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Crop diversity in homegardens of southwest Uganda and its importance for rural livelihoods

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Abstract Homegardens are traditional food systems that have been adapted over generations to fit local cultural and ecological conditions. They provide a year-round diversity of nutritious foods for smallholder farming communities in many regions of the tropics and subtropics. In southwestern Uganda, homegardens are the primary source of food, providing a diverse diet for rural marginalized poor. However, national agricultural development plans as well as economic and social pressures threaten the functioning of these homegardens. The implications of these threats are difficult to evaluate, because the structure and functions of the homegardens are not well understood. The aim of the study was to identify patterns and influencing factors in the diversity of homegardens by documenting the floristic diversity and its interactions with spatial, environmental and socio-economic factors. A geographically and socially focused assessment of floristic diversity in 102 randomly selected homegardens in three districts of southwest Uganda was conducted along a deforestation gradient following a human ecology conceptual framework and testing multiple quantitative hypotheses regarding the above mentioned factors. A merged mixed-method approach was followed to provide context and feedback regarding quantitative findings. Results show a high total richness of 209 (mean 26.8 per homegarden) crop species (excluding weeds and ornamentals) dominated by food species, which constituted 96 percent of individuals and 44 percent of all species. Forest-edge homegardens maintained higher plant diversity compared to homegardens in deforested areas and near degraded wetlands. Multiple linear regression models indicated elevation, location, homegarden size, distance to market, additional land ownership (outside the homegarden) and livestock ownership as significant predictors of crop diversity. Cluster analysis of species densities revealed four garden types: 'diverse tree gardens', 'small forest-edge gardens', 'large, old, species-rich gardens', and 'large, annual-dominated herb gardens', with 98% correct classification. Location, elevation, and garden size were also important determinants in the cluster assignment. We conclude that the diversity of the studied homegardens may be changing as part of adaptive traditional practices and in response to external drivers. The identified patterns illustrate the importance of homegardens for rural livelihoods and may offer some ways to support farmers to maintain these systems as relevant mechanisms for development in Uganda.

Keywords Agrobiodiversity · Human ecology · Smallholder farmers · Traditional farming

Abbreviations

HH	Household
HQI	House Quality Index
LDA	Linear discriminant analysis
J′	Pielou's measure of species evenness
H′	Shannon Diversity index

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SDR	Summed dominance ratio
TLU	Tropical Livestock Units

Introduction

A major portion of global agrobiodiversity thrives in complex agro-ecosystems such as homegardens, which are managed by smallholder farmers (Galluzzi et al. 2010). Homegardens are characterized as 'intimate multi-story' gardens around homesteads (Kumar and Nair 2004). They are diverse systems containing a variety of woody and non-woody crops and wild plants (Kehlenbeck et al. 2007; Kumar and Nair 2004), and an associated diversity of traditional knowledge (Huai and Hamilton 2009). This plant diversity represents the careful selection over generations for optimal food and nutritional security and cultural value (Nair 2006).

Homegardens are designed to meet household food consumption needs (Kehlenbeck et al. 2007; Kumar and Nair 2004), and they are well adapted to the local ecological conditions and socio-economic systems (Altieri 2002; Schneider 2010). Homegardens are often highly productive despite restricted access of garden managers to modern agricultural technology (Nair 2006). They maximize the sustainable use of socio-economic and ecological resources in variable production environments (Galluzzi et al. 2010) and can provide both ecological sustainability and agricultural productivity (Nair 2006). Such small-scale systems provide a diverse, year-round supply of food that is crucial for the nutrition of millions of poor and marginalized people (Altieri 2002; Galluzzi et al. 2010).

Homegarden diversity is constantly changing both as part of adaptive traditional practices and as traditional systems are abandoned (Nair 2006). The changes in crop diversity are often due to several interacting factors (Kehlenbeck and Maass 2006). Homegarden agrobiodiversity is often positively correlated with homegarden size, age, soil fertility, and the available labor force (Kehlenbeck et al. 2007; Kehlenbeck and Maass 2006). It can also be associated with other socio-economic factors, e.g. the age, gender, ethnicity and market access of the gardener and household head (Howard 2003; Moreno-Black et al. 1996; Quisumbing et al. 2014). Notably, the dominance of certain crops in the homegarden changes with changing household dietary habits (Fernandes et al. 1985) and the needs for specific homegarden products, e.g. for trade or technical uses (Coomes and Ban 2004) such as timber (Hemp 2006). As farmers move towards more intensive management with shortened cultivation cycles, the diversity of crops decreases, and the dominance of annual crop species increases (Scales and Marsden 2008), often with an emphasis on exotic commercial species (Kumar and Nair 2004).

Homegardens and other small-scale farming systems in Uganda contain a high diversity of plants (Oduol and Aluma 1990; Tabuti et al. 2011), particularly in the Western Region (Eilu et al. 2003; Nyamukuru et al. 2015). The southwestern highlands of the Western Region are well-known for their diverse homegardens dominated by cooking banana varieties (collectively referred to as 'Tooke') (Musa [AAA-EAHB group]) (Gold et al. 1999), the primary staple food of many Ugandans. These traditional homegardens are threatened by many factors, including the loss of knowledge and traditional crops (Tabuti et al. 2011), poor physical health of local community members (UBOS and ICF 2012), crop pests and diseases (Tripathi et al. 2009), land shortage, and drought (Nyamukuru et al. 2015). The most pressing threat to these homegardens, however, is the government development plan, calling for the urbanization of rural populations and the replacement of small-scale rural farming systems with industrialized agriculture (NPA 2007; Whitney et al. 2017).

Specific implications of these threats to the rich crop diversity of Uganda's homegardens are difficult to evaluate, particularly as the structure and functions of these homegardens are not well understood. Human ecology conceptual approaches (e.g. Rambo 1983; Whitney et al. 2016) may offer tools for dissecting the complex interactions between social and ecological systems.

The study aimed to identify patterns and influencing factors in the diversity of homegardens by documenting their floristic diversity and its interactions with spatial, environmental and socio-economic factors. The many specific hypotheses are shown in Fig. 1. They posited, for example, that homegarden crop diversity would be higher in gardens of wealthier households with older and better educated household heads, as well as in gardens that are older, larger and located close to forests and far away from markets (Fig. 1). We expected that clustering, based on the density and diversity of homegarden crops, would identify specific homegarden types with similar crop diversity and dominance of crops in similar use categories, which share similar socio-economic and production system traits (cf. Bernholt et al. 2009; Wiehle et al. 2014).

Conceptual framing

We used a conceptual framework representing relationships between homegarden agrobiodiversity and related socio-economic and ecological systems (cf. Kehlenbeck et al. 2007). Accordingly, we considered both households and homegardens as systems which: (i) retain their integrity as they change their structural configuration according to internal dynamics, (ii) influence each other through exchange (e.g. of planting materials and other inputs from the household to the homegarden and nutritious food and medicine from the homegarden to the household), and (iii) are influenced

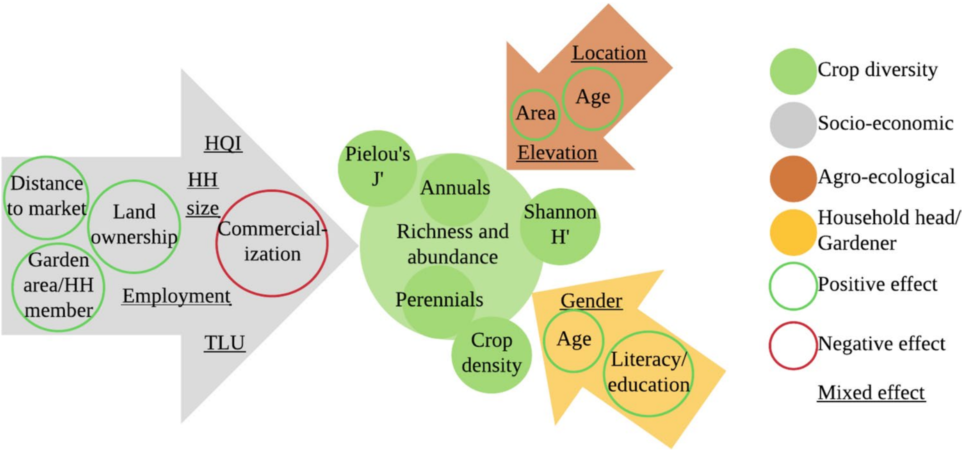

Fig. 1 Model of multiple hypotheses regarding crop diversity (center bubbles) influenced by factors of socio-economic conditions (center left arrow), agro-ecological and production system characteristics of the homegarden (upper right arrow) and characteristics of the household head or gardener (lower right arrow). Colored circle outlines indicate hypothesized positive or negative influence on crop diversity variables, otherwise hypothesized to be an influencing variable without specific direction. *HQI* House Quality Index, a simple measure of house construction quality. *TLU* Tropical Livestock Units, measured as the fraction of an animal of 250 kg live weight

by neighboring social systems (e.g. remittances) and ecosystems (e.g. crop pests and diseases).

Human ecology is a field of inquiry that seeks to apply ecological concepts to study human and environment interactions (Young 1974), with a focus on complex system interactions (Vayda 1983). As a framework for the study, we used a human ecology model of the complex dynamic interactions between ecological and socio-economic systems (cf. Rambo 1983), with a focus on plant species (Whitney et al. 2016). To support our model approach, we merged qualitative and quantitative methods, drawing on the strengths of each (cf. Creswell and Clark 2011) in describing these interactions. The results of this study may offer some evidence to policymakers on the importance of homegardens as neglected and threatened systems. The findings could be useful for NGOs and extension workers, as well as scientists, to develop garden-type specific interventions for food and nutrition security and conservation of plant genetic resources.

Materials and methods

Study area

The studied homegardens of the indigenous Banyankole and Bakiga people are located in a collection of districts known as Greater Bushenyi in the southwestern highlands of Uganda's Western Region (Fig. 2). The area is characterized by ecological and cultural richness, in conjunction with high levels of both poverty and malnutrition (UBOS 2014). Greater Bushenyi is located at an elevation between 910 (valleys, mostly protected forests in Rubirizi) and 2500 m above sea level (mountain peaks in the hills east of Igara; Fig. 2). Mean annual rainfall ranges between 1500 and 2000 mm and mean monthly temperatures between 18.9 and 19.7 °C (UNMA 2016). Through major deforestation, the natural vegetation, classified as 'Lake Victoria drier peripheral semi-evergreen Guineo-Congolian rainforest' interspersed with freshwater swamps (van Breugel et al. 2015), mostly of paper reed (*Cyperus papyrus* L.), has been largely transformed into densely planted banana-based homegardens. Soils in the study area are loamy and fertile with varying proportions of sand and clay (FAO 2014); agricultural soils are heavily used and partly depleted (Bekunda and Woomer 1996).

Poverty levels are high in Uganda; 25% of the population lives below the poverty line. However, the study area has a relatively even wealth distribution compared to the national average with fewer households in the lowest wealth brackets (30 vs. 43% at the national level; UBOS and ICF 2012). Much of Uganda's population is considered food insecure (44%; WFP 2006), and many people cannot meet minimum energy requirements (35%). Consequently, many young children (<5 years) are underweight (14%; IFPRI 2016). Agriculture is the main economic activity in the study area, consisting primarily of small-scale production of cooking bananas, robusta coffee (*Coffea canephora* Pierre ex A. Froehner), arabica coffee (*Coffea arabica* L.,), tea (*Camellia sinensis* (L.) Kuntze.) and dairy (UBOS 2014).

The populations within the study area have been greatly impacted by colonialism and subsequent war in Uganda, but still retain their traditional relationship to plants (Konczacki and Konczacki 1977), often through diverse traditional crops maintained in homegardens (Goode 1989). Homegardens in

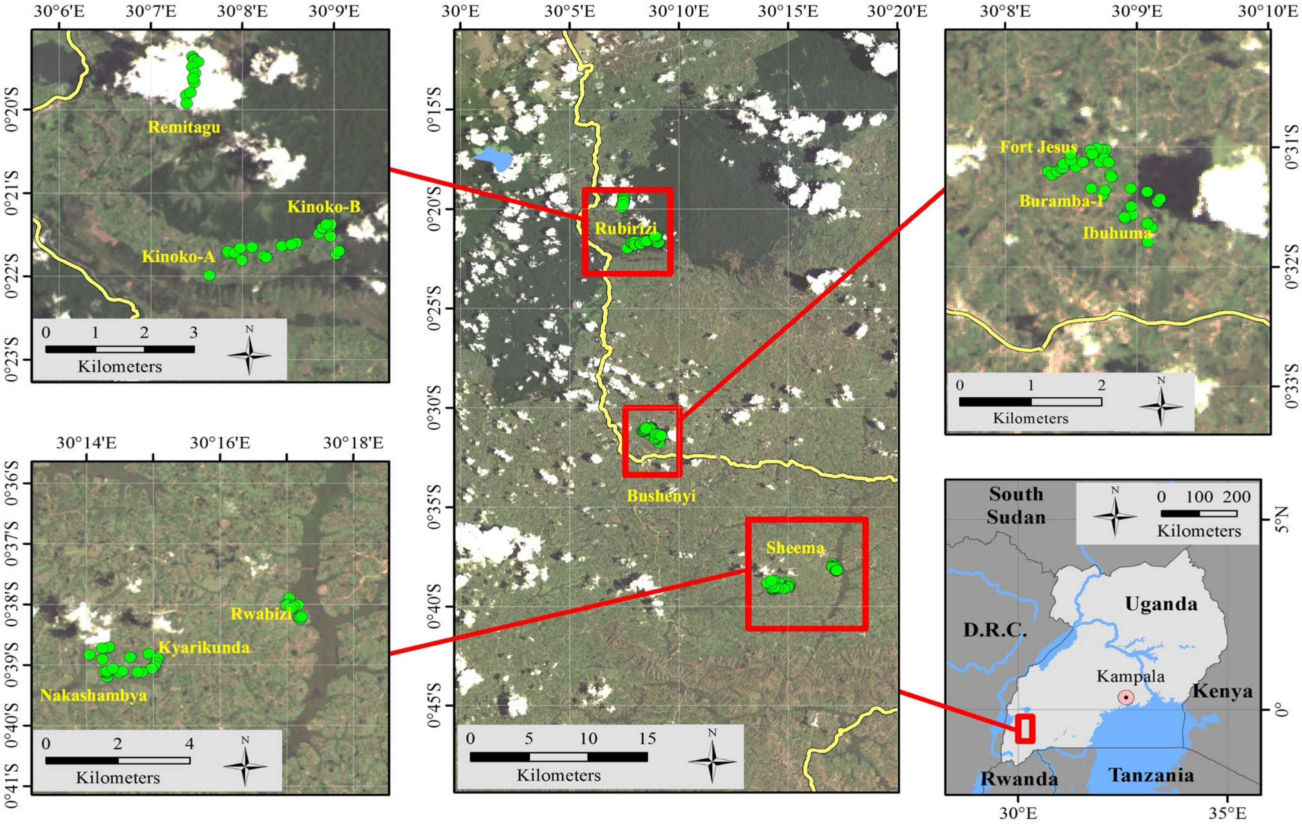

Fig. 2 Location of 102 surveyed homegardens in nine villages in Bushenyi, Rubirizi, and Sheema districts in the highlands of southwest Uganda. Green points mark homegarden locations. Upper left: Forest-edge homegardens in Kinoko-A, Kinoko-B, and Rwemitagu (Remitagu), Rubirizi; Lower left: Wetland edge homegardens in Kyarukunda (Kyarikunda), Nykashambya (Nakashambya), and Rwabizi, Sheema; Upper right: homegardens in deforested areas Ibuhuma, Buramba-1, and Fort Jesus, Bushenyi. Background imagery (Landsat 8 image captured on 7 Oct 2015) courtesy of the U.S. Geological Survey. (Color figure online)

the region are very diverse systems and often contain close to 100 different plant species (e.g. Eilu et al. 2003).

The study area has a population of roughly 53,600 people, with half in semi-urban areas around the central towns of Bushenyi and Ishaka. The population density, 64 per square kilometer, was less than half of the national average in 2010 (Weidmann et al. 2010). The population growth rate was around two percent in 2014, lower than the national average of three percent (UBOS 2014).

Sampling and data collection

The study followed a stratified, random design with three distinct regional ecological zones, defined by their distance to remnant native forests and wetlands (close to forests, away from forests close to a town, away from forests close to a wetland). The strata were identified by map (cf. Fig. 2; map from USGS 2015) and later confirmed through discussions with local officials in each of the districts where the strata happened to be located (Rubirizi, Sheema, and Bushenyi). Complete lists of villages in each of the strata were obtained from local officials; three villages were then randomly selected within each of these zones. Villages in Bushenyi were on sparsely forested lands with high deforestation, on the outskirts of Ishaka town. Villages in Sheema were located on the edge of large wetlands. Villages in Rubirizi were located on the edge of the Kashyoha-Kitomi (Kashoha Kitome) native forest (Fig. 2). Villagers in Bushenyi and Sheema were mostly from the indigenous Banyankole ethnic group, whereas villagers in Rubirizi were largely of the Bakiga ethnic group (Fig. 3). In each of the nine villages, 11–12 households were randomly selected from a complete list of all households, resulting in a total number of 102 surveyed households (all owned a homegarden). After collecting the first interview data, the representativeness of the sample was further evaluated with relevant demographic literature (e.g. UBOS and ICF 2012; UBOS 2014). Samples were found to be generally representative (Table 1). We also identified several key informants with detailed and specialist knowledge, including a mix of village chairpersons, elders and farmers (both men and women).

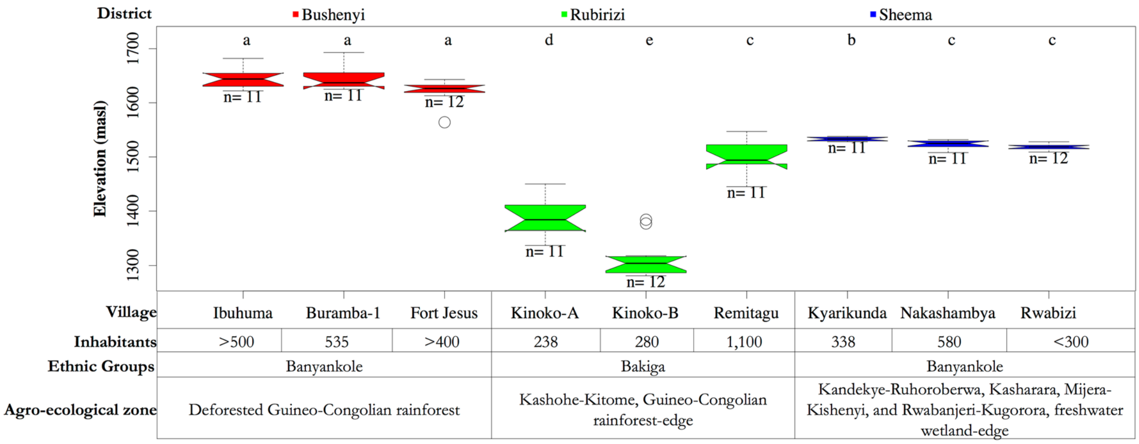

Fig. 3 Basic statistics for 102 surveyed homegardens in nine villages in Bushenyi, Rubirizi, and Sheema districts in the highlands of southwest Uganda. Notched boxplots show the median and 95% confidence interval of the median. Boxplots not sharing a letter are significantly different according to multiple Mann–Whitney tests with Bonferroni correction ($p < 0.05$)

Table 1 Comparison of key characteristics of the household head or gardener and the homegarden agro-ecological and production system

	Present study	Literature	
Mean household size	6.9 people	5.1 people	UBOS and ICF (2012) (National survey)
Home ownership	99%	66%	
Illiteracy	25% of household heads	23% of females and 14% of males over 6 years of age	
Unemployment	6%	4%	
Ownership of farm animals	80%	61%	
	Median 0.44 TLU	Approx. 4.3 TLU	Oduol and Aluma (1990) (Central Uganda)
Mean homegarden size	0.19 (range 0.3–0.52) ha	1 ha	
		Range 0.02–2 ha	Buyinza (2009) (Eastern Uganda)

Data from the present study of 102 homegardens in Bushenyi, Rubirizi, and Sheema districts of southwest Uganda and other national studies

Data collection took place in 2014 and 2015. It began with meetings with farmers (managers of homegardens) and local chairpersons, to discuss and plan the research. Households were defined as homes in which all people live permanently together, and share food from the same kitchen. Household classification followed Quisumbing et al. (2014), using categories such as male-headed, or *de-jure* female-headed (e.g. widowed women). Household heads were identified and introduced to us by the village chairperson, whenever possible. Interviews then took place with the head gardener of the household (usually the eldest healthy woman in the house).

Several visits were made to each household, starting with a collective survey of all plant species during a period of ‘short rains’ in February to May of 2014. Homegarden areas, locations, and cropping patterns were recorded via walk-through with GPS and map sketching (cf. Whitney et al. 2016). Information regarding the number of individual plants (abundance) was used to describe the relative representation of plant species in the homegardens. Abundance data was gathered by counting plants (e.g. for large plants) or extrapolated from densities in smaller subplots measured by tape or GPS (e.g. for small uniformly planted crops). Estimated vegetation cover was determined based on observations of ground-cover and canopy area. All plant species present were recorded with scientific names as well as Runyankole, Rukiga and Luganda names for species and varieties, for determination of intraspecific diversity (cf. Gessler and Hodel 2010). Species were identified and classified according to their native or exotic status (e.g. naturally occurring in sub-Saharan Africa or introduced from elsewhere) (cf. Bernholt et al. 2009; Abebe et al. 2006), and specimens were conserved in field presses for addition to the Makerere University Herbarium (MHU). The vertical garden structure was described based on plant height (Huai and Hamilton 2009) by distinguishing between four layers (0–0.99, 1–1.99, 2–5.99 and ≥ 6 m) (cf. Bernholt et al. 2009; Wiehle et al. 2014). Plant heights were measured by tape measure when possible or estimated with a rudimentary tangent method (cf. Korning and Thomsen 1994). Plant types were classified by their life-form into annual herbs, perennial herbs, shrubs, trees, and vines (herb refers to all herbaceous plants, including grasses, vine refers to all trailing and climbing plants).

During a second set of visits in January to April 2015, we followed up with household interviews (cf. Coomes and Ban 2004; Turner 2003), in which farmers were asked to describe crop uses and provide estimations for annual yields and sales. Farmers also answered basic demographic and socio-economic questions regarding their households and homegardens (i.e. number of household members, age, level of education, employment status, and number of land parcels owned in addition to the homegarden). Questions were asked in a semi-structured conversational format, allowing us to gather consistent data across gardens, while also learning about qualitative aspects of homegardens through farmers' perspectives and insights. Ten key informant discussions were held to provide feedback on the preliminary findings, shared in the form of stories and artwork.

Data analysis

Plant use categorization was based on farmers' cited primary uses (usually the first use mentioned) resulting in a list with a single use for each plant per homegarden, common in similar studies (e.g. Coomes and Ban 2004). This allowed for later multivariate analysis of crop use. Use classes included 11 categories (fruit, vegetable, staple, pulse/seed, spice, medicine, animal feed, trade, wood, fence, and technical). Here, and throughout this study, we use the term 'crop' not in the strict agronomic sense, but referring to all useful plant species, including for example fodder, wood and medicinal species, but excluding species that respondents classified primarily as weeds and ornamentals.

The House Quality Index (HQI), a simple measure of house construction quality, was used as a proxy for wealth status:

$$\mathrm{HQI} = 1(\mathrm{F} + \mathrm{R} + \mathrm{WA} + \mathrm{WI})/4$$

where HQI is calculated from presence (score of 1) and absence (0) data of: F = flooring other than soil, R = roofing other than grass or banana leaves, WA = walls other than sticks and mud, WI = windows. We also recorded Tropical Livestock Units (TLU), measured as the fraction of an animal of 250 kg live weight (cf. Jahnke et al. 1988), as an additional proxy for wealth.

All qualitative and quantitative data were recorded digitally in the field and subsequently imported into the R programming environment (R Core Team 2015) for analysis. Biodiversity analysis was performed with 'BiodiversityR' (Kindt and Coe 2005) and 'vegan' (Oksanen et al. 2016) to calculate and compare species richness, Shannon Diversity index (H′) and Pielou's measure of species evenness (J′). Species accumulation curves were plotted to compare the number of plant species recorded as a function of cumulative areas of inventoried homegardens, added in random order (cf. Pinard et al. 2014). The expected number of unobserved species (extrapolated species richness) was calculated with jackknife predictions (Kindt and Coe 2005). A Venn and Euler diagram was plotted with 'venneuler' (Wilkinson 2011) to show shared and dissimilar species across districts (cf. Gebauer et al. 2007).

We followed a merged mixed-method approach by using farmer interviews and key informant discussions to enrich the quantitative work with additional qualitative data and context and gain an in-depth local perspective about homegarden diversity and its relationship to socio-economic systems and processes. Qualitative data from interviews and key informant discussions were coded and sorted thematically to support or contrast the quantitative data (cf. Creswell and Clark 2011). Themes were generated following the human ecology conceptual framework (cf. Rambo 1983). Validity checks included member-checking (e.g. sharing findings and asking for feedback) and triangulation (e.g. using several sources to generate themes) (Creswell and Clark 2011).

The summed dominance ratio (SDR; cf. Chen et al. 2014) was calculated from relative density and relative frequency of crops, to identify the most important crops per district and per cluster.

$$\mathrm{SDR} = (\mathrm{RD} + \mathrm{RF})/2$$

where SDR = summed dominance ratio, RD = relative density (sum of individuals of a crop/sum of all individuals of all crops), RF = relative frequency (sum of homegardens in which a crop occurred/sum of counts of all crop occurrences in all homegardens surveyed).

Significance tests were performed with Mann–Whitney–Wilcoxon tests for two groups and Kruskal–Wallis rank sum followed by pairwise comparison with Mann–Whitney tests with Bonferroni correction (Pohlert 2014) for more than two groups. Pearson's Chi-squared was used for tests of independence in categorical data.

The socio-economic and agro-ecological/production system variables that were included in regression models were determined with a model of multiple hypotheses based on homegarden literature, updated with farmers' feedback and our own observations (Fig. 1). Multiple linear regression analysis was performed with stepwise (backward and forward) variable selection, using the Akaike information criterion, and plotted with 'stargazer' (Hlavac 2015). Non-factor variables were standardized (Venables and Ripley 2002). Models aimed to identify factors influencing nine response variables: richness and abundance for all homegarden plants and for annual and perennial plants, individual plant density (number of individual plants per 1000 m^2), H′ and J′. Stepwise regression was performed starting with 15 and reducing to between one and seven explanatory variables of homegarden agro-ecological/production system and household socio-economic conditions. Socio-economic variables included five continuous [years of formal education of the homegarden manager, number of household members, HQI, distance to the nearest market (km), TLU owned] and five categorical variables [literacy level (illiterate or not) and gender of household head, employment status (any household member with outside employment for income or barter), ownership of other land, commercialization (whether or not the household sold homegarden products)]. Agro-ecological and production system variables included four continuous [elevation (m.a.s.l.), total homegarden area and area per household member (m^2), homegarden age] and one categorical variable (district location [forest-edge, wetland-edge or deforested area]; Fig. 2).

To divide the homegardens into distinct types with similarities in crop species composition, we used Ward's minimum variance hierarchical cluster analysis method (Murtagh and Legendre 2014) with squared Euclidean distances of the log(e) transformed individual densities (number of individual plants per 1000 m^2) of the crop species per garden (Ryota and Hidetoshi 2015). Linear discriminant analysis (LDA) was used to perform multivariate tests of differences between cluster groups. Stepwise variable selection was used to identify crops most responsible for clustering, i.e. that significantly affected overall Wilk's λ, contributing to the largest F-value and smallest λ when entered into the model (Claus et al. 2005).

Results

Household socio-economic conditions

Interviews were conducted with 102 households, all of whom managed homegardens as their primary source of food. Eighty-seven were male-headed households (intact families with males and females) and 15 were *de-jure* female-headed households (14 widows and one orphan girl). No significant differences were detected for any of the tested socio-economic indicators between male ($n=87$) and female ($n=15$) headed households.

Households in Bushenyi had better homes (greater HQI) than in Sheema and Rubirizi ($\chi^2[2]=23.5$, $p<0.001$). Farmers in Bushenyi and Sheema had more years of formal education than in Rubirizi ($\chi^2[2]=16.7$, $p<0.001$; Fig. 4). Ownership of TLU also differed significantly between the regions ($\chi^2[2]=11.4$, $p=0.003$); Sheema homegardens had more animals than in Bushenyi (median TLU = 1.0 vs. 0.3; $p=0.015$) and more than in Rubirizi (median TLU = 1.0 vs. 0.2; $p=0.001$).

Homegarden size also differed between the three regions ($\chi^2[2]=35.9$, $p<0.001$) (Table 1; Fig. 4) as did total farmed area per household. Just over half of the farmers (53 households) had small plots (< 500 m^2) in addition to their homegardens, often planted with light demanding annual crops, plantations of trees or tea, or grazing areas. However, farmers expressed difficulty in accessing quality land (21% of respondents).

Homegarden management

The level of commercialization was low across all homegardens. Over half (67%) of the households surveyed had sales, although most homegardens contained cash crops that were bartered locally. Sales were mostly done on farm with local traders. Men arranged the sale of higher value crops, e.g. fresh or dried coffee, and timber such as eucalyptus (*Eucalyptus* spp.), whereas women were responsible for selling lower value products, e.g. bananas and vegetables.

Many farmers (72% of respondents) reported that there were crops (species and varieties) that they had once planted but discontinued or lost (median 1 species/variety per respondent; range 0–6) in the recent past, mostly due to pests and diseases. Major pests included olive baboons (*Papio anubis*) and vervet monkeys (*Chlorocebus pygerythrus*). Major diseases included Banana Xanthomonas wilt, coffee leaf rust and East African cassava mosaic virus. Farmers cited a labor shortage (e.g. lack of labor and physical exhaustion) as a challenge for both pest and disease management. As a result, vulnerable plants such as cocoyam (*Xanthosoma sagittifolium* [L.] Schott.) are threatened by replacement with more resilient tubers such as cassava (*Manihot esculenta* Crantz). Sweet bananas for eating fresh (*Musa* [AAA group] 'Bogoya', [AB group] 'Kabaragara', 'Sukali ndiizi', [AAA-EAHB group] 'Embire', 'Gonja'), as well as bananas for juice and alcohol (*Musa* [ABB group] 'Kayinja', 'Kivuvu', 'Kisubi') are threatened with replacement by cooking banana types that are not preferred by monkeys. Many farmers (76% of respondents) also intended to plant new crop species (median 1; range 0–5) in the near future, e.g. beans (22%), peanuts (*Arachis hypogaea* L.) (12%) and coffee, cooking bananas and cassava (11% each).

Knowledge and exchange

Farmers in the surveyed homegardens continuously exchange and select species and varieties of homegarden crops. Planting materials were largely inherited from family members or received as gifts from neighbors [cited for 55% of all crops (note that there were several sources per crop)].

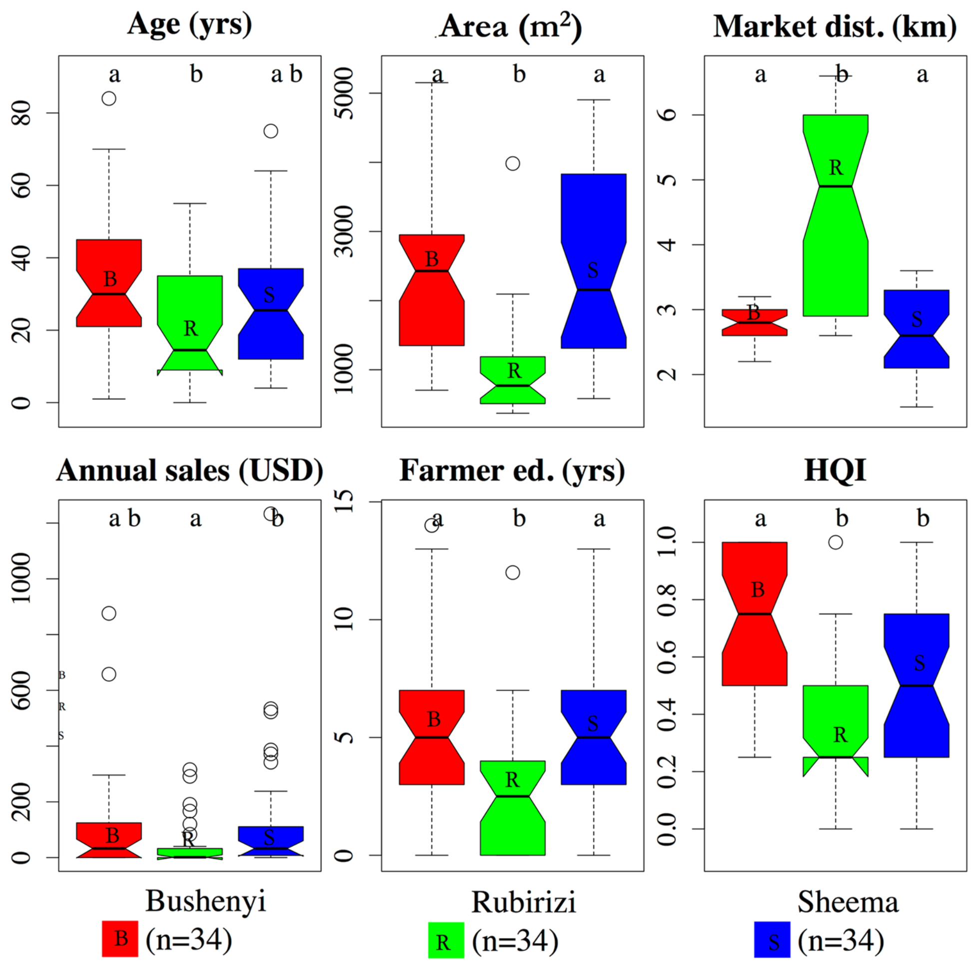

Fig. 4 Socio-economic and agronomic characteristics of 102 homegardens and households in three districts of the highlands of southwest Uganda: significance of nonparametric tests of homegarden age (years), homegarden area (m^2), distance to nearest market (km), estimated value of annual sales of homegarden products (USD), years of education for the manager of the homegarden, and House Quality Index (HQI). Notched boxplots show the median and 95% confidence interval of the median. Boxplots not sharing a letter are significantly different according to multiple Mann–Whitney tests with Bonferroni correction ($p < 0.05$)

Other common sources included collecting from local forests and wetlands (51%), e.g. African basil (*Ocimum gratissimum* L.) and receiving as a gift from friends (34%), e.g. sunflowers (*Helianthus annuus* [Cass.] Cass.). According to key informants, the exchange is free and also reciprocal.

> "[…] friends and neighbors give planting materials for free if you give for free […] ask the neighbor for some seeds then at harvest give them back. If they gave ten cups give back 15 cups. No need to go and buy seeds when the neighbor already has them […] we also give them away."

Some planting materials were purchased locally (28%) or from local markets (19%), e.g. pumpkin (*Cucurbita pepo* L.) purchased for eating, whose seeds were then planted in the homegarden. Some improved varieties (e.g. the cooking banana variety 'NAADS/Kawanda') came from local extension services (12%). However, few planting materials (7%) came from nurseries.

Large variation in homegarden characteristics (e.g. crop diversity and cover) within villages was apparent. Traditional management practices for soil fertility were observed in some homegardens, including mulching, applications of pit-composted household and farm wastes and farmyard manure, as well as intercropping (e.g. nitrogen fixing *Fabaceae* spp. planted under bananas). These tended to coincide with dense vegetation and humic (dark decomposed organic matter) soils. We used artwork (cf. Fig. 5) to describe these findings to key informants who confirmed that homegarden quality varies, e.g. "[…] soil fertility depends on the person […]". They concluded that endogenous solutions may be available through sharing local knowledge, for example they said that "[…] good practices are the answer to solving the wilt problem [of bananas]".

Crop diversity and composition

Total homegarden crop richness was 209 species (overall H′ was 1.61); 94 crops were of exotic origin, mainly fruit (73% of the total of 30 fruit species were exotic) and other food species (69% exotic), whereas most of the medicinal and wood species were native (63 and 75% respectively). The 102 surveyed gardens contained 25 annual herb, 64

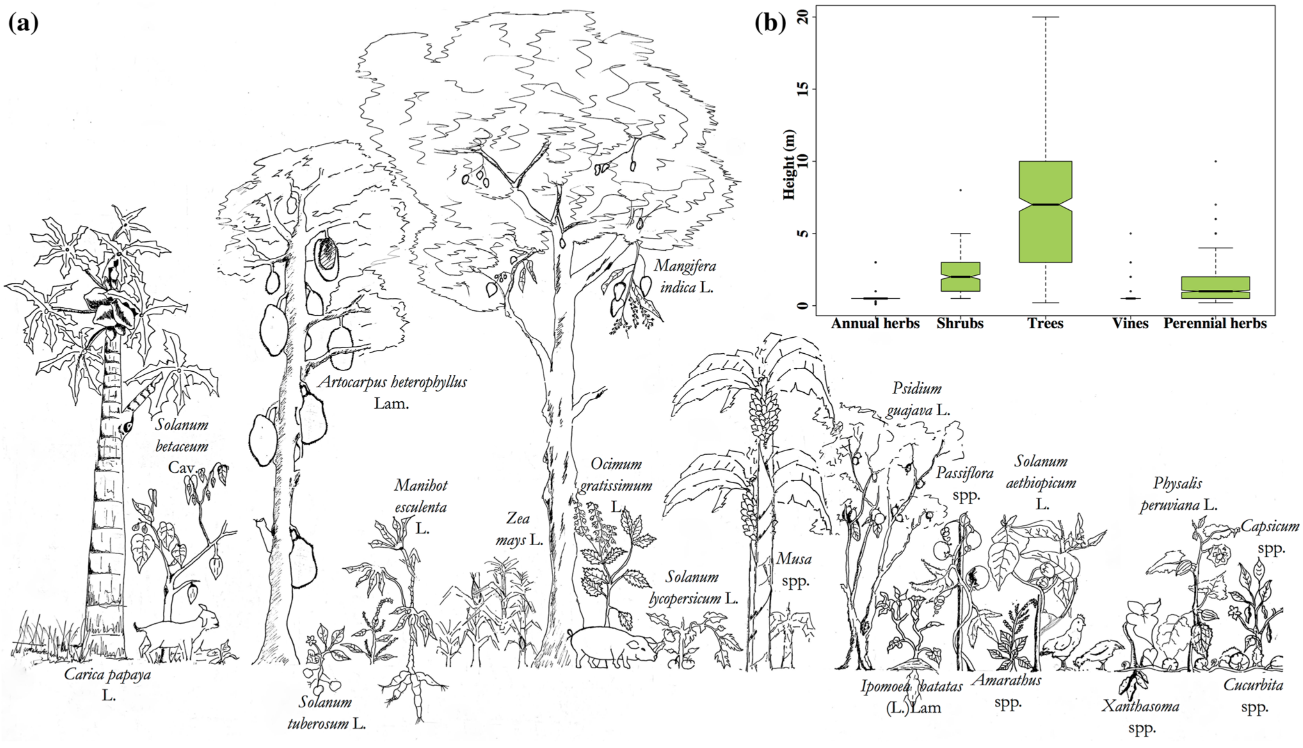

Fig. 5 Multi-layered homegarden structure in southwest Uganda. **a** Structure of a typical homegarden showing some common plant and animal species. Art by Carolyne Nakaketo. **b** Height data for species life forms (seedlings and adults) of 305,633 individual stems of 209 crop species found. Notched boxplots show the median and 95% confidence interval of the median. Barplot widths proportional to square of richness

perennial herb (dominated by bananas), 13 vine (lianas, climbing shrubs and climbing herbs), 49 shrub and 58 tree crops (including one palm) (Annex).

Medicine was the most species-rich use category (total 110 species) followed by fruits, vegetables and technical plants (30–50 species each; Table 2). Crops from the 'pulse/seed' group had over half of the total abundance (212,810 individuals), mostly made up of common bean (*Phaseolus vulgaris* L.) planted as a dense cover crop. Staples and vegetables also showed high abundance (around 36,000 and 35,000 individuals, respectively; Table 2). Plants used primarily as fruits were common to all gardens, with a high mean richness per garden of 7.9 species and a mean abundance of 108 (Table 2). Staple crops were found in all but one homegarden (mean richness 4.4, mean abundance 352) and vegetable crops were found in all but five homegardens (mean richness 5.2, mean abundance 357; Table 2). Crops used primarily for trade were found in all but 11 homegardens (mean richness 1.7; mean abundance 45; Table 2), although many were bartered locally only. Many crops had a shared use across all gardens but some (59%) also had secondary uses, including trade (for 32% of crops), food (30%), medicine (33%), technical (19%), wood (13%), animal feed (4%), and fencing (3%).

Folk classification of crop varieties (Runyankole and Rukiga names) suggests high intraspecific diversity, e.g. for different types of amaranth (*Amaranthus* spp.) (73 local names), common bean (68) and cassava (36). Bananas had the highest intraspecific diversity (75 names), with many varieties of cooking and sweet bananas.

With regard to location, Rubirizi had the greatest total richness of crops (147 species) followed by Bushenyi (143 species) and Sheema (111 species). Thirty-two percent of all crops were shared between the three districts and 41% were unique to only one district (Fig. 6b). Species accumulation curves indicate that the sample of 34 homegardens per district was not adequate to capture the full diversity of crop species that likely exists in homegardens (Fig. 6a). The number of total estimated crop species for Rubirizi was 195 (± 13.5), 191 (± 16.7) for Bushenyi and 143 (± 9.2) for Sheema, a mean predicted increase of 48, 48 and 32 species, respectively.

Despite the lowest covered area of surveyed homegardens (Figs. 3, 6a), richness of all crop species, as well as of trees and perennial herbs, was significantly higher in Rubirizi than in Bushenyi, and lowest in Sheema (Figs. 6a, 7c). The same order (Rubirizi highest, Bushenyi medium, Sheema lowest) was detected for trees and perennial herbs,

Table 2 Primary uses for plants (reported by farmers); description, total richness, and total individual plants (with means and standard deviations per garden in brackets), and total number of homegardens that had plants in the use category, for 209 crop species in 102 homegardens in southwest Uganda

Code	Description	Richness[a]	Abundance[b]	Gardens
Fruit	Sweet and fleshy plant products, mostly eaten raw	30 (7.9 ± 2.8)	11,009 (108 ± 181)	102
Vegetable	Used as part of savory meal, esp. greens	43 (5.2 ± 2.5)	34,607 (357 ± 539)	97
Staple	Carbohydrates, dominant portion of diet, e.g. bananas, grains, roots, and tubers	17 (4.4 ± 1.8)	35,518 (352 ± 475)	101
Pulse/seed	Edible seeds of legumes/ oil seeds	8 (1.4 ± 0.64)	212,810 (3130 ± 4919)	68
Spice	Added flavor for food or tea	11 (1.4 ± 0.68)	457 (7.1 ± 9.1)	64
Medicine	Healing, e.g. medicinal, spiritual; hygienic, e.g. bathing, washing	110 (3.7 ± 4.7)	2087 (29 ± 50)	73
Animal feed	Fodder, e.g. cut and carry for overnighting livestock near homes	7 (1.2 ± 0.42)	241 (24 ± 36)	10
Trade	Sold or bartered	9 (1.7 ± 0.73)	4124 (45 ± 39)	91
Wood	Used for timber, firewood, charcoal	24 (1.8 ± 1.1)	184 (5.6 ± 6.0)	33
Fence	Making fences, living or built, as well as shade, shelter, and wind protection	24 (1.6 ± 0.84)	2426 (36 ± 48)	67
Technical	Various technical uses from holding soil in place to building, lashing, basketry, manure, and pesticide	50 (2.3 ± 1.6)	2134 (27 ± 47)	78
Total		209[c]	305,597[d]	102

[a] The cumulative number of unique crop species mentioned for a particular primary use

[b] Total count of individuals (stems of plants)

[c] 162 crop species were used across categories

[d] Excludes 36 individual plants that were too young to yet have an active primary use

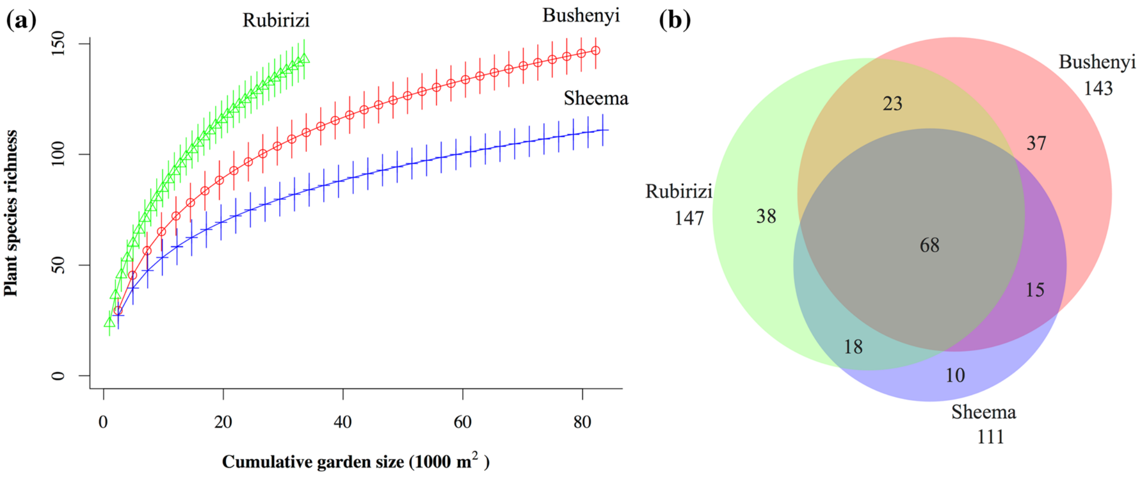

Fig. 6 Crop diversity of 102 homegardens in Bushenyi, Rubirizi, and Sheema districts of southwest Uganda. **a** Species accumulation curves comparing the cumulative number of 209 crop species (excluding ornamentals) recorded as a function of the cumulative area of the homegardens inventoried (homegarden areas added in random order). Standard deviation displayed for richness. **b** Venn diagram of shared and dissimilar crop species. Proportional Venn-Euler diagram with colors (Red = Bushenyi, Green = Rubirizi, Blue = Sheema), overlapping richness (shared species) indicated in overlapping colored areas. Total richness for each district indicated outside the circles below the location name. Red = Bushenyi, Green = Rubirizi, Blue = Sheema. (Color figure online)

when dividing all crop species into their life form types. Median richness per homegarden was greatest in Bushenyi (Fig. 7a), as was richness and abundance of annual herbs and richness of shrubs (Fig. 7b).

Homegarden vertical and horizontal structure

Trees formed an upper layer of the homegarden vertical structure. At around six meters height and above, they accounted for 27.4% of the total crop species richness in the homegardens, 0.5% of the total abundance and 11.6% of the estimated vegetation cover. A second layer, between two

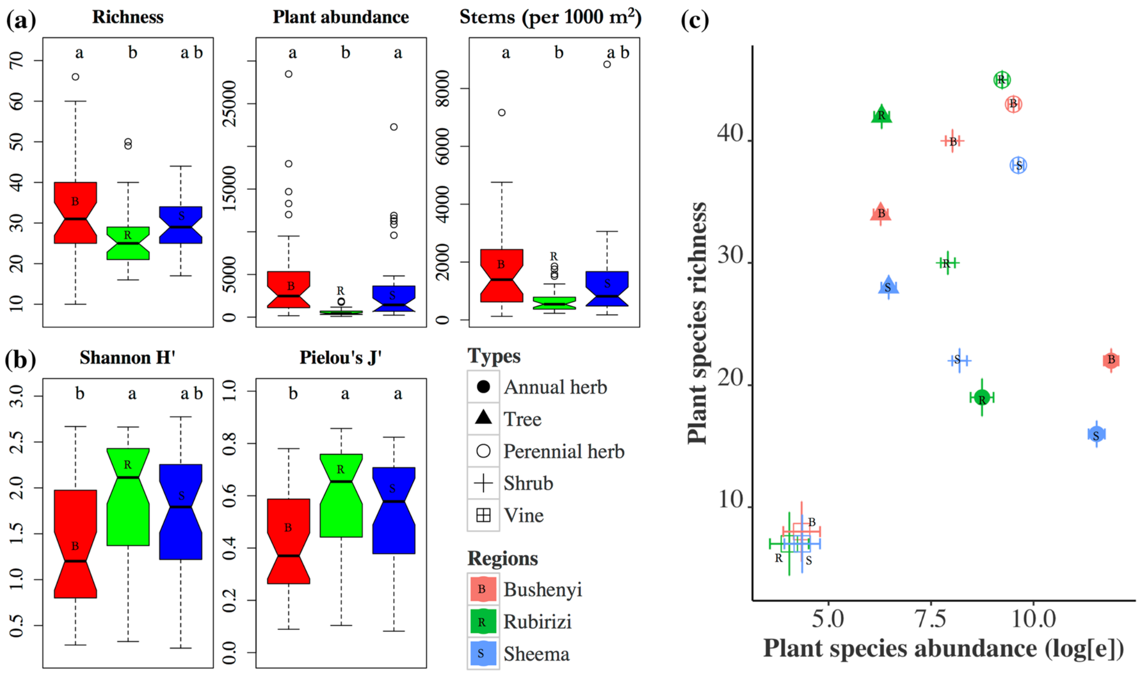

Fig. 7 Crop diversity of 102 homegardens in Bushenyi, Rubirizi, and Sheema districts of southwest Uganda. **a** Median richness, plant abundance (number of individual plants) per homegarden, individual plant density (stems per 1000 m^2), **b** Shannon H′, and Pielou's J′, of crop species (excluding ornamentals) in 102 homegardens of three districts of southwest Uganda. Notched boxplots show the median and 95% confidence interval of the median. Boxplots not sharing a letter are significantly different according to multiple Mann–Whitney tests with Bonferroni correction ($p<0.05$). **c** Sum of richness and log(e) transformed abundance of 305,633 individuals of 209 crop species (excluding ornamentals) documented in 102 homegardens: 58 trees, 49 shrubs, three vines, 64 perennial herbs and 25 annual herb species. Standard error for richness (top, bottom bars) and abundance (side bars)

and six meters height, was formed by shrubs (21.1% richness, 2.5% abundance, 20.2% cover), perennial forbs (29.7% richness, 25.6% abundance, 52.1% cover) and vines (5.6% richness, 0.1% abundance, 0.3% cover). Other perennial and annual forbs were mixed between two layers, one at around one to two meters and another below one meter (11.3% richness, 66.5% abundance, 13.2% cover). This lowest layer of the homegarden, below one meter, was dominated by grasses (4.9% richness, 4.9% abundance, 2.6% cover) but also contained seedlings and small herbs of many species (Fig. 5b).

Regarding the horizontal structure, many of the surveyed homegardens had a space in front of the house that was left bare or covered with grass, often with a few trees planted for shade. Vegetable plots were mainly arranged close to the house at a location with few trees, and banana plantations were usually completely surrounding the yard and home. Trees were scattered within the banana plantation or along the borders. In Sheema farmers sometimes kept fences of African milk bush (*Euphorbia tirucalli* L.). However, homegardens were generally not fenced but were marked by single stems of cornstalk dracaena (*Dracaena fragrans* [L.] Ker Gawl.). Common lantana (*Lantana camara* L.) was sometimes also used for this purpose.

Most frequent, abundant and dominant plant species

The plant species with the highest SDR (≥ 0.01) included 9 native and 19 exotic crops (Table 3).

The most frequent crops encountered in the homegardens were cooking bananas, robusta coffee, avocado (*Persea americana* Mill.), and cocoyam, found in more than 86% of the surveyed gardens. The most abundant crops were common bean, cooking bananas, and green amaranth (*Amaranthus hybridus* L.) (Table 3). All were grown for food or as cash crops.

Comparison of SDR per plant use category indicated differences in plant dominance by district, and plant origin (exotic or native). Homegardens in Bushenyi had greater dominance of the category pulse/seed (e.g. common bean; Fig. 8). Rubirizi homegardens had greater dominance of fruits [e.g. mango (*Mangifera indica* L.)], medicinal plants (e.g. *Indigofera atriceps* Hook. f.), technical plants (e.g. *Melochia corchorifolia* L.) and plants for trade (e.g. coffee). Homegardens in Sheema had a comparatively even dominance of crop species in different use categories with slightly greater dominance of staples (e.g. cooking bananas) than in the other two districts. With regard to plant origin, exotic species had a high SDR in the categories pulse/seed,

Table 3 The 20 most frequent, abundant, and dominant species out of the 209 crop species found in 102 homegardens in Bushenyi, Rubirizi, and Sheema districts of southwest Uganda from greatest to lowest summed dominance ratio (SDR) ranking

Botanical name	Origin	Gardens		Abundance		SDR	
		Total	Rank	Total	Rank	Total	Rank
Phaseolus vulgaris L.	e	59	11	212,724	1	0.359	1
Musa (AAA-EAHB Group)	e	102	1	12,425	2	0.039	2
Saccharum officinarum L.	e	70	8	7262	5	0.025	3
Amaranthus hybridus L.	n	47	21	8934	3	0.023	4
Coffea canephora Pierre ex A. Froehner	n	93	2	3227	11	0.022	5
Xanthosoma sagittifolium (L.) Schott	e	88	4	3750	9	0.022	6
Amaranthus dubius Mart. ex. Thell	n	38	27	8631	4	0.021	7
Manihot esculenta Crantz	e	68	10	5159	8	0.021	8
Persea americana Mill.	e	91	3	238	39	0.017	9
Musa (AAA Group)	e	83	5	946	18	0.017	10
Musa (AB Group)	e	82	6	866	21	0.016	11
Zea mays L.	e	32	29	6333	6	0.016	12
Musa (AAB Group)	e	74	7	683	23	0.015	13
Amaranthus cruentus L.	n	20	45	5712	7	0.013	14
Psidium guajava L.	e	69	9	165	48	0.013	15
Dracaena fragrans (L.) Ker Gawl.	n	58	12	1361	15	0.013	16
Ipomoea batatas (L.) Lam	e	36	28	2921	12	0.011	17
Ananas comosus (L.) Merr.	e	42	24	2023	14	0.011	18
Solanum anguivi Lam.	n	56	13	415	30	0.011	19
Solanum lycopersicum L.	e	50	20	936	19	0.011	20
Solanum aethiopicum L.	n	53	18	531	28	0.011	21
Cucurbita pepo L.	e	56	13	163	49	0.011	22
Coffea arabica L.	n	47	21	1063	17	0.010	25
Mangifera indica L.	e	56	13	110	54	0.010	23
Carica papaya L.	e	55	16	221	40	0.010	24
Amaranthus spinosus L.	n	22	40	3728	10	0.010	26
Artocarpus heterophyllus Lam.	e	54	17	147	50	0.010	27
Passiflora edulis Sims.	e	52	19	134	51	0.010	28
Sorghum bicolor (L.) Moench.	n	25	35	2570	13	0.009	29
Euphorbia tirucalli L.	n	23	39	931	20	0.006	35
Arachis hypogaea L.	e	2	122	1230	16	0.002	53

Abundance, number of individuals per crop species; homegardens, number of homegardens where species was present

SDR summed dominance ratio, *n* native, *e* exotic

and fruits (e.g. mango), whereas native species had a high SDR in the category vegetables (e.g. green amaranth), and non-food uses such as medicine [e.g. aloe (*Aloe vera* (L.) Burm.f.)] and trade (e.g. coffee; Fig. 8).

Crop diversity characteristics and influencing factors

Median species richness per homegarden was 25, H′ was 1.64, and J′ was 0.53. Significant differences were detected for plant abundance ($\chi^2[2] = 36.2$, $p < 0.001$), density ($\chi^2[2] = 14.2$, $p = 0.001$), H′ ($\chi^2[2] = 10.2$, $p = 0.006$), and J′ ($\chi^2[2] = 13.9$, $p = 0.001$) across the three districts (Fig. 7a,b). Abundance and density tended to be greater in homegardens in Bushenyi, whereas H′ and J′ tended to be greater in Rubirizi, indicating more stable crop diversity. No significant differences in crop diversity characteristics were found between male and female-headed households.

Regression models indicated weak but significant relationships, explaining 12–42% of variance ($p < 0.001$), between crop diversity parameters and six selected socio-economic and agro-ecological/production system predictor variables (Table 4). These included four continuous variables [elevation (m.a.s.l.), homegarden area (m^2), distance to the nearest market (km) and TLU] and two factor variables (ownership of other land in addition to the homegarden and district location). Plant species richness was positively influenced by the location Rubirizi and homegarden area, and negatively influenced by the

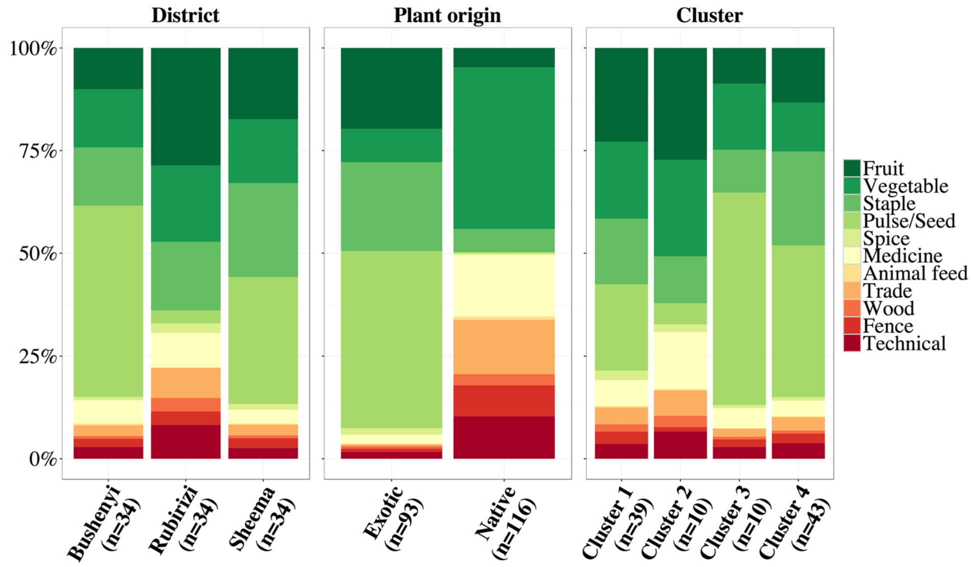

Fig. 8 Proportion of primary uses as measured with the summed dominance ratio (SDR) for 209 crop species (excluding ornamentals) found in 102 homegardens in southwest Uganda; displayed for three districts (Bushenyi, Rubirizi, and Sheema districts), native or exotic plant species origin, and four clusters. Food uses indicated in shades of green, other uses indicated in shades of red and yellow. (Color figure online)

Table 4 Results of stepwise multiple regression analyses of selected socio-economic and bio-physical factors affecting floristic diversity characteristics of 209 crop species (excluding ornamentals), further subdivided into annual and perennial plants, in 102 homegardens in southwest Uganda

Floristic diversity response variables

	All crops		Ind. dens. per 1000 m^2	Shannon	Pielou's	Annual crops		Perennial crops	
	Rich.	Abund.		H′	J′	Rich.	Abund.	Rich.	Abund.
Elevation (m.a.s.l.)				−0.383*** (0.091)	−0.451*** (0.087)				
Owns other land (factor)				0.374** (0.181)	0.376** (0.174)	−0.259* (0.152)			
Location Rubirizi (factor)	0.37 (0.324)					−1.115*** (0.21)			0.480** (0.22)
Location Sheema (factor)	−0.530** (0.224)					−0.465** (0.186)			0.075 (0.199)
Homegarden area m^2	0.325*** (0.108)	0.651*** (0.076)	0.353*** (0.094)			0.282*** (0.089)	0.626*** (0.078)	0.227** (0.096)	0.645*** (0.094)
Nearest market (km)	−0.371*** (0.132)								
TLU (0–15)								0.262*** (0.096)	
Adjusted R^2	0.152	0.418	0.116	0.169	0.228	0.417	0.386	0.133	0.337
F statistic	5.543***	73.393***	14.272***	11.272***	15.920***	19.054***	64.526***	8.768***	18.103***

Predictor variables (rows) and response variables (columns). Predictor variables top to bottom: homegarden elevation (m.a.s.l.), ownership of other land, district location, homegarden area (m^2), distance to the nearest market (km), and TLU. Response variables (left to right): Richness (Rich.) of all crop species, abundance (Abund.) of all crops, individual crop density (Ind. dens.) per 1000 m^2, Shannon H′ (all crops), Pielou's J′ (all crops), richness of annual crop species, abundance of annual crops, richness of perennial crop species, abundance of perennial crops. Each predictor in a model is followed by standardized regression coefficient, with standard errors below in parentheses. Significance is indicated following the regression coefficient. Model significance is indicated after the F Statistic (***$p < 0.0001$, **$p < 0.001$, *$p < 0.01$)

location Sheema and the distance to the nearest market (only 15% of variance explained). The model was stronger (42% of variance explained) for crop abundance, which was positively influenced by homegarden area. These models changed slightly when considering annuals and perennials separately (Table 4). Homegarden area also had a positive influence on the individual density of plants (12%

of variance explained). Regarding H′ and J′, elevation had a negative influence, whereas ownership of other land had a positive influence in models explaining 17 and 22% variance, respectively.

Cluster assignment

Cluster analysis revealed four distinct clusters (Fig. 9), with 98% correct classification according to LDA. Stepwise variable selection of cluster assignment and plant species densities indicated 11 species that significantly affected Wilk's λ ($p < 0.001$ for all F-values). These species (in descending order of importance) were spiny amaranth (*Amaranthus spinosus* L.), common bean, arabica coffee, green amaranth, turkey berry (*Solanum torvum* Sw.), spiderwisp (*Cleome gynandra* L.), cranberry hibiscus (*Hibiscus acetosella* Welw. ex. Hiern.), china root (*Gynura scandens* O. Hoffm.), silky oak (*Grevillea robusta* A.Cunn. ex. R.Br.), red spinach (*Amaranthus dubius* Mart. ex. Thell) and antiaris (*Antiaris toxicaria* Lesch).

Homegardens in the four clusters differed in their species composition and diversity parameters (Fig. 10b,c), and in agro-ecological/production system and socio-economic conditions (Fig. 10a). Cluster 1 comprised 39 'diverse tree gardens' (Fig. 9) with the greatest richness of trees and of vines (Fig. 10c), and cluster 2 comprised 10 'small forest-edge gardens' (Fig. 9). These two clusters had the greatest H′ and J′ (Fig. 10b). Fifty-one percent of the homegardens in cluster 1 were located in Sheema and 60% in cluster 2 were in Rubirizi (Fig. 9). Cluster 3 comprised 10 'large, old, species-rich gardens' (Fig. 9) that tended to be larger, older and at higher elevation (Fig. 10a). They had the highest species richness, but only medium H′ and J′ (Fig. 10b). Cluster 4 contained 43 'large, annual-dominated herb gardens' (Fig. 9). Clusters 3 and 4 had the greatest abundance and density of plants (Fig. 10a,b). Homegardens in cluster 4 also had the greatest abundance and richness of annual and perennial herbs (Fig. 10c). Pearson's Chi-squared test for independence was significant for cluster assignment and districts ($\chi^2[3] = 20.6$, $p = 0.002$). Seventy percent of gardens in cluster 3 and 46% of gardens in cluster 4 were in Bushenyi (Fig. 9).

Comparison of the SDR across the use categories revealed differences between the four clusters. Cluster 1 showed no specific dominance but had a mixture of different use categories (Fig. 8). Cluster 2 had a greater dominance of plants primarily used as fruits (e.g. mango), vegetables (e.g. *Solanum* spp.), medicine (e.g. African basil), for trade (e.g. coffee) and for technical uses (e.g. *Pennisetum purpureum* Schumach.). Cluster 3 had the greatest dominance of plant species primarily used as pulse/seed

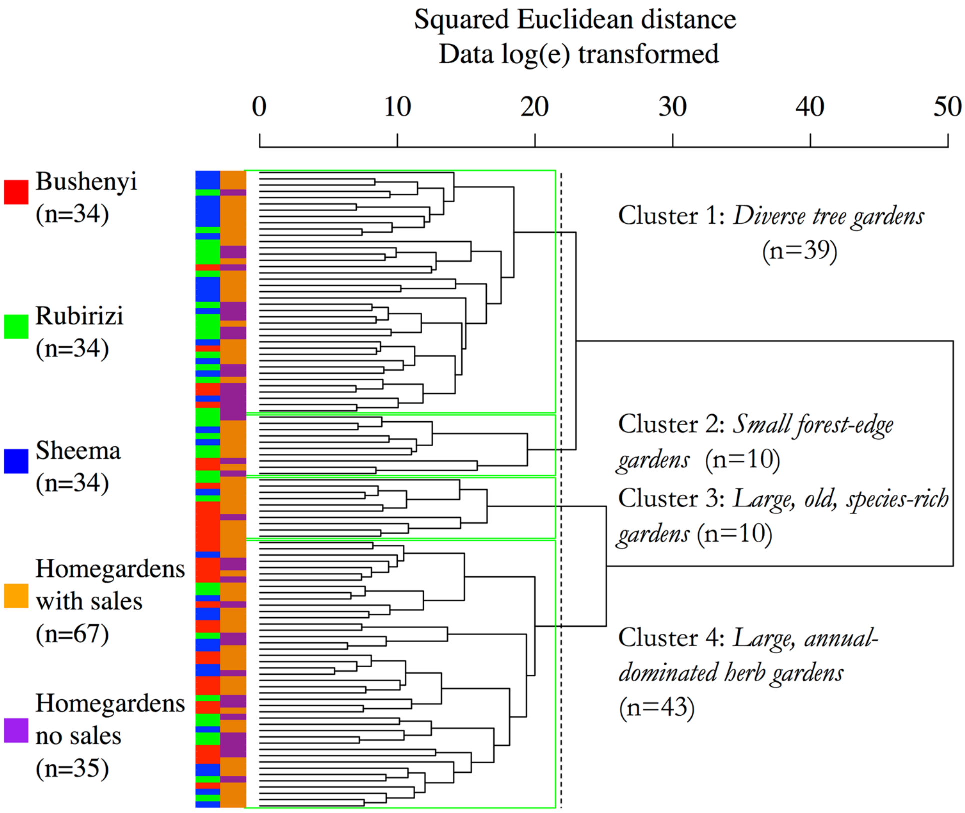

Fig. 9 Dendrogram of cluster assignment for 102 homegardens in southwest Uganda based on Ward's minimum variance (squared Euclidean distance) cluster analysis of log(e) transformed density data (individuals per 1000 m^2 homegarden area) of 209 crop species (excluding ornamentals). Clusters, outlined in green, dotted line at the cut-off point to define the correct number of clusters according to the 'elbow' criterion, shown together with geographic locations and homegardens with and without sales. Names for different garden types generated after analysis. (Color figure online)

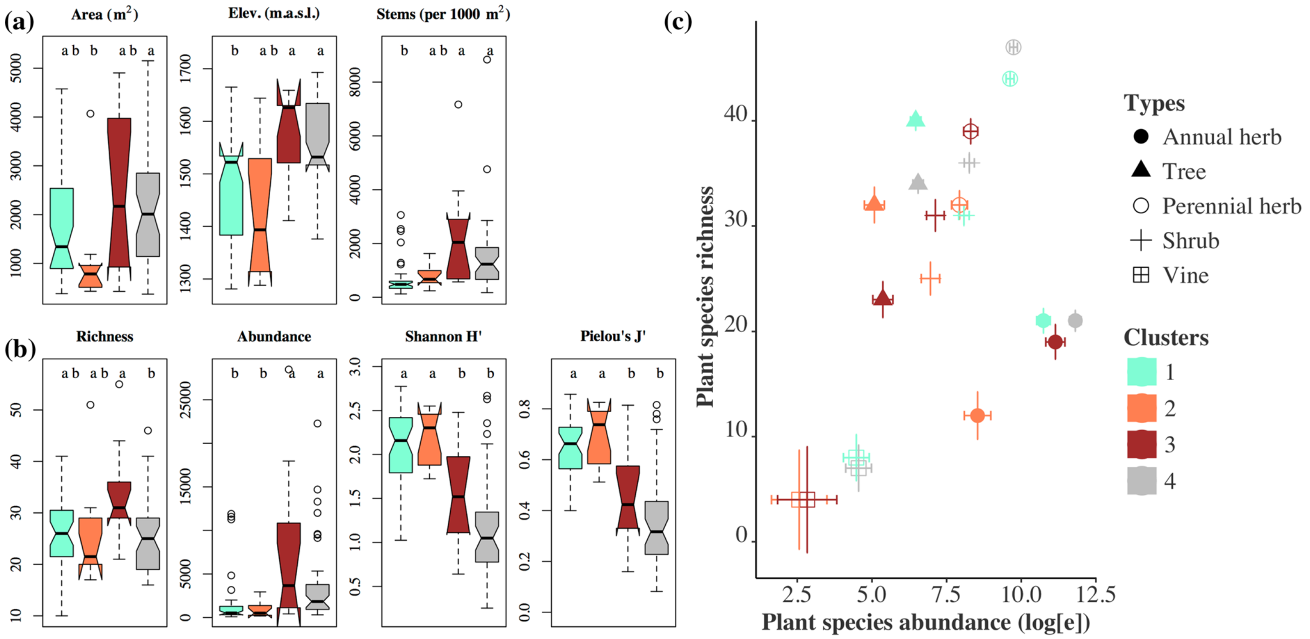

Fig. 10 Cluster assignment by socio-economic and crop diversity variables for 102 homegardens in southwest Uganda. **a** Homegarden area (m^2), homegarden elevation (m.a.s.l.), and individual plant density (stems per 1000 m^2). **b** Floristic diversity across clusters: total crop species richness, total crop abundance (count of individual plants), Shannon H′, and Pielou's J′. Notched boxplots show the median and 95% confidence interval of the median. Boxplots not sharing a letter are significantly different according to nonparametric tests ($p < 0.05$). **c** Sum of richness and log (e) transformed abundance of 305,633 individuals of 209 crop species (excluding ornamentals): 25 annual herbs, 58 trees, 64 perennial herbs, 49 shrubs, and three vines. Standard error (error bars sides and top, bottom) displayed for both plant species richness and abundance

(e.g. common bean and sunflower). Cluster 4 also had a high dominance of pulse/seed crops, and a high dominance of staples (e.g. cocoyam; Fig. 8).

Discussion

Approach

The human ecology conceptual model provided the study with focus on the analysis of internal dynamics and system interactions of households and homegardens and the influences of their surrounding social and ecological systems. Following this approach could also provide tools for exploring relationships regarding aspects of the systems for which direct measurements would be difficult, e.g. the cultural value of the homegarden. This approach may be expanded in future homegarden studies to include external political and climatic systems, and socio-cultural factors in more detail (cf. Schneider 2010). It could be expanded to include specific issues of relevance to farmers (cf. Altieri 2002) to develop interventions based on farmers' perceived needs and advantages (Anderson 2015), e.g. regarding food security (Jacobi et al. 2017).

Crop diversity and structure

Overall crop richness and richness within the different use categories was comparable to other studies of regional small-scale farming systems (Table 5). For example, homegardens in central Uganda were similarly dominated by bananas and intercropped with fruits and vegetables (Oduol and Aluma 1990). Coffee agroforestry systems in Kenya's Aberdare Mountains had similarly high tree species richness (Pinard et al. 2014). The Chagga homegardens on Mt. Kilimanjaro in Tanzania had a lower abundance of bananas (330–1200 per ha; Fernandes et al. 1985) and contained fewer cultivated plants (100 vs. 209 crops and 46 ornamentals in the present study), but more forest and ruderal species (194 and 128 respectively vs. 100 for both in the present study) (Hemp 2006). Coffee was found in greater abundance in other regional homegardens and small-scale farming systems (Fernandes et al. 1985; Hemp 2006; Oduol and Aluma 1990; Pinard et al. 2014). Greater commercial production is likely to be a future trend in the homegardens of the study region, since farmers intend to plant more cash crops in the future (including coffee). As access to trade and markets increases, this upward trend may increase, with subsequent benefits to income, yet with serious risks to traditional homegarden biodiversity and household nutrition.

Table 5 Comparisons of selected floristic diversity characteristics, including total richness of crop species, mean H′, mean J′ and richness of different use categories among the present study and other studies of small-scale farming systems in Sub-Saharan Africa

Location		Cases studied	Total richness of crops	H′	J′	Fruit	Vegetables	Wood	Citation
Uganda	Bushenyi, Rubirizi and Sheema, Southwest	102 homegardens	209	1.632	0.499	30	43	24	Present study
	South and Central	–	40 (common species)	–	–	12	7	9	Oduol and Aluma (1990)
	Balawoli Sub-county, Eastern	320 plots	51 (woody species)	–	–	22	–	21	Tabuti (2012)
	Nawaikoke sub-county, Eastern	238 farmers	26 (woody species)	–	–	3	1	17	Tabuti et al. (2011)
	Bushwere Parish, Western	198 plots	> 149	0.565–2.585	–	–	–	–	Eilu et al. (2003)
	Kiruhura and Arua, Western	181 households	138 (37 described)	–	–	16	–	32	Nyamukuru et al. (2015)
Ethiopia	Sidama	144 homegardens	198	1.41	0.5	> 1	> 2	> 25	Abebe et al. (2006)
Kenya	Mumias and Vihiga districts	30 small-holder farms	81	1.05	0.4	30	24	–	Ng'endo et al. (2015)
	Aberdere Mountains	62 coffee farms	59 (trees)	1.6	0.7	12	> 1	31	Pinard et al. (2014)
Niger	Niamey (mean of 3 seasons)	51 gardens	116	0.753	0.347	34	25	17	Bernholt et al. (2009)
Sudan	Nuba Mountains	61 homegardens	110	1.43	0.45	19	22	28	Wiehle et al. (2014)
Tanzania	Mt. Kilimanjaro	–	> 50	–	–	6	4	43	Fernandes et al. (1985)
		62 homegardens	~ 500 useful spp.						Hemp (2006)

–, not reported

The studied homegardens were dominated by crops used as fruits, vegetables, staples and pulses/seeds (Table 2; Fig. 8), similar to the gardens in Niamey, Niger (mostly dominated by vegetables and fruits; Bernholt et al. 2009) and the Nuba Mountains, Sudan (mostly dominated by vegetables and staples; Wiehle et al. 2014). These were largely exotic perennials and annual field crops, which may, in part, reflect a tendency toward plants with higher yields and shorter and more regular cultivation cycles. Homegardens that contain a balanced dominance of a variety of crop types (cf. Cluster 1 and 2; Fig. 8) are likely to be more efficient and sustainable mechanisms for supplying families with diverse food throughout the year.

Although more than half of the plant species the surveyed farmers kept in their homegardens were native (56%), similar to homegardens in Tanzania (73%; Hemp 2006) and in Sudan (60%; Wiehle et al. 2014), exotic plants still made up the majority of individual plants in the surveyed homegardens (87%), similar to gardens in Niger (70%; Bernholt et al. 2009). This was largely due to the dominance of important fruits and pulses/seeds, of which many species were of exotic origin. Exotic species are likely to be a major factor in the future diversity of these homegarden systems, since farmers expressed an interest in planting more exotic species in the future. This may have implications on the function of homegardens for in-situ conservation of important native crop genetic resources, e.g. with regard to traditional cultures and food habits, but also to ecological functions of these species. Furthermore, the dominance of exotic crops may lead to less diversity in the types of food that are available for farmer families.

Farmers planted their homegardens as diverse multilayered vegetation structures, with advantages in reducing soil erosion and efficient use of water, nutrients, light and space (Fig. 5a). The complex vertical structure of the studied homegardens was similar to that of homegardens elsewhere in the humid tropics (Fernandes et al. 1985; Huai and Hamilton 2009; Kumar and Nair 2004), but many still had potential for more production above the banana layer (e.g. more fruit trees in homegardens of clusters 3 and 4; Fig. 8). Key informants confirmed the potential for more vertical production, when considering the variety of vertical homegarden structures (cf. Fig. 5). Increasing abundance of crops of lower vegetation layers, such as shade-tolerant vegetables and staples, may increase the potential of a homegarden to produce a more balanced, diverse diet for the family. Whether or not farmers choose to take advantage of the vertical productive capacity will determine the extent to which their homegardens resemble species-rich agroforestry systems and provide the many benefits of mixing trees and crops.

The diversity of local names for crops indicates high intraspecific diversity. However, the folk classification approach may be confounded by multiple local names for single varieties, shared names for multiple varieties (Gessler and Hodel 2010), and gendered differences in describing plants (Schneider 2010). Studies about the variation in naming and descriptions of plants may be an important part of understanding local priorities for homegarden agrobiodiversity and for monitoring loss of intra-specific crop diversity over time.

Factors influencing crop diversity in homegardens

Socio-economic conditions

The homegardens in our sample had a strong role in subsistence food production and income generation. Farmers within our sample often adopted new cash crops but also saved planting materials for maintaining their traditional banana-dominated crop diversity for household consumption, similar to small-scale farmers elsewhere in Uganda (Whyte and Kyaddondo 2006). Commercially oriented homegardens showed no significant differences in crop diversity compared to gardens without sales. Sales were also not a significant factor in any of the regression models (Table 4). Contrary to our hypothesis, commercialization did not negatively influence floristic diversity, similar to homegardens of the Nuba Mountains (Wiehle et al. 2014). The wealth indicator house quality (HQI) also had no significant effect in regression models (Table 4) and was not significantly different among garden clusters (Fig. 9). These findings suggest that some access to markets and income can be complementary to homegarden diversity, thereby allowing households to benefit from access to planting materials for cash crops and marketing channels for their products. Given that the more valuable homegarden products tend to be sold by men, it may be useful to study the benefits of markets for household economies disaggregated by gender, so that specific interventions aiming to increase incomes of female farmers can be developed.

The wealth indicator TLU had a weak but significant positive influence in a regression model of richness of perennial crops (Table 4). However, contrary to our hypotheses, TLU did not influence other models and was not significantly different among homegarden clusters (Fig. 9). Although ownership of farm animals was higher in our study than at the national level (Table 1), it was low compared to other small-scale farming households in East Africa, indicating that animals could potentially play a larger role in the surveyed garden systems, which could provide animal based foods for the households and valuable manure for soil fertility (Bekunda and Woomer 1996).

The wealth indicator ownership of additional land had a positive influence on H′ and J′ (Table 4). However, it had a negative influence on the richness of annual species. These effects are possibly due to the shifting of abundant light-demanding annual crops to plots outside the homegarden, generating higher species evenness with more perennials in homegardens. This was the case in Peru, where homegarden floristic diversity was positively related to field holdings outside the homegarden (Coomes and Ban 2004). Farmers' access to additional cropping areas in the future will likely determine the role of homegardens either for the production of annual crops or for maintaining their diverse and multi-layered perennial structures.

Household head/gardener characteristics

Farmers' education had no significant effect on homegarden crop diversity. This lack of effect was partly due to the generally very low levels of education, but also to differing access to education in different regions, with farmers at the forest-edge tending to have fewer years of formal education. No significant effect of farmers' age was detected, which may be explained by the complex exchange systems regarding both knowledge and planting materials among kin and neighbors, which is not necessarily related to the age or formal education level of the farmer. Further studies on regional homegardens should gather more qualitative data on the role of exchange on homegarden diversity.

Most households were male headed, as is common in many traditional African societies and throughout Uganda (UBOS and ICF 2012), yet headedness showed no significant effect. This unitary measure does not consider the important roles of other household members (Quisumbing et al. 2014). It may be irrelevant to homegardens since women tend to be responsible for homegarden management regardless of headedness, similar to small-scale farms in Eastern (Whyte and Kyaddondo 2006) and Central Uganda (Goode 1989). Women were the custodians of the seeds and knowledge handed down over many generations, following a matrilineal transmission (cf. Howard 2003). Through these traditions they manage their homegardens as the primary source of food security for their families (cf. Moreno-Black et al. 1996). As a group of women key informants in Kyarikunda agreed: "[…] plant the gardens because you don't want hunger and the whole family is looking up to you." In-depth exploration of gendered decision-making and its effects on garden diversity could help to generate tailored interventions, e.g. helping women gain access to desired planting materials.

Labor (largely from women) was the primary input for homegarden management, similar to homegardens elsewhere in Uganda (Oduol and Aluma 1990) and Mexico, where labor was the largest investment (Cuanalo et al. 2008). Respondents in our survey cited a labor shortage, mostly due to illness, pregnancy, and the migration of youth to urban areas, similar to homegardens in Tanzania (Fernandes et al. 1985). Labor shortage in our surveyed gardens also led to poor management practices, which could impact both crop diversity (Bernholt et al. 2009; Kehlenbeck et al. 2007) and prevalence of crop diseases (Tripathi et al. 2009). Targeting labor constraints in homegardens (e.g. by improving access to medicine and labor-saving horticultural practices) could increase their productivity.

Agro-ecological factors and production system characteristics

Geographic location was an important factor influencing crop diversity, as indicated by both regression (Table 4) and cluster analysis (Fig. 9). Location is a deeply complex variable with many confounding factors and influences, including strong correlations with some socio-economic variables. The species-rich rainforest (van Breugel et al. 2015) around Rubirizi may partly explain the higher diversity and evenness in forest-edge homegardens (Fig. 7b), which may be promoted by natural regeneration of seeds already in the soil or traveling from the forests (Norfolk et al. 2013). The remoteness of these villages also forces farmers to produce all the needed food and non-food items, leading to high values for many plant diversity parameters in their farms (Fernandes et al. 1985). Similarly, in Southern Ethiopia, a positive effect was found for the distance away from major roads on the number of trees in gardens, and the distance away from markets on total richness of crops (Abebe et al. 2006). This was only partly observed in forest-edge homegardens, which had a higher number of tree species (Fig. 7c), but a low overall species richness (Fig. 7a). Furthermore, forest-edge villagers collected products from the forests, supplementing homegarden production. To maintain year-round food and nutrition security, as barriers to forest access increase and deforestation continues, forest-edge gardeners should be encouraged to integrate more food-yielding forest species into their homegardens.

Elevation may be a proxy for many other variables, e.g. temperature, rainfall, soil characteristics, market access and ethnicity (Bakiga were in forest-edges at lower elevation, whereas Banyankole were in higher elevation deforested and wetland-edges; Fig. 3). It tended to differ between clusters (Fig. 10a) and had a negative influence in regression models of H′ and J′ (Table 4). Similarly, elevation negatively influenced plant species richness in Indonesian homegardens (Kehlenbeck et al. 2007), although these covered much larger elevation ranges (1000 vs. 400 in the present study). Disaggregation of the many variables that are correlated with elevation may yield important information about specific factors that influence homegarden agrobiodiversity.

Homegarden size was within the same range as those elsewhere in Uganda (Table 1) and in Sudan (mean 0.19 ha; Wiehle et al. 2014) but smaller than those in Tanzania (mean 0.68 ha; Fernandes et al. 1985) and in Ethiopia (mean 0.90 ha; Abebe et al. 2006). As in past studies (e.g. Bernholt et al.

2009; Cuanalo et al. 2008; Kehlenbeck et al. 2007; Pinard et al. 2014), floristic diversity of homegardens generally increased with the homegarden area. It had a significant influence in all regression models apart from H′ and J′ (Table 4) and was significantly different between clusters (Fig. 10a). The small garden sizes and relatively low population density of the study area would suggest that the homegarden areas could be expanded. However, access to additional land is lacking and, as a consequence, homegardens may become too small to meet future needs. Interventions that support efficient use of multilayered production in smaller homegardens may be effective in curbing future food insecurity.

Knowledge and exchange

As is the case with homegardens elsewhere in the tropics (Coomes and Ban 2004; Schneider 2010) and among other regional smallholder farmers (Nyamukuru et al. 2015), complex knowledge and seed exchange among kin and neighbors played a major role in the diversity of the surveyed homegardens. These exchange networks offer farmers access to a diverse collection of planting materials. Any reduction in these networks may constrain homegarden diversity, as was reported in Sudan (Wiehle et al. 2014). Homegardens could come to be dominated by annual crops (cf. Fernandes et al. 1985; Scales and Marsden 2008) and exotic commercial crops (cf. Bernholt et al. 2009; Hemp 2006; Kumar and Nair 2004; Wiehle et al. 2014). Future projects that encourage traditional seed exchange and promote the maintenance of traditional crops may help preserve traditional diversity.

The unexplained variation in homegarden crop diversity, shown in the rather weak results of the regression (Table 4) and the several non-supported hypotheses (Fig. 1), may be indications of a number of complex interacting socio-economic, cultural and environmental factors that were not included in the scope of this analysis. Future projects should seek to expand the theoretical human ecology approach by working with farmers and other stakeholders to identify and explore the broader political and ecological external influential factors, as well as specific individual and cultural habits and characteristics of the garden managers that constrain or foster homegarden crop diversity.

Conclusions and recommendations

The homegardens of southwest Uganda are the mainstay for rural livelihoods and the source of food and nutrition security for rural families. Following a human ecology conceptual framework and applying explanatory statistics was useful for exploring homegarden systems, identifying important influencing factors on their crop diversity and differentiating between the ‘diverse tree gardens’, ‘small forest-edge gardens’, ‘large, old, species-rich gardens’, and the ‘large, annual-dominated herb gardens’ of the study area. In future studies, the methodology could be extended for more detailed exploration of the broader political, climatic and socio-cultural factors, such as commercialization of production, that affect homegarden crop diversity to help develop interventions that increase the value of homegarden systems for rural livelihoods, particularly for improved food and nutrition security.

Women are largely responsible for the homegardens, which they manage as the primary source of food for their families. Good management practices and strong networks of knowledge and material exchange allow them to maintain homegardens that are resilient to changing social and environmental conditions. However, challenges such as the lack of access to land and labor, problems with crop pests and diseases and poor access to trade and markets, together with the increasing tendency towards cultivating high yielding annual crops, may reduce crop diversity and threaten the current multilayered structure of homegardens, with negative consequences for their sustainability and their role for food and nutrition security. Collaborative efforts that support farmers to deal with these issues should be explored and addressed in a gender disaggregated way. This strategy may have the dual benefit of increasing the level of knowledge and awareness among local farmers and contribute to the successful implementation of any proposed positive changes for homegarden diversity and rural livelihoods. The findings presented here suggest that homegardens could provide a valuable contribution to the agricultural development agendas of small-scale farmer based economies in Uganda and in areas with similar biophysical and socio-economic conditions.

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Annex

See Table 6.

Table 6 209 crop species according to their life-form (type), origin (native or exotic status), primary uses (most important and minor uses reported by farmers), frequency of occurrence and total abundance in 102 homegardens in southwest Uganda

Botanical name	Life-form	Origin	Primary uses		Occurrence[a]	Abundance
			Most important	Minor		
Acalypha wilkesiana Muell.Arg.	S	e	fe		1	10
Achyranthes aspera L.	P	n	me, te		2	9
Aframomum angustifolium (Sonn.) K.Schum.	P	n	fr		1	40
Ageratum conyzoides L.	A	e	me		4	30
Albizia coriaria Welw. ex Oliv.	T	n	wo, te		2	3
Alchornea cordifolia (Schumach. & Thonn.) Muell.Arg.	T	n	fe		1	2
Allamanda cathartica L.	V	e	te		1	3
Allium cepa L.	A	e	sp	ve	7	58
Aloe vera (L.) Burm.f.	S	n	me		13	38
Alternanthera ficoidea (L.) P. Beauv.	P	e	me		1	1
Amaranthus cruentus L.	A	n	ve	me	20	5712
Amaranthus dubius Mart. ex. Thell	A	n	ve	me	38	8631
Amaranthus hybridus L.	A	n	ve		47	8934
Amaranthus spinosus L.	A	n	ve		22	3728
Ananas comosus (L.) Merr.	P	e	fr	me	42	2023
Annona muricata L.	T	e	me		1	2
Annona senegalensis Pers.	T	n	fr, me	te	5	7
Antiaris toxicaria Lesch.	T	n	te	wo	3	4
Arachis hypogaea L.	A	e	pu		2	1230
Artocarpus heterophyllus Lam.	T	e	fr		54	147
Aspilia africana (Pers) C. D. Adams	P	n	me, te		6	34
Basella alba L.	V	n	me	ve	3	3
Bersama abyssinica Fresen.	T	n	me		1	1
Bidens pilosa L.	A	e	me		2	130
Blighia unijugata Bak.	T	n	te		1	1
Brachiaria ruziziensis R. Germ. & C. M. Evrard	P	n	te	me, an	4	191
Brassica oleracea L.	A	e	ve		26	583
Bridelia micrantha (Hochst.) Baill.	T	n	wo		1	3
Brillantaisia owariensis P. Beauv.	S	n	me		5	9
Brugmansia suaveolens (Humb. & BonpL.ex Willd.) Bercht. & J.Presl	S	e	an		1	4
Bryophyllum pinnatum (Lam.) Oken	P	e	me		2	8
Buddleja davidii Franch	S	e	wo, fe		2	5
Bulbine frutescens (L.) Willd.	P	e	me		1	1
Cajanus cajan (L.) Millsp.	P	e	pu	me	7	41
Calliandra haematocephala Hassk.	T	e	an	me, te	4	18
Callistemon citrinus (Curtis) Skeels	T	e	me	fe	5	8
Callistemon viminalis (Sol. ex Gaertn.) G.Don	T	e	fe		1	1
Camellia sinensis (L.) Kuntze.	S	e	ve		2	16
Canavalia virosa (Roxb.) Wight & Arn.	P	n	me	pu	3	7
Capsicum annuum L.	P	e	ve	sp	9	30
Capsicum frutescens L.	S	e	sp	me	44	123
Cardiospermum halicacabum L.	V	e	me		1	2
Carica papaya L.	P	e	fr	me, tr	55	221
Cascabela thevetia (L.) Lippold.	T	e	me		1	1
Casuarina equisetifolia L.	T	e	wo	tr, fe, te	14	59
Ceiba speciosa (A. St.-Hil., A. Juss. & Cambess.) P. Ravenna	T	e	me		2	2
Centella asiatica (L.) Urb.	A	n	me		1	3

Table 6 (continued)

Botanical name	Life-form	Origin	Primary uses		Occurrence[a]	Abundance
			Most important	Minor		
Cestrum nocturnum L.	S	e	me	sp	3	5
Chenopodium ambrosioides (L.) Mosyakin & Clemants	P	e	me		1	1
Chenopodium opulifolium Schrad, ex G. C. T. Koch &. Ziz	P	n	me		7	18
Chlorophytum subpetiolatum (Baker) Kativu	P	n	te		2	2
Cissus rotundifolia (Forssk.) Vahl.	V	n	te		2	3
Citrus limon (L.) Burm	T	e	fr	me	7	7
Citrus sinensis (L.) Osbeck	T	e	fr	tr	25	50
Citrus tangerina Tanaka	T	e	fr		2	3
Cleistopholis patens (Benth.) Engl. & Diels	T	n	wo, fe		2	2
Clematis hirsuta Guill.& Perr.	V	e	me		1	1
Clerodendrum formicarum Guerke	S	n	me		1	2
Clerodendrum rotundifolium Oliv.	S	n	me		2	9
Coffea arabica L.	S	n	tr	fr	47	1063
Coffea canephora Pierre ex A. Froehner	S	n	tr	fr	93	3227
Cola acuminata (P. Beauv.) Schott & Endl.	T	n	me		1	1
Colocasia esculenta (L.) Schott	P	e	st		1	49
Cordia africana Lam.	T	n	wo		1	1
Costus afer Ker Gawl.	P	n	me		1	2
Crassocephalum mannii (Hook.f.) Milne-Redh.	P	n	te	me	3	6
Crotalaria laburnifolia L.	S	n	me		1	2
Croton macrostachyus Hochst. ex Delile	T	n	me		2	4
Cucurbita pepo L.	A	e	ve		56	163
Cyathula uncinulata (Schrad.) Schinz	S	n	me		1	1
Cymbopogon citratus (DC.) Stapf.	P	e	sp	me	21	219
Cyperus alternifolius L.	P	n	me	te	6	20
Cyperus papyrus L.	P	n	me, te		2	202
Cyphostemma cyphopetalum (Fresen.) Desc. ex Wild & R.B.Drumm.	V	n	me		1	1
Dichrocephala integrifolia (L.f.) Kuntze.	A	n	me		2	4
Dioscorea cayenensis Lam.	V	n	st		7	21
Dodonaea viscosa Jacq.	S	n	ve, me		2	6
Dracaena steudneri Engl.	S	n	fe		2	25
Dracaena fragrans (L.) Ker Gawl.	S	n	fe	me, te	58	1361
Duranta erecta L.	S	e	te	fe	9	175
Eleusine coracana Gaertn.	A	n	st		5	820
Eriobotrya japonica (Thunb.) Lindl.	T	e	fr	ve, sp	41	81
Erythrina abyssinica Lam. ex DC.	T	n	me	wo, fe, te	19	41
Erythrococca atrovirens (Pax) Prain	S	n	me		1	1
Eucalyptus globulus Labill.	T	e	wo	te	12	20
Eucalyptus grandis A. Hill ex Maiden	T	e	te	wo, fe	21	286
Euphorbia cotinifolia L.	S	e	fe	me	5	62
Euphorbia tirucalli L.	S	n	fe	me, te	23	931
Euphorbia umbellata (Pax) Bruyns	S	n	me	fe	3	7
Euryops chrysanthemoides (DC.) B.Nord.	S	e	te		3	30
Faurea saligna Harv.	T	n	wo		1	1
Ficus asperifolia Miq.	T	n	te		4	7
Ficus exasperata Vahl	T	n	te		1	10
Ficus thonningii Bl.	T	n	te	me, an, wo, fe	8	14

Table 6 (continued)

Botanical name	Life-form	Origin	Primary uses		Occurrence[a]	Abundance
			Most important	Minor		
Fittonia albivenis (Lindl. ex Veitch) Brummit.	P	e	me		2	2
Fleroya rubrostipulata (K.Schum.) A.F.Deng	T	n	me		1	2
Funtumia africana (Benth.) Stapf.	T	n	wo		3	3
Glycine max (L.) Merr.	A	e	pu		1	20
Gouania longispicata Engl.	S	n	me		1	1
Grevillea robusta A.Cunn. ex R.Br.	T	e	fe	wo	6	12
Gutenbergia cordifolia var. *marginata* (O. Hoffm.) C. Jeffrey	P	n	me		2	21
Gynandropsis gynandra (L.) Briq.	P	n	ve		5	19
Gynura scandens O. Hoffm.	P	n	me	ve	5	73
Harpagocarpus snowdenii Hutch. & Dandy	P	n	me		4	11
Harungana madagascariensis Lam. ex Poir.	T	n	te	me	5	7
Helianthus annuus (Cass.) Cass.	A	e	pu		21	271
Hibiscus acetosella Welw. ex Hiern.	S	n	sp	me	9	30
Hibiscus fuscus Garcke	S	n	me	an	4	25
Impatiens meruensis Gilg.	P	n	fr, ve		2	8
Imperata cylindrica (L.) P. Beauv.	P	n	ve		1	50
Indigofera atriceps Hook. f.	A	e	me	ve	3	390
Ipomoea batatas (L.) Lam	A	e	st		36	2921
Iresine herbstii Hook. ex Lindl.	P	e	me		1	1
Juniperus procera Hochst. ex Endl.	T	n	te	me	5	32
Justicia betonica L.	S	n	me		3	5
Justicia engleriana Lindau	S	n	me		7	60
Kalanchoe densiflora Rolfe.	P	n	me	te	8	85
Khaya senegalensis (Desr.) A. Juss.	T	n	wo		1	1
Kigelia africana (Lam.) Benth.	T	n	me		1	1
Kotschya africana Endl.	P	n	me		1	3
Lantana camara L.	S	e	fe	me, wo, te	11	213
Leonotis melleri Bak.	P	n	me	ve	6	18
Leucaena leucocephala (Lam.) de Wit	T	e	me		1	7
Leucas martinicensis (Jacq.) R.Br.	A	n	me		1	2
Luffa acutangula (L.) Roxb.	V	e	te	me	8	10
Macrotyloma axillare (E. Mey.) Verdc.	V	e	me		1	2
Maesopsis eminii Musizi.	T	n	fe, te		2	4
Mangifera indica L.	T	e	fr		56	110
Manihot esculenta Crantz	P	e	st	ve	68	5159
Manihot glaziovii Muell.Arg.	T	e	fe		1	1
Markhamia lutea (Benth.) K.Schum.	T	n	wo, te	fe	7	42
Melia azedarach L.	T	e	me		1	2
Melochia corchorifolia L.	P	n	te		18	372
Morus alba L.	S	e	fr		7	55
Musa (AA-EAHB Group)	P	e	st		2	12
Musa (AAA Group)	P	e	fr	ve, st, te	83	946
Musa (AAA-EAHB Group)	P	e	st	fr, ve, tr, te	102	12,425
Musa (AAB Group)	P	e	fr	ve, st, te	74	683
Musa (AB Group)	P	e	fr	ve, st, te	82	866
Musa (ABB Group)	P	e	fr	st, te	26	267
Myrianthus arboreus Beauv.	T	n	me		1	1
Nicotiana tabacum L.	S	e	me	tr, te	24	239

Table 6 (continued)

Botanical name	Life-form	Origin	Primary uses		Occurrence[a]	Abundance
			Most important	Minor		
Ocimum gratissimum L.	S	n	sp	me	10	30
Parinari excelsa Sabine	T	n	wo		1	2
Passiflora edulis Sims.	V	e	fr		52	134
Passiflora quadrangularis L.	V	e	fr		1	1
Pennisetum purpureum Schumach.	P	n	te	an, wo	17	579
Persea americana Mill.	T	e	fr	me	91	238
Phaseolus lunatus L.	A	e	pu		4	5
Phaseolus vulgaris L.	A	e	pu	ve	59	212,724
Phoenix reclinata Jacq.	T	n	te		1	3
Physalis peruviana L.	S	e	fr	ve, me	40	281
Phytolacca dodecandra L'Her.	A	n	me		4	44
Pisum sativum L.	P	e	pu		2	72
Plantago palmata Hook. f.	P	n	me	te	6	29
Plumbago zeylanica L.	P	n	me		1	3
Prunus africana (Hook.f.) Kalkman	T	n	me		1	3
Psidium guajava L.	T	e	fr		69	165
Raphanus sativus L.	A	e	ve		1	2
Rhus pyroides Burch.	T	e	fr, me		2	4
Ricinus communis L.	T	n	te	me	29	208
Rosmarinus officinalis L.	P	e	sp	tr	4	9
Rubus keniensis Standl.	S	n	fr		1	30
Rumex usambarensis (Dammer) Dammer	S	n	me	tr	6	12
Saccharum officinarum L.	P	e	st	me, fe	70	7262
Salvia splendens Ker-Gawl.	P	e	sp		1	2
Sambucus africana Standl.	S	n	fe		1	3
Sansevieria trifasciata Prain	P	n	me	te	3	18
Sapium ellipticum (Hochst.) Pax.	T	n	wo		5	5
Sechium edule (Jacq.) Sw.	V	e	ve	me	6	13
Senecio hadiensis Forssk.	A	n	me		5	7
Senna occidentalis (L.) Link	P	e	me	ve	5	6
Sesbania sesban (L.) Merr.	S	n	me, te	ve	5	12
Shirakiopsis elliptica (Hochst.) Esser	T	n	wo		5	5
Sida rhombifolia L.	P	e	te	me	17	53
Solanecio angulatus (Vahl) C.Jeffrey	V	n	me		5	15
Solanecio cydoniifolius (O. Hoffm.) C.Jeffrey	P	n	me		6	27
Solanum aculeastrum Dunal.	T	n	me	ve	6	12
Solanum aethiopicum L.	S	n	ve		53	531
Solanum anguivi Lam.	S	n	ve		56	415
Solanum betaceum Cav.	T	e	fr	ve	20	43
Solanum giganteum Jacq.	S	n	ve		1	2
Solanum lycopersicum L.	P	e	ve		50	936
Solanum macrocarpon L.	P	n	me		4	15
Solanum nigrum L.	P	e	ve		28	610
Solanum torvum Sw.	S	n	ve		24	203
Solanum tuberosum L.	P	e	st		30	663
Sorghum bicolor (L.) Moench.	A	n	st		25	2570
Spathodea campanulata P. Beauv.	T	n	te	wo	3	8
Stachytarpheta cayennensis (A. Rich.) Vahl	S	e	fe, te		4	57

Table 6 (continued)

Botanical name	Life-form	Origin	Primary uses		Occurrence[a]	Abundance
			Most important	Minor		
Strombosia scheffleri Engl.	T	n	wo		1	1
Symphytum officinale L.	P	e	ve, me, an		3	19
Syzygium cumini (L.) Skeels.	T	e	fr		2	2
Tephrosia vogelii Hook.f.	S	n	me		2	13
Tetradenia riparia (Hochst.) Codd.	P	n	me	ve	7	12
Tithonia diversifolia (Hemsl.) A.Gray	P	e	me		9	247
Tristemma mauritianum J.F. Gmel.	P	n	fr		1	1
Triumfetta althaeoides Lam.	S	n	te		1	5
Urtica massaica Milder.	P	n	ve, me		2	41
Vangueria apiculata K. Schum.	S	n	fr	ve, wo	22	48
Verbena officinalis L.	P	e	me		1	20
Vernonia amygdalina Delile	S	n	me		1	3
Vernonia brachycalyx O. Hoffm.	S	n	me		1	2
Vernonia kirungae R. E. Fries.	S	n	me		1	2
Xanthosoma sagittifolium (L.) Schott	P	e	st	ve	88	3750
Xanthosoma violaceum Schott	P	e	st	ve	5	447
Xymalos monospora (Harv.) Baill.	S	n	te		1	2
Zea mays L.	A	e	st		32	6333
Zingiber officinale Rosc.	P	e	sp	me	5	40

[a] Number of gardens where the plant was recorded

Codes for life-forms: A = annual herbs, P = perennial herbs, S = shrub, T = tree, and V = vines

Codes for origin: n = native and e = exotic

Codes for uses: fr = fruit, ve = vegetable, st = staple, pu = pulse/seed, sp = spice, me = medicine, an = animal feed, tr = trade, wo = wood, fe = fence, and te = technical

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