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Pollination knowledge among local farmers in northern Tanzania and the role of traditional agroforestry practices in promoting pollinator forage plants

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A R T I C L E I N F O

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A B S T R A C T

Pollination services by insects contribute strongly to food security and ecosystem stability. However, especially in Africa, little is known about farmer's knowledge and awareness of pollination services. Here, we first surveyed home garden farmers about their knowledge on pollination services, and their ability to recognize insect pollinators. Then we evaluated their home gardens for the availability of pollinator forage resources. We found that a majority of the farmers (89.1%) were not aware of pollination services and that awareness was higher for males and those with higher education levels. All farmers were able to recognize at least one insect species (especially, *Apis mellifera*) but most farmers did not know them as pollinators. We also found that 293 woody plant species from 62 families in Chagga home gardens (CHGs), provided insect pollinator forage. There was higher alpha diversity for exotic forage plants but higher gamma diversity for natives. The increase in diversity of pollinator forage plants reduced the temporal variability of flower richness. Our findings suggest that farmers should be made more aware of pollination services as well as insect pollinators specifically regarding their benefits to increase willingness to conserve them. Awareness programs should be accessible to women and those with little formal education as they exhibit the least knowledge. Also, various media tools should be used for effective dissemination to the different target audiences. Our findings also provide evidence that if managed properly some traditional agricultural land use systems can enhance pollination services by providing diverse forage resources for insect pollinators.

1. Introduction

Insect pollination is an essential ecosystem service that greatly contributes to global food security and ecosystem stability (Ollerton, 2017; Klein et al., 2007). However, this ecosystem service is under threat due to the ongoing global decline of insect pollinators (IPBES et al., 2016; Potts et al., 2010; Kosior et al., 2007). Conversion of natural habitat to agricultural land, increased use of agricultural inputs, and climate change are among the major factors contributing to pollinator declines (Sánchez-Bayo and Wyckhuys, 2019; Altman and Mesoudi, 2019). This decline in insect pollinators will have major negative effects on global food production in the future (Potts et al., 2016; Garibaldi et al., 2011), thus pollinator conservation especially in agricultural landscapes is crucial and requires the participation of different partners including conservationists, beekeepers, agronomists, and most importantly farmers (Kumsa and Ballantyne, 2021; Tarakini et al., 2020; Mpondo et al., 2021). Through their practices, farmers have a great potential to enhance pollinator populations in agricultural landscapes, for instance, by supporting woody plants (trees and shrubs) in their farms as many of them provide food and nesting resources for insect pollinators (Centeno-Alvarado et al., 2023; Bentrup et al., 2019). To effectively achieve that, farmers need to be aware of pollination services and insect pollinators and their importance for agricultural production. Our understanding of farmer's knowledge and perceptions about

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pollination services and insect pollinators is, however, scarce, especially in sub-Saharan Africa (Kumsa and Ballantyne, 2021; Tarakini et al., 2020; Ojija and Leweri, 2022; Mpondo et al., 2021). Furthermore, little is known about the role of traditional agroforestry practices such as home gardens in promoting floral resources for insect pollinators (Kumsa and Ballantyne, 2021). Addressing this knowledge gap will help establish strategies to support insect pollinator conservation, especially in agricultural areas.

Knowledge about pollination services is important for farmers to comprehend the relationship between pollinating insects and agricultural productivity (Elisante et al., 2019). It is also important so that farmers can recognize insect pollinators since many see insects negatively and collectively as pests or disease vectors (Smith et al., 2017; Marques et al., 2017). Knowledgeable farmers are more likely to convert to sustainable farming practices that support pollinators (Elisante et al., 2019; Marques et al., 2017; Trip et al., 2020; Nicholls et al., 2020; Schonfelder and Bogner, 2017), and creating awareness about pollinators and pollination services for farmers is therefore imperative. The first step is to evaluate the farmer's knowledge about pollinators and pollination services. Previous studies have reported that gender, age, and education level determine peoples knowledge about pollination services (Ojija and Leweri, 2022; Mpondo et al., 2021; Silva and Minor, 2017). For example, Mpondo et al. (2021) observed that a greater proportion of men among the pastoralist community in Tanzania demonstrated a more comprehensive understanding of pollination services than women. The study also indicated that higher educational level was associated with a greater awareness of these services.

In sub-Saharan Africa, farmers knowledge about pollination services and pollinators remains largely un-documented (Kumsa and Ballantyne, 2021; Munyuli, 2011) and insect pollinators are poorly understood (Ojija and Leweri, 2022; Mpondo et al., 2021; Sawe et al., 2020a,b; Elisante et al., 2019). In Tanzania for example, there is no initiative by the government to create awareness about pollination services and to promote the conservation of insect pollinators although insect pollinated crops such as beans, watermelon and avocado are commonly cultivated by farmers. However, despite the lack of initiative to conserve and protect insect pollinators, some traditional agricultural land use systems in Tanzania may be beneficial for insect pollinators (Arnold et al., 2021). For example, Chagga home gardens (CHGs) is a traditional agroforestry practice that involves integrating numerous multipurpose trees and shrubs with food crops and animals and is practiced along the lower slopes of Mt Kilimanjaro in northern Tanzania (Mbeyale and Mcharo, 2022). With more than 500 native and exotic plant species (including herbaceous plants), this traditional land use system maximizes land utilization while also ensuring environmental protection (Hemp, 2005). There is, however, inadequate information regarding the potential of CHGs in enhancing pollination services by providing floral resources to insect pollinators.

The diversity of woody plants in CHGs and in most agricultural landscapes largely depends on farmer decisions and preferences (Nath et al., 2016; Jose, 2011). Farmers usually retain and plant woody plants based on specific functions such as providing shade to crops (coffee and bananas), live fences/boundary marks fodder, food, and honey bee forage (especially for beekeepers) ((Hemp and Hemp, 2008); Hemp, 2005; Fernandes et al., 1985a, b). Environmental factors such as elevation also play a great role as they restrict which species are suitable due to climatic conditions (Cirimwami et al., 2019). For example, higher elevations have lower temperatures and heavier rainfalls which may not support the growth and performance of some plant species (Cirimwami et al., 2019; Malizia et al., 2020).

The diversity of woody plants in CHGs remains high despite a long history of human management in the lower slopes of the mountain Kilimanjaro (Hemp, 2005). The high tree diversity was initially a result of the retention of naturally grown trees over more than 100 years (Fernandes et al., 1985a, b). Intensification of coffee production in the 1990s however resulted in the replacement of native trees with fast-growing exotic tree species such as *Grevillea robusta* to provide shade to coffee (Mbeyale and Mcharo, 2022). Exotic species are often associated with negative effects on pollinator diversity and the structure of pollinating networks (Zaninotto et al., 2023) as they tend to attract more generalist pollinators while specialized and native pollinator species are more strictly dependent on native plants (Parra-Tabla and Arceo-Gómez, 2021; Staab et al., 2020). Therefore, understanding how native and exotic forage plants affect forage resource availability is critical to sustaining rich and functionally diverse insect pollinator communities in CHGs.

Therefore, to address this knowledge gap, we 1) assessed CHG farmers knowledge about pollination services and insect pollinators, 2) investigated the composition and utility of CHGs for pollinators and how these are affected by elevation, and 3) Evaluated how species choices of CHG farmers (especially native vs exotic species) affect the availability of insect pollinator forage resources.

2. Materials and methods

2.1. Description of the study area

The study was conducted in Moshi rural district which is situated on the lower slopes of Mount Kilimanjaro in northeastern Tanzania (Fig. 1a). The area experiences a bimodal rainfall pattern, with a long rainy season from March to May and a short rainy season from November to December (Appelhans et al., 2016). The average daily minimum and maximum temperatures are 18 and 26 °C respectively (Gebrechorkos et al., 2019). The district's primary economic activity is agriculture, benefiting from favorable climatic conditions for crop and tree growth. Agriculture is mainly practiced in home gardens popularly known as Chagga Home Gardens (CHGs). In CHGs, farmers integrate numerous multipurpose trees and shrubs with food crops (coffee, banana, beans, maize, sunflower vegetables etc.) and/or animals. In general, CHGs maintain a high diversity of woody plants, with the most common species including *Grevillea robusta* (A. Cunn ex R. Br.; Proteaceae), *Cordia africana* Lam. (Boraginaceae), *Persea americana* Mill. (Lauraceae), and *Albizia schimperiana* Oliv. (Fabaceae) (Hemp, 2005). Chagga Home Gardens are predominantly found at elevations between 800 m and 1900 m.a.s.l. on the lower slopes of Mount Kilimanjaro (Hemp, 2005). CHGs are small, with an average size of 0.68 ha (range: 0.2–1.2 ha) (Hemp, 2005).

2.2. Sampling design and data collection

Systematic random sampling was employed to select 101 home gardens (CHGs) along seven road transects that span between 800 and 2000 m.a.s.l. Each home garden was located at least 1 km from one another and at least 100 m away from the road. The number of CHGs selected along each road transect was determined by the length of the road up to the Mount Kilimanjaro National Park border.

Data collection was conducted for 6 months between March and October 2022 by the two research teams, each consisting of one researcher and one field assistant. At each CHG, we started by conducting an ethnographic survey of the selected 101 home garden households using a structured questionnaire (Ojija and Leweri, 2022; Tarakini et al., 2020). The respondents were not necessarily owners of the home garden but could be any household member except children. The questionnaire was designed to collect socio-demographic information (gender, age categories, level of education, household size, and occupations) and core study questions about pollination services, insect pollinators, and their benefits (Appendix 1). The core study questions started by asking whether farmers have knowledge about pollination services and insect pollinators. The ability to identify insect pollinators was tested by providing respondents with the pinned specimens of the following insect pollinator species; *Apis mellifera* (Linnaeus, 1758), Honey bee; *Xylocopa caffra* (Linnaeus, 1767), Carpenter bee; *Synagris*

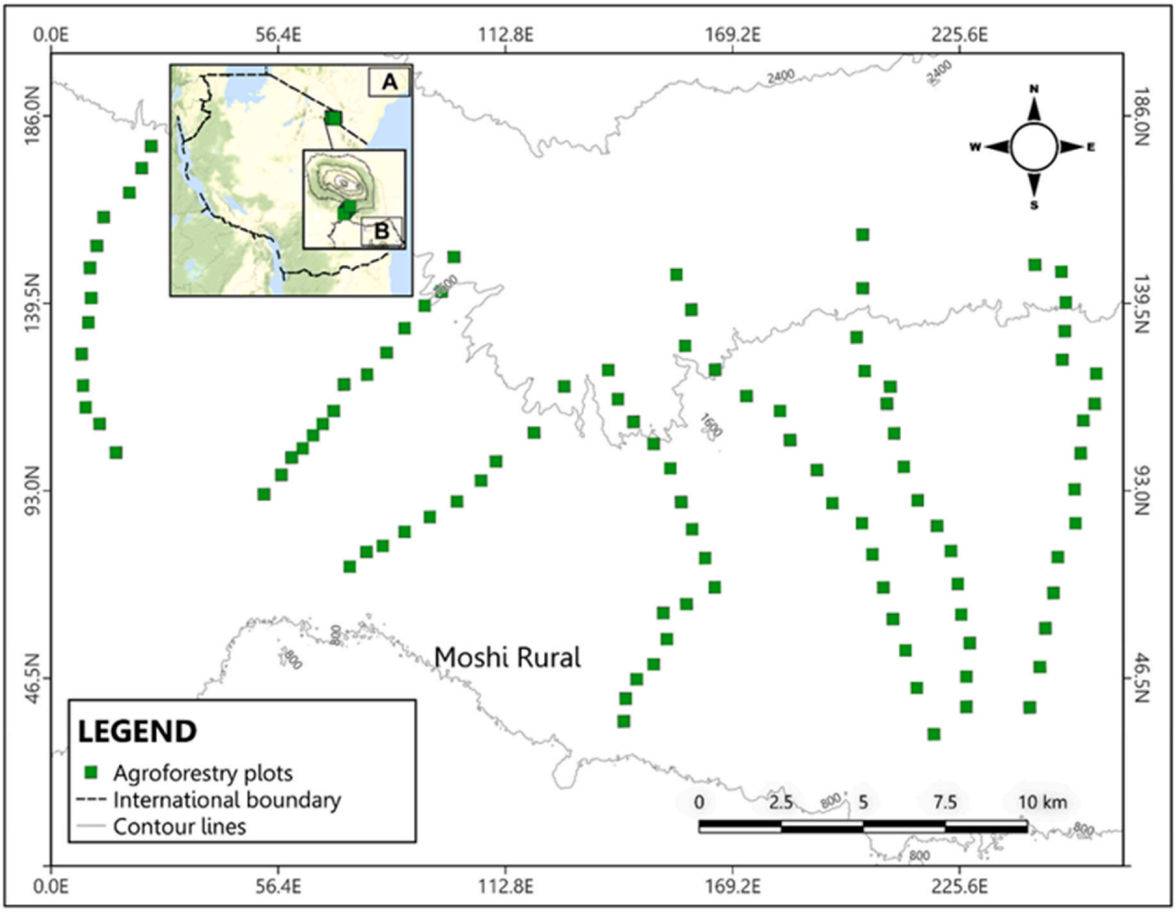

Fig. 1. Map of Tanzania showing Moshi rural district with the selected gardens incorporated in this study.

Fig. 2. Example of Chagga home gardens (CHG) in Moshi rural district.

analis (Fabricius, 1804), Wasps; *Phytomia varians* (Fabricius, 1787), Fly and *Junonia hierta* (Fabricius, 1798), Butterfly. The pinned specimens were collected in the study area during the reconnaissance survey. Finally, we asked farmers to identify plants that the identified insects visit/forage on.

After the questionnaire survey, we surveyed all 101 home gardens to identify woody plants (trees and shrubs) that are forage resources for insect pollinators. We first identified all woody plant species in each garden and counted their abundance (except seedlings). Thereafter, to determine whether the woody plants provide forage for insect pollinators, we monitored for 6 months their flowering time and whether their flowers were visited by insect pollinators. We visited each garden twice per month for three months during the dry and wet seasons respectively of the year 2022. During each visit, we recorded all the flowering trees and shrubs, estimated their flower abundance, and observed whether they were visited by insects known as pollinators such as bees, butterflies, flies, wasps, and beetles (Ollerton, 2017). Flower abundance was subjectively estimated using a scale of 1–4 as per Samnegård et al. (2016). One (1) was given to a tree or shrub with <10 flowers while 2 = 10–100 flowers, 3 = 101–1000 flowers, and 4 = >1000 flowers. Subsequently, this was translated into an estimated average number of flowers per individual tree/shrub, with category 1 = 5 flowers, 2 = 50 flowers; 3 = 500 flowers, and 4 = 5000 flowers (Samnegård et al., 2016). For example, a tree with less than 10 flowers will be given a scale of 1 and its estimated average number of flowers will be 5. During the field survey, we estimated the number of flowers for all species that were flowering during the visit regardless of whether they were insect pollinator forage plants or not. The aim was to sort them later during the analysis, after having full information about them.

To observe whether the flowering trees/shrubs were visited by insect pollinators, we selected 3 individuals from each flowering species for observation. In each tree/shrub, we visually created (estimated it by eye) three 1 m^2 quadrats at different sides of the tree/shrub for pollinator observation. We observed pollinators for 10 min on each quadrant established on tree/shrub and whenever necessary we also used binoculars. For trees, we preferred shorter trees so we could easily see the insects visiting flowers and for species with no shorter trees available, we used binoculars or relied on information from the literature. Likewise, in situations where we could not observe any insects visiting specific flowering plants in the field, we checked the literature to see whether their flowers are visited by insects so that we can conclude if they are insect forage or not. The observation was conducted on days with no or very low rainfall and low wind speed between 9:00 a.m. and 5:00 p.m. when insect pollinators are known to be active (Tarakini et al., 2021). We considered plants as pollinator forage when we observed insects absorbing nectar or carrying pollen from their flowers (Waykar and Baviskar, 2015).

2.3. Data analysis

2.3.1. Pollination knowledge among home garden farmers

For the questionnaires, the analysis aimed to address the following questions 1) Do CHG farmers have knowledge about pollination services? 2) What are the factors influencing farmer's knowledge on pollination services? 3) Can CHG farmers recognize, name, and mention the importance of different insect pollinators? 4) How knowledgeable are CHG farmers about insect pollinator forage plants? For the first question, the response on knowledge of pollination services was categorized as "Yes" or "No" where "Yes" was used for respondents who correctly explained what a pollination service is and the role it has in crop production, while "No" was used for respondents who were unable to provide such explanations. For the second question, we tested whether age, gender, and education levels influenced farmer's knowledge on pollination services. In the third question, the answers for insect specimen names were categorized as honey bee, wild bee, other wasps, flies, and butterflies, while I don't know was for respondents who did not recognize any of the specimens. The responses about the importance of the insect recognized were classified as either honey production, pollination, medicinal purpose or I don't know. The fourth question was open-ended whereby, respondents were asked to identify plants that are visited by insects in their gardens. Descriptive statistics for the closed-ended questionnaire (questions 1 and 2) were performed using frequency tables, figures, and percentages (Ojija and Leweri, 2022). A binary logistic model was used to determine the factors influencing pollination knowledge status among CHG farmers, with age, gender, and education level being explanatory variables (Ojija and Leweri, 2022). For the third question, we just provide a list of the plants that were identified by the farmers.

2.3.2. Pollinator forage plants in CHGs

For the survey of pollinator forage plants, The following research questions were tested 1) Do woody plants in CHGs provide floral resources to insect pollinators? 2) What is the proportion of exotic and native forage plants in CHGs? 3) Does farmers knowledge on pollination and elevation affect the proportion of exotic and native forage plants in CHGs? 4) Does farmers knowledge on pollination and elevation affect the diversity, species richness, and abundance of insect pollinator forage plants in CHGs? 5) Does the elevation and forage diversity in CHGs affect the temporal stability of flower richness and abundance? 6) Does the abundance and richness of exotic and native forage plants affect the temporal stability of flower richness and abundance?

We performed a descriptive analysis for questions 1 and 2 using tables with percentages, and ratios. We also computed alpha and gamma diversity whereby alpha diversity refers to diversity (richness) at the local scale (plot level) while Gamma diversity refers to overall species diversity across communities within a geographical area/study area (Andermann et al., 2022). For the third question, we used generalized linear mixed models (GLMMs) with negative binomial distribution to determine whether elevation and farmers knowledge of pollination affected the proportion (abundance and richness) of native and exotic forage plants in CHGs. For the fourth question, we first calculated the Shannon diversity of pollinator forage plants using the function "diversity" in the R package "vegan". The Shannon diversity index is a mathematical measure of species diversity in a community that takes into account species richness and their abundance ($H = -\Sigma P_i \ln P_i$ where; H = the Shannon diversity index, Pi = proportion of each species in the sample, lnPi = natural logarithm of this proportion). Thereafter, we used Linear mixed models (LMMs) with Gaussian distribution to assess whether the diversity of pollinator forage plants in CHGs was affected by elevation and farmer's knowledge on pollination. Also, we used GLMMs with negative binomial distribution to assess whether the abundance and species richness of pollinator forage plants in CHGs respectively were affected by elevation and farmer's knowledge on pollination. For the fourth and fifth questions, we first estimated the total number of species and their flower abundance that flowered each month in each garden within the study time (six months). We then calculated the coefficient of variation (%) in flower abundance and richness in each garden over the study time using the function "coefvar" in the R package "DescTools". Thereafter, we used GLMMs with negative binomial distribution to assess whether the coefficient of variation in flower abundance and richness was affected by elevation and the diversity of pollinator forage (question 5) as well as the abundance and richness of exotic and native forage plants in CHGs (question 6). In all models, transects were included as random effects.

For each model, we first checked for multicollinearity between independent variables using the "vif" function in the R package "fmsb". Only variables with a VIF value of less than three (3) were included in the global/full models (Zuur et al., 2010). After that, we selected the best candidate models based on the Akaike Information Criterion (AIC) (with lower than 2 delta AIC compared to the best model) (Burnham and Anderson, 2004) using the "dredge" function in the MuMIn R package (Barton, 2012). Finally, we used the "model. avg" function in the MuMIn R package to perform model averaging of the candidate models. We did not execute model averaging when there were no competing models. All analyses were performed in R software version 4.2.3 (R Core Team 2023).

3. Results

3.1. Pollination knowledge among home garden farmers

Of the 101 home garden farmers interviewed, 53 were males and 48 were females with different ages, education levels, and occupations (Table 1). The majority of them (89.1%) reported not to have knowledge about pollination services. Farmer's knowledge on pollination was

Table 1
Characteristics of the 101 CHG farmers interviewed.

Descriptor	Category	Percentage
Age	21–35	15.8%
	36–55	25.7%
	56–85	58.5%
Gender	Male	52.4%
	Female	47.6%
Education level	Primary	84.2%
	Secondary	7.9%
	College	7.9%
Occupation	Employed	3.9%
	Farmers	96%

influenced by education level ($X^2 = 30.867$, df = 2, p > 0.001) and gender ($X^2 = 5.162$, df = 2, p = 0.02) where respondents with higher education levels and males were more likely to have knowledge. In contrast, age had no effect on the likelihood to have knowledge about pollination services ($X^2 = 0.22$, df = 2, p = 0.6). Among those with knowledge on pollination services, 9 (81.8%) of them reported having obtained their knowledge from college, while 2 (18.2%) had obtained their knowledge from agricultural researchers.

All 101 farmers were able to identify at least one insect pollinator species among the five pinned specimens provided to them. All respondents were able to recognize and correctly identify the honeybee, *Apis mellifera* (Linnaeus, 1758), while 62.1% and 72.1% of all respondents were able to correctly identify *Xylocopa caffra* (Linnaeus, 1767) and *Synagris analis* (Fabricius, 1804) all Hymenoptera respectively. *Phytomia varians* (Fabricius, 1787) Diptera and *Junonia hierta* (Fabricius, 1798) Lepidoptera were recognized and identified by 51.2% and 92.1% of all respondents respectively. Regarding the benefits of the recognized insects, farmers were able to mention the benefits of only two insects, *Apis mellifera* (Linnaeus, 1758) and *Junonia hierta* (Fabricius, 1798). All farmers knew about the benefit of *Apis mellifera* (Linnaeus, 1758) as a honey producer but only 9 of them mentioned crop pollination as an additional benefit. Only one (1%) of all 101 interviewed farmers knew about the benefit of *Junonia hierta* (Fabricius, 1798) as a pollinator. A total of 21 plants from 14 families were mentioned as plants in their gardens that are visited by the pinned insect pollinators (Fig. 3; Appendix 3). Among the mentioned species, 61.9% of the woody species were exotic and 38.1% were native species while 47.6% were trees, 33.3% were shrubs, and 19.1% were herbaceous plants.

3.2. Pollinator forage plants in CHGs

In CHGs, we found that 293 out of in total 301 woody plant species from 62 families were insect pollinator forage (Appendix 4, Fig. 4). The most species rich family was *Fabaceae* with 47 forage species (15.8%), followed by *Euphorbiaceae* and *Solanaceae* with 18 species each (6.1%). The most common native species based on frequency of occurrence in CHGs was *Rauvolfia caffra* which was planted on about 65% of the surveyed gardens to provide food, timber, and fences according to farmers. The most frequent exotic species was *Grevillea robusta* (80.2%) which was used for shade and timber (Table 2). Among the 293 forage plant species, 152 were native and 141 were exotic. Also, 170 woody species were trees (88 native and 82 exotic) and 123 species were shrubs (63 native and 60 exotic). Per garden, the overall richness of woody forage species ranged from 4 to 61 with a mean of 24.6 while abundance ranged from 33 to 627 with a mean of 228.4. Moreover, although the overall richness (Gamma diversity) of native woody forage species (152) was higher than exotic (141), the mean richness of woody forage species per garden (Alpha diversity) was higher for exotic species (14.68) than for native species (9.89). Also, the mean abundance of exotic woody forage species per garden (171.3) was higher than native species (57.1).

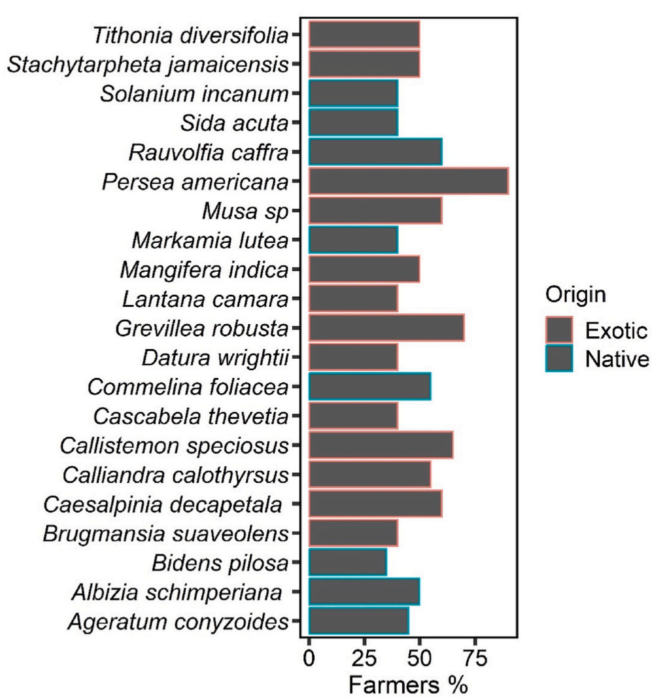

Fig. 3. Insect pollinator forage plants mentioned by farmers during the questionnaire survey (n = 101).

The abundance and species richness of exotic forage plants in CHGs were neither affected by elevation (p = 0.71, Table 3) nor by farmers knowledge (p = 0.39, Table 3). The abundance and richness of native forage plants significantly decreased with increased elevation (p < 0.001 both, Table 3, Fig. 5a and b) but none of the variables were significantly affected by the farmer's knowledge on pollination (p = 0.76 and 0.69 respectively, Table 3). The Shannon diversity and species richness of pollinator forage plants in CHGs significantly decreased with elevation (p < 0.001 and p = 0.001 respectively, Fig. 6a and b, Table 3) while farmers knowledge did not have a significant effect (p = 0.975 and 0.39 respectively, Table 3). The abundance of pollinator forage plants was neither significantly affected by elevation nor by the farmer's knowledge on pollinators (p = 0.41 and 0.41 respectively, Table 3). Additionally, the coefficient of variation in flower abundance over time significantly increased with elevation (p < 0.001, Fig. 7a, Table 3) but was not significantly affected by pollinator forage diversity (p-value = 0.45, Table 3). The coefficient of variation in flower richness over time was not significantly affected by elevation (p = 0.86, Table 3) but decreased with an increase in pollinator forage diversity (p = 0.05, Fig. 7b). Also, the coefficient of variation in flower abundance and richness was not significantly affected by exotic forage abundance (abundance: p = 0.22, richness: p = 0.13), exotic forage richness (abundance: p = 0.06, richness: p = 0.32), and native forage abundance (abundance: p = 0.36, richness: p = 0.89) (Table 3). Native forage richness was not included in the final model due to a high correlation with other variables VIF>3.

The 8 woody species that were not visited by insects included those that are either non-flowering/invisible flowers such as *Ficus* sp. and *Cupressus* sp. or nocturnal such as *Kigelia Africana* (Lam.) Benth. as this paper focused on diurnal.

4. Discussion

4.1. Pollination knowledge among home garden farmers

This study found that the majority of CHG farmers do not have knowledge about pollination services. The limited knowledge about pollination services among CHG farmers may be due to a lack of public education as most agricultural extension services focus only on educating farmers on the use of agricultural inputs such as fertilizers and pesticides in crop production (Güneralp et al., 2018; Gollin, 2014). This is despite the fact that enhancing pollination is more effective than increasing conventional agriculture inputs for improving the yield of some crops such as watermelon (Sawe et al., 2020).

Our study confirmed that high education levels increased the likelihood of home garden farmers having knowledge about pollination services (Misganaw et al., 2017). This may be because pollination knowledge is normally taught at secondary school and college level and a majority of home garden farmers only had a primary education level. We also found that gender had a significant effect on pollination knowledge among CHG farmers with more men having the knowledge than women. In our case, this may be because men were more educated than women and education level increased the likelihood of home

Fig. 4. Insect pollinators foraging on different woody plants in CHGs; A = *Calliandra calothyrsus* Meisn. visited by honey bees, B = *Caesalpinia decapetala* (Roth) Alston visited by honey bees, wild bees, and beetles, C = *Lantana camara* L. visited by butterfly (*Hypolimnas misippus* (Linnaeus, 1764)), D = *Crotalaria* sp visited by wild bees. (Photo by Nanyika Kingazi, field survey, 2022).

garden farmers having knowledge about pollination services. However, our results are contrary to other studies such as Elisante et al. (2019) and Misganaw et al. (2017) who reported gender to have no significant effect on pollination knowledge among farmers. In agreement with other studies, we found no significant influence of age on knowledge about pollination services among CHG farmers Misganaw et al. (2017); Elisante et al. (2019).

Although most home garden farmers did not know about pollination services, all of them were able to correctly identify honey bees *Apis mellifera* (Linnaeus, 1758). Their knowledge of honey bees may be attributed to their utilization of honey as most of them mentioned honey production as the benefit of *Apis mellifera* (Linnaeus, 1758) Ojija and Leweri (2022); Kasina et al. (2009). Also, the ability to correctly identify honey bees *Apis mellifera* (Linnaeus, 1758) may be because, they are very common foragers visiting various flowering plants, and therefore farmers are always in contact with them in their environment (Ojija and Leweri, 2022; Burns et al., 2021; Bhattacharyya et al., 2017). Wild pollinators such as *Xylocopa caffra* (Linnaeus, 1767), *Synagris analis* (Fabricius, 1804), *Phytomia varians* (Fabricius, 1787), and *Junonia hierta* (Fabricius, 1798) were correctly identified by more than half of the interviewed home garden farmers but not as pollinators but just as insects that they normally see in their environment. This indicates that pollinator-focused training and public education for farmers are important as they may result in an improved understanding of insect pollinators and provide a better motivation for their conservation (Elisante et al., 2019).

Home garden farmers were able to mention some woody plants that are visited by insect pollinators in their gardens. The most mentioned species was *Persea americana* Mill. (Fig. 2) and this may be because it is among the most common species in home gardens producing large amounts of flowers that are visited by especially bees (Sagwe et al., 2022). A majority of the forage plant species mentioned by home garden farmers such as *Tithonia diversifolia* (Hemsl.) A. Gray and *Caesalpinia decapetala* (Roth) Alston have been previously reported as pollinator food sources (Elisante et al., 2019; Mwangi et al., 2012; Kasina et al., 2009). Most of the listed forage plants are exotic species, and this may be because they are more abundant in CHGs and produce a large number of flowers which attract common insect pollinators like honey bees that are well-known by the farmers (Zaninotto et al., 2023). Most forage species were not mentioned by farmers during the interview but were recorded during the inventory in their home gardens.

4.2. Pollinator forage plants in CHGs

This study found that, despite a lack of knowledge on pollination services among home garden farmers, their traditional agricultural land use system (CHGs) harbors a significant number of pollinator forage plants which is critical for sustaining rich and functionally diverse insect pollinator communities. Nearly all woody species in CHGs (293 out of 301 species) were found to provide forage for insect pollinators in CHGs. The high species richness of forage plants in CHGs is likely to produce diverse pollen/nectar qualities and thus promote a balanced nutrition for insect pollinators through a mixed diet (Mensah et al., 2017; Blüthgen and Klein 2011).

We found higher alpha diversity and abundance for exotic forage species in CHGs than natives. This indicates that farmers prefer exotic species over native which may be because most exotic species are fast-growing and serve almost the same purpose as native species (Nath et al., 2016; Kehlenbeck et al., 2011). Previous studies have reported variable results on the response of insect pollinators to exotic plant species as compared to native species. Most studies have reported that insect pollinators prefer to forage on native than exotic plant species (Zaninotto et al., 2023; Parra-Tabla and Arceo-Gómez, 2021; Staab et al., 2020; Morandin and Kremen, 2013). Others found that if exotic plant species in a community can supply necessary nutrients, insect pollinators may readily incorporate them into their diets but if not, exotic plants may be avoided (Harmon-Threatt and Kremen, 2015). Therefore, the higher abundance and richness of exotic species in CHGs than native species may not be good for some insect pollinator species, especially native pollinator species and specialists with specific dietary needs, as they are more strictly dependent on native plants (Zaninotto et al., 2023). The gamma diversity of native species was higher than that of exotic species, indicating that a similar set of exotic species was planted across farms, whereas the composition of native plants varied across farms. This highlights the importance of native woody species in maintaining pollinator diversity at the landscape scale.

We found a decrease in native forage abundance and species richness as elevation increased (Fig. 5). This may be due to the intensification of

Table 2
Ten most common (based on frequency of occurrence in CHGs) woody forage plants across 101 gardens surveyed.

Rank	Species	Family	Origin	Floral reward	Occurrence out of 101 gardens
1	*Rauvolfia caffra*	Apocynaceae	Native	Nectar and pollen	64.4%
2	*Albizia schimperiana*	Fabaceae	Native	Nectar and pollen	60.4%
3	*Solanum incanum*	Solanaceae	Native	Pollen	50.5%
4	*Cordia africana*	Boraginaceae	Native	Nectar and pollen	43.6%
5	*Markhamia lutea*	Bignoniaceae	Native	Nectar and pollen	39.6%
6	*Commiphora zanzibarica*	Burseraceae	Native	Nectar and pollen	29.7%
7	*Margaritaria discoidea*	Phyllanthaceae	Native	Nectar and pollen	28.7%
8	*Solanum nigrum*	Solanaceae	Native	Pollen	24.8%
9	*Bridelia micrantha*	Phyllanthaceae	Native	Nectar and pollen	22.8%
10	*Olea capensis*	Oleaceae	Native	Nectar and pollen	22.8%
11	*Grevillea robusta*	Proteaceae	Exotic	Nectar and pollen	80.2%
12	*Persea americana*	Lauraceae	Exotic	Nectar and pollen	73.3%
13	*Mangifera indica*	Anacardiaceae	Exotic	Nectar	61.4%
14	*Duranta repens*	Verbenaceae	Exotic	Nectar and pollen	58.4%
15	*Lantana camara*	Verbenaceae	Exotic	Nectar	48.5%
16	*Cascabela thevetia*	Apocynaceae	Exotic	Nectar	40.6%
17	*Eriobotrya japonica*	Rosaceae	Exotic	Nectar and pollen	40.6%
18	*Psidium guajava*	Myrtaceae	Exotic	Nectar and pollen	36.6%
19	*Senna siamea*	Fabaceae	Exotic	Pollen	36.6%
20	*Senna spectabilis*	Caesalpiniaceae	Exotic	Pollen	34.7%

coffee farming at higher elevations which made farmers plant more exotic wood plants such as *Grevillea robusta* (A. Cunn ex R. Br.; Proteaceae) for shade (Mbeyale and Mcharo, 2022). Also, exotic fruit trees such as avocado are commonly planted in higher elevation CHGs (Hemp, 2005). This may affect some insect pollinator species that are found in higher elevations and depend more on native species as their foraging resources. The decrease in native tree species as elevation increased was also found in farmlands along Mt. Kenya slopes (Kehlenbeck et al., 2011).

Elevation was found to have a significant negative effect on the diversity (Shannon diversity) and species richness of pollinator forage plants in the CHGs (Fig. 6). This implies that, although farmers play a great role in determining the diversity of woody plant species in home gardens since they plant or retain woody plants based on their preferences, elevation is likely to restrict which species are suitable due to

Table 3
Final Models and models averaging result for assessing factors (variables) affecting forage resources in CHGs. Note: $\mathbf{R^2m}$ = marginal R^2, $\mathbf{R^2c}$ = conditional R^2, **t-value** was for only forage plant diversity.

Response variable	Variables	Estimates ± Standard error	z/t-value	p-value	R^2m/ R^2c
Exotic forage abundance	• Intercept •Elevation •Farmers knowledge on pollination	4.99 ± 0.25 0.00 ± 0.00 0.23 ± 0.14	20.18 0.38 0.87	<0.001*** 0.71 0.39	0.01/ 0.25
Exotic forage richness	•Intercept •Elevation •Farmers knowledge on pollination	2.82 ± 0.22 −0.00 ± 0.00 0.10 ± 0.10	12.87 −1.52 0.99	<0.001*** 0.13 0.32	0.02/ 0.58
Native forage abundance	•Intercept •Elevation •Farmers knowledge on pollination	4.94 ± 0.33 −0.00 ± 0.00 0.05 ± 0.17	14.99 −4.06 0.31	<0.001*** <0.001*** 0.76	0.12/ 0.56
Native forage richness	•Intercept •Elevation •Farmers knowledge on pollination	3.06 ± 0.33 −0.00 ± 0.00 0.06 ± 0.14	9.25 −4.21 0.39	<0.001*** <0.001*** 0.69	0.09/ 0.68
Forage plant diversity	•Intercept •Elevation •Farmers knowledge on pollination	3.16 ± 0.26 −0.00 ± 0.00 0.00 ± 0.13	12.41 −3.57 0.03	<0.001*** <0.001*** 0.98	0.07/ 0.58
Forage plant abundance	•Intercept •Elevation •Farmers knowledge on pollination	5.51 ± 0.23 −0.00 ± 0.00 0.10 ± 0.12	24.15 −0.83 0.83	<0.001*** 0.41 0.41	0.01/ 0.42
Forage plant richness	•Intercept •Elevation •Farmers knowledge on pollination	3.57 ± 0.24 −0.00 ± 0.00 0.08 ± 0.09	15.02 −3.26 0.84	<0.001*** 0.001** 0.39	0.05/ 0.69
Coefficient of variation in flower abundance over time	•Intercept •Elevation •Forage plant diversity	2.37 ± 0.33 0.00 ± 0.00 −0.08 ± 0.10	7.14 4.41 −0.76	<0.001*** <0.001*** 0.45	0.19/ 0.29
Coefficient of variation in flower richness over time	•Intercept •Elevation •Forage plant diversity	3.27 ± 0.30 0.00 ± 0.00 −0.22 ± 0.11	10.83 0.18 −2.01	<0.001*** 0.86 0.04*	0.11/ 0.20
Coefficient of variation in flower abundance over time	•Intercept •Exotic forage abundance •Exotic forage richness •Native forage abundance	3.17 ± 0.16 0.00 ± 0.00 −0.02 ± 0.01 0.00 ± 0.00	20.08 1.22 −1.89 0.93	<0.001*** 0.22 0.06· 0.36	0.05/ 0.15
Coefficient of variation in flower	•Intercept •Exotic forage abundance	3.04 ± 0.13 −0.00 ± 0.00	23.14 −1.53	<0.001*** 0.13	0.12/ 0.23

(continued on next page)

Table 3 (*continued*)

Response variable	Variables	Estimates ± Standard error	z/t-value	p-value	R^2m/R^2c
richness over time	•Exotic forage richness	−0.01 ± 0.01	−0.99	0.32	
	•Native forage abundance	−0.00 ± 0.01	−0.14	0.89	

climatic conditions (Cirimwami et al., 2019; Malizia et al., 2020). The decrease in the diversity and species richness of forage plants in higher elevations is likely to affect the abundance and richness of insect pollinators due to limited food resources as indicated in previous studies (Mtui et al., 2022; McCabe and Cobb, 2021). Furthermore, we found no significant effect of pollination knowledge among farmers on the diversity of wood forage plants which suggests that farmers do not primarily plant or retain trees and shrubs to support pollinators but they do it based on their preferences and uses (Hemp, 2005; Fernandes et al., 1985a, b).

We found an increase in the coefficient of variation in flower abundance over time as elevation increased (Fig. 7a). This indicates that there is reduced temporal stability in flower resource availability between months in the higher elevation home gardens. This may be due to the low diversity of pollinator forage plants in the higher elevation home gardens (Fig. 6). When species diversity is high it ensures the supply of floral resources over an extended period of time due to non-synchronous flowering among different species (Schuldt et al., 2019). In support of this, we found that an increase in the diversity of pollinator forage plants decreased the temporal variability in flower richness (Fig. 7b).

5. Conclusion

This study found that the majority of home garden farmers have limited knowledge about pollination services and insect pollinators. This indicates the need for extension education and awareness training on pollinators and pollination services. Also, given that most of the interviewed home garden farmers affirmed farming to be the major source of their livelihood, it further emphasizes the necessity of pollinator conservation education as most of their crops are insect pollinated such as coffee, vegetables, and fruits. Education and awareness raising on pollinators and pollination services for farmers can be effectively achieved through extension services from agricultural extension officers, media such as radio and television, training and workshops as well as by using flyers and leaflets, etc. (Mpondo et al., 2021; Tarakini et al., 2020). We also found that CHGs contain diverse woody plants that provide forage species to insect pollinators. This suggests that CHGs are a good example of a traditional agricultural land use system that can enhance pollination services in agricultural areas. The higher alpha diversity and abundance for exotic forage plants compared to native species indicates the need for

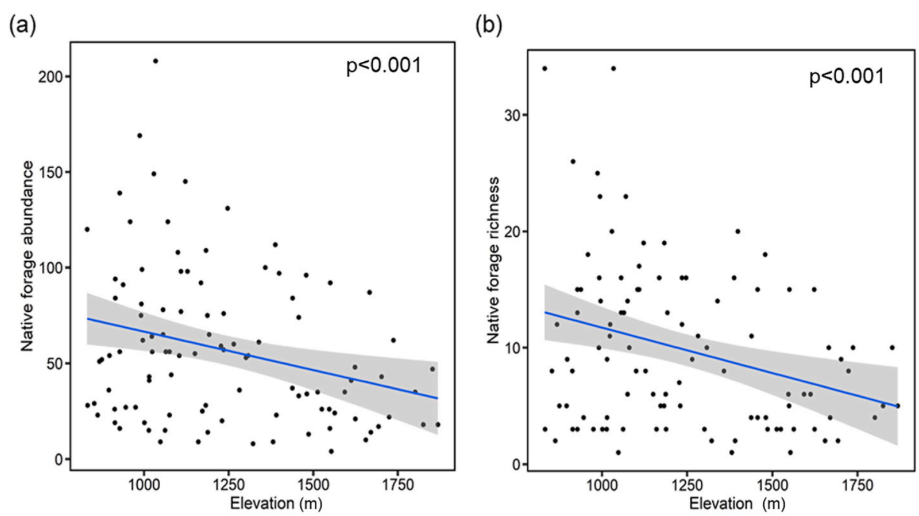

Fig. 5. The relationship between elevation and (a) abundance, and (b) richness of native pollinator forage plants on each farm.

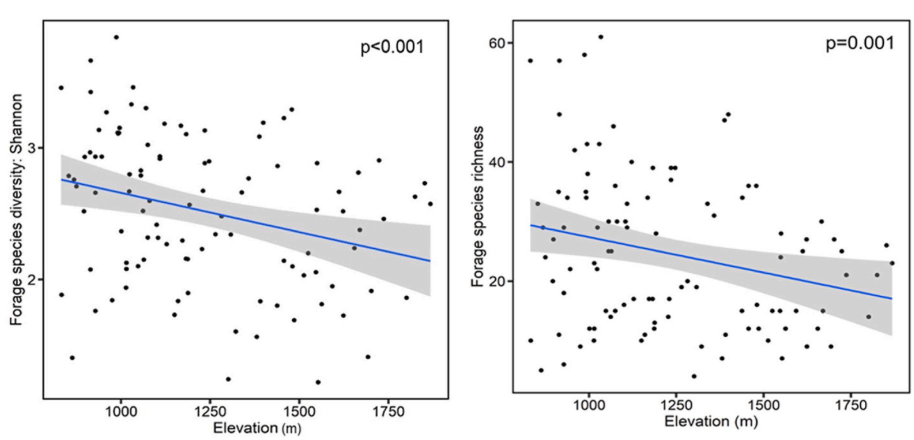

Fig. 6. The relationship between elevation and (a) the diversity, and (b) species richness of pollinator forage plants in CHGs.

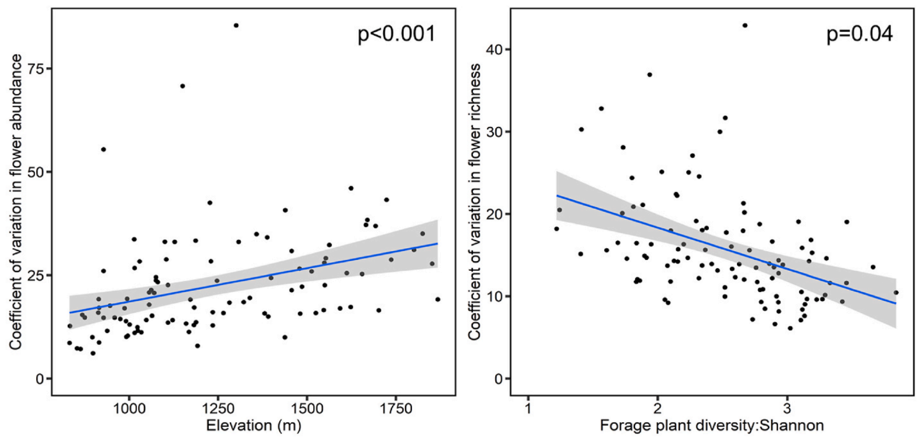

Fig. 7. The relationship (a) between elevation and coefficient of variation in flower abundance, and (b) between forage plant diversity and coefficient of variation in flower richness.

educating farmers on the benefits of native species not only to insect pollinators but to biodiversity in general. Moreover, this study also shows that an increase in the diversity of pollinator forage plants reduces the temporal variation in flower resource availability throughout the year. This is because different plant species bloom at different times, which helps to ensure a more consistent supply of floral resources over time. Therefore, to effectively conserve insect pollinators in agricultural areas, it is important to diversify farmlands and increase overall plant diversity. However, emphasis should be given to native species due to their ecological benefits as compared to exotic species. We recommend future studies to assess the effect of these forage resources on insect pollinator communities across elevation gradients as well as to study plant-pollinator networks in CHGs to understand the importance of different woody plant species on insect pollinators.

CRediT authorship contribution statement

Nanyika Kingazi: Writing – original draft, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation. **Ruwa-Aichi Temu:** Writing – review & editing, Supervision, Conceptualization. **Agnes Sirima:** Writing – review & editing, Supervision, Conceptualization. **Mattias Jonsson:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.indic.2024.100435.

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