoir of plant genetic resources; thus, active stakeholder involvement is necessary for their conservation.

Keywords: Damot Gale, genetic diversity, home-gardens, species diversity, useful plant

1. Introduction

Home gardens are defined as an integrated system of land and cropping systems which have been maintained over centuries within the tropics (Christanty, 1990). These systems feature multiple species of crops, including annual, perennial, root, and climber crops, arranged in a multi-layered manner close to the homestead in the form of a home-garden (Watson & Eyzaguirre, 2002). They are known globally by many terms such as home-garden, backyard, kitchen-garden, homestead-garden, etc. (MacKinnon *et al.*, 2008). Therefore, the home-garden established a relationship between the

garden and the house to cover ecological as well as social functions and to enable high species and gene diversity (Asfaw, 2001a).

Home gardens play a crucial role in sustaining biodiversity, ensuring ecological stability, and serving as a reservoir of plant gene pools that bridge farmed species and wild ecosystems (Asfaw, 2001b). Depending on the country, they have a local name; for instance, in Cuba and Venezuela they are called 'Conuco' (Watson & Eyzaguirre, 2002), 'Vuonnha' in Vietnam (Trinh *et al.*, 2001) and 'Pekarangan' in Indonesia (Abdoellah *et al.*, 2001). These gardens, maintained by millions of households in tropical areas, support food and nutrition for both human beings and household economic status through sales of excess products, as well as health status; besides, they have other multiple functions that could provide practical lessons for sustainable management of Biodiversity (Buchmann, 2009). Since they are located around residential areas, it is possible to find most plant species available there, including rare or even endangered species. They consist of a wide array of plants selected for various purposes, including, but not limited to, food, fuelwood, forage, medicines, building materials, fruits, vegetables, spices, and ornamental species (Molebatsi, 2011). Home gardens, due to diversity and multiple components, improve household food security and livelihood resilience, enhance sustainability, and reduce vulnerability to external shocks (Bernholt *et al.*, 2009). Due to diversity and multiple components, home gardens improve household food security (Buchmann, 2009; Mallick *et al.*, 2024).

Resource efficiency of home gardens stems from year-round provision of food products, reduction of the risks of crop failure thanks to the diversity of the cultivated varieties, and optimum use over time of resources (Mmom, 2009). For Ethiopian households, home gardens fall generally into two major categories (Asfaw, 2001a; Abebe, 2005). The first type represents small vegetable gardens, fruits, spices and oilseeds that complement cereals and pulses and are commonly integrated into cereal farming systems and city areas, while the second type is a representation of mixed cultivation comprising diversified plants on an 'enset-frame' comprising *Ensete ventricosum*. These systems are spread in the south-west region of the country; these home gardening systems are a good example of adaptive home-gardens which sustainably sustain household food production and livelihoods. (Posey, 1999). Plant diversity in a yard generally reflects the level of biological systems functioning (Asfaw, 2001b). The biodiversity in residential gardens faces problems due to increased population size, deforestation, urbanization, and global climate change (Lerch, 1999; FAO, 2019). The growing demand for the expansion of cities creates pressure on agricultural production due to the space limit required for food and construction (Maredia *et al.*, 2023). The impact on biodiversity under this condition is huge, but urban or peri-urban home gardens can play a crucial role in the preservation of biodiversity on the one hand and the production of food on the other hand; they can contribute to influencing the microclimate (Hinsa, 2012; Girma, 2024) and provide breeding and refuge for various living things (FAO, 2019). Home gardening provides essential food materials and livestock fodder for households, as well as domestic uses of plants, herbs, timber, fibres, fuel, and other household needs (Asfaw, 1997; Asfaw, 2001b).

The selection of plant species has historically resulted in gardens based on materials used by humans for constructing houses, making clothes, or other cultural articles (Cotton, 1996). Traditional plant use for healing purposes makes home-garden plants an essential source of medicine, and this influence selection and conservation of plant species that have cultural significance (Asfaw, 1997). Studies on Ethiopian home gardens were limited to some areas in the beginning, like Wolaita, Gurage, and Sidama communities, where a vast body of indigenous knowledge is transferred verbally through generations (Asfaw & Woldu, 1997; Abebe, 2005; Seta, 2012). Protecting this rich diversity of indigenous knowledge, embedded in home gardening, is crucial to sustainable livelihoods and biodiversity management for sustainable development in facing ecological changes (Mallick *et al.*, 2024). The emerging approach to these home gardens has demonstrated the necessity for the development of an innovation system that could address the threats imposed on biodiversity and also maximize the production potential of the home garden for Food Security and Environmental resilience (Mengistu, 2008; Chinelo *et al.*, 2024). The present study aimed to provide comprehensive

data on the diversity, composition, and traditional management practices of home-garden plants in Damot Gale Woreda in SNNPR Regional State, Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Geographical location

The research undertaken was in SNNPRS of Ethiopia, which is located in the Wolaita Zone, part of the woreda called Damot Gale. To the southwest, Damot Gale is bounded by Sodo Zuria; to the north, the Hadiya Zone; to the east, Diguna Fango; and to the southeast, the woreda of Damot Pulasa (Fig. 1). The woreda lies between 6°05'0"N and 7°11'0"N Latitude and 37°0'0"E and 37°50'0"E Longitude. Boditi is the capital of Damot Gale woreda. It is administratively subdivided into 27 kebeles.

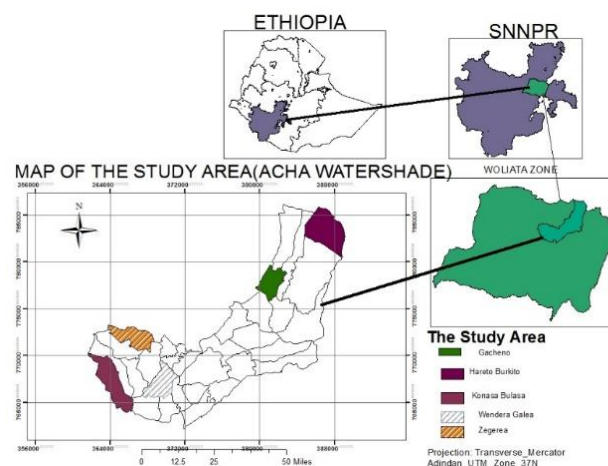


Fig. 1: Source physical map of SNNP (2007)

2.1.2. Climate and Topography

From known climatic zonation (DGWAO, 2014) Within the study area, three agro-climatic zones exist, which are Dega, Woina-Dega, and Kola. The altitudes of these zones change gradually between 1,501 m and 2,950 m above sea level, which affects both temperature and precipitation.

2.1.3. Temperature and Rainfall

Average monthly temperature ranges from 12°C during the coolest season to a high of 24°C during the hottest season and has two seasons: Kiremt 'the higher season of rain,' commonly occurring from June to August; and the 'Belg' 'low season rains,' typically from mid-February to the middle of May (Gbedomon *et al.*, 2015) which are critical for food Security. Average annual rainfall of 900- 1400 mm falls across the study area (Getachew *et al.*, 2021). These fluctuations necessitate a study of the effect of spatial and temporal variability on agro-production.

2.1.4. Natural Vegetation and Soil Characteristics

The natural vegetation of the research region, as reported by (Asfaw & Woldu, 1997; Abebe & Asfaw, 2023a), comprises different tree species such as *Ficus sycamorus*, *Podocarpus falcatus*, *Olea europaea*, *Juniperus* spp., and *Cordia africana*. However, increasing population pressure has resulted in extensive deforestation for fuelwood, construction materials, agricultural equipment, and lumber (Ewuketu *et al.*, 2014; Singh *et al.*, 2021).

Local communities define soils based on color and potential for cultivation, recognizing black and red soil types. Black soils are noted for their capacity to hold organic materials obtained from degraded leaf litter and animal manure. However, more scientific classification of these soil types is needed (Kumar *et al.*, 2024).

2.1.5. Population and Livelihood

A woreda is characterised by its relative uniformity in land use type. Damot Gale Woreda is one of the highest population densities; it ranks 2nd out of all woredas found in Southern Nations, Nationalities, and Peoples' Region (SNNPR), after Wonago woreda in terms of population, with the total number in the national census being 152,878 in 2007 (74,443 men and 78,435 women). Of these populations, 24,133 (15.97%) were from urban areas (Zekaria, 2007).

There were two local terms for home gardens in Damot Gale Woreda, indicating their different and distinct importance. The study considered the cultural importance of all plant species in Damot Gale home gardens by studying the roles played in the community, the importance of roles, and the frequency of usability of plants (Tynsong & Tiwari, 2010). A plant species' greater uses would represent its higher cultural value. The quality of usage was measured by the scale values 1-3 that summed up the uses in a given area for the sustainability and well-being of local livelihoods (Agize *et al.*, 2016).

2.2. Methods

2.2.1. Research design

This was a mixed-methods study, and both qualitative and quantitative approaches were used in the study (Tashakkori & Teddlie, 2008). A greater emphasis was placed on using quantitative approaches in order to measure the number of plant species present within the home gardens. Qualitative data were gathered and analysed as a means to cross-validate with, or triangulate, the quantitative information. The quantitative descriptive survey design was employed, and this allows quantitative statistical results to be compared and contrasted with those obtained from qualitative results. Quantitative results could be enhanced or confirmed with the introduction of qualitative data (Creswell, 2009). This mixed-methods design provides a deeper and more informed understanding of the problem under investigation, exploiting the advantages offered by both quantitative and qualitative data (Creswell & Creswell, 2018).

2.2.2. Selection of Study Kebeles and Households

The kebeles selected to represent the 27 kebeles found in the Damot Gale Woreda were stratified on the basis of their respective agro-ecological zones. Then, from those selected clusters, 5 kebeles representing Dega, Woyina Dega, and Kola were sampled (Table 1). This was done so that representatives of each ecological zone could be included, as changes in ecological conditions & agricultural practices might affect the results.

Table 1: List of Sample Respondents and kebeles with their climatic zone.

Study Kebele	Total HH	Sample HH	Percentage	Weather condition
Gacheno	224	69	25.0	Woyane Dega
Harto Burkuto	149	46	16.7	Kola
Konasa pulasa	214	66	23.9	Dega
Wandar Gale	158	49	17.7	Dega
Zegere	147	46	16.7	Woyne Dega

In total, 276 households (from Selected Kebeles) were sampled using a Purposive-Systematic Sampling strategy. In so doing, to ensure selection of households that fulfil the given conditions relevant for the particular study goal and yet include the element of randomness (Cochran, 1991; Lohr, 2019).

2.2.3. Data Gathering Instruments

2.2.3.1. Household Survey

Data were collected for this study during the period March–July 2020 using several methods to gather relevant data of primary as well as secondary sources. Primarily, the collection of data was done by

use of structured interviews ([Supplementary file 1](#)) in order to gather first-hand data from owners of home gardens. Informants were therefore requested, by use of structured questions, to list the plants within their respective home gardens by their common names/local terms, and this enabled a characterisation of how gardening knowledge and practices within production differed among home-garden owners.

A complete field survey was conducted for all selected home gardens in the study area. A complete survey was made during a trip to document useful plant species that are contained in the home gardens ([Supplementary file 2](#)). 'Useful plant species' are those considered useful for food, medicinal products, for sale, live fence, building or construction material, fuel wood, shade, and ornamental use (Cotton, 1996). However, a significant number of home-garden species had more than one use. Thus, the categorization focused on the primary uses provided by home garden owners in order to give emphasis to the degree to which each plant was beneficial to the home gardens and livelihoods of inhabitants living in those homes. Home garden composition was analysed based on direct observation in the field. During the survey, plant inventory and recording of useful plants, attention was given to the recording of common names (local languages), botanical names of the useful plant species, their uses, useful plant parts, and life-form/habitat of species (Martin, 2010). Direct observation and plant species identification were often guided by common local names that facilitated the integration of local ecological knowledge.

2.2.3.2. Key Informant Interview

Collection of data from key informants is another important method. Local key informants include local plant experts, development agents, elderly people, and local leaders, selected from information obtained from the local Agriculture and Development Office and Kebele Administration (Guest *et al.*, 2006). To capture variation across different scales of home gardens, four Kebele-level key informants were selection from small, medium, and large-size home gardens each, from the above five selected Kebeles, to collect varying ideas from informants for the above-said issues (Bernard, 2017).

2.2.3.3. Focus Group Discussion

To further triangulate the data collected from household surveys and key informant interviews, focus group discussions (FGDs) were conducted (Morgan, 1997). One FGD was performed at each of the five sampled kebeles, with participants composed of elders, women, and youth from the different communities, with an average of 7-10 persons per FGD. The main topics discussed during the FGDs included the varieties of plant species cultivated in the home gardens, the roles of the home gardens for food provision, and an estimation of the income expected from the home gardens every year. The results gathered from the FGDs were then compared with data from the household survey (Krueger & Casey, 2014). Additionally, participants were asked to specify what the constraints are on the productivity of the home gardens. Studying these problems could provide interesting information on the obstacles home-garden owners face.

Home garden observations were carried out by field trips in conjunction with the plant inventory survey. The information recorded during home-garden observations was structured with standard and botanical names of the plant species, their uses (food, medicine, and ornamental values), plant parts used (leaf, root, and fruit), and pattern of growing, for each plant species.

2.2.3.4. Direct Observation

Primary data relating to the species diversity of the plant species in the study area were collected using transect walks (Kent, 2010). The quadrants (5m x 10m) were placed at intervals along the transect walks, and all the species present within each plot were identified and recorded by the researcher. Transect walks are good for observing first-hand data on the distribution and composition of plant species in the study area (Bonham, 2013). Also, first-hand observations were done by visiting

people's home gardens that were selected to verify the information the interviewees and focus group participants were giving on the plants present in their home gardens.

2.2.3.5. Voucher Specimen Collection

Plant identification from participatory observation (with emphasis given to vernacular names for each plant) was carried out. Plant species of economic and cultural importance and value were collected and processed following conventional techniques in plant preparation of voucher herbarium specimens (Bridson & Forman, 1998).

The plants documented were identified with the help of the Flora of Ethiopia and Eritrea (Hedberg, 1989-2006), a 1-10 volume work based mainly on published literature, floristic description, and in consultation with available reference books.

2.3. Data Analysis

The inventoried plant species were categorized according to their primary use, allowing for an analysis of home-garden composition based on functional groups. Descriptive statistics, including frequency distributions and percentages, were generated to summarize the data. Statistical analysis was performed using SPSS (Statistical Package for the Social Sciences). To assess plant diversity within the home gardens, several indices were calculated (Magurran, 1988). The Shannon-Wiener diversity index (H' or SWI) was calculated using the following formula:

$$H' = - \sum_{i=1}^S (p_i \times \ln(p_i))$$

Where;

H' = Shannon-Wiener diversity index

S = Number of species

$\ln$ = Natural logarithm (base e)

p_i = Proportion of species i^{th} relative to the total number of species (abundance of species i)

$$p_i = \frac{n}{N}$$

n = Individuals of a given type/species

N = Total number of individuals in a community

The Shannon-Wiener diversity index increases with an increase in the number of species and their evenness (relative abundance). The maximum possible value of H' is determined by the number of species present ($H'_{\text{max}} = \ln(S)$).

Evenness (E), which describes the equitability of species abundance within the home gardens, was calculated as:

$$E = \frac{H'}{\ln(S)}$$

Evenness values are standardized to a scale from 0 to 1, where 1 indicates perfect evenness (all species equally abundant), and 0 indicates complete dominance by one species.

Simpson's index of dominance (λ , often represented as 'I' in your text) was used to quantify the extent to which a community is dominated by one or a few common species. It is calculated as:

$$\lambda = \sum (p_i)^2$$

Simpson's index ranges from 0 to 1. A value of 1 indicates complete dominance by a single species ($p_i = 1$ for that species), while a value closer to 0 indicates lower dominance. Often, Simpson's index is expressed as $1-\lambda$ to represent diversity rather than dominance.

3. Results and Discussion

3.1. Characteristics of Household Respondents

The survey carried out among 276 households in 5 kebeles found that 65.9% of the households were male-headed and 34.1% of the households were female-headed. The sample respondents are in the age group range of 18-61 years. Their mean age is 43 years, and the 29-39 years age range has 51.44% of people, followed by the 18-28 years age range with 31.5% of people, then the 40-50 years age range with 10.86% of people, and finally the 51-61 years age range with 6.15% of the population. 54.34% of the respondents were illiterate, 27.89% had elementary-level education, and 10.5% and 7.2% had obtained the secondary school certificate and diploma, respectively.

About 93.8% of the respondents belong to the poverty group, and 6.2% belong to a middle-income group. Their family size differs: about 59.7%, 32.97%, and 7.24% belong to 1-4, 5-8, and 9-12 household members, respectively. The landholding of each household includes both farming and home gardens. Of all the interviewed households, 85.4% had farming land varying from 0.5-1 ha. Among the respondents, 62.68% were farmers, 22.1% were daily labourers, and 15.21% were housewives. The result is in line with the findings of (Asfaw & Woldu, 1997) and (Agize *et al.*, 2025). However, the family situation is different from the study of Mengistu (2008) in Gedeo Zone, Dilla Zuria Woreda, while the study of (Abebe & Asfaw, 2023b) focuses on socio-economic issues with regard to land holding and income.

3.2. Characteristics of Home Gardens in the Study Area

3.2.1. Types of Home Gardens

Various types were observed to vary in the spatial distribution of home gardens, and the following types were observed. Backyard gardens were found to be the highest number, representing 63.76% of the total home gardens (Table 2). They varied in shape, such as rectangular, square, circular, and random, but backyard gardens remained the dominantly observed type, as found in several previous studies (Seta, 2012; Agize *et al.*, 2013). The circular or all-round garden was the least common type, comprising 2.24% of the home gardens investigated. These findings were more in line with the previous works on Ethiopian home garden systems, particularly Gurage and Wolaita zones (Asfaw & Woldu, 1997) and Damot Gale Woreda (Agize *et al.*, 2013). Recent studies by (Korpelainen, 2023) and Tadesse *et al.* (2024) showed the importance of home gardens for household food security and income generation in rural Ethiopia.

Table 2: Home gardens surveyed in the study area.

Yard type	Frequency	Percentage
Front yard gardens	25	9.05
Back yard gardens	176	63.76
Side yard garden	40	14.49
Front yard and back yard garden	10	3.62
Front yard and side yard garden	8	2.80
Back yard and side yard gardens	10	3.62
All round or circular	7	3.25

3.4.2. Size of Home Garden

Darkkuwa, as locally referred to and as mentioned in the study area, is considered one of the major contributors to household food security at the community level as it's a complement to field crop yields. These gardens are seen as an essential constituent of a traditional agrarian society, providing a variety of edible plants, medicinal herbs, and a means for earning income from the sale of produce. According to the size classification, three types of home gardens were identified in the kebeles covered by this study.

The size of an individual home garden was primarily influenced by the availability of the total amount of land that each family had. Approximately 50% (Table 3) of all surveyed families own medium-sized home gardens (between 500-600 m²). A home garden of this size was used to grow many different plant types to meet varying household needs. Home gardens have been documented in similar studies with equivalent outcomes in Gurage and Wolaita regions by (Asfaw & Woldu, 1997)

and in Demot Gale woreda by (Agize *et al.*, 2025). It is also noted, as demonstrated by (Zasada,2011 and Korpelainen, 2023), that the multifunctional roles of home-gardening have been emphasized over the last few years in Ethiopia for food and livelihood security and for conservation of plant biodiversity and sustainable development.

Table 3: Size of home-garden in study area.

Home-garden types	Area (in hectare)	Number of households have home-garden	Percentage
Large	>0.06	51	18.47
Medium	0.05-0.06	138	50.00
Small	<0.05	87	31.52

3.3. Taxonomic diversity of plants in the study area

A systematic plant inventory of useful plant species in the study area revealed a total of 57 useful plant species belonging to 55 genera under 30 botanical families ([Supplementary file 3](#)). Among the documented useful species, the family Solanaceae showed high representation with 5 species and was around 8.77% of the total useful plant species recorded, followed by the families Rutaceae, Poaceae and Lamiaceae, each represented by 4 species contributing 7%. From these 57 species, Cucurbitaceae, Myrtaceae, Brassicaceae and Asteraceae shared 3 species each with 5.26%, whilst Alliaceae, Musaceae, Apiaceae, Caricaceae, Amaranthaceae and Fabaceae contributed 2 species each, representing 3.5%. The remaining families are represented by only one species, accounting for 1.75% of total species richness recorded for the area (Fig. 2). In comparison with other published literature for a study done in Gedeo Zone, Dila Zuria Woreda, the number of species collected was lower. (Mengistu, 2008) reported 75 species; however, with a total of 59 species, (Seta, 2012) results are quite close to the findings. Recent studies have shown the variation in the number of species of Ethiopian home gardens as per the agroecological factors; land use; practices and socio-cultural practices that affect the selection and maintenance practices of these useful plant species (Kassa *et al.*, 2023; Mallick *et al.*, 2024).

3.4. Habit of Diversity of Plants in the Home Gardens of the Study Area

There was documentation of a total of 57 beneficial plant species which were classified into different habit types; of which, 29 plants were herbs, 14 plants were trees, 11 plants were shrubs and 3 plants were climbers (Table 2; Fig. 2). Relating to plant domestication categories, 45(78.9%) plants were planted, while 12 plants (20%) were wild or semi-wild. Furthermore, of the total 45 cultivated plant species, 30 were primarily planted as food plants. Plant habitat prevalence as reported in this study is consistent with the study of Seta (2012), who reported a similar dominance of herbaceous plants and a few climbers. Similarly, (Kassa *et al.*, 2023) and (Tadesse *et al.*, 2024) suggest that in home gardens of Ethiopia, herbaceous plants have a greater number as compared with other plant categories due to a shorter growth cycle and due to easier in its cultivating and in their food contribution.

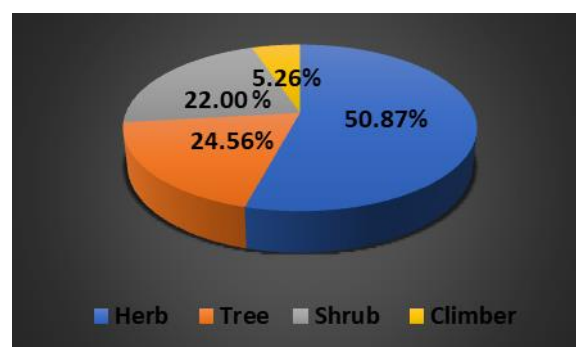


Fig 2: Pie chart indicating growth forms of plants in percentage from home-gardens of the study area.

3.5. Distribution of Plant Species in the Home-gardens

Home-gardens could be considered a critical centre for protecting biodiversity as well as sustainable land use. The results of our study reported that the recorded numbers of plant species were 10, 25 and 22 for small-sized home-gardens, medium-sized home-gardens and large-sized home-gardens, respectively. From these results, it appears that plant species richness was highest in the medium-sized home-gardens. The possible causes could be population pressure and degraded land conditions or local people adopting a common integrated farming system.

Species diversity among home-gardens study indicated that 17.5% of species diversity of tiny home-gardens was lower than that of medium-sized home-gardens 43.8% of species diversity (Table 4). The difference in species diversity could relate to ways of handling the land and in-situ removals or uprooting plants for building purposes; in addition, selection on cultivation of important species only by the householder is possible for smaller gardens. On the contrary, the larger home gardens provide large area, but generally a larger portion was the non-plant area, like a cattle field or place of rest. The findings were in agreement with the study by (Agize *et al.*, 2025) in Damot Gale Woreda, and the patterns of species diversity of home gardens in this case were similar to our findings. However, studies by Kabir & Webb (2008) & Trinh *et al.*, (2003) also suggested that the effect of land-use practice on the diversity of species of home gardens confirmed our assumption that a balanced management approach of larger area could result in the highest level of diversity in plant species.

Table 4: Species diversity of the different home gardens of the study area.

Home-garden size	Number of species	Percentage
Small	10	17.5
Medium	25	43.8
Large	22	38.5
Total	57	100

3.6. Plant Species Listed in Each Household in the Selected Kebeles

The study of plant species diversity in home gardens was undertaken across different locations, where quadrants were methodically established to determine species richness and dominance. In Gacheno, 69 houses or quadrants were studied, revealing a high level of species richness. Among these, Quadrant 2 (Q2) had the highest number of species, with 11 reported species ([Supplementary file 4](#)). Similarly, in Harto Buirqto, 46 quadrants were surveyed, exhibiting considerable species richness. The most frequently occurring and dominant plant species were reported, with Q35 showing the highest diversity (nine species). In Zagare also, 46 quadrants were established, where residential gardens revealed considerable species variety. Among these, various quadrants, including Q5, Q8, Q17, Q22, Q26, Q28, Q30, Q33, Q34, Q35, Q45, and Q46, recorded six species each ([Supplementary file 4](#)). In Wadara Gale, 49 quadrants were surveyed, and significantly diversified residential gardens were identified. The quadrants with the highest species richness included Q2, Q3, Q8, Q17, Q22, Q26, Q28, Q30, Q33, Q35, Q44, Q45, and Q46, each containing six species ([Supplementary file 4](#)). Meanwhile, in Konasa Pulsa, 66 quadrants were surveyed, where species diversity remained high. The quadrants with the most species included Q6, Q8, Q11, Q19, Q21, Q24, Q30, Q31, Q32, Q34, Q46, Q51, Q55, Q59, Q61, Q64, and Q66, each including six species ([Supplementary file 4](#)). All these findings were correlated with the outcomes as reported by (Agize *et al.*, 2025). They found comparable patterns in plant species diversity in Ethiopian home-gardens. However, Das & Das (2005) and Galhena *et al.* (2013) further emphasise the value of home-gardens as reservoirs of biodiversity, which might play a significant role in sustainable agriculture and ecological conservation.

3.7. Plant Categories According to Known and Mentioned Use Value

The plant species utilized by the local peoples were classified into respective use groups according to their assigned uses ([Supplementary file 3](#)). Classification yielded that 34 species (59.6%) served as

food crops, 13(22.8%) as medicine, and 8(14%) for material culture. Moreover, 4(7%) as garden species, 8(14%) for cattle feed, 3(5.3%) as living fences, 7(12.2%) for fuel wood, 3(5.3%) as stimulants, and 4(7%) as shading trees. Note that if a plant species serves many purposes, then each of its use groups includes it, indicating that the species has more uses. 42 species (70.68%) have varied uses, but 11 species (19.29%) serve as multi-purpose plants because they fall into 3 or more categories of use-groups. Thus, our study confirmed the important contribution of home gardens to providing various ecosystem services and serving family demands. The wide species richness of food plants, among others, confirms the important contribution of home gardens to the food security of households. This result is in accordance with the findings of previous researchers, who stated the occurrence of high food plant diversity in home gardens (Asfaw & Nigatu, 1995; Solomon, 2011; Tadesse *et al.*, 2024). Similarly, studies by Galluzzi *et al.* (2010) and Mohri *et al.* (2013) also emphasize the importance of home gardens for conservation and livelihood support for the people of this region.

3.7.1. Direct Uses of Home Garden Components in the Areas

3.7.1.1. Edible Plants Obtained from Home Gardens

A total of 34 edible plant species (59.6%) of plants identified in the home gardens of Damot Gale Woreda represent 32 genera belonging to 27 families (Supplementary file 3). The importance of home gardens for balanced nutrition and food provision was highlighted by several researchers (Kanshie, 2002; Hailu & Asfaw, 2011; Edo *et al.*, 2024) who documented 126 species (75% of the total plants in Ethiopian home gardens), 48 and 37 edible plants from Ethiopian home gardens in Arbaminch and Sebeta, respectively. It is evident from our results that 34 plant species having high nutritional value highlight the significance of home garden plants for food endowment in Ethiopia.

Among the 34 edible species identified, 29 species (85.3%) were cultivated edible plants (50.9% of all useful plants) and 5 were wild or semi-wild species. According to the plant part consumed, 13 species (39%) were mostly fruits, 6 species (17.6%) seeds and seed products, 5 species (14.7%) underground parts, and 13 species (39%) leaves, though stems and leaves were utilized in most species. Cultivated edible species are distributed in 27 plant families (Supplementary file 3), of which 5 species from the Solanaceae family are prominent, followed by 4 species from Poaceae. While 3 species each belong to Rutaceae and Brassicaceae, 2 species each belong to Myrtaceae, Asteraceae, Cucurbitaceae, Apiaceae, Musaceae, Caricaceae, Alliaceae, Fabaceae, and the rest of them contained one species each. Considering the horticultural aspects, 13 species were listed under fruit crops, 10 for the vegetables, and 11 for the root and tuber crops category (Supplementary file 3).

Our results are in agreement with the findings by earlier researchers (Asfaw, 2002; Kanshie, 2002; Hailu, 2008; Kassa *et al.*, 2023), who also reported vegetables and root crops to be dominant in home-garden production. Preference in cultivation of root and tuber crops and vegetables may also have been linked to the increased market value. Five edible plant species (non-cultivated, wild/semi-wild species) were identified in and around households in the study area. These species often serve as shading facilities, live fences, and play a role in other agro-forestry systems (Supplementary file 3). This result demonstrates that most plants cultivated in home gardens for food purposes, wild/semi wild were at a considerably lesser extent. This finding is similar to the study of (Tadesse *et al.*, 2024), who reported that cultivated crops dominate Ethiopian home gardens.

3.7.1.2. Medicinal Plants from Home Gardens

During the present study, a total of 13 therapeutic species were found, which constituted 22.8% of the total cultivated plant species in home gardens. The therapeutic plants came from 12 genera and 9 families (Supplementary file 3). Of these, Asteraceae contributed 3 species, followed by Myrtaceae with 2 species. The other families were Musaceae, Euphorbiaceae, Cucurbitaceae, Poaceae, Alliaceae, Rutaceae, and Lamiaceae, each with only one species.

Of the growth forms, the medicinal plants collected are represented by 2 tree species, 8 herbaceous species, and 3 shrubs. Regarding the parts used, leaves were the most common, accounting for 7 species (53.8%), either solely or mixed with other parts of the plants. Roots/bulbs, fruits, and seeds

consisted of 2 species (15.3%) each, out of the medicinal plants studied. Only 2 species (15.3%) collected were wild, while the remaining 11 species were cultivated with multipurpose importance in home gardens. There were overlapping species reported for various plant parts used in the treatment of ailments in the various categories during data processing. The percentage of medicinal plants found in the present study (22.8%) is less than other previous studies (Trinh *et al.*, 2003). They conducted the research in Vietnamese home gardens and found medicinal plants as the primary component in home gardens, followed by vegetables and fruits, while ornamental components were insignificant (Wezel & Bender, 2003), in Cuban home gardens, also report a 33% high percentage of therapeutic plants, second to ornamental species. Several past researchers also reiterate the use of medicinal plants in home gardens (Albuquerque *et al.*, 2007; Santayana *et al.*, 2013; Khan *et al.*, 2018).

3.7.1.3. Plants Used for Material Culture from Home Gardens

A total of 8 plant species (14% of the total plant species identified) were documented for material culture by the current study in Damot Gale Woreda ([Supplementary file 3](#)). The 8 plant species belong to 7 plant families and 8 plant genera, respectively. Only one plant is useful in building construction, fencing, and furniture, etc. Thus, many of them have a number of functions that are adapted to structural and domestic needs. Out of them, 6 are trees, and 2 are herbs in nature as development types. Tree species are dominant in this group, that is coincide with traditional material culture findings that are dominated by tree species. Also, there are more wild plant species than cultivated species for the material culture products that have been identified in the study. Besides this, stem parts were the most commonly used part for material culture. That clearly indicates that trees and big shrubs are useful for construction and building purposes. Our findings are in agreement with findings of prior studies that indicate building is the second most important function for which people cultivate and tend trees and shrubs in home gardens, farms, and landscapes, and in home-garden agroforestry systems trees are maintained along with food value; they are also used for building, fencing, and furniture making (Kumar & Nair, 2006; Mbow *et al.*, 2014). Therefore, the home garden is a repository for plant resources useful for material culture, as indicated by (Lerch, 1999) and (Andel *et al.*, 2012).

3.7.1.4. Forage Plant Species from Home Gardens

The present study identified 8 species comprising 8 genera and 7 botanical families, which are used as fodder crops in home garden practices. Two species were identified as wild/semi-wild species ([Supplementary file 2](#)). Of the identified forages, most were herbaceous (7 species) in habit, while one species was classified as a shrub.

In the areas of the study, livestock frequently consume wastes derived from various field crops, including *Zea mays* (maize); *Saccharum officinarum* (sugarcane); *Musa paradisiaca* (banana); *Sorghum bicolor* (sorghum); and *Musa ventricosum* (enset) as fodder. Unlike areas with intensive cereal-based farming systems in northern parts of Ethiopia, where free grazing is a common practice (Ayenew, 2009). Livestock in the area of study do not have unconditional access to cropland, but a structured way of feeding with cut-and-carry techniques; the fodder obtained by hand was observed. These findings are comparable to work done by (Alemtsehay, 2008). Controlled feeding system practices are driven by scarcity of land resources and the necessity for integrating crop production and livestock production. Furthermore, recent studies on home gardens reported by FAO (2019) and (Ewuketu *et al.*, 2014) indicated the potential of home gardens to supply livestock feed, especially in regions where there is scarce pasture resources, whereby increasing dependency on waste materials from home gardening and feed production in home gardens, especially among smallholder farmers.

3.7.1.5. Plants Used as Firewood

The present study identified 7 plant species from 7 genera and 7 botanical groups that were in use as firewood species within the area under study ([Supplementary file 3](#)). Three out of 7 species were wild or semi-wild, and 4 species are intentionally cultivated in homestead or home-garden practices. Based

on plant life forms, woody species are the main source of firewood, with 3 tree species and 2 herbaceous plant species as fuelwood sources for households. As regarding tree, it comprises 66.6%, while herbaceous are 33.4%.

According to household members of Damot Gale Woreda, they prioritize trees for use as fuelwood at the level of household members on their calorific and burn values. Based on the importance ranking conducted with key informants that reported the species the most important in the culture of the local people for the use of fuelwood include *Croton macrostachyus*, *Olea africana*, and *Eucalyptus camaldulensis* in the top 3 ranking order, respectively ([Supplementary file 3](#)). This evidence corroborates previous results suggesting the home-garden's importance in providing fuelwood, especially in settings that land use changes lead to the demise of natural forests (Mbow *et al.*, 2014; FAO, 2019). *E. camaldulensis* is commonly grown for firewood in the Ethiopian smallholder agricultural sector due to its higher yield and better suitability for fuelwood due to faster-growing characteristics and high biomass productivity (Bekele & Regasa, 2020; Singh *et al.*, 2021). Recently conducted studies by Tadesse *et al.* (2024) and Agize *et al.* (2025) revealed that home gardens can reduce external fuelwood input requirements, with appropriate application of sustainable land-use management in the home garden ecosystem. These agroforestry techniques not only improve the meeting of fuel demand but also protect natural habitat resources.

3.7.2. Indirect Uses of Home Garden Plants

3.7.2.1. Shade and Live Fence Plants from Home Gardens

Our findings reported that 3 species of shade plants from 3 different genera and families exist in the natural environment ([Supplementary file 3](#)). Also, there were 3 species of live fence plants, each from a different genus and family. All live fence species were identified as from semi-wild or natural environments, while the trees were most commonly observed as growth forms. Overall, consistent with findings of (Asfaw, 1997), live fence represents another kind of home-garden management practiced for the conservation of home-garden elements. Recent findings have recognized live fence for the management of home gardens, and agriculture is emerging in various systems (Kumar *et al.*, 2021).

3.7.3. Multipurpose Plant Species

This study identified 36 plant species for multipurpose uses in the area of study. Among them, 19 plant species are used for three or more purposes ([Supplementary file 3](#)). The 19 species identified here in multi-purpose use groups include 14 for home-garden cultivation and 5 found to be wild or semi wild nature plants. Regarding mode of growth, no species were identified as climbers. 9, 6, and 3 species are grouped as trees, herbs, and shrubs with plant types respectively. The findings also agree with those of Kanshie (2002) in finding multifunctional plant species in crop fields and in home gardens, and explain why the importance they confer on household income and livelihoods is also very wide. Multipurpose plants have significance for agroforestry practices, integrated and sustainable home garden-based livelihood development, and are also important in home gardening management and practices according to new research works (Mahmud *et al.*, 2020; Singh *et al.*, 2021).

3.7.4. Structure of Plants in Darkuwaa

3.7.4.1. Vertical Structure of Plants in Darkuwaa

The presence of a multi-layered organization in most home gardens is observed, which has resulted in a more complex system in both vertical and horizontal dimensions. Home gardens are a combination of various components. The arrangement of different plants in a complex structure leads to climbers, trees, shrubs, and herbs existing together. From the observational study, home gardens in the study area can be vertically classified into several levels by plant height:

Tree species including *E. camaldulensis*, *C. lusitanica*, *P. gracilior*, *C. macrostachyus*, *C. africana*, and *P. americana* make up the majority of the top most layer (> 4 m). The lower layers benefit greatly from the shade that these canopy trees give which lowers transpiration rates and preserves soil moisture.

Rhamnus prinoides, *C. edulis*, *E. ventricosum*, *C. arabica*, *M. indica*, *M. paradisiaca*, *Carica papaya*, and *S. officinarum* are among the staple and economically important crops that make up the middle layer (> 1 m and < 4 m). Various crops, spices, and medicinal plants, such as *Ipomoea batatas*, *B. oleracea*, and *S. lycopersicum* are found in the ground or herbaceous layer (<1 m). Because they frequently tolerate shade, these lower-layer plants can adjust to the decreased amount of sunshine below the canopy.

Similarly, multi-layered arrangements were observed by (Kumar & Nair, 2004) in tropical home gardens. The same type of layered structures were also developed by Asfaw (2002), and Seta (2012). These results revealed that how vital vertical layering in such systems is; recent research indicates more information on ecological benefits, the importance of sustainable resources, including food security through the conservation of biodiversity within stratified home-garden landscapes (Kumar *et al.*, 2021). It seems that household livelihood demands are the main factor influencing the choice of plant species in home gardens. More than 83.14% of the home gardens assessed had a number of plants that are important for ecological stability, revenue creation, and food security. *Eucalyptus* species, *C. sativum*, *P. gracilior*, *E. ventricosum*, *S. tuberosum*, *M. paradisiaca*, *C. arabica*, and *C. africana* are a few of them. The most common tree species found were *Eucalyptus* species, *C. africana*, *M. indica*, *C. arabica*, and *C. lusitanica*.

Through the breakdown of organic matter, upper-layer trees greatly increase soil fertility, according to key informant interviews and household surveys. Specifically, the comparatively quick decomposition of *P. gracilior*, *C. macrostachyus*, and *C. africana* leaves enriches soil nutrients. Furthermore, *E. ventricosum* and other middle- and lower-layer crops lose less water when the trees in the upper canopy offer necessary shade. These findings are consistent with those of Asfaw (2002) and Seta (2012), who emphasised the many uses of trees in home gardens. The significance of these agroforestry systems in boosting soil fertility, promoting microclimate conditions, and bolstering household resistance to environmental changes has also been reaffirmed by several studies (Mbow *et al.*, 2014; Barman *et al.*, 2022; Sharma *et al.*, 2022).

3.7.4.2. Horizontal Structure of Darkuwaa

The home garden (Darkuwaa) is where the Wolaita people originally identified the distinct parts with different compositions and placements within. Their horizontal composition of the Darkuwaa is a mosaic of patches and concentric zones based on the crop types and variety of species used in it. The five main parts of the Darkuwaa identified by the elderly informants during the study include: 'Kare'a' (front yard), 'Ketasa'a' (house-site), 'Darincha' (spice patch), 'Utta Darkuwaa' (enset garden), and 'Shukaare Gadiyaa' (sweet potato garden). The other area of land is out field referred to as 'Shoka'. The location of these zones relative to the household is the most important criteria which defines these zones.

Front Yard (Kare'a)

The Kare'a symbolises the area of Darkuwaa in front of the home where trees of cultural significance are purposefully kept intact. These trees provide shade, fuel wood, and areas for rituals and social gatherings, among other uses. In this region, tree species like *C. africana*, *P. gracilior*, and *O. europaea* are frequently preserved. An informant from Gacheno, Pa, claims that these trees provide shady spaces that are appropriate for social and religious events where coffee, roasted grains, and traditional bread are provided. However, because there is less land available, this practice has been dwindling. These results are in line with earlier research conducted by Agize *et al.* (2016) in Damot Gale Woreda, and Seta (2012) in Wolaita Zone.

House-Site (Ketasa'a)

The Ketasa'a is only allowed to be used for building homes. A small, plant-free, cleared area known locally as Bassuwaa sits in front of this area and is used as a playground for young children.

Spice Patch (Darincha)

The main focus of Darkuwaa's Darincha department is the production of medicinal plants and spices. This patch, known locally as 'mizaa aquwaa', is situated near the house but on the other side of the animal enclosure, which is situated at the rear downhill. To improve soil fertility, a channel is frequently excavated across mizaa aquwaa to convey soft dung and urine from the livestock pen to the garden. Herbaceous plants like *Artemisia afra*, *A. absinthium*, *Ruta chalepensis*, *Cymbopogon citratus*, *Coriandrum sativum*, and *Ocimum basilicum*, as well as shrubby plants like *Solanum dasyphyllum*, are frequently grown in this section. These findings are consistent with earlier research (Seta 2012; Agize *et al.*, 2016). The Darincha's local relevance as a main health centre and traditional pharmacy, where medicinal plants are easily accessible to cure common ailments, was highlighted by informants. "Traditional pharmacy and local market," or 'Nuuyoo xaale keetannee mattaa qoccaa giyaa', refers to the vital function that these plants play in home health care. While plants like *Colocasia esculenta* and *Brassica* species are frequently planted close by, climbing plants like *Phaseolus lunatus* and *Dioscorea canensis* are frequently grown along walkways leading to the house.

Enset Garden (Utta Darkuwaa)

Ensete ventricosum (enset) is the main plant grown in the Uttu Darkuwaa, an area of the home garden, as the name implies. With its dense enset groves, this section makes up the darkuwaa's greatest area. To increase land productivity, commercially significant crops like coffee (*C. arabica*) are frequently interplanted with inset.

Sweet Potato Garden (Shukaare Darkuwaa)

Sweet potatoes (*I. batatas*), which are frequently interplanted with various herbaceous plants, are the main crop grown in the Shukaare Darkuwaa. But as an alternative cultivation method, sweet potatoes are also cultivated in 'Shoka', or agricultural fields. Furthermore, because of their ecological and financial advantages, bananas (*M. paradisiaca*) are frequently planted next to garden fences. These observations align with research conducted by Agize *et al.* (2016). An adaptive agroforestry system that maximises land usage, biodiversity conservation, and household resilience is reflected in Darkuwaa's traditional spatial organisation. The ecological and economic importance of these integrated home-garden systems in improving food security and sustainable resource management has also been emphasised by recent studies (Kumar *et al.*, 2021; Korpelainen, 2023).

3.8. Plant Species Diversity and Evenness Value in the Home Gardens

Gacheno home gardens have a higher plant species variety ($H' = 2.94$), according to the Shannon–Weaver diversity index and species evenness values (Table 5). Konasa Pulasa ($H' = 2.51$), Wandara Gala ($H' = 2.34$), Harto Buriqto ($H' = 2.05$), and Zagare ($H' = 2.03$) are next in line. The results of this study are in contrast to those of Pandey *et al.* (2007), who found that South Andaman home gardens had a lower plant species diversity index ($H' = 1.38$).

Ade Damot home gardens had the lowest diversity index, suggesting that a small number of species predominated there. Particularly, in Ade Damot home gardens, species including *Z. mays*, *Eucalyptus* spp., *E. ventricosum*, *C. arabica*, and *I. batatas* were substantially more prevalent than other species. On the other hand, Wogera and Shasha Gale's home gardens showed a fairly even distribution of tree and herbaceous species. *Dioscorea alata*, *B. oleracea*, *B. carinata*, *A. afra*, *C. sativum*, *O. europaea* ssp. *africana*, *C. lusitanica*, *L. esculentum*, *E. tef* (Zucc.) *trotter*, and *C. macrostachyus* were among the plants that were commonly found in these regions.

According to the species evenness index, the species distribution uniformity was highest in Gacheno home gardens ($E = 0.27$), followed by Konasa Pulasa ($E = 0.25$), Harto Buriqto ($E = 0.23$), Zagare ($E = 0.22$), and Wandara Gala ($E = 0.26$). These results are consistent with those of (Mengistu, 2008), who documented comparable patterns in the evenness and diversity of plant species in Dilla Zuria Woreda's home gardens. Furthermore, by preserving a variety of species, home-garden agroecosystems greatly aid in the conservation of biodiversity and sustainable food production, according to recent studies by (Kassa *et al.*, 2023).

Table 5: Diversity and evenness index of plant species across the different home gardens of the study Kebeles.

Study Kebeles	Shannon-Weaver diversity index (H')	Evenness (E)
Konasa pulasa	2.51	0.22
Zagare	2.03	0.26
Wadara gale	2.34	0.25
Gacheno	2.94	0.27
Harto Burqito	2.05	0.23

4. Conclusion and Recommendation

Our study identified a total of 57 plant species, grouped into 30 families with 55 genera. The proportion of plant growth forms across the three types of home gardens (small, medium, and big) was as follows: trees made up 19%, shrubs 25%, herbs 51%, and climbers 5%. Poaceae, Asteraceae, Lamiaceae, Brassicaceae, Solanaceae, and Fabaceae were the most varied plant families identified in the study. 5 species from the Solanaceae family were most prevalent, followed by 4 species from the Poaceae, Lamiaceae, and Rutaceae families. Furthermore, the Musaceae, Apiaceae, Caricaceae, Amaranthaceae, Alliaceae, and Fabaceae families each had 2 species, but the Brassicaceae, Asteraceae, Myrtaceae, and Cucurbitaceae families each had 3 species. The home gardens under study showed a high level of plant diversity, especially in species like *Zea mays*, *Musa paradisiaca*, and *Coffea arabica*. Both functional group classifications and differences within and between home gardens across various kebeles were taken into account when evaluating species diversity. The study identified plant species based on their multifunctional traits in addition to their diversity.

Nine functional groupings were found in all, with 2 to 18 species in each. Medicinal plants (13 species, 22.8%), material culture plants (8 species, 14%), forage species (8 species, 14%), ornamental plants (4 species, 7%), shade-providing plants (4 species, 7%), firewood species (7 species, 12.2%), live fence species (3 species, 5.3%), and stimulant plants (3 species, 5.3%) made up the largest percentage (60%) of all plants. Notably, some plant species were categorised under more than one use category and served numerous roles. Given how common it was for homes in the research area to grow fruits, vegetables, and tubers, home gardens were shown to be important to local food security. Plant species cultivated in home gardens also had cultural importance and helped with household medical requirements and financial gain. Particularly prevalent in the home gardens was the cultivation of edible plants, suggesting that plant species were largely managed for their practical use rather than for conservation. However, because of growing human influence, traditional knowledge about the usage of home-garden plants is in danger. As a result, several beneficial plant species have become less common, endangering the local biodiversity and ethnobotanical knowledge. Shrubs, trees, herbs, and climbers coexisted in most home gardens, which showed a varied diversity of plant forms. The most prevalent of them were found to be herbaceous plant species. The following recommendations from this study are mentioned below;

- Training and educational programs centred on the sustainable management of home garden plant resources should encourage the active involvement of local communities. Long-term conservation initiatives depend on raising awareness of the financial and ecological advantages of home gardens.
- Households that are either unaware of the advantages of home gardens or are not actively involved in them should receive special attention. To promote their participation, targeted awareness campaigns must be put into place.
- Since home gardens play a major role in the food security and financial stability of households, farmers should be encouraged and supported to maintain them well. It is necessary to create policies and initiatives targeted at increasing the output of home gardens.
- The importance of home-garden plants in supplying dietary, therapeutic, and financial demands should be made clear to the community. Initiatives for community-based learning should be implemented in order to increase awareness of these advantages, as many people might not be completely aware of them.

- Sustainable plant management techniques should be incorporated into conventional coping strategies for land shortage. In home gardens, promoting native methods for making the best use of available space can support the preservation of ecosystem health and biodiversity.
- The preservation and home garden cultivation of multipurpose plant species should be the focus of conservation initiatives. Since these species give households vital resources, it should be a top priority to manage them sustainably.
- To lessen the loss of valuable plant species—especially those having edible and medicinal applications—more research should be done. Enhancing these species' conservation and productivity should be the main goals of scientific research.
- It is important to honour, record, and maintain indigenous knowledge and customs around the management of plant species. The sustainable utilisation of biodiversity in home gardens can be facilitated by combining contemporary conservation techniques with traditional ecological knowledge.

Author Contributions

BD: Conceptualization, Methodology, and Experimental Layout; MA: Methodology, Statistical Analysis, and Drafting; MAK: Resources, Writing, Review and Editing.

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Ethics, Consent to Participate, and Consent to Publish

The data collected in this manuscript is collected in the form of questionnaires, interviews. It does not contain any research data on involvement of human participants or animals.

Consent to Publish

Not applicable. This manuscript does not contain any person's data in any form.

Clinical Trial Registration

Not applicable. This manuscript does not report any clinical trial data involving human participants.

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The authors declare that they have no known competing financial interests.

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Supplementary Materials

- [Supplementary file 1](#)
- [Supplementary file 2](#)
- [Supplementary file 3](#)
- [Supplementary file 4](#)

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