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Coffee Agroforestry and the Food and Nutrition Security of Small Farmers of South-Western Ethiopia

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Agroforestry generally contributes to rural food and nutrition security (FNS). However, specialization on commodity-oriented agroforestry practices or management strategies can weaken local food sourcing when terms of trade fluctuate, as is the case of coffee in Ethiopia. Hence, this study assessed the trade-offs that smallholder farming households in south-western Ethiopia face between growing coffee in agroforestry systems and their food and nutrition security based on home production as well as markets. Data collected from 300 randomly selected households included: (i) attributes of agroforestry practices (AFP) and plants: structure, use type, edibility, marketability, nutritional traits, and (ii) the householders' FNS attributes: food security status, nutritional adequacy, and nutritional status. Data were collected both in food surplus and shortage seasons, during and after coffee harvesting. Within these data, the number of plant species and vegetation stories were significantly correlated with household food access security in both seasons and for all AFP identified, i.e., homegarden, multistorey-coffee-system, and multipurpose-trees-on-farmlands. The number of stories in homegardens and the richness of exotic species in multipurpose-trees-on-farmlands were significantly correlated with the biometric development of children below 5 years old during the shortage season. The richness of "actively-marketed" species in all AFP correlated with the food access security of the household, except in the multistorey-coffee-system, oriented to coffee production. Also, families that cultivate all three AFP showed significantly higher household diversity dietary during the shortage season. We conclude that no single AFP can secure FNS status of the households by itself, but the combination of all three can. Household and individual dietary scores were positively correlated with the AFP diversity-attributes, especially in the shortage season. Thus, the diversity of useful groups of plant species deserves to be promoted for instance by enriching AFP with edible and storable crops needed during the shortage season.

Keywords: food and nutrition security metrics, homegarden, livelihoods, multipurpose trees, multistorey coffee, traditional agroforestry, Yayu biosphere reserve

INTRODUCTION

Agroforestry systems, among other virtues (van Noordwijk, 2019, 2021), can help address various dimensions of food insecurity through local production and market exchange, and supply non-food agricultural tree products while contributing to maintenance of environmental quality (Mbow et al., 2014; Iiyama et al., 2015; Catacutan et al., 2017). This is particularly important for the rural poor in the global south, where improving people's food and nutritional security, bettering their livelihoods, and maintaining environmental quality are fundamental goals (Duguma et al., 2001; Ickowitz et al., 2014; Mbow et al., 2014).

Agroforestry can contribute to the five pillars of food and nutrition security (FNS): food availability, utilization, stability, sovereignty, and access (Duguma et al., 2001; Jamnadass et al., 2013; Ickowitz et al., 2014; Mbow et al., 2014; Sarvade et al., 2014). Agroforestry can contribute to food availability, directly via the production of food from the perennial component(s), and indirectly through the enhancement of the production of related crops and/or animal component(s) (Jamnadass et al., 2013; Sarvade et al., 2014; Toensmeier et al., 2020). For example, the enset-coffee homegardens of the Sidama and Gedeo communities in southern Ethiopia include the perennial *Ensete ventricosum*, which serves as staple food for about 15 million people in the region (Abebe, 2013). In Sudan it was estimated that scattered trees of *Faidherbia albida* have increased the harvests of surrounding cereals and groundnut up to 200% (Fadl and El sheikh, 2010). Pearl millet yield was recently found to be three times higher below the tree crown than at five tree-crown radii (Roupsard et al., 2020).

Firewood is a major contribution of agroforestry to the food utilization pillar as cooking increases digestibility of many food sources and boiling drinking water prevents diseases. The diversity of products and byproducts that diverse AFS generate is reported to be the most affordable and sustainable way to abate micronutrient deficiency (Thompson and Amoroso, 2010; Susila et al., 2012). For instance, data from 21 African countries collected between 2003 and 2011 with up to 50% forest cover, show a strong correlation between tree cover and dietary diversity (Ickowitz et al., 2014). Mbow et al. (2014) identified fruits, nuts, and leafy vegetables that grow in AFS as the farmers' major source of micronutrients; and Abebe (2005) and Méndez et al. (2001) highlighted homegardens as the key practice for such nutrient.

Food stability relates to all other pillars and requires consistent availability of edible species throughout the year, and is favored by agroforestry systems composed of multiple species, some of which can serve as "emergency foods" if needed. For example, in the Konso community in southern Ethiopia, *Moringa stenopetala*, growing in successional agroforestry systems, fill the gaps between annual crop harvests (Förch, 2003). Similarly, *Vitellaria paradoxa* and *Sclerocarya birrea*, components of agroforestry parklands in the Savannah are reported to be source of food to locals during droughts and crop failure in several parts of Africa (Maranz et al., 2004; Mojeremane and Tshwenyane, 2004; Jamnadass et al., 2013).

The food sovereignty pillar refers to the ability of a local household to choose what food to cultivate, purchase and/or eat, while maintaining the required nutritional value (Altieri et al., 2011; Wilson, 2015; Ngcoya and Kumarakulasingam, 2017). The polyculture farming system of agroforestry promotes households' food sovereignty by permitting farmers to cultivate food and non-food crops that are demanded by both the household and the market. It may also allow both genders to realize the species complements they prefer (Sari et al., 2020). In addition, this type of farming system allows integrating cash crops into farming plots, which may improve the household's financial capacity to purchase other foods. For example, smallholders of Yayu, south-western Ethiopia, use their homegarden to grow plenty of native food species of less market demand, but of greatly demanded by the majority household as a food of shortage season such as *Ensete ventricosum*, *Brassica carinata, Brassica oleracea* var. *oleracea*, *Colocasia antiquorum*, and *Dioscorea alta* (Jemal, 2018).

Finally, regarding the food access pillar, agroforestry practices or management strategies that focus on the production of easily marketable products, like *Coffea arabica* and *Theobroma cacao* and other merchantable products like fruits, stimulants, spices, wood, resins, etc., can generate cash for the household, and the earnings gained can be used to buy food when insufficient food is produced (Duguma et al., 2001; Gole et al., 2009; Abebe, 2013). As discussed by van Noordwijk et al. (2014), this can, depending of the terms of trade, take the form of "outsourcing" staple foods where these can be more efficiently be produced elsewhere and be easily stored and transported, while other components of the diet, including fruits, spices, and vegetables remain locally sourced.

Although the contributions of agroforestry to each of the pillars of food security have been acknowledged, much of the evidence is only partial and qualitative, and it is not clear that all five pillars have been simultaneously addressed. This contrasts with other types of farming systems where comprehensive account of FNS were examined, for example by Walton (2012), for smallholder dairy farms in Kenya and by Jones et al. (2014) for smallholder mixed farm households in Malawi. These studies identified entry points for future interventions to improve FNS, which are still missing in agroforestry systems.

The first four pillars of FNS, availability, utilization, sovereignty, and stability, are mostly endogenous and therefore depend on the households themselves, within the environmental opportunities and constraints. The fifth, access, is mostly determined by external market forces, where householders have limited leverage. For agroforestry systems whose main component has a commercial value, fallback local food sourcing may be essential to bridge periods of unfavorable terms of trade (farmgate prices), as is the case with coffee in southern Ethiopia (Beghin and Teshome, 2016; Kuma et al., 2016; Shumeta and D'Haese, 2018).

Aiming to narrow this gap, the present study assessed the tradeoffs that smallholder farming households in south-western Ethiopia face between growing coffee in agroforestry systems and ensuring the food and nutrition security of their own households. Our specific objectives were to estimate (i) the structure and composition of agroforestry practices (AFP); (ii) AFP utilization and marketability of products; (iii) the edibility and nutritional traits of AFP component species; and (iv) the associations

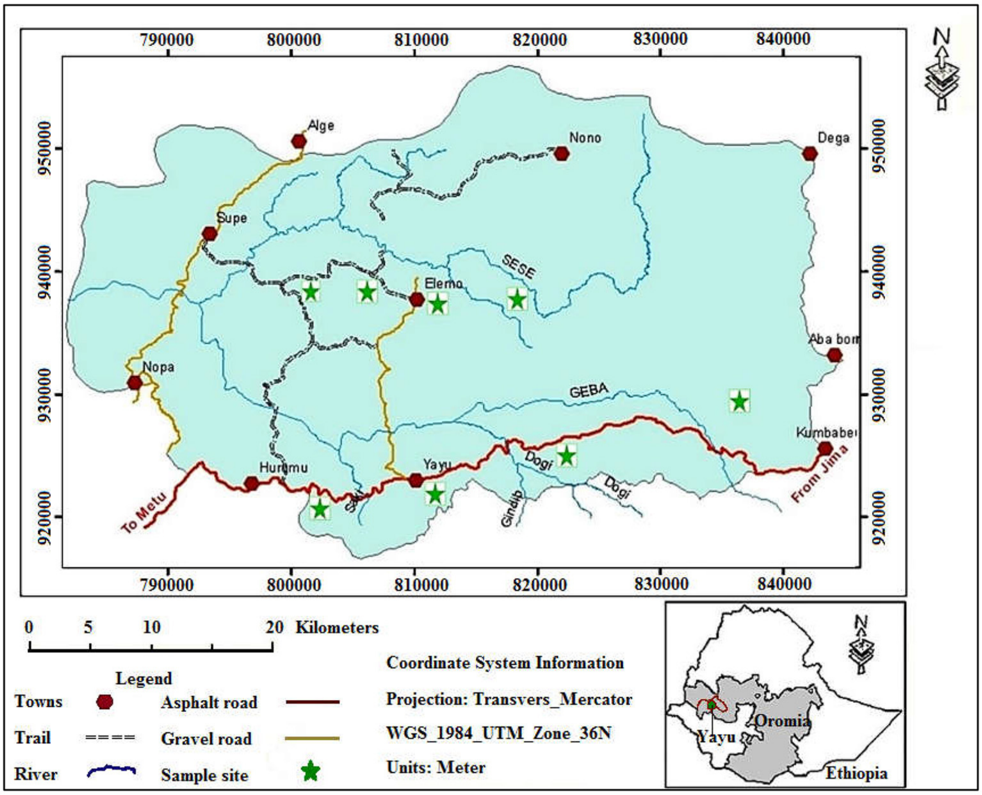

FIGURE 1 | Map of Yayu in Ethiopia (adapted from Ilfata, 2008).

between the main identified features of AFP's and the FNS indices of smallholding farming households.

MATERIALS AND METHODS

Study Area

The study was performed in the Yayu biosphere reserve area (∼168,000 ha), located in the south west of Ethiopia, at a distance of about 550 km from Addis Ababa (**Figure 1**). The elevation of the area ranges from 1,140 to 2,562 m above sea level. According to the 2007 population census, Yayu was home to 308 994 people (CSA (Central Statistics Authority), 2007; Gole et al., 2009).

This research is part of several studies that analyzed the potential of agroforestry systems in the FNS of smallholding farmers in Yayu (Jemal et al., 2018, in review; Callo-Concha et al., 2019; Aragaw et al., 2021; Usman and Callo-Concha, 2021). Hence, the sampled households were the same ($n = 300$) belonging to 8 kebele[1] units.

Two data sets, (i) the characterization of AFP ($n = 300$) and (ii) the householder FNS attributes ($n = 140$), were collected separately between January 2014 and August 2016, aiming to cover the food surplus and shortage seasons. The surplus season refers to the post-harvest period of coffee and cereals between January and March, where farmers have money available and foodstuff appears to be plentiful; the shortage season refers to the pre-harvesting period from June to September, when normally there is a scarcity of both food and cash.

[1]*Kebele* is the smallest administrative unit of Ethiopia, population reaching up to 4,000 peoples.

Characterization of AFP

Three major agroforestry practices dominate Yayu, i.e., homegarden (HG), multistorey-coffee-system (MCS), and multipurpose-trees-on-farmland (MTF) (Jemal et al., 2018). HGs locate nearby the homestead, are relatively small and composed with multiple species that overall produce food and eventually generate income. MCS are intended for the cultivation of coffee mainly and thought of as provider of cash; they include other naturally grown and/or planted species in various strata, often intended for shade and productive functions. MTF are generally devoted to the production of the household's food, operating in specific units of land destined for annual crops in combination with woody perennials to maximize the overall output (Jemal et al., 2018).

The characterization of the AFP was carried out by an extensive household and ethnobotanical survey, field observation, and plot measurements. The data included: (i) AFP composition and structural characterization, including the species, number, growth habits, origin, and number of strata, were supported by a local taxonomist and specific literature (Mooney, 1963; Kelecha, 1987; Mesfin and Hedberg, 1995; Das and Das, 2005; Bekele-Tesemma, 2007; Teketay et al., 2010); (ii) Species utilization and marketability potential, the species richness and diversity of use types, and "marketable" crops per plot were considered; and; (iii) Species edibility and nutritional traits, were assessed through the species richness and diversity of the following categories: "total (potentially) edible," "active food," and 10 pre-defined food groups adopted from FAO (Kennedy et al., 2011). "Active food" represent species primarily cultivated for food, whereas "total edible" includes both the "active food" and the "potentially edible species" which are not primarily grown as food but with at least one of its parts are edible. Similarly, the 10 plant food groups considered were "cereals," "white root and tubers," "vitamin-A-rich vegetables and tubers," "dark green leafy vegetables," "other vegetables," "vitamin-A-rich fruits," "other fruits," "legumes, nuts, and seeds," "sweets," and "spices, condiments, and other food & beverage additives." The richness of each of these groups was calculated using Menhinick's index (Equation 1) (Marrugan, 1988).

$$D = S/\sqrt{N} \tag{1}$$

Where D, Menhinick's index; S, number of species of a given use type/food group of a given plot; and N, total species per plot.

Finally, (iv) the type of AFP by household was assessed. Seven types of potential combinations were identified, i.e., only MTF, only MCS, only HG, MTF and MCS, MTF and HG, MCS and HG, and all three: MTF, MCS, and HG.

Household FNS Attributes

For the assessment of the population FNS, a subset of 140 households were selected as in these existed individuals of the sensitive groups: Non-Breast-Feeding children under 5 years (NBF <5), and Women at Reproductive Age (WRA). In a case where more than one child existed, the youngest was chosen; in case of twins, a lottery method was applied (Mulu and Mengistie, 2017).

Data on the household FNS included: dietary intake history and anthropometric measurements. The former was collected after the criteria set by the Household Food Insecurity Access Scale (HFIAS) (Coates et al., 2007) and the Household Dietary Diversity Score (HDDS) (Swindale and Bilinsky, 2006). The HFIAS consists of nine questions focusing on the household food access history termed as "occurrence questions," each of which is contrasted with the "frequency questions" related to the previous 4 weeks. The HDDS counts the food groups that a household has consumed in a given period of time (Kennedy et al., 2011). Twelve (12) food groups were considered as they capture the dietary sources for all members of a household (Swindale and Bilinsky, 2006). Furthermore, data from a 24-hour and 7-day dietary intake history data were used to generate Individual Dietary Diversity Scores (IDDS) (Kennedy et al., 2011) for the targeted sensitive groups. For the latter, the age, weight, and height of the householder belonging to the sensitive groups was measured. Electronic scales precise to 100 g, and wooden collapsible length/height measuring devices precise to 1 mm were used. The age of the children was captured in years and months and of women in years. After these, three z-score indicators were calculated to determine the nutritional status of children, i.e., weight for height z-score (WHZ), weight for age z-score (WAZ), and height for age z-score (HAZ) (WHO, 2006) (Equation 2).

$$z - score_{ij} = \frac{\left(X_{ij} - \left(Reference\ median_i\right)\right)}{SD_i} \tag{2}$$

Where X_{ij}, measurement of jth child at ith age/height; Reference median, median of the reference population at ith age/height; SD_i, standard deviation of the reference population at ith age/height. Reference population was obtained from WHO (2006); age in months; weight in kg and height in cm.

And for women the body mass index (BMI) was used to determine WRA nutritional status (WHO, 1999; FANTA (Food Nutrition Technical Assistance III Project), 2016) (Equation 3).

$$BMI_i = \frac{(Wt_i)}{{Ht_i}^2} \tag{3}$$

Where Wt_i, weight of ith woman in kg; Ht_i, height of ith woman in cm.

The variables detailed above were cross-analyzed using one-way Analysis of Means (ANOM) and Pearson correlation. Minitab 17.0 and Statistica 7.1 software were used.

RESULTS

Composition and Structural Characterization of AFP

The number of plant species and the number of vegetation stories per plot had a significant negative correlation with the household HFIAS index in both seasons and for all agroforestry practices; but when cross analyzed with the scores for Household Dietary Diversity, HDDS, the relation was statistically significant only for the shortage season. Additionally, richness of woody and native species in MCS was negatively (and highly significantly) correlated with HFIAS in both seasons, whereas in the homegardens, the correlation was significant only in the shortage season (**Table 1**).

The number of species in MCS was significantly correlated with the HDDS and IDDS scores of both target population sections (NBF <5 and WRA) during the shortage season. Richness of herbaceous species in HG showed a negative significant correlation with the HDDS and IDDS of both targets (NBF <5 and WRA) during the shortage season only. In contrast, the richness of exotic plant species in HG had a significant correlation with HDDS and IDDS in both target groups during the surplus season (**Table 1**).

Furthermore, the number of stories in HG was significantly associated with height-for-age relation (HAZ) during both seasons; the richness of exotic species in MTF showed a significant negative correlation with the HAZ and the WAZ of NBF <5 during the shortage season. No correlation was detected between AFP attributes and the BMI of WRA (**Table 1**).

TABLE 1 | Pearson correlation among the attributes of three dominant agroforestry practices against food and nutrition security indices of two sensitive groups of rural smallholders in in Yayu during shortage and surplus seasons.

Attribute	AFP type	Household				NBF children <5 yrs								WRA			
		HFIAS		HDDS		IDDS		WAZ		HAZ		WHZ		IDDS		BMI	
		Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage
No. Species	HG	- -	-	0	+	0	0	0	0	0	0	0	0	0	0	0	0
	MCS	- - -	- - -	0	+ +	0	+	+	0	0	0	+	0	0	+ +	0	0
	MTF	- -	- -	0	0	0	+	0	0	0	0	0	0	0	0	0	0
No. stories	HG	- -	-	0	+ +	0	0	0	+	+	+	0	0	0	0	0	0
	MCS	- - -	- - -	0	+ +	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	- - -	- - -	0	+	0	+ +	0	0	0	0	+	0	0	+	0	0
Richness of woody species	HG	0	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MCS	-	- -	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	0
Richness of herbaceous species	HG	0	0	0	-	0	-	0	0	0	0	0	0	0	-	0	0
	MCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of native species	HG	0	0	0	0	-	0	0	0	0	0	0	0	0	0	0	0
	MCS	-	- -	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of exotic species	HG	0	0	+ +	0	+	0	0	0	0	0	0	0	+	0	0	0
	MCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	0	0	0	0	0	0	0	-	0	-	0	0	0	0	0	0

"+" same direction significant association at $p < 0.05$; "+ +" same direction significant association at $p < 0.01$; "-" opposite direction significant association at $p < 0.05$; "- -" opposite direction significant association at $p < 0.01$; "- - -" opposite direction significant association at $p < 0.00$; "0" no significant association.
AFP, agroforestry practice; HG, homegarden; MCS, multi-story coffee system; MTF, multipurpose tree on farmland; HDDS, household dietary diversity score; IDDS, individual dietary diversity score; HFIAS, household food insecurity access scale; WAZ, weight-for-age z-score; HAZ, height-for-age z-score; WHZ, weight-for-height z-score; BMI, body mass index; NBF, non-breast feeding; WRA, women of reproductive age.

Species Utilization and Marketability Potential

Species utilization and marketability potential of AFP were represented by using the count of different uses extracted from the species in each types of AFP and the richness of "actively marketed" plant species in each types of AFP. The count of types of uses of species in all AFPs was negatively (and statistically significantly) correlated with the Household Food Insecurity Access Scale (HFIAS) in both seasons. Whereas, the richness of "actively-marketed" species of HG and MTF have shown a highly and a very highly, respectively, significant negative correlations with HFIAS in both seasons (**Table 2**).

Consistent with these results, the number of species' uses from all types of AFP were observed to have shown at least a significant positive association with household dietary diversity (HDDS) during the shortage season, meanwhile only the richness of "actively marketed" species in HG showed a highly significant correlation during the shortage season. Additionally, the IDDS of NBF <5 and WRA was significantly correlated with the count of species' uses in MCS and MTF and the richness of "actively marketed" species in MTF during the shortage season (**Table 2**).

Regarding the anthropometric indices, a significant positive association was observed between the number of species' uses in HG and the WAZ and the HAZ of the targeted children during the shortage season and both seasons, respectively. Similarly, the number of species' uses in MCS had a significant positive correlation with WAZ and WHZ of the target children group during the lean season. None of the assessed attributes of AFP was significantly correlated with the BMI of WRA (**Table 2**).

Species Edibility and Nutritional Traits

Species edibility-related attributes like the richness of "total edible" species in all AFP plots showed a significant negative correlation with HFIAS in all seasons, except MCS during shortage season, with the strongest association observed in MTF. Similarly, richness of "active food" species in HG and MTF exhibited a significant negative correlation with HFIAS in all seasons, with the strongest association observed in MTF (**Table 3**).

Whereas, both proxies had a significant correlation with the HDDS at HG during the shortage season only. Regarding the IDDS, the "total edible" and "active food" species in MTF showed a significant correlation with both sensitive groups during the shortage season (**Table 3**).

Concerning the anthropometric scores, both proxies in MTF there was at least a significant correlation with the WAZ of the children in both seasons. In addition, HAZ of the target children were detected for significant association with both, the richness of "total edible" and "active food" species during shortage time only (**Table 3**).

Concerning the nutritional diversity traits of AFP, among the available food groups, the species richness of "cereals" in HG and MTF had at least a significant negative correlation with HFIAS during both seasons. Similarly, species richness of "other vegetables & tuber" and "other fruits" food groups in HG had a significant negative association with HFIAS in all season.

TABLE 2 | Pearson correlation among uses and marketability of species composing the three dominant agroforestry practices against food and nutrition security status indices of two sensitive groups or rural smallholders in Yayu during shortage and surplus seasons.

Attribute	AFP type	Household				NBF children <5 yrs								WRA			
		HFIAS		HDDS		IDDS		WAZ		HAZ		WHZ		IDDS		BMI	
		Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage
No. of type of uses per species per system	HG	-	-	0	++	0	0	0	+	+	+	0	0	0	0	0	0
	MCS	- - -	- -	0	+	0	+	0	+	0	0	0	++	0	++	0	0
	MTF	- - -	- - -	-	++	0	+++	0	0	0	0	0	0	0	++	0	0
Richness of "actively-marketed" species	HG	- -	- -	0	++	0	0	0	0	0	0	0	0	+	0	0	0
	MCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	- - -	- - -	0	0	0	+	0	0	0	0	0	0	0	+	0	0

"+" same direction significant association at p < 0.05; "+ +" same direction significant association at p < 0.01; "+ + +" same direction significant association at p < 0.001; "-" opposite direction significant association at p < 0.05; "- -" opposite direction significant association at p < 0.01; "- - -" opposite direction significant association at p < 0.00; "0" no significant association.

AFP, agroforestry practice; HG, homegarden; MCS, multi-story coffee system; MTF, multipurpose tree on farmland; HDDS, household dietary diversity score; IDDS, individual dietary diversity score; HFIAS, household food insecurity access scale; WAZ, weight-for-age z-score; HAZ, height-for-age z-score; WHZ, weight-for-height z-score; BMI, body mass index; NBF, non-breast feeding; WRA, women of reproductive age.

TABLE 3 | Pearson correlation among species edibility and food group diversity of the three dominant agroforestry practices, against food and nutrition security status indices of two sensitive groups or rural smallholders in Yayu during shortage and surplus seasons.

Attribute	AFP type	Household				NBF children <5 yrs								WRA			
		HFIAS		HDDS		IDDS		WAZ		HAZ		WHZ		IDDS		BMI	
		Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage
Richness "total edible" species	HG	-	-	0	+	0	0	0	0	0	+	0	0	0	0	0	0
	MCS	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	- - -	- -	0	0	0	+ +	+	+ +	0	+	0	0	0	+ +	0	0
Richness "active food" species	HG	-	-	0	+	0	0	0	0	0	+	0	0	0	0	0	0
	MCS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	- - -	- - -	0	0	0	+ +	+	+	0	+	0	0	0	+ +	0	0

"+" same direction significant association at $p < 0.05$; "+ +" same direction significant association at $p < 0.01$; "-" opposite direction significant association at $p < 0.05$; "- -" opposite direction significant association at $p < 0.01$; "- - -" opposite direction significant association at $p < 0.00$; "0" no significant association.

AFP, agroforestry practice; HG, homegarden; MCS, multi-story coffee system; MTF, multipurpose tree on farmland; HDDS, household dietary diversity score; IDDS, individual dietary diversity score; HFIAS, household food insecurity access scale; WAZ, weight-for-age z-score; HAZ, height-for-age z-score; WHZ, weight-for-height z-score; BMI, body mass index; NBF, non-breast feeding; WRA, women of reproductive age.

Furthermore, species richness of the "spices, condiments, and other food & beverage additive" food group in MCS were highly significantly and negatively correlated with HFIAS in all season (**Table 4**).

Regarding dietary diversity, only the richness of "other fruits" food groups of HG had a year-round significant association with HDDS, whereas, species richness of "spices, condiments, and other food & beverage additives" food group in all AFP were significantly correlated with HDDS during the shortage season. On other aspect of dietary diversity, richness of "cereals" in HG and MTF had a highly significant correlation with individual DDS of both sensitive groups during the shortage season. Likewise, richness of "other vegetables & tuber" in HG had a significant association with IDDS of both targets in all season (**Table 4**).

Regarding the association of nutritional diversity traits of AFP with anthropometric scores, a positive significant correlation was detected between richness of "cereals" in MTF and WAZ of the target children during both seasons, whereas richness of "cereals" in HG was significantly and negatively correlated with WHZ of the children during both seasons (**Table 4**).

Types of Agroforestry Practices

Households that concentrated on cultivating only MCS had a significantly higher HFIAS during the shortage and surplus seasons, and the ones focusing on HG have significantly higher HFIAS during the shortage season but ($\alpha = 0.05$; **Figure 2A**). In contrast, households with all AFP showed significantly higher HDDS only during the shortage season ($\alpha = 0.05$; **Figure 2B**).

MCS contributed the most to preventing overall food insecurity followed by HG (especially in the shortage season). Interestingly, qualitative aspects of the diets improved slightly in the shortage season for the households that practice all three AFP. That may be due to the reported regular financial input generated by coffee, and the reliance of local farmers to it for the acquisition of food.

Regarding the IDDS, a significant variation was observed only in the shortage season. Households practicing all AFP had a significantly higher dietary diversity ($\alpha = 0.05$) for NBF <5 (**Figure 3A**) and WRA (**Figure 3B**).

Regarding the anthropometric indicators for NBF children under 5, WHZ and WAZ were significantly superior in households practicing all AFP combinations in the surplus and shortage seasons ($\alpha = 0.05$) (**Figure 4**), and households counting with only HG scored significantly lower WHZ in both seasons ($\alpha = 0.05$) (**Figure 4**).

For the individual nutritional status, only households having all AFP were significantly better than others. The same was observed for anthropometric indicators, but interestingly HG was outperformed by the MCS and MTF. It appears that households depending only on HG are facing the risk of lacking staples (mainly provided by MTF) and cash (related to MCS).

TABLE 4 | Pearson correlation among species nutritional diversity traits of the three dominant agroforestry practices, against food and nutrition security status indices of two sensitive groups or smallholders in Yayu during shortage and surplus seasons.

Attribute	AFP type	Household				NBF children <5 yrs								WRA			
		HFIAS		HDDS		IDDS		WAZ		HAZ		WHZ		IDDS		BMI	
		Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage	Surplus	Shortage
Richness of "cereal"	HG	+ + +	+	0	0	0	- -	0	0	0	0	-	-	0	- -	0	0
	MTF	- - -	- - -	0	0	0	+ +	+	+	0	+	+ +	0	0	+ +	0	0
Richness of "white roots and tubers." E.g., enset	HG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of "vit-A rich vegetables and tubers." E.g., carrot, pumpkin, green paper	HG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of "dark green leafy vegetables." E.g., Ethiopian kale	HG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of "other vegetables and tubers." E.g., tomato, red beet	HG	-	-	0	0	+ + +	+ +	0	0	0	0	0	0	+ + +	+	0	0
Richness of "vit-A rich fruits." E.g., mango, papaya	HG	0	-	0	0	0	0	0	0	0	0	0	0	+	0	0	0
Richness of "other fruits." E.g., orange, banana	HG	- - -	-	+	+ +	+	0	0	0	0	0	0	0	+	0	0	0
Richness of "legumes"	HG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	MTF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of "sweets." E.g., sugarcane	HG	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Richness of "spices, condiments, and other food and beverage additive."	HG	-	0	0	+	0	0	0	+	0	+	0	+	0	0	0	0
	MCS	- - -	- -	0	+	0	0	0	0	0	0	+	0	0	0	0	0
	MTF	0	-	0	+ + +	0	0	0	0	0	0	0	0	0	0	0	0

"+" same direction significant association at $p < 0.05$; "+ +" same direction significant association at $p < 0.01$; "+ + +" same direction significant association at $p < 0.001$; "-" opposite direction significant association at $p < 0.05$; "- -" opposite direction significant association at $p < 0.01$; "- - -" opposite direction significant association at $p < 0.00$; "0" no significant association.

AFP, agroforestry practice; HG, homegarden; MCS, multi-story coffee system; MTF, multipurpose tree on farmland; HDDS, household dietary diversity score; IDDS, individual dietary diversity score; HFIAS, household food insecurity access scale; WAZ, weight-for-age z-score; HAZ, height-for-age z-score; WHZ, weight-for-height z-score; BMI, body mass index; NBF, non-breast feeding; WRA, women of reproductive age.

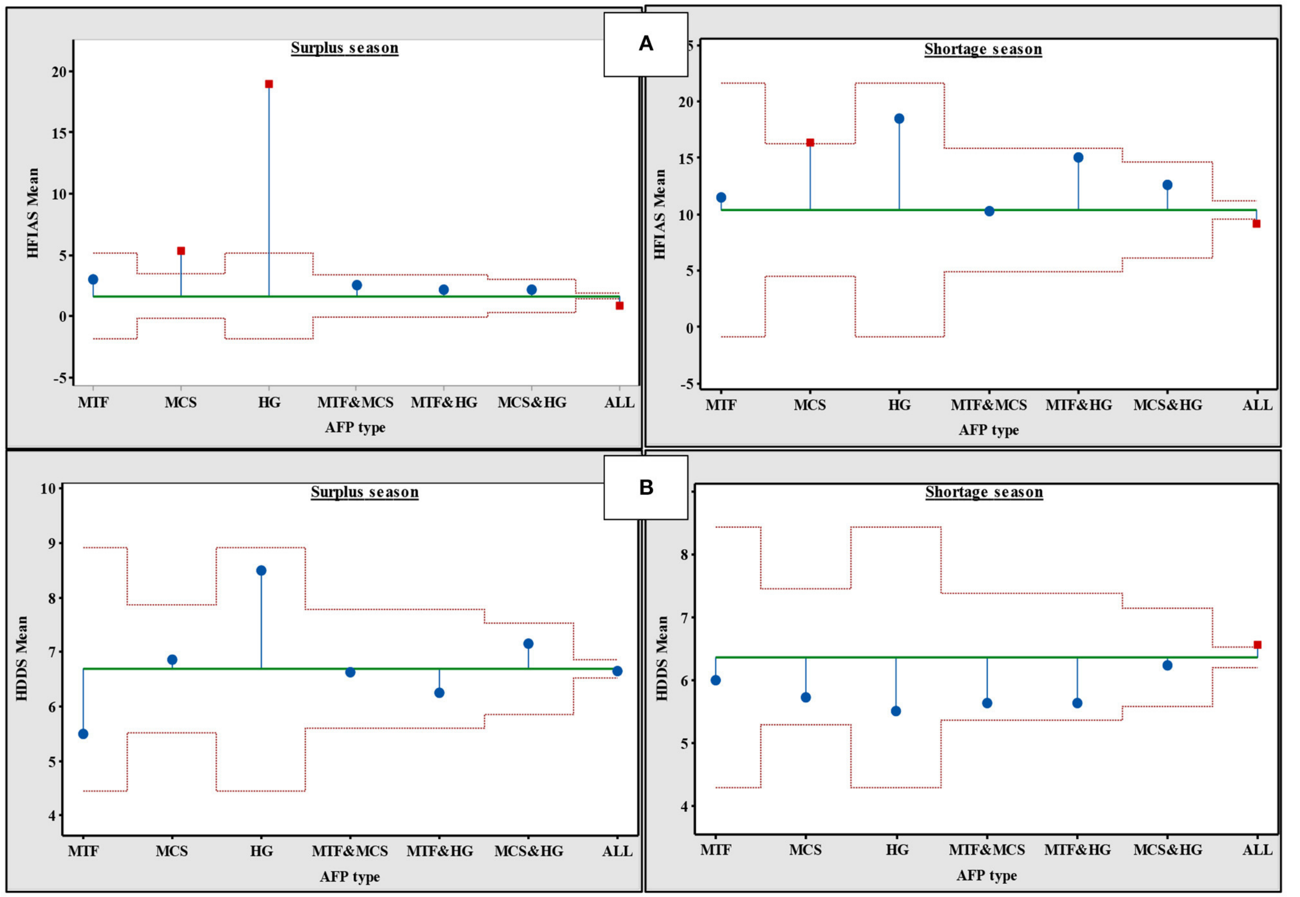

FIGURE 2 | One-way ANOM of household food security indices across seven AFP combinations by household in two seasons ($\alpha = 0.05$). **(A)** HFIAS; **(B)** HDDS. HG, homegarden; MCS, multi-storey coffee system; MTF, multipurpose tree on farmland; HFIAS, household food insecurity access scale; HDDS, household dietary diversity score.

DISCUSSION

For all AFP, more species and stories are related with the decrease of the household food insecurity, as demonstrated by the various indicators. Actually, a farming system involving more plant species mimicking the structure of a forest will likely enhance the FNS of smallholders, i.e., by availing diverse food, enhancing productivity food production, generating cash for accessing market foods, and improving environmental and economic protection from production and market failures (Ickowitz et al., 2014; Jemal et al., 2018). Regarding the richness of species, the higher the number of woody species in MCS the lower the household food insecurity. As Jemal et al. (2018) found, MCS in Yayu are used primarily for income generation which ultimately enable smallholders to access food from market. Thus, as the MCS of Yayu originated from natural coffee forest, a higher number of native woody plant species can happen either because of the larger plots size which in turn guarantee larger coffee harvest, or from other additional high-value forest products beside coffee, mostly honey, spices or timber, whose optimum production required a maintenance of additional woody species over the common coffee and its shade tree species (Senbeta et al., 2013; Jemal and Callo-Concha, 2017), which in both cases improve household income to access market food. Similarly, the more exotic species in HG the higher food security of the household, because of enlarged list of merchantable and or edible crop, mostly with different harvesting season from native crops (Fernandest and Nair, 1986; Abebe, 2005) (**Table 1**).

Both the household's and individual's dietary diversity scores during the shortage season were higher for households with more plant species in their MCS (the mostly heterogeneous AFP). Besides the cash-generating role of MCS plots, they provide wild foods that play a considerable role in enhancing dietary diversity, especially for children and women as vulnerable groups (Powell et al., 2011; Senbeta et al., 2013). Meanwhile, with the increasing number of herbaceous species in HG (mostly dominated by low-story species), a degradation in household's and individual's dietary diversity was detected; this might arise from the dominance of herbaceous food crops during the shortage season. Most of these food sources come from specific plant families such as *Araceae, Dioscoreaceae,* and *Brassicaceae* which are classified as belonging to only a few food groups,

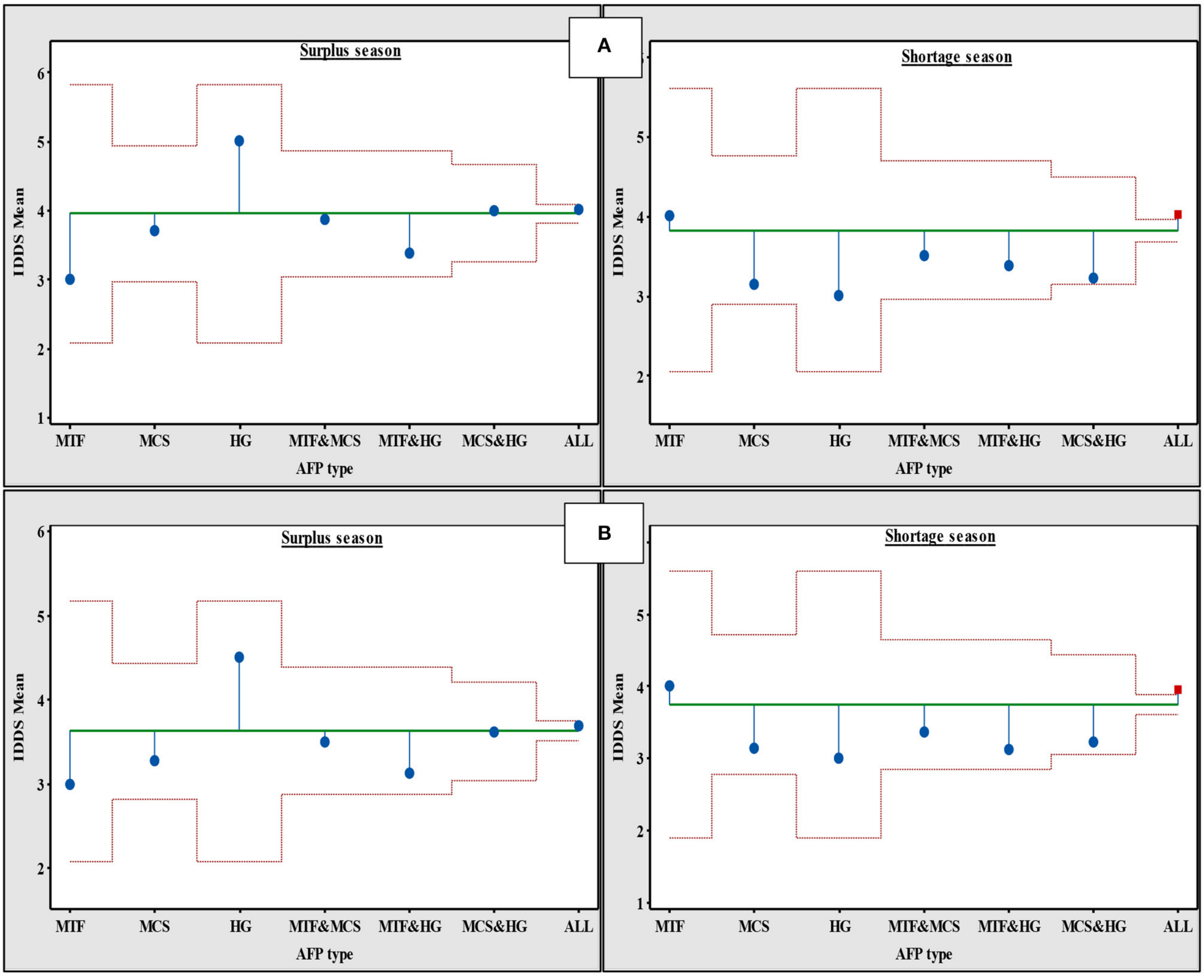

FIGURE 3 | One-way ANOM of IDDS across seven AFP combinations by sensitive groups in two seasons (α = 0.05). **(A)** Non-breast-feeding children under age of 5; **(B)** Women of reproductive age. HG, homegarden; MCS, multi-story coffee system; MTF, multipurpose tree on farmland; IDDS, individual dietary diversity score.

jeopardizing dietary diversity (Jemal et al., 2018). This argument is supported by the perceived association between the number of vegetation stories and HAZ of target children. Both species diversity and structural complexity of HG contribute to FNS of sensitive members of the household. The rest of the proxies used had limited impact on the anthropometry of target groups, with the exception of HG as a land use.

In general, these results suggest that the most diverse AFP (HG and MCS) can have high positive impacts on landholders' food security and nutrition (Jemal et al., 2018). These two agroforestry practices differ from each other in composition and purpose, i.e., MCS hold multiple strata and focus on coffee production while HG are very diverse and provide foodstuff, also generating eventual income. But their diversity in species composition (woody vs. herbaceous) and structural arrangements (number of story), matter. Also, the correlation values were slightly higher in the shortage season, what is explained that during the surplus season, most households have access to similar types of acquired and shopped foods, whereas in the shortage season the dependence on local foods increases, and diets tend to be similar. These findings agree with previous studies (Savy et al., 2006; Ngala, 2015) (**Table 1**).

In Yayu, the number of species' uses in all AFP also matter for the household FNS. In contrast, the richness of "actively marketed" species in MCS was not detected as an important factor. As coffee is the key and dominant cash crop, the marketability of other species had a limited influence on householders' food and nutrition. Where such effects occurred, in HG and MTF, they could be attributed to alternative cash sources before the harvesting season of coffee (Jemal et al., 2018). This finding was confirmed by the present study, when the richness of "actively marketed" species of HG positively correlated with the dietary diversity score of smallholders. The positive impacts of the tradable species on households and individual's food and

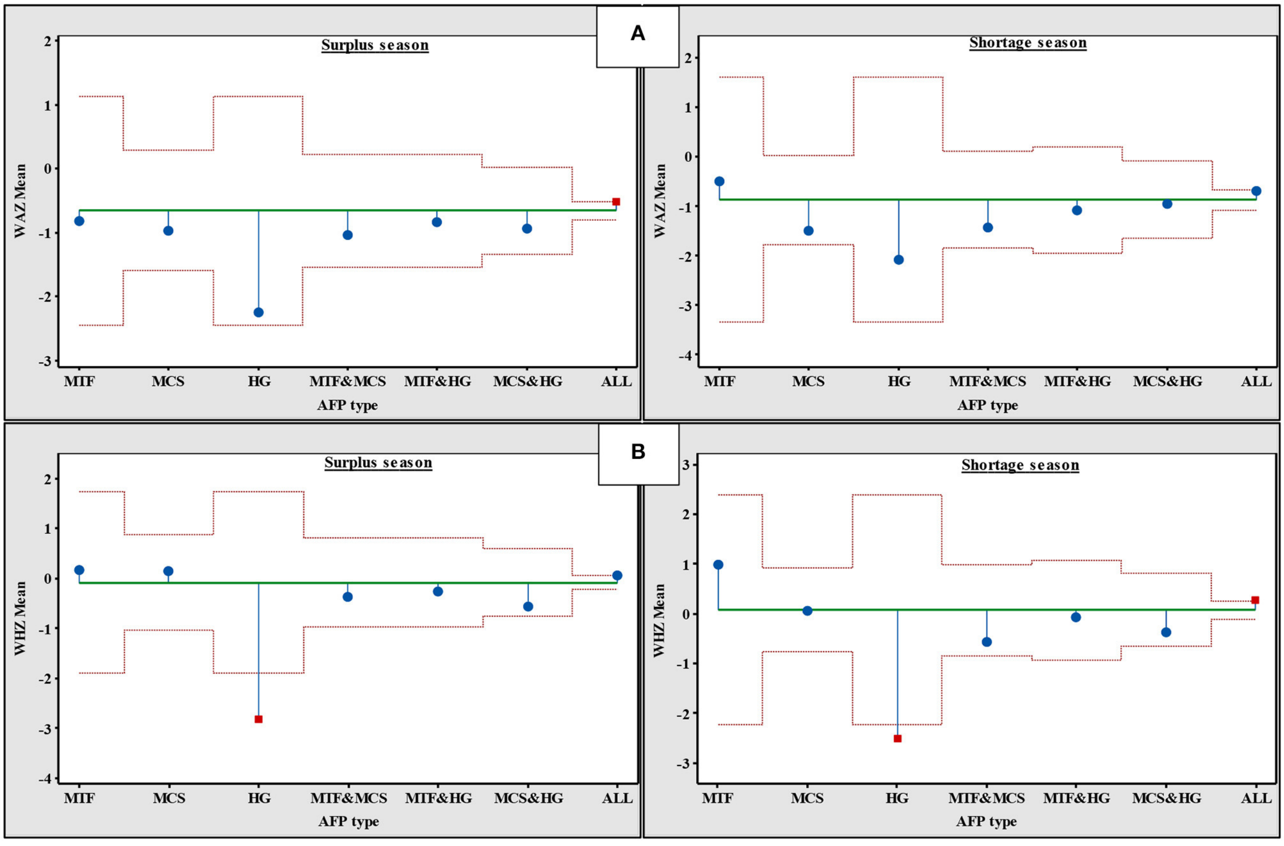

FIGURE 4 | One-way ANOM of WAZ and WHZ across seven AFP combinations in two seasons (α = 0.05). **(A)** Weight for age *z*-score (WAZ); **(B)** Weight for height *z*-score (WHZ). HG, homegarden; MCS, multi-story coffee system; MTF, multipurpose tree on farmland.

nutrition security, adds up and complement to the ones on the number and richness of species. Evidently here the role of coffee is key. Similar finding of farmers' HG in southern Ethiopia were reported by Mellisse et al. (2017), and by Remans et al. (2011) for smallholders in Malawi (**Table 2**).

Regarding the number and richness of edible species, the results align with previous findings that the diversity of all, or of specifically marketable, species diminishes the risks of malnutrition. Diversity effects were less pronounced in MTF, assumedly focused to the production of staples, where woody components perform rather other roles, like fencing or fodder provision, and stronger in HG and MCS (**Table 3**) (Jemal and Callo-Concha, 2017).

Predictably, cereals, as primary staple, were the most relevant food group for the reduction of malnutrition risks, and correspondingly for the increase of households and individuals' food and nutrition security. Beyond that, we found that vegetables and root species, likely enset, appear to specifically benefit sensitive groups, NBF<5 and WRA. Fruit provision appears also to be important, in general coming from HG, especially for children development through the provision of micronutrients, especially in the shortage season (**Table 4**).

In general, AFP attributes and features related to their diversity, showed a consistent association with the decrease of household food insecurity. Regarding household and individual diet diversities, the associations tended to be more marked based during the shortage season, which surely relate to the oscillation in the householders' diets themselves: determined by the dominance of purchased foods -more homogeneous and dominated by starchy foods - in the surplus season. Consumption of locally-produced foods in the shortage season qualitatively improved diets (Jemal, 2018).

Finally, while comparing the overall roles of the practices, it became clear that there is no single superior AFP that can ensure FSN of the households. Rather, a combination of all three AFP generated better nutritional outcomes, through both direct food provisioning and income. Each AFP appears to fulfill a specific role in the local livelihoods and missing any of these AFPs would weaken the household's ability to address the FSN pillars. In Yayu, the main food supply comes from MTF, and the cash from MCS. Households who do not own at least one of both practices confront difficulties to meet food security across the year. In most cases, the observed seasonal gap in food and cash supply is filled by the HG. Similar results were observed in Myanmar (Choa et al., 2016) and in other sub-Saharan African countries (Munyua and Wagara, 2015).

CONCLUSIONS

Food and nutrition security of smallholding farming households of Yayu were correlated with household ownership of all the three dominant Agroforestry Practices in Yayu, namely Homegardens, Multistorey Coffee Systems, and Multipurpose Trees on Farmlands. No single Agroforestry Practice could guarantee the overall Food and Nutrition Security status of the households, but the combination of all three could.

Several attributes of the Agroforestry Practices, mainly related to their overall and specialized species diversity, are inversely correlated with household food insecurity. Regarding the household and individual dietary scores, these are positively correlated, especially in the shortage season, with the Agroforestry Practices attributes (mainly diversity of species, tradable species). Furthermore, the correlations if specific traits with anthropometric scores of sensitive household members were weak. Market-based cash inflow from coffee selling was a key factor in determining the diet and food intake of the households, especially during the surplus season. Local dietary preferences did not always match nutritional advice under these conditions.

After our findings, few suggestions can be made: biodiversity of useful groups of species should be promoted, especially in all strata for Multistorey Coffee Systems and in the lower strata of Homegardens. The latter are particularly important, as they are the main providers of micronutrients for small children. Enriching the currently used Multipurpose Trees on farmlands and Homegardens with edible, storable crops, e.g., cereals, can contribute to prevention of food insecurity during the shortage season. All three dominant Agroforestry Practices should be promoted and where possible further diversified, as together they increase the local food and nutrition security of small farming households.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Center for Development Research (ZEF) ethical clearance team. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

OJ conducted the fieldwork, performed the statistical analysis, and wrote the first draft of the manuscript. All authors contributed to the conception and design of the study, manuscript revision, read, and approved the submitted version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2021.608868/full#supplementary-material

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