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The Role of Homegardens for Food and Nutrition Security in Uganda

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Abstract

The contribution of homegardens to the food and nutrition security of rural farmers has rarely been explored empirically. Our study assesses the influence of homegarden agrobiodiversity, production system parameters, and socioeconomic factors on household dietary diversity and anthropometric conditions in southwest Uganda. Plant inventories of 102 homegardens were followed by two 24-h recalls ($n = 589$) and anthropometric measurements ($n = 325$) of household members, as well as household food insecurity questionnaires ($n = 95$). Regression models explained between 16 and 50% of variance in dietary diversity and between 21 and 75% in anthropometric measurements. Results indicate that supporting diverse homegarden systems can in part reduce food insecurity in Uganda. We conclude with recommendations for further strengthening the role of homegardens in improving dietary and anthropometric outcomes.

Keywords Food security · Dietary diversity · Anthropometry · HFIAS · Plant species diversity · Banyankole · Bakiga · Southwest Uganda

Introduction

There is global consensus that ending hunger and malnutrition is a prerequisite for both development and socioeconomic well-being (Müller and Krawinkel 2005; United Nations 2015). Reaching the rural poor is a major challenge to achieving these goals (Kharas *et al.* 2017), particularly in remote areas (UBOS and ICF 2012). Small-scale traditional farming systems such as homegardens, often remarkably sustainable and designed primarily for subsistence and occasional product sales, may be an important way to supply rural populations with adequate nutrition and access to livelihoods (Altieri and Koohafkan 2008; Denevan 1995; Fernandes and Nair 1986; Goode 1989; Harwood 1979; Remans *et al.* 2011), e.g., through provision of a diverse and year-round food supply (Atta-Krah *et al.* 2004; Kehlenbeck *et al.* 2007; Kumar and Nair 2004).

The Ugandan economy is predominantly agricultural, with a majority of households reliant on subsistence farming systems (UBOS and ICF 2012) such as homegardens. Many Ugandan households are unable to meet minimum international standards for well-being (Levine *et al.* 2012) and live with little infrastructure and high levels of disease (World Bank 2012). The challenges of hunger and malnutrition are severe, particularly for women and children (NPA 2011). The Human Development Index is low (0.483), ranking Uganda 163rd among 188 countries listed worldwide (UNDP 2016). The immediate causes of malnutrition in Uganda include food insecurity, lack of safe water, poor hygiene and sanitation, and gender inequality (UBOS and ICF 2012; UNICEF 2003) in addition to poor dietary habits and lack of nutrition education and awareness. Many people eat unbalanced diets with large amounts of staple foods high in carbohydrates but lacking

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sufficient proteins and micronutrients such as vitamins and minerals, e.g., from fruits, vegetables, pulses, or animal-sourced food (ASF), contributing to the high prevalence of micronutrient deficiency (Rambeloson *et al.* 2012; Ssewakiryanga 2015), particularly in children. As of 2012, 33% of children below five years of age were stunted, 14% were wasted, and 5% were acutely thin. In addition, 49% of children and 23% of mothers of reproductive age were anemic (UBOS and ICF 2012), and 15% of children under five in Western Uganda had Vitamin A deficiency (FANTA-2 2010).

Homegardens in Uganda are of high cultural significance and regarded as important for household nutrition (Goode 1989; Remans *et al.* 2011). For many rural Ugandans, food production is considered to be a practical activity, a moral act, and a demonstration of social, cultural, and technical capacity (Whyte and Kyaddondo 2006). Homegardens are often managed as diverse intercropped banana plantations under constant harvest and can contain a high diversity of plants that may be directly linked to household food and nutrition security, although empirical evidence for such a relationship is lacking (Oduol and Aluma 1990; Tabuti *et al.* 2011; Tabuti 2012). Such diverse gardens are common in the remote areas of the Western region, which has contrasting agro-ecological zones, different strata of land use, and high levels of malnutrition (Eilu *et al.* 2003; Nyamukuru *et al.* 2015; Remans *et al.* 2011; Whitney *et al.* 2018a).

This study, following a theoretical human ecology approach outlined in Whitney *et al.* (2018a), is designed to determine the level of impact that homegardens have on the health of rural Ugandans both in terms of dietary diversity and in terms of anthropometric outcomes. We developed and tested multiple hypotheses regarding household diets, nutritional status, and levels of household food insecurity as they relate to homegarden botanical agrobiodiversity and production system and household socioeconomic status. Our specific goals are to better understand the contribution of homegarden agrobiodiversity to household food and nutrition security and to develop recommendations for further strengthening the role of homegardens in improving health and nutrition in rural Uganda.

Materials and Methods

Study Area

The study area in the Bushenyi, Rubirizi, and Sheema districts is in the highlands of southwest Uganda (Fig. 1). The three districts differ in terms of ecology and socioeconomic factors such as urbanization and access to commodities (Whitney *et al.* 2018a). Subsistence homegardens, mainly managed by women and with a high diversity of crops, are ubiquitous (UBOS and ICF 2012; Whitney *et al.* 2018a). The area is characterized by ecological and cultural richness, but also has high levels of poverty and malnutrition (UBOS 2014). High rates of deforestation have transformed large tracts of rainforest (van Breugel *et al.* 2015) into densely planted banana-based homegardens that are the main agricultural production systems (Whitney *et al.* 2018a). Agriculture is the main economic activity, consisting predominantly of small-scale producers cultivating a wide range of crops and other commodities, notably staple cooking bananas (*Musa* spp.), robusta and arabica coffee (*Coffea* spp.), tea (*Camellia sinensis* [L.] Kuntze), and livestock (UBOS 2014). However, few people are employed (UBOS and ICF 2012) and many are living below the poverty line. The population density of the study area, 64 people/km^2, is less than half of the national average (Weidmann *et al.* 2010), yet a high population growth rate and low average age are likely to exacerbate land scarcity, poverty, (UBOS and ICF 2012) and food insecurity.

Approach

Permission and ethical approval for the study was granted by the Ugandan National Science Foundation (Registration number: A 477), the President's Office, the local Regional District Coordinators and Chief Administrative Officers of Bushenyi, Rubirizi and Sheema, and each of the nine villages' Local Chairpersons (LC). With their support, and with the understanding that knowledge generation and transmission should be participatory and transparent (Anderson 2015) and aim to benefit local people (cf. Altieri 2002), we were able to interview many village members and homegarden owners (Whitney *et al.* 2018a). We were invited to stay with the family of the LC in every village for the duration of the fieldwork, providing the opportunity for close participant observation and informal follow-up on interview questions (cf. Houghton *et al.* 2013). Based on these observations, as well as the literature, we developed multiple testable hypotheses with the underlying expectations that (i) variables related to homegarden production and agrobiodiversity would have a positive impact on the dietary diversity and anthropometry of household members while (ii) low performance in indicator variables of household socioeconomic conditions would have a negative influence (Fig. 2).

Data Collection and Analysis

Data collection took place in 102 indigenous Banyankole and Bakiga households managing homegardens. Villages were selected as part of a stratified, random design from groupings of those that fell within three ecological strata: (i) the edge of the rainforest (Kashohe-Kitome forest-edge communities of the far western highlands near Rutoto town in Rubirizi district, ~1400 m above sea level), (ii) deforested areas (Bushenyi center around Ishaka town, ~1600 m above sea level), and (iii) wetlands (Sheema in the southeast, near Bugongi town, ~1500 m above sea level) (Fig. 1). Three villages were then randomly selected in each strata, and 11 to 12 households

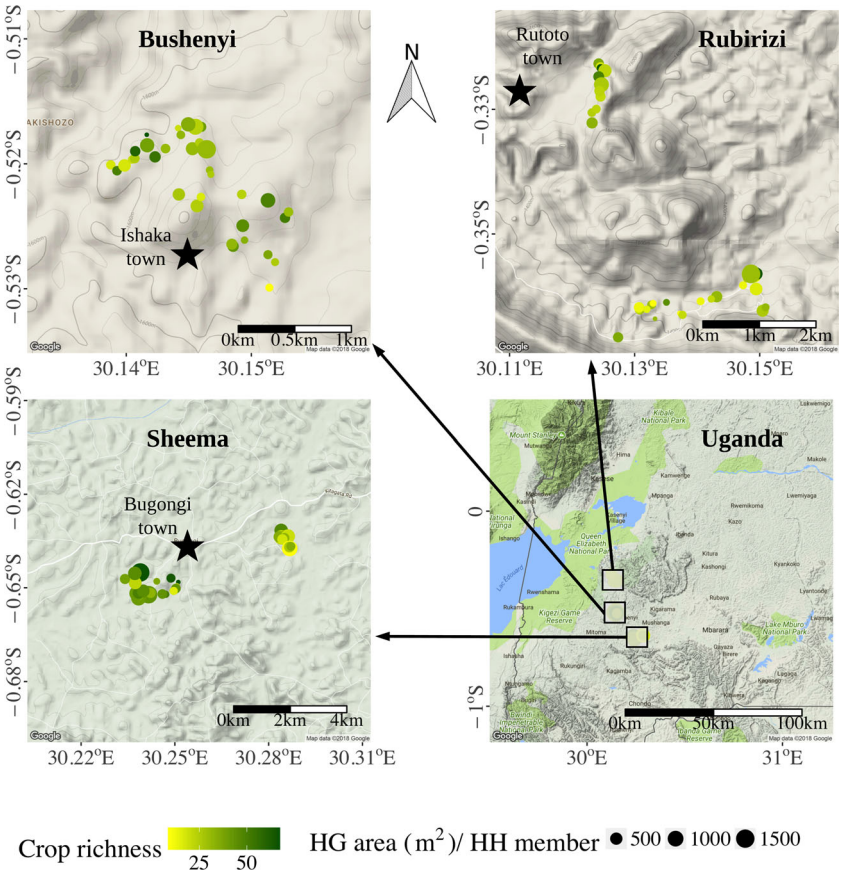

Fig. 1 Location, crop richness, and homegarden (HG) area per household (HH) member for 102 randomly selected homegardens in nine villages in Bushenyi, Rubirizi, and Sheema districts in the highlands of southwest Uganda. Background map from Google maps data 2017. Map developed in R ggmap2 (Kahle and Wickham 2013). Coordinates are geographic, using the WGS84 datum

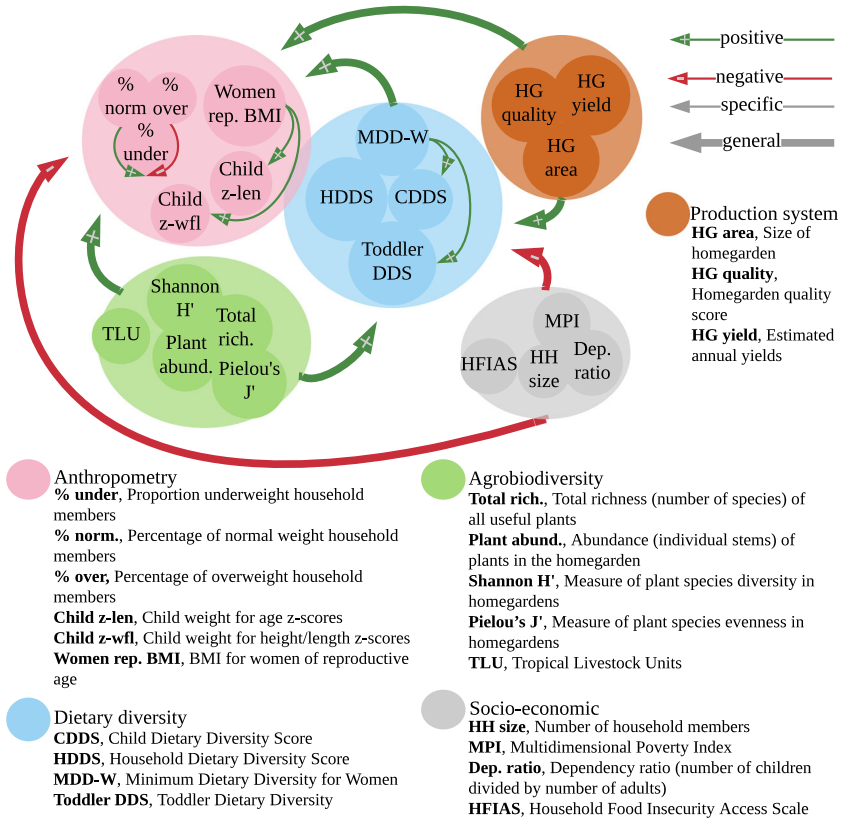

Fig. 2 Hypotheses of the possible influence of agrobiodiversity, production system parameters and socio-economic factors on the dietary diversity and anthropometric conditions of households in southwestern Uganda (variables listed in Table 1). Large arrows indicate influence of groups of variables, narrow arrows indicate specific relationships between variables. Overlapping circles indicate strong relationships among specific variables. Red and green circles around '% under' indicate reversed hypotheses

were randomly selected from lists of households in the village; all lists of villages and households were provided by local officials (Whitney *et al.* 2018a).

Agrobiodiversity

Agrobiodiversity surveys of the selected homegardens took place during the 'short rains' in February–May of 2014. Homegardens had a median size of 0.15 ha (range 0.04–0.52), with a total richness of 209 useful plant species (median per homegarden 25 species, range 10–55) used mainly for food (97% of all individual plants and 50% of all species), but also for medicinal and technical purposes. The homegardens had relatively high botanical richness, Shannon Diversity index (H′) and Pielou's measure of species evenness (J'), but relatively low livestock diversity (median 2, range 0–8 species) and numbers of Tropical Livestock Units (TLU) (Whitney *et al.* 2018a). Additionally, a simple homegarden quality score was generated (scale from 1 ['poor'] to 5 ['excellent']) based on general and qualitative observations of the research team of a number of factors regarding overall garden health, e.g., overall crop health, extent of tree canopy cover, level of crop layering (use of vertical space), soil quality, and level of soil erosion.

Dietary Diversity and Anthropometry

Dietary and anthropometric assessment of the same 102 households subsequently took place in the early part of the dry season, February and March, of 2015. Interview data included two 24-h recalls (cf. Gibson and Ferguson 2008) of nearly all household members (first round $n = 360$, second round $n = 485$, total[1] $n = 589$); others were unavailable or declined to be interviewed. Food recall data was recorded twice (two 24-h recalls roughly two weeks apart) for verification of dietary diversity. Results of 24-h recalls were used to calculate dietary diversity scores (Swindale and Bilinsky 2006) as a proxy for nutrient adequacy and as a measure of household access to diverse diets. Plant based foods in the 24-h recalls were categorized by plant species and assemblies (when respondents could specify only the broader type and not the exact species, e.g., 'eggplant').

Foods cited in 24-h recalls were grouped into 16 categories (Kennedy *et al.* 2013) and then aggregated to form food groups for specific age and gender dietary diversity scores. We calculated four different dietary diversity scores, (i) the Household Dietary Diversity Score (HDDS) for households (Kennedy *et al.* 2013) with a maximum possible score of 12 food groups counted, (ii) Child Dietary Diversity Score (CDDS) for children 2–5.9 years of age (Kennedy and Nantel 2006) with a maximum possible score of nine, (iii) Toddler Dietary Diversity Score (Toddler DDS) for children 0.5–1.9 years of age (WHO 2008) with a maximum possible score of seven, and (iv) the Minimum Dietary Diversity for Women of Reproductive Age (MDD-W) for women 15–49.9 years of age with a maximum possible score of 10 (FAO 2016). Primary caretakers were usually able to list all foods for the young children (under 10 years) within their households. Whenever possible, children were also asked to confirm and list any additional snacks (e.g., gifts from neighbors or eaten while playing in the forest or garden). Questionnaires for HDDS were carried out with the person who was responsible for meal preparation for the household the previous day (Kennedy *et al.* 2013) (usually the eldest healthy mother). For all dietary diversity score variables, first the median scores per participant group per household (e.g., median CDDS of all children 2–5.9 years of age in the household) were calculated and then the means of the two survey rounds per group were used for statistical tests. The mean dietary diversity for the richest 33% of households, i.e., lowest tertile of the Multidimensional Poverty Index (MPI), was used as the cut-off point (minimum number of food groups) to indicate adequate or inadequate dietary diversity (Swindale and Bilinsky 2006). This resulted in cut-offs of 5.9 and 4.5 for HDDS and CDDS respectively. A cut-off of five was used for MDD-W (FAO 2016) and four for toddler DDS (WHO 2008).

Interviews also included the Household Food Insecurity Access Scale (HFIAS) questionnaire, administered to the person responsible for preparing the food for the family (usually the mother) ($n = 95$). Seven out of the targeted 102 households were unavailable or declined to participate. The HFIAS included nine questions about household food insecurity by counting incidences and severity of food insecurity in the last 30 days (Coates *et al.* 2007). The HFIAS category variable was used to classify the food insecurity of the household (severely food insecure, moderately food insecure, mildly food insecure, and not food insecure), verified using Rasch model infit t-statistics with the eRm package (Mair *et al.* 2016). The HFIAS score variable was used as a continuous measure of the degree of food insecurity with a score ranging from 0 (no food insecurity) to 27 (severe food insecurity) (Coates *et al.* 2007).

Anthropometric measurements were taken of as many members of the surveyed 102 households as possible ($n = 325$). Some household members were unavailable or declined to be either weighed and/or measured (or asked us not to use their data). Measurements were performed with a scale (Seca model 874 'Mother/Child Platform Scale') and measuring tape. The resulting anthropometric scores were calculated with the WHO R igrowup package (WHO 2011) for children of or below five years of age (de Onis 2006; WHO and UNICEF 2009), the WHO AnthroPlus software R macro package (WHO 2007) for adolescents from five to 19 years

[1] The term 'total' is used here to indicate the sum of informants who participated in either or both the first and/or the second pass of the 24 h recalls.

of age (de Onis *et al.* 2007), and following the World Health Organization standards for measuring hunger and micronutrient deficiency (WHO 2007) for adults.

Comparison of anthropometric scores across ages and sexes was done using z-scores (continuous scale of the number of standard deviations [SD] away from the mean), which also allows for quantification of the extreme values (Wang and Chen 2012). Following the growth references of the World Health Organization, we used a z-score cut-off point between two and three standard deviations (SD) below the median to classify children up to five years of age with a low weight-for-age (both stunting and wasting), low height-for-age (stunting: indicating chronic malnutrition), and low weight-for-height (wasting: thinness indicating acute malnutrition) as moderate under-nutrition. Scores more than three SD below the median were defined as severe under-nutrition. Anthropometric scores greater than two SD above the median were interpreted as indicating that a child was large for their age group (WHO 2006). For adolescents z-score cut-offs for height, weight, and Body Mass Index (BMI) for age were used to classify severe under-nutrition, undernourished, and overweight nutritional status (−3, −2 and > 2 respectively) (WHO 2007). Adults over 19 years of age were classified using BMI scores: those with scores below 18.5 kg/m^2 were classified as undernourished, and those with scores of 25 kg/m^2 or above were classified as overweight (WHO 2016). Outliers (considered biologically implausible) were removed using z-score cut-off values (<−6 or > 5 weight for age, <−6 or > 6 height-for-age, and < −5 or > 5 BMI-for-age).

Interview data were used to calculate the MPI, generated with weighted counts of a household's inability to meet minimum quality-of-life standards (deprivations) (Alkire and Santos 2010). Ten indicators from three poverty dimensions were counted: two for health (nutrition and child mortality), two for education (years of schooling and school attendance), and six for living standards (cooking fuel, water, sanitation, floor, and assets). These 10 indicators were calculated following the same indicator dimensions and weights as the Human Development Index (UNDP 2016). Where the sum of the weighted deprivations was 30% or more of possible deprivations, the household was considered multi-dimensionally poor.

All qualitative and quantitative data were recorded digitally in the field and subsequently imported into the R programming language (R Core Team 2015). Our many hypotheses were first tested using correlation tests, performed with pairwise Spearman's rho statistic and plotted using the qgraph package (Epskamp *et al.* 2012). Differences between medians were tested with pairwise Wilcoxon rank sum test with continuity correction for two groups and Kruskal-Wallis rank sum tests for more than two groups (Pohlert 2014). For multivariate tests we used median scores per household (and the mean of these for two 24-h recalls for dietary diversity) rather than specific individual scores for the different age and gender groupings. For all tests we chose the significance level of $p < 0.05$ (see Table 1).

Projection to Latent Structures (PLS) regression analysis was used to develop predictions based on our hypotheses (Fig. 2). PLS can handle strongly collinear, noisy data, deal with large numbers of independent variables and multiple dependent variables (Wold *et al.* 2001). It was performed in R with the pls package (Mevik *et al.* 2015) using the orthogonal scores algorithm (Martens and Naes 1992) and cross-validated predictions based on the root mean squared error of prediction (RMSEP) (Mevik and Wehrens 2007). Coefficients were used as estimates of the population regression parameters in PLS models. Variable Importance in Projection (VIP) statistic was used to indicate how much variation in a given independent variable is correlated with variation in the response variable. The average of squared VIP scores is equal to one; therefore VIP values greater than one were used as a criterion for variable selection (cf. Chong and Jun 2005).

Results

The selected study sample was compared to the 2011 National Demographic and Health Survey of Uganda (UBOS and ICF 2012). Mean household size in our study was slightly larger than in Uganda's rural household population (6.9 vs. 5.1). Home ownership (99% vs. 66% respectively) and animal ownership (80% vs. 61% respectively) were also higher in the study households than at the national level. Social issues such as unemployment (6% vs. 4% respectively) and illiteracy rates (25% vs. range of 14–23% respectively) were greater in the study households than in the southwest component of the national survey (UBOS and ICF 2012).

Dietary Diversity

Two separate 24-h recall dietary surveys were recorded with 589 members of the 102 surveyed households who took part in either or both 24-h recalls. They were 58% female and 42% male, aged three weeks to 90 years (median age of 13 years). Informants reported 109 different food and drink items within the 16 documented food groups, with highest diversity in the food groups 'cereals' (21 items), 'condiment and beverages' (13), and 'other fruit' and 'sweets' (12 each). With regard to plant-based products, and sorting by main ingredient, 44 plant species and assemblies were mentioned, with the most diverse groups being the fruit (14 species/species assemblies), staple (11), and vegetable (9) groups (Table 2). Most of the meals mentioned in 24-h recalls (97%) were taken at home. The majority of foods were grown for subsistence; they were harvested and consumed on the same day and made mostly with ingredients sourced from homegardens (observation). Less

Table 1 The main dietary diversity, anthropometric, agrobiodiversity, socio-economic, and production system variables considered in the analysis of household food and nutrition security and malnutrition for 102 households in southwest Uganda

Category	Abbreviation	Description
Dietary diversity	CDDS	Median Child Dietary Diversity Score: count of diversity of foods eaten by all children 2–5.9 years within the HH in the last 24 h (9 food groups)
	HDDS	Household Dietary Diversity Score: count of diversity of foods eaten by the household members in the last 24 h (12 food groups)
	HDDS fruit	Binary of fruits in the Household Dietary Diversity Score
	HDDS veg.	Binary of vegetables in the Household Dietary Diversity Score
	HDDS legume	Binary of legumes in the Household Dietary Diversity Score
	HDDS animal	Binary of animal sourced foods (ASF) in the Household Dietary Diversity Score
	HDDS staple	Binary of staples in the Household Dietary Diversity Score
	MDD-W	Median scores of Minimum Dietary Diversity for Women of Reproductive Age: count of diversity of foods eaten by all women of reproductive age (15–49.9) within the HH in the last 24 h (10 food groups)
	Toddler DDS	Median Toddler Dietary Diversity: count of diversity of foods eaten by all toddlers (0.5 to 1.9 years) within the HH in the last 24 h (7 food groups)
Anthropometry	Adult BMI	Median Body Mass Index (BMI [weight in kilograms divided by the square of the height in meters]) for all adults over 19 years of age in the household
	% under	Percentage of household members who are underweight‡
	% norm.	Percentage of household members who are normal weight‡
	% over	Percentage of household members who are overweight‡
	Child z-len	Median height for age z-scores for all children up to five years of age in the household
	Child z-wfl	Median weight for height/length z-scores for all children up to five years of age in the household
	Women rep. BMI	Median BMI for all women of reproductive age (15–49.9) in the household
	Adolescent BMI	Median BMI for all adolescents (above five and up to 19 years of age) in the household
Agrobiodiversity of the homegarden (HG) (Whitney *et al.* 2018a)	Total rich.	Total richness (number of species) of all useful plants
	Rich. fruit	Total richness of homegarden plants used as fruit
	Rich. pulse	Total richness of homegarden plants used as legumes and nuts
	Rich. staple	Total richness of homegarden plants used as starchy staples
	Rich. veg.	Total richness of homegarden plants used as vegetables
	Plant abund.	Abundance (individual stems) of plants in the homegarden per 1,000 m^2 garden area
	Fruit abund.	Total abundance of homegarden plants used as fruit
	Pulse abund.	Total abundance of homegarden plants used as legumes and nuts
	Staple abund.	Total abundance of homegarden plants used as starchy staples
	Veg. abund.	Total abundance of homegarden plants used as vegetables
	Shannon H′	Shannon H′ measure of plant species diversity in homegardens
	Pielou's J'	Pielou's J' measure of plant species evenness in homegardens
	TLU	Tropical Livestock Units measured as equivalents of 250 kg live animal weight
Socio-economic status of the household (HH)	Child death count	Total number of children in the household below 10 years of age who died within the last 10 years
	HH size	Total number of household members
	MPI	Multidimensional Poverty Index based on quality-of-life standards (Alkire and Santos 2010) (higher values indicate higher levels of poverty)
	Dep. ratio	Dependency ratio as number of children divided by number of adults
	HFIAS	Household Food Insecurity Access Scale calculated as both a categorical (used as descriptive) and a continuous variable (used in models; higher values indicate higher food insecurity)
Homegarden (HG) production system	HG area	Total area of homegarden (m^2)
	HG quality	Homegarden quality score based on qualitative observations (1–5 scale; higher values indicate higher quality, see detailed explanation in the main text)
	HG yield	Estimated annual yields (kg) according to gardeners

‡ Based on BMI for adults and adolescents, and weight for height/length and height for age z-scores for children

than 4% of the meals were taken outside the home, e.g., were given to children at school, were purchased from local restaurants or shops, came from neighbors, or were collected as snacks from non-farmed areas (forests, swamps, fallows). Likewise, few food items, e.g., tea, rice and bread, were sourced from local markets (Table. 2).

Food items from the carbohydrate-rich staple food group (mostly bananas, but also roots and tubers as well as cereals) were consumed by 98.8% of respondents to the 24-h recalls. Legumes, nuts, and seeds (mainly beans) were the second most important food group (consumed by 91.4%), followed by vegetables (83.4%), fruits (56.1%), sweets (47.9%), and ASF (37.0%). The last consisted mainly of dairy products; only 9.7, 0.2, and 2.1% of the respondents had consumed any meat, eggs, or fish, respectively.

Assessment of dietary diversity based on two 24-h recalls, revealed adequate to slightly poor diets (Fig. 3). HDDS tended to be slightly above the minimum dietary diversity requirement of 5.9 food groups, with a median of six for both rounds (range 2.5–11; Fig. 3a). Many household diets included fruits (62% in a mean of the two 24-h recalls) and vegetables (mean 91%). MDDW was below the minimum requirement of five groups in the two single passes (median 4 in rounds 1 and 2, range 0–9) and the mean for both passes (median 4.5; Fig. 3b). Child DDS was below the minimum requirement of 4.5 with a median of four on the first and second 24-h recall pass (range 2–8; Fig. 3c), but the mean of the two passes was just adequate (4.5). Toddler DDS also tended to be below (or just adequate to) the minimum requirement of four. Median Toddler DDS was three on the first and four on the second 24-h recall pass (range 1–5; Fig. 3d) and 3.5 across both passes. Vitamin A rich fruits and vegetables were rarely included in the individual diets of women, children and toddlers (15%, 11%, and 4%, respectively, across two 24-h recall passes; $n = 163$, 143, and 25, respectively). Diets also rarely included dark leafy greens (included in 52%, 57%, and 44% of diets of women, children and toddlers, respectively) and ASF items (34%, 42%, 40%), with little or no meat (10%, 10%, 0%), dairy (26%, 30%, 40%), eggs (1%, 0%, 0%), or fish (1%, 5%, 0%). No significant differences were found for median dietary diversity scores between the first and second 24-h recall passes.

Anthropometry

Individual anthropometric measurements of 325 children, adolescents, and adults belonging to the 102 surveyed households revealed a high prevalence of under-nutrition. Measurements of children five and younger ($n = 61$; 6 outliers removed) showed 46% stunting (including 20% severe stunting), 13% underweight (had a low weight-for-age; including 3% who were severely underweight), and 3% wasting. Measurements of adolescents from above five to 19 years of age ($n = 114$; 2 outliers removed) revealed that 5% were underweight, including 2% who were severely underweight, 3% had a low BMI-for-age (including 1% severely low BMI), and 40% were stunted (including 11% severely stunted). Measurements of adults over 19 years of age ($n = 142$; 93 women and 49 men) showed that 15% were underweight and 17% were overweight.

Household Food Insecurity and Access

HFIAS interviews ($n = 95$, seven of the 102 surveyed households declined or were not available) revealed a high prevalence of food insecurity in the study area with a median score of 10 (range 0–23). Of the surveyed households, 39% were rated as severely food insecure, 45% as moderately food insecure, 11% as mildly food insecure, and just 5% as not food insecure. About half (49%) of respondents had worried that their households would not have enough food to eat. Most households had at least some members who ate some foods they did not want to eat (80%). Over half of the households had at least one member who had to eat a smaller meal than they felt they needed (68%), or had to eat fewer meals a day (56%). Some households had no food to eat of any kind in their household (16%), had household members who went to sleep at night hungry because there was not enough food (14%), or who went a whole day and night without eating anything (6%). The Rasch model indicated a good fit for the HFIAS categories and household scores (infit t-statistics range − 2.5 to +2.5).

Poverty

At the time of the interviews, poverty was severe throughout the study area (median MPI 0.28, range 0.11–0.67). Of the 102 households interviewed 44% were considered poor (i.e., have a MPI > 0.3). All households suffered at least two out of the ten deprivations counted in the MPI, with some suffering as many as seven. Deprivations measured in the poverty dimensions for health were severe with 44 households suffering the loss of at least one infant or child (44 of the surveyed households lost between 1 and 8 children below about the age 10 within the last 10 years), and 29 households with at least one household member who was malnourished. In the six poverty dimensions for living standards all 102 households suffered from having no electricity; 14 used either open defecation or shared their toilet with other households; 36 had no access to safe drinking water or water collection was more than a 30 min walk; 46 had a dirt floor, all cooked with wood or charcoal; and 12 had no more than one asset (e.g., radio, telephone, bicycle). No significant differences in MPI were detected between the three studied regions, although households at the wetland edge and in the semi-urban locations of Sheema and Bushenyi tended to suffer fewer deprivations (median 3, range 2–6) than those of the forest-edge area of

Table 2 The 44 plant species (or assemblies of plant species) present in individual diets and in homegardens and the main methods of preparation of the mentioned food items for 102 households in southwest Uganda

Code	Description	English name	Botanical name	Food preparation*	Present in meals†	Present in gardens††
Fruit	Sweet and fleshy plant products, mostly eaten raw	Pineapple	*Ananas comosus* (L.) Merr.	r	6.3%	41%
		Jackfruit	*Artocarpus heterophyllus* Lam.	r	7.9%	53%
		Papaya §	*Carica papaya* L.	r	7.4%	54%
		Watermelon	*Citrullus lanatus* (Thunb.) Matsum. & Nakai	r	1.1%	*n. p.*
		Lemon	*Citrus limon* (L.) Burm	r	1.1%	7%
		Orange	*Citrus sinensis* (L.) Osbeck	r	7.4%	25%
		Strawberry	*Fragaria x ananassa* Duchesne	r	1.1%	1%
		Tree tomato§	*Solanum betaceum* Cav.	r	1.1%	20%
		Mango §	*Mangifera indica* L.	r	3.2%	55%
		Sweet banana	*Musa* spp. (AAA, AA, AB, ABB, EA)	r, b, s	17.4%	80%
		Passion fruit types §	*Passiflora* spp.	r	7.9%	52%
		Avocado	*Persea americana* Mill.	r	33.2%	89%
		Guava	*Psidium guajava* L.	r	13.8%	68%
		Ken Fern	*Vangueria apiculata* K. Schum.	r	0.5%	22%
Legumes, nuts and seeds	Edible seeds of legumes and other species	Groundnut	*Arachis hypogaea* L.	b, f, rs, s	26.8%	2%
		Common bean	*Phaseolus vulgaris* L.	b	91.6%	58%
		Field Pea	*Pisum sativum* L.	b, r	1.6%	2%
Condiments and beverages	Added flavor for food or tea	Garlic	*Allium sativum* L.	b, f	1.1%	*n. p.*
		Tea	*Camellia sinensis* (L.) Kuntze.	d, b	37.9%	2%
		Peppers	*Capsicum annuum* L., *C. frutescens* L.	d	1.6%	53%
		Coffee types	*Coffea arabica* L., *C. canephora* Pierre ex A. Froehner	d, rs, b	1.1%	92%
		Lemongrass	*Cymbopogon citratus* (DC.) Stapf.	d, f	2.1%	21%
Staple	Carbohydrates, dominant portion of diet, e.g. bananas, grains, roots, and tubers	Coco yam types	*Colocasia* and *Xanthosoma* spp.	b, s, rs	12.1%	86%
		Yams	*Dioscorea cayenensis* Lam.	b, s	1.1%	7%
		Finger millet	*Eleusine coracana* Gaertn.	b	45.8%	5%
		Sweet potato	*Ipomoea batatas* (L.) Lam.	b, f, rs, s	47.4%	35%
		Cassava	*Manihot esculenta* Crantz	b, d, s, rs	29.5%	67%
		Cooking banana	*Musa* spp.	b, s, rs	83.7%	100%
		Rice	*Oryza sativa* L.	b, f	4.2%	*n. p.*
		Potato	*Solanum tuberosum* L.	b, s, f	2.1%	29%
		Sorghum	*Sorghum bicolor* (L.) Moench.	b	5.3%	25%
		Wheat	*Triticum aestivum* L.	f, d, rs	13.2%	*n. p.*
		Maize	*Zea mays* L.	r, b, rs, f, s	58.9%	31%
Vegetable	Used as part of savory meal	Onion	*Allium cepa* L.	f, b	54.7%	7%
		Amaranth types (leaves) §	*Amaranthus* spp.	b, f, s	53.7%	46%
		Cabbage, Kale	*Brassica oleracea* L.	b, f, rs	5.8%	25%
		Sweet Pepper	*Capsicum annuum* L.	b	0.5%	9%
		Pumpkin types (leaves, fruit) §	*Cucurbita* spp. (e.g. *C. pepo*, *C. maxima*)	b, s, f	8.9%	57%
		Carrot §	*Daucus carot*a L. subsp. *sativus* L.	r, b	1.6%	*n. p.*
		Tomato	*Solanum lycopersicum* L.	b, f	64.2%	49%
		Black nightshade (leaves) §	*Solanum nigrum* L.	b, s, f, rs	5.8%	27%
		Eggplant types (fruits and leaves)	*Solanum* spp. (e.g. S. *aethiopicum*, S. *anguivii*, S. *torvum*)	b, s, f	41.6%	52%
Sweets	Snacks	Sugarcane, sugar	*Saccharum officinarum* L.	r, d	51.6%	69%

*b = boiled, d = dried, f = fried, r = raw, rs = roasted, s = steamed

† Percent of households wherein the food item was cited in 24-h recalls (number of households per recall = 95)

†† Percent of households with this plant growing in their homegardens (Whitney *et al.* 2018a). n. p. = not present

§ Vitamin A rich

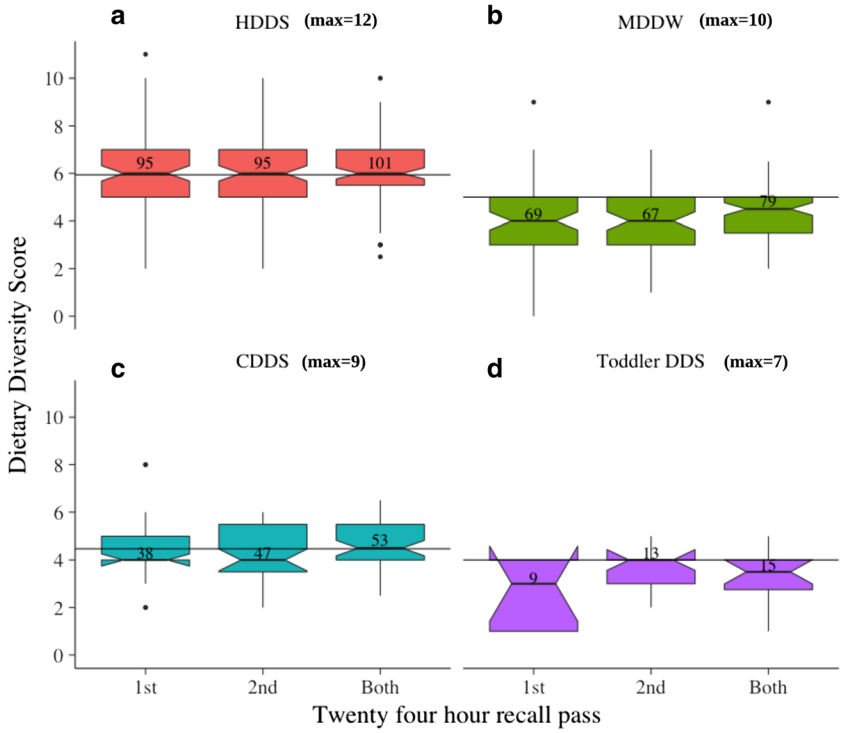

Fig. 3 Dietary diversity scores for whole households or respondents of different age groups (median scores given for all individuals of the respective group) in 102 households in nine villages in southwestern Uganda, **a.** Household Dietary Diversity Score (HDDS), **b.** Minimum Dietary Diversity for Women age 15.0 to 49.9 years (MDD-W), **c.** dietary diversity for children age two to 5.9 years (CDDS), **d.** Dietary diversity for toddlers age six months to 1.9 years (Toddler DDS). '1st' on the x-axis indicates households and individuals who participated in the first 24-h recall, '2nd' for those who participated in the second 24-h recall and 'Both' for the household mean for the two 24-h recalls. The number of households (HDDS) and number of households with members in the respective categories (MDDW, CDDS, Toddler DDS) is indicated above the boxplot median. A black line across the boxplot is used to indicate the target level for adequate dietary diversity

Rubirizi (median 5, range 2–8). They also were closer to markets, had greater levels of employment (Bushenyi), and had more income generating outside employment, e.g., as farmhands and brick makers (Sheema). In Rubirizi households had lower levels of formal education and employment and lower access to resources such as medicine and markets.

Interviews and observations indicated that poor health was a major challenge for households and for homegarden management. For a variety of reasons cited by respondents, sick household members often failed to access medicine. Modern medicine and trained medical experts rarely made it to the village level in the research area (we could find only two medically trained people). Consequently, household members who were ill often went undiagnosed and accessed medicine only in dire circumstances causing a major shock to the household economy (two households sold critical portions of their land to pay for unexpected medical expenses). Respondents cited many health issues including frequent outbreaks of malaria (1–3 times annually per household), typhoid (small outbreaks every few years), and infestations with intestinal parasites (frequent in all households). Common chronic health problems included physical disability (three households had a severely physically disabled person), AIDS (in at least two households), onchocerciasis (river blindness; two households), and non-communicable diseases, e.g., high blood pressure, and diabetes mellitus type II. Mental disability was also common, notably alcoholism was observed and cited as a major issue in the study area (five households had severely alcoholic members). Many children suffered from diarrhea (observed in four households with open defecation). We commonly observed poor health conditions (those listed above and others) that could suggest a combination of malnutrition and diseases such as infections as well as endo- and exoparasites, such as fleas and bedbugs, which were commonly found in all villages.

Hypothesis Testing

The many hypotheses regarding dietary diversity (Fig. 2) were partially confirmed with correlation (r_s range − 0.52 to 0.96; Fig. 4) and with regression models explaining between 16 and 50% of variance in dependent variables (Fig. 5). Women's diets (MDD-W), household diets (HDDS), and fruits within household diets were strongly positively correlated with children's diets (CDDS) (r_s > 0.7; Fig. 4). Women's diets also had a strong positive influence on children's diets (Fig. 5). Concerning socioeconomic conditions, MPI showed an expected negative effect on

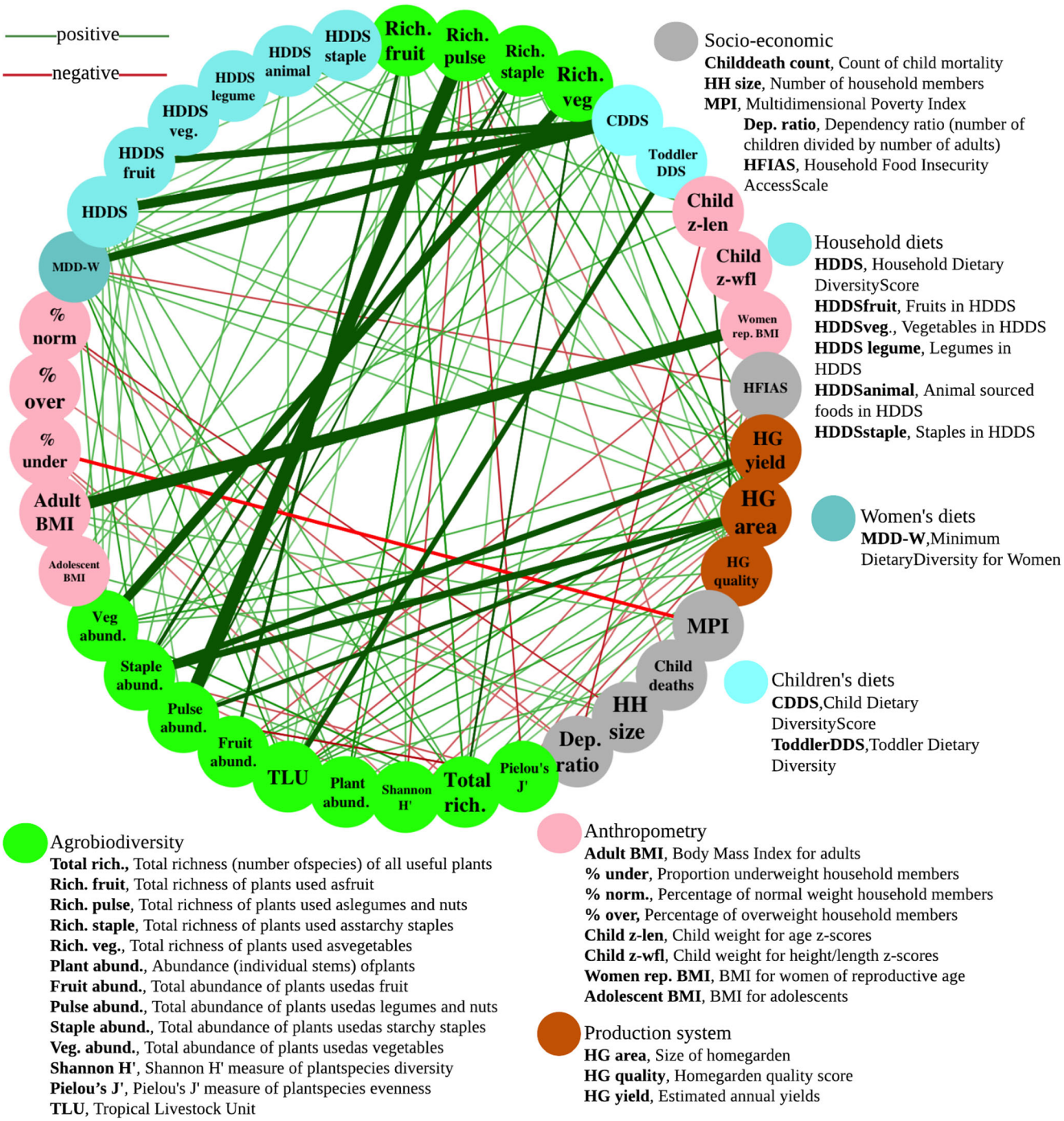

Fig. 4 Spearman's rho correlational analysis for homegarden agrobiodiversity and production system parameters, and socio-economic status, median dietary diversity scores per age group and per household, and median anthropometric measurements per age group and household assessed for 102 households (HH) in southwestern Uganda (variables listed in Table 1). Green for positive and red for negative correlation. Size of edges relative to r_s (range − 0.52 to 0.96), darkness of edges relative to significance. Correlations shown only for significant ($p < 0.05$) relationships related to hypotheses presented in Fig. 2

household diets. Regarding production systems, homegarden yield showed a positive effect on women's diets, as did homegarden area on children's diets. Concerning agrobiodiversity, plant species richness had a positive influence on women's diets and household diets, as did plant abundance on household diets, and TLU on women's and toddler's diets (toddler DDS). The richness of staples had a positive influence on toddler's diets, and the richness of vegetables had a positive effect on household diets. The abundance of staples had a positive influence on toddler's diets, women's diets, and household diets, as did vegetable abundance on household diets (Fig. 5).

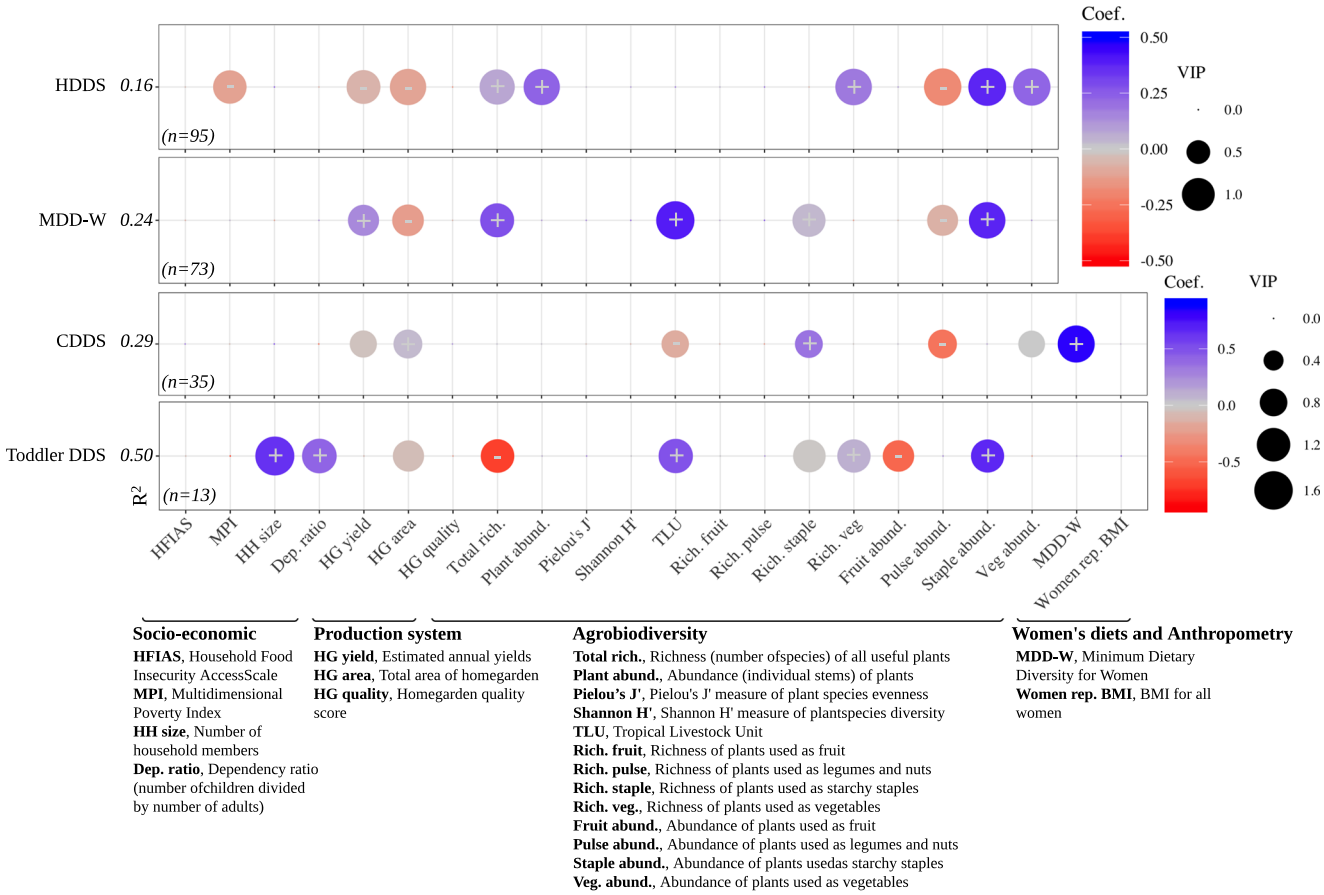

Fig. 5 Four PLS regression models of dietary diversity of households (HDDS), women (MDD-W), children two to six years (CDDS) and toddlers six months to two years of age (Toddler DDS) as dependent variables (y-axis) and socio-economic, agrobiodiversity and production system (as well as MDD-W and anthropometry of women for the model of CDDS and Toddler DDS) as independent variables (x-axis) (variables listed in Table 1). Regression coefficients (Coef.) indicated with circle colors and variable importance in the projection (VIP) indicated with circle size shown in the main plot area. Strength of the model R^2 is shown for each model

Contrary to our hypotheses (Fig. 2) household diets and women's diets were not correlated with toddler's diets and no or only very weak statistical correlations were detected between agrobiodiversity and production system variables and dietary diversity (Fig. 4). Household size and dependency ratio had an unexpected positive influence on toddler's diets (Fig. 5). Homegarden area had a negative effect on household diets and women's and toddler's diets. Plant species richness had a negative effect on toddler's diets, as did TLU on children's diets. The abundance of fruit had a negative effect on toddler's diets, as did the abundance of pulses on children's diets, women's diets, and household diets. Homegarden quality was not significant in any model and no effect was detected for the BMI of women on children's or toddler's diets (Fig. 5).

The many hypotheses regarding anthropometry (Fig. 2) were partially confirmed with regression models explaining between 21 and 75% of variance in dependent variables (Fig. 6). Regarding dietary diversity, household diets had a strong positive effect on adult anthropometry (adult BMI and women's BMI) and on the percentage of household members who were overweight. HDDS animal, the binary for ASF within the household diets, also had a positive effect on children's height (z-len) and weight for height (z-wfl), as well as the percentage of household members who were overweight and those of normal weight. Concerning socioeconomic conditions, HFIAS had a negative effect on child z-wfl; MPI had a negative effect on child z-len, and the anthropometry of adolescents and adults (adolescent, adult, and women's BMI) and an expected positive influence on the percentage of household members who were underweight. Family size had an expected negative effect on the percentage of household members who were normal weight, and dependency ratio had a negative effect on the percentage of household members who were normal weight and overweight. Regarding production systems, homegarden yields had a positive effect on child z-len and adolescent BMI, as did homegarden quality on child z-len. Concerning agrobiodiversity, total plant species richness had a positive influence on child z-len, H′ had a positive influence on child z-wfl and a negative influence on the percentage of household members who were underweight. The richness of staples had a positive influence on adolescent BMI (Fig. 6).

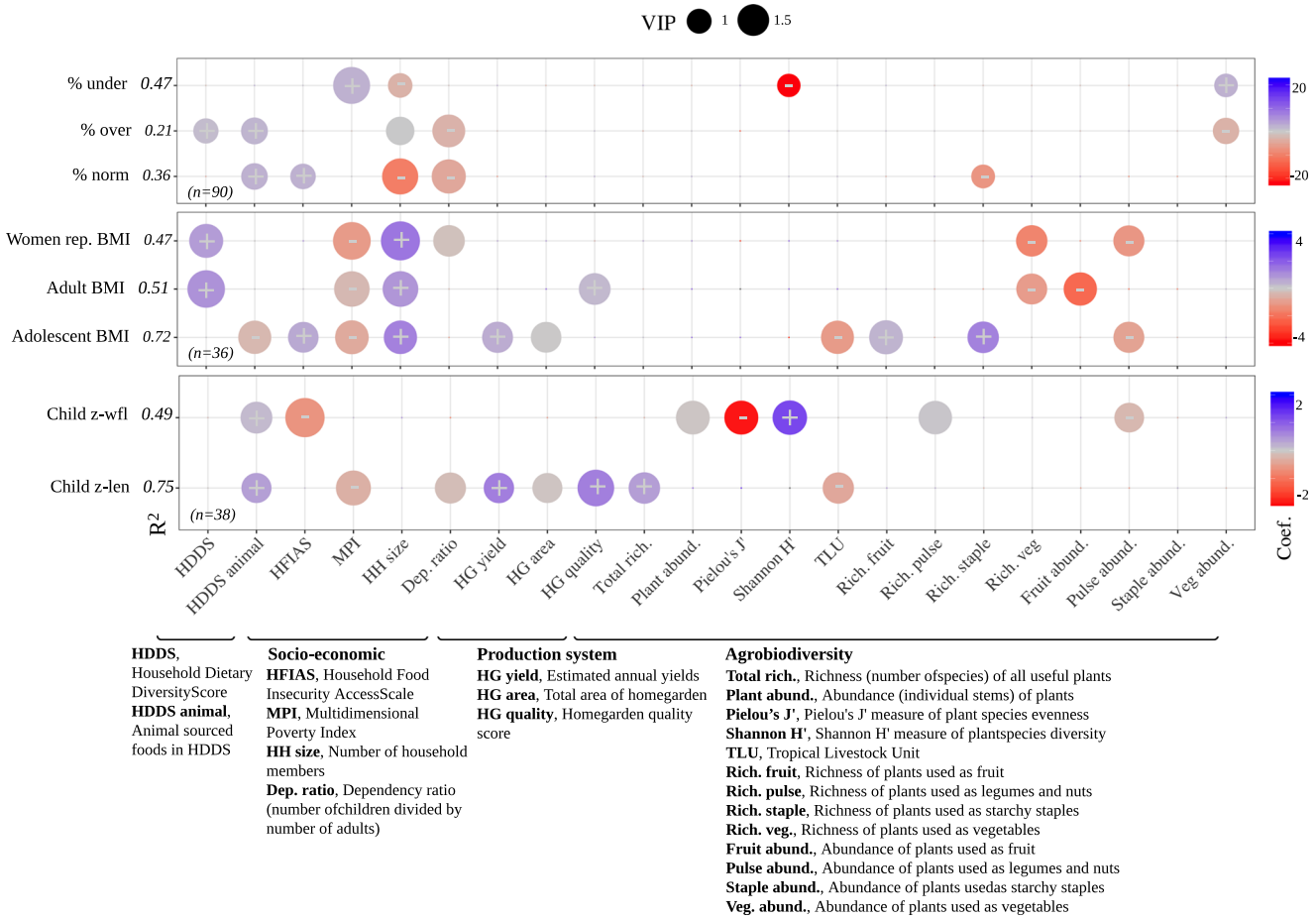

Fig. 6 Three PLS regression models with anthropometric measurements as dependent (y-axis) and with socio-economic, agrobiodiversity and production system variables as independent variables (x-axis) for 102 randomly selected households in southwest Uganda (variables listed in Table 1). Legends (right) refer to adjacent panels. Regression coefficients (Coef) indicated with circle colors and variable importance in the projection (VIP) indicated with circle size shown in the main plot area (only relationships with VIP > 1 are shown). Strength of the model R^2 is shown for each dependent variable

Contrary to our hypotheses (Fig. 2) no or only very weak statistical correlations were detected between agrobiodiversity and production system variables and anthropometric variables (Fig. 4). Family size also had an unexpected positive effect on the anthropometry of adolescents and adults and a negative influence on percentage of household members who were underweight (Fig. 6). We also detected an unexpected positive influence of HFIAS on the percentage of household members of normal weight. Plant species evenness (Pielou's J') had an unexpected negative effect on child z-wfl, as did TLU on child z-len and adolescent BMI. Unexpected negative effects were revealed for richness of staples on the percentage of household members with a normal weight, richness of vegetables on BMI for women and all adults, fruit abundance on adult BMI, pulse abundance on child z-wfl and BMI for women and adolescents. The abundance of vegetables also had an unexpected negative influence on the percentage of household members who were overweight and positive influence on those who were underweight (Fig. 6).

Discussion

Our findings suggest that the households in the study region face many challenges related to poverty and malnutrition, similar to other small-scale farmers globally (Altieri 2002; Galluzzi *et al.* 2010; Huai and Hamilton 2009; Kumar and Nair 2004). The region's homegardens are well adapted to local agro-ecological conditions (Whitney *et al.* 2018a) and diets. However, diets and health outcomes are problematic in the region and both short and long-term nutrition interventions are required to mitigate food insecurity and malnutrition, as is the case in many subsistence systems (FAO 2011). The Ugandan government seeks to improve these conditions (United Nations 2015) and is on track to reduce poverty and malnutrition (UBOS and ICF 2012). Promotion and development of small-scale farming systems such as homegardens that provide a diversity of nutritious foods throughout the year may serve to help the country meet these ambitious goals.

The most critical effects on dietary diversity and anthropometry revealed through this study were related to the

interactions between poverty, food insecurity, and homegarden crop diversity. Homegarden agrobiodiversity and production systems had some positive effects on anthropometry and dietary diversity (Figs. 5 and 6). There were also many weak or counterintuitive relationships among agrobiodiversity, diets, and anthropometry (Figs. 4, 5, and 6), which indicate the system complexity that is difficult to capture. Further investigations into these systems should start with these confounding relationships to gain a deeper understanding of the influencing factors for diet diversity and anthropometry. The strength and direction of relationships between agrobiodiversity and dietary and anthropometry outcomes (Figs. 5 and 6) could be used to generate specific interventions to household food and nutrition. Gathering and further enhancing local knowledge on plants of economic, ecological, and socio-cultural significance (Whitney *et al.* 2018b) may help create more sustainable nutritional and agricultural development approaches.

Our approach of working closely with farmers helped us to generate multiple testable hypotheses (Fig. 2) that were seen as a general guidance for the methods and inputs to the models. It may be useful to follow these approaches with more transdisciplinary investigations that include social, agronomic, and nutritional scientists, working in tandem with farmers to improve agriculture and nutrition. Such studies could raise awareness among governmental and non-governmental organizations, including extension workers, to acknowledge and further support resilient traditional local food systems.

Dietary Diversity and Anthropometry

Households managed their homegardens as a source of regular and diverse food. The majority of foods cited in 24-h recalls were harvested and consumed on the same day, which reflects the importance of continuous supply from the homegarden. This is further illustrated by the effect of homegarden agrobiodiversity (e.g., richness and H′) on child anthropometry (Fig. 6) and production systems (e.g., homegarden area and quality) on dietary diversity (Fig. 5). These results are similar for rural poor farmers in Kenya, where a positive relationship was found between agricultural and dietary diversity (Romeo *et al.* 2016). It is also consistent with other studies on the importance of homegardens for food in Uganda (Oduol and Aluma 1990) and around the world (Atta-Krah *et al.* 2004; Kehlenbeck *et al.* 2007; Kumar and Nair 2004).

Crop diversity in the surveyed homegardens also acts as a kind of food availability insurance that may have an effect on dietary diversity in times of food scarcity and ultimately an effect on anthropometry over the longer term. Many plants (e.g., tubers such as *Xanthosoma* and *Dioscorea* spp.) have a flexible harvest time and are intended for times of food scarcity. The diverse fruiting times can allow production even in seasonal hunger periods (Kehlenbeck *et al.* 2013) and the variety of products can provide resilience in local food systems (Powell *et al.* 2013). Rural households in Malawi, Mozambique, and Zambia, for example, rely on fruits as a coping strategy during these times (Akinnifesi *et al.* 2004). Further investigations into the seasonality of harvests and the relationship to periods of hunger (e.g., crop damaging droughts and storms) could provide information about crop combinations that are best suited for dealing with food insecurity in times of food scarcity, e.g., resulting from future climate variability.

Many household members were receiving an unbalanced diet (Fig. 3) and their diets were generally very homogenous, mostly starchy foods and legumes, similar to other studies in Uganda (cf. Rambeloson *et al.* 2012). Children ate highly monotonous diets (cf. Ssewakiryanga 2015) with low diversity (cf. Isingoma *et al.* 2017; Masumo *et al.* 2013) that often did not meet the minimum acceptable diet (UBOS and ICF 2017). Child anthropometry revealed high rates of stunting (46%) as well as some wasting (3%), similar to past studies of Uganda's Western region (44.8% stunting and 2.7% wasting; Jilcott *et al.* 2007), which may be at least partly due to a poor diet. Low and inconsistent dietary diversity across the study area is mainly due to a lack of knowledge about the importance of diverse foods. Collaborative workshops on dietary diversity could work to generate more knowledge on good horticultural practices, food preparation, and the benefits of consuming vegetables and fruits.

The positive effect of ASF on anthropometry outcomes (Fig. 6) indicates that increasing access to animals may be part of the solution to the frequent poor health in the study region, i.e., from lack of protein and vitamin B_{12} (Allen and Dean 1965; Rambeloson *et al.* 2012). However, ASF were eaten by few participants in our study, similar to other areas of Uganda (Ssewakiryanga 2015). Given the limited access to foraging, hunting, and agricultural land, households are reliant on very limited animal production in smaller homegardens (Whitney *et al.* 2018a) thus limiting access to ASF. Poultry and other small livestock production could improve diets (Romeo *et al.* 2016) since the addition of at least small amounts of animal-sourced foods may be very beneficial, especially for young children (Reinbott *et al.* 2016a).

The low dietary diversity of women compared to children and toddlers (Fig. 3) indicates that mothers provide a more diverse diet to the family than they eat themselves. Their diets had a strong positive influence on child diets (Fig. 5). Targeting women for implementation of diet related interventions is likely to have a positive effect across households (cf. Anderson 2015; Müller and Krawinkel 2005).

Our results indicate that changing diets across the study region may have negative health outcomes. One major concern is that the consumption of sugars and sweets (mostly raw sugarcane and sugar in tea) was relatively high (consumed by 58% of respondents). These foods were made up of less

refined sugar than those in urban areas (Masumo *et al.* 2013). However, as people transition from subsistence homegardens to market-oriented food systems, the negative health implications of refined sweets may increase (e.g., obesity and subsequent diabetes mellitus type II). Preserving traditional farming systems with their associated food diversity may be one means to prevent non-communicable nutrition-related diseases, already a significant burden in urban areas and in wealthier regions of Uganda (Turi *et al.* 2013).

Poverty Related Issues

The impacts of poverty indicators (MPI, family size, dependency ratio) on household diets and anthropometry (Figs. 5 and 6) indicates that increases in household wealth can help reduce some of the pressures on diets and anthropometry. However, some results were contrary to the proposed hypotheses (family size on BMI for all age groups and percentage of household members who were underweight, and both household size and dependency ratio on toddler dietary diversity; Figs. 5 and 6) and may indicate a synergistic role of poverty on malnutrition. Stunting prevalence was higher in the study area (46% vs. 33%) compared to the wealthier communities of east-central Uganda, whereas child underweight (13% vs. 27%) and wasting (3% vs. 18%) were lower (Lwanga *et al.* 2015). This is an indication of a higher risk of chronic child under-nutrition in the subsistence-based food systems, despite protecting children from acute undernutrition.

In the current study slightly more women (73% vs. 72%), but fewer men (59% vs. 75%), were found with normal BMI (within the 18.5 to 24.9 kg/m^2 range) than in the health survey (UBOS and ICF 2012). However, more households had a malnourished adult (28% vs. 14%) (Levine *et al.* 2012). Poor health is exacerbated by extreme difficulty in accessing medicine (UBOS and ICF 2012). According to our observations, many of the village sick go undiagnosed and access medicine only in dire circumstances. Only one person reported taking medicine in the 24-h recall (diabetes medication), although many people were sick at the time of the interviews (~15%) and many plants were also used for medicine (60% of plant species, Whitney *et al.* 2018b). Research into the effectiveness of these plants and supplementation with modern medicine (cf. Chapman 2018) may be an effective strategy in improving health outcomes in the study area.

Households with more children tended to suffer more food insecurity, i.e., child height was negatively correlated with household dependency ratio (r_s −0.33, p = 0.03; Fig. 4). Similarly, in sugarcane growing communities of east-central Uganda, the percentage of households with malnourished children significantly increased with the number of children in the households (Lwanga *et al.* 2015). Malnutrition in these households may start from an early age and such households should be targeted for early childhood nutrition efforts.

Market Based Interventions

The households in this study suffered less food insecurity in comparison to the market oriented sugarcane growing communities of east-central Uganda, where cash crops have replaced subsistence food production (Lwanga *et al.* 2015). Fewer were considered food insecure (5% in the present study vs. 12% in east-central Uganda) and fewer had mild (10% vs. 15%) and severe food insecurity (40% vs. 50%) (Lwanga *et al.* 2015). The negative effects found for plant abundance on diets and anthropometry (Figs. 5 and 6) suggest that greater production does not necessarily increase the volume and quality of food for the household. Similarly, the negative effect of TLU on children's diets, child z-len, and adolescent BMI (Figs. 5 and 6) indicates that greater animal production does not necessarily offer the benefits of increased ASF.

Market interactions may play a role in the poverty outcomes of the study region, i.e., Bushenyi and Sheema had lower MPI and higher market access, whereas Rubirizi had higher MPI and little market access. Markets could be utilized to improve local livelihoods. They can supplement household nutrition in times of scarcity (Whyte and Kyaddondo 2006), reducing hunger (Ng'endo *et al.* 2015) and leading to better anthropomorphic outcomes (Galvin *et al.* 2015). However, without a secure income households cannot be expected to access markets to get foods for a balanced diet (Ssewakiryanga 2015). For this reason, caution should be used when implementing agricultural changes proposed in the government's development agenda 'Vision 2040,' which emphasizes a shift from small-scale farming to industrial agriculture (NPA 2007). Agricultural extension under Vision 2040, such as the National Agricultural Advisory Services program, tends to benefit households with high-value enterprises (Benin *et al.* 2011). There is a danger that these interventions will function to displace farmers, thereby reducing their access to diverse foods and decreasing dietary diversity and household nutrition (Whitney *et al.* 2017). A better strategy may be to help farmers use their local resources and capacities to access sources of income, e.g., through sales of traditional homegarden products. This may have the multiple benefits of increasing food and nutrition security and dietary diversity while at the same time maintaining traditional agrobiodiversity.

Household Food Insecurity

The negative effects of experiences of food insecurity (HFIAS) on child anthropometry (Fig. 6) indicate the strength of this measure for capturing food insecurity incidents. Almost all households with a malnourished child were food

insecure according to HFIAS. Fewer of our sampled households experienced worry about fulfilling their food needs (49% vs. 59%), despite more of them experiencing insufficient food quality and quantity (Kabunga *et al.* 2014) and more frequent food shortages (68% vs. 50%) compared to households throughout Uganda (Ssewakiryanga 2015). This discrepancy between the impression of potential and actual food insecurity events may be due to the experience of unexpected food shortages. Local food shortages fluctuate throughout the year due to seasonal pressures, e.g. at the end of the dry season and before the harvest season. It may be useful for future studies to apply these methodologies at the end of a dry season to compare the relative change in times of greater need and any supplementation of homegarden production, e.g., through wild food collection.

Nutrition Interventions

The quality of diets in the study area is insufficient, as is the case with diets across Uganda (Imamura *et al.* 2015). This indicates a great need for nutrition interventions and raising awareness at all levels. However, no formal nutrition-related efforts were cited in our study area, compared to 69% in a study across Uganda (Ssewakiryanga 2015). A variety of interventions including diet related education and support, with special attention to gender issues and vulnerable groups such as pregnant women and young children, is likely to be most effective in addressing severe malnutrition (Müller and Krawinkel 2005). Food and nutrition security interventions may be successful if they focus on these traditional food systems (Anderson 2015; Pillai *et al.* 2016; Reinbott *et al.* 2016b; Waswa *et al.* 2015) and customs, since any successful changes to these systems will require a perceived need or proven advantage, convenience and ease of use, and a demonstration model (Anderson 2015). These rural small-scale farming communities define food security as access to food grown at home (Whyte and Kyaddondo 2006). Therefore, collaborative interventions (with health extension workers, NGOs, local council officials, and community members) that complement homegarden production, e.g., cooking classes and nutrition-related village meetings to raise awareness of the importance of eating fruits and greens, are likely to be most effective in addressing food and nutrition insecurity.

Conclusions

Understanding food and nutrition security in dynamic and variable production environments is important when attempting to address the inter-related problems of hunger and poverty faced by rural farmers. This study documents the varied influences of biophysical and socioeconomic factors on homegarden-based food systems and their dietary and anthropometric outcomes. Homegardens are the main source of food for households in the southwest of Uganda. They can offer a diverse range of products and may be seen as an endogenous tool for strengthening rural livelihoods and productivity, as well as generating resilient landscapes that contribute to food, nutrition, and income security for smallholder farmers.

Traditional homegardens may hold endogenous solutions for the many confounding issues related to household poverty and food insecurity. However, low dietary diversity and high stunting rates show that these systems can be improved, through both the integration of specific micronutrient-rich crops and by offering nutrition information and training to impress the importance of frequently eating fruits and vegetables. Balancing interventions with important local knowledge, e.g., homegarden management, health and nutrition, and postharvest processing for preserving food over lean periods, can tackle the many challenges of overcoming poverty and food insecurity while maintaining traditional culture and agrobiodiversity.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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