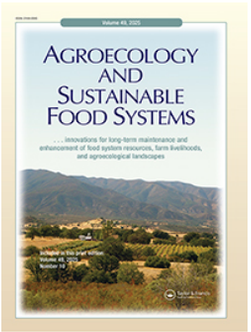

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Understanding agrobiodiversity and nutritional outcomes: a study of socio-economic differentiation among smallholder vegetable farming in northern Vietnam

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ABSTRACT

In recent years, smallholder farmers in northern Vietnam improved their vegetable cultivation with positive results for agrobiodiversity and nutrition. An unresolved question was if socio-economic differences among smallholder farmers influenced these outcomes, which this article addresses through a combined descriptive, bivariate, and multivariate analysis of household survey data. The study provides critical insights into the relationship between agrobiodiversity and dietary diversity among three ethnic groups in the uplands of northern Vietnam. Concerning crop diversity, the Hmong group cultivated the lowest number of crops (14) and the Thai group the highest (19), with Dao in-between (17). Total area of land cultivated and the area of vegetable production impacted positively on farm-level agrobiodiversity. Findings indicate that the vegetable production area is the main driver of vegetable species richness, with farmers allocating larger areas to these crops having considerably more diversity than farmers with smaller vegetable areas. Larger vegetable production areas, higher Fruit Species Richness, lower Staple Species Richness, larger household, and higher education contributed to a more diverse diet. The findings call for a more careful analysis of how differences in assets, ethnicity, and household characteristics influence livelihood improvement outcomes. These differences need to be better accounted for in policy interventions.

KEYWORDS

Agrobiodiversity; ethnic minorities; nutritional diversity; socio-economic differentiation; Vietnam

Introduction

In the highlands of northern Vietnam, many smallholder farmers engage in vegetable farming (Ha et al. 2019; Pham and Shively 2019), but they face multiple

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challenges related to insufficient water, erosion, loss of soil fertility, inadequate market access, limited support from extension and research, and poor-quality vegetable seeds (Nabuuma et al. 2021). The CGIAR initiative Nature-Positive Solutions for Shifting Agrifood Systems to More Resilient and Sustainable Pathways (Nature+ Initiative) addressed these challenges through targeted development activities. The Initiative aimed to re-imagine, co-create, and implement nature-positive solutions, such as agrobiodiversity-based farming, agroecological practices, improved soil and water management, sustainable value chain development, and reuse and recycling of agricultural waste. Expected benefits included improved critical ecosystem services, enhanced social and economic benefits, and livelihood resilience. In Vietnam, this Initiative builds on a trajectory of collaborative interventions in the northern highlands to improve smallholder livelihoods through improved vegetable farming.

Participating farmers in selected communes in Sa Pa and Mai Son adopted various agricultural practices, such as pre-sowing seed treatment, bed preparation, crop distancing, mulching, intercropping, use of organic fertilizers and biopesticides, and vegetable seed saving. These practices could also be applied to other crops. They also learned crop rotation, intercropping, economical irrigation, and minimum tillage farming skills. In parallel, participating farmers, particularly those organized in "Diet Health Clubs," enhanced their nutrition knowledge and skills (Swaans and Nabuuma 2023). Diet Health Clubs are groups of 15–20 farmers from the same village that function as a platform for capacity building and knowledge and skill exchange on seeds, production, and nutrition to enhance utilization and demand for diverse crops. Group members exhibited a heightened understanding of nutrition, particularly the importance of dietary diversity, and identifying and incorporating different food groups into their diets. As a result, farmers embraced a more diverse approach to their household diets, consuming a greater variety of vegetables.

In their assessment of the Nature+ Initiative in Northern Vietnam, farmers expressed satisfaction with the activities and willingness to continue improving their knowledge and skills, e.g. through participatory variety selection, community-based seed saving, and value chain development of crops with good market potential (Nguyen et al. 2023). However, some key questions remained unanswered about understanding better how these results came about in each location; if results varied among different farmer households based on socio-economic characteristics and ethnicity; and what other factor-(s) could have influenced (these different) results. Building on Nabuuma et al. (2021), who observed a high level of agrobiodiversity at village/district level in the same locations, but with some marked differences among households within a village/district, this study addresses four questions about differentiation and agro- and nutrition diversity outcomes: 1) How do farm size, area allocated to vegetables, level of agrobiodiversity managed, and seed management practices differ with farming household locations, ethnic group, and

farmer-group membership? 2) To what extent do farm size, area allocated to vegetables, location, ethnicity, and participation in vegetable sales, drive higher levels of on-farm agrobiodiversity? 3) How do these factors impinge on seed management practices? 4) How do the following factors contribute to healthier and more diverse diets: level of on-farm agrobiodiversity, area allocated to vegetables, location, ethnicity, participation in vegetable sales, and household's socio-economic characteristics? These questions address a broader development challenge that economies in transitions, such as the Vietnamese economy, face: Are there differences among the many Vietnamese smallholder farmers in how they manage their farms and livelihoods and what do these differences mean in terms of agrobiodiversity and nutritional diversity? By addressing these complex questions, this study contributes to a better understanding of the role of ethnicity and socio-economic factors in maintaining on-farm agrobiodiversity. It also provides novel critical insights into the relationship between on-farm agrobiodiversity and dietary diversity among three ethnic groups in the highlands of northern Vietnam.

This study combined descriptive, bivariate, and multivariate analysis of household survey data collected by the Nature+ Initiative in Sa Pa and Mai Son in 2023 and 2024. The findings point to key socio-economic factors that can enable or disable the effective conservation and sustainable use of crop diversity and household dietary diversity. Linkages between agricultural production (including agrobiodiversity) and dietary diversity are a critical determinant of nutritional outcomes, but in south-east Asia, the relationships between these are under-researched (Tacconi et al. 2023). Some suggestions for further research and development interventions are presented.

Literature review

Due to its varied landscapes, climatic conditions, and agroecological systems, combined with its ethnic diversity, Vietnam is an agrobiodiversity-rich country with about 12,000 plant species. Agroforestry, with its multiple ecosystem and livelihood benefits, is practiced in various regions, including the northern region (Dien Bien, Yen Bai, and Son La provinces). However, farmers could further benefit from more knowledge about appropriate tree–crop combination and related management practices (Hung et al. 2020). Home-gardens across the country are often rich in diverse species used for firewood, fodder, food, medicine, and ornamental uses. Ethnobotanical home-garden research in Central Vietnam identified 67 useful species belonging to 35 families (Vlková et al. 2011). Our own research by Sa Pa and Mai Son identified the use of a total of 90 different plant and (fruit) tree species (some with multiple varieties) by the studied ethnic groups (Loc et al. 2023). Over the last decades, the modernization and intensification of agriculture have, on the one hand, tremendously enhanced the country's food security and rural livelihoods but,

on the other hand, also dramatically contributed to the reduction of the agrobiodiversity managed by farmers, especially of major crops, such as rice (Ky, Tuyen, and Lan 2003). Changes in the extent of cultivation and diversity of major crops impact the cultivation of minor crops in terms of land allocation, use of agricultural inputs, and time and labor required to adequately grow and maintain their diversity. These changes in crop portfolios at farm level are very likely to influence nutrition.

However, we acknowledge that the interlinkages between agricultural diversity and nutrition are not easy to determine given that multiple factors influence farming practices and household food consumption behavior (Estrada Carmona et al. 2020). Researchers have presented different analyses. Pellegrini and Tasciotti (2014), in an eight-country study based on representative national rural household data including Vietnam (not pertaining to any specific site), observed that crop diversification can positively impact farm income and household dietary diversity. Le et al. (2023), in a study of household dietary diversity and associated factors among the Khmer ethnic minority group in the Mekong River delta in Vietnam, concluded that, there was no correlation between vegetable or rice farming and dietary diversification, as larger crop diversity did not lead to increased dietary diversity. The contradictory findings of these studies might be attributed to differences in location, as the latter was conducted in the region of Vietnam with the largest average farm size and where agriculture is most intensified and specialized. This would be consistent with the results of Tacconi et al. (2023) who, in a cross-country study in South and South-East Asia (including Vietnam) on farm diversification, dietary diversity, and farm size, found that farm diversification is significantly influenced by environmental and climate variables and socio-economic factors, such as household and farm characteristics (e.g., farm size and education level). They noted that farm diversification, market orientation, and off-farm income generation can improve household and individual dietary diversities. However, farm size influenced the relative effects, as the positive effect of farm diversification on dietary diversity was larger for smaller farms. The effect decreased for larger farms, whose landholders could improve their diet through increased engagement in off-farm activities and markets. In their meta-analysis of 47 studies on the same topic, Sibhatu and Qaim (2018) come to a more nuanced conclusion, suggesting that farm production diversity is lightly positively associated with household-level and individual-level dietary diversity and nutrition in some situations but not in others, and could even be negative. Negative effects can occur when production diversity is already high, where the production of a large or larger number of crop species could lead to income losses through foregone gains from specialization.

Socio-economic differentiation in Vietnam has been studied in terms of various differences between ethnic majority and minority groups concerning education, income, natural resources (especially land and water; but little to none about access

to seed and seed management), government policies, and social relationships (Bui, Nguyen, and Pham 2016, Nguyen et al., 2020). In the northern highlands of the country, a region with rich ethnic cultural diversity and socio-economic differentiation can have its roots in multiple factors related to access to natural resources (land, water), access to markets, and social relationships.

Regarding land tenure, Vietnam is characterized by the presence of approximately 14 million households with less than 1 ha of land, representing approximately 80% of all rural households (2019 data; To, Sango Mohanty, and Wells-Dang 2019), forming a very large class of small landholders. The remaining 20% have more than 1 ha of land. The position of these small landholders is far from secure. To make things even more precarious, landholding in Vietnam is also characterized by a high degree of land fragmentation, affecting even the smallest landholders (Nguyen et al. 2023). Nguyen et al. (2023) observed that in Vietnam this high degree of fragmentation affects farmer's livelihood options as it leads to higher labor and transportation costs, lower farm efficiency, reduced income, and food insecurity. Concerning water, Jourdain et al. (2011), in a study of an upper-catchment area in Yen Bai province (in the north of the country), identified access to water (during one or two cropping seasons, individually or collectively) and terraced land (vs sloping land) as key factors. Our own research in northern Vietnam confirms that ethnic minority smallholder farmers face these challenges.

To address these challenges, the Vietnamese government's recent agricultural policy is geared toward restructuring the agricultural sector from small-scale farming to large-scale commercial farming through the mobilization of capital, technology (mechanization), and financial resources held by the private sector (To, Sango Mohanty, and Wells-Dang 2019). The Vietnamese government acknowledges that such a transition can only be realized by amending the land policy to enable landholdings to be transferred from smallholders to private companies. More recently, the government has addressed these questions of agricultural change through the development of a national food system transformation agenda with a stronger focus on sustainable agriculture (Prime Minister of the Government Socialist Republic of Vietnam 2023). Our study questions are directly relevant to this agenda.

Materials and methods

Study area

The study was conducted in two distinct locations in northern Vietnam, namely the Mai Son district in Son La province and the Sa Pa township in Lao Cai province. Both study sites are located in mountainous regions and are home to diverse ethnic minority populations. Son La is primarily inhabited by the Thai and Hmong communities, while Lao Cai, particularly Sa Pa, is known for its large

population of Dao and Hmong peoples (Asian Development Bank ADB 2015). Although both areas share similarities in terrain and cultural richness, their climatic conditions, agricultural systems, and economic development levels differ notably, shaping distinct agroecological and livelihood patterns.

Mai Son district spans 1,410 km^2 at elevations ranging from 800 to 1,500 m, with a 2023 population of approximately 169,000. It has a tropical monsoon climate and four distinct seasons: spring, summer, autumn, and winter. The area is characterized by a rainy season (April to September) and a dry season (October to March), with an average annual rainfall of 1,415 mm, an average humidity of 80%, and an average temperature of 20.9°C. Of its 49,000 ha of cultivated land, 39% are used for industrial crops, such as cassava and sugarcane, 30% for food crops and vegetables, and 23% for fruit trees. Notably, nearly 2% (1,000 ha) benefit from water-saving irrigation systems, 9% (4,200 ha) employ high-tech farming methods, and 4% (1,800 ha) are cultivated organically. High-value market crops include coffee and custard apple, cultivated on a combined area of 1,373 ha (Son La PSO 2023).

Sa Pa township, by contrast, covers 685 km^2 at altitudes from 1,500 to 1,800 m and had a 2023 population of 72,000. It features a subtropical highland climate with mild winters and cool summers, making it suitable for growing vegetables, herbs, and medicinal plants. The average annual temperature is between 15°C and 18°C, and the region receives abundant rainfall, especially during the monsoon season from May to September. Additionally, Sa Pa is often enveloped in mist and fog, contributing to its unique microclimate. Of Sa Pa's 9,632 ha of agricultural land, 37% consist of terraced fields and 18% are used for vegetable cultivation. The area includes 70 ha certified under VietGAP and 1.5 ha meeting organic standards. Medicinal plants, important to the livelihoods of the Dao community, are cultivated on 280 ha (3%), including 50 ha of artichokes under-certified good agricultural practices. Temperate fruit trees such as peach, pear, and plum are grown on 763 ha (8%) (Son La PSO 2023).

The study focused on the members of Diet Health Clubs (DHC) and Value Chain Groups (VCGs) in Co Noi and Chieng Chan communes (Mai Son district, Son La province) and Ngu Chi Son commune (Sa Pa township, Lao Cai province). DHCs, established in conjunction with the village women's union, aimed to enhance household nutrition security and promote healthy diets through capacity building and knowledge sharing from seeds, production, to nutrition. VCGs, comprising both male and female farmers, focused on cultivating and jointly marketing vegetables and vegetable seeds, with an emphasis on increasing agricultural revenue.

Ethics

The study received approval from the Institutional Review Board of the Alliance of Bioversity International and CIAT on July 4, 2023. Relevant authorities at provincial and commune levels approved the research. Informed consent was obtained from all participants prior to their involvement in the survey. All data analyses and results were anonymized and aggregated to ensure confidentiality and prevent participant identification.

Sampling and data collection

The study included 181 households, all members of seven DHCs and two VCGs that participated voluntarily in Nature+ activities across the project intervention area. These households represented three ethnic groups: Dao, Hmong, and Thai. The seven DHCs were chosen from a total of 36 based on the following criteria: (i) the leader's demonstrated capacity to train club participants in both seed management and nutrition and willingness to continue leading the group, (ii) the attendance rate for training sessions in the previous related research project on vegetables was at least 70%, and (iii) active support from local departments and village unions. The two VCGs in Co Noi (Mai Son) and Ngu Chi Son (Sa Pa) were both included. A detailed breakdown of the number of study households per group is provided in Table 1.

Participation in the study was facilitated by staff at the Fruit and Vegetable Research Institute (FAVRI), a Nature+ Initiative research partner, who coordinated with DHC and VCG leaders to identify eligible participants. Of each household, demographic information about the household head, mostly male, and the household members, predominantly female, who participate in DHCs or VCGs, was collected. One person per household was interviewed, with priority given to the DHC or VCG registered member, followed by household head or persons who have comprehensive knowledge of agricultural production, household diets, and group activities. The structured interview survey tool was pre-tested

Table 1. Distribution of the study households by size, location, group, and ethnicity.

District	Commune	Group	Ethnicity	Number of households
Mai Son (95)	Co Noi (55)	Nong Quynh DHC	Thai	21
		Nong Mon DHC	Hmong	17
		Van Phuc cooperative (VCG)	Thai	17
	Chieng Chan (40)	Na Hun DHC	Thai	19
		Tong Tai B DHC	Hmong	21
Sa Pa (86)	Ngu Chi Son (86)	Phin Ho DHC	Dao	19
		Xin Chai DHC	Dao	21
		Sin Chai DHC	Hmong	19
		Can Ho seed production group (VCG)	Dao	27
Total				**181**

Data collected by the authors.

in Lech village (Co Noi commune) and Ta Van Mong village (Muong Hoa commune) to ensure linguistic and logical consistencies and administered to the sampled households by trained enumerators using the Kobo Toolbox application on tablets. The survey consisted of modules covering household and participant characteristics, land tenure and use, crop production, nature-positive practices, household food consumption, gender equity, and participation in the project activities (in this study, we are not using all the questionnaire data). Data collection took place in July 2023. The survey successfully interviewed 174 of the total of 181 households including 95% (130 out of 137) of households affiliated with the DHCs and 100% (44 households) of those belonging to the VCGs. Based on our dataset, we can combine ethnicity and land tenure as analytical variables.

Outcome variables

We calculated agrobiodiversity indices based on the diversity of food crops, including total crop species richness (CSR), and more specific vegetable species richness (VSR), fruit species richness (FSR), and staple species richness (SSR). These indices measure the total number of different crop species in a given area, such as a farm (used in this study) or a community or particular landscape, e.g. a watershed (Jones 2017). These indices provide a straightforward approach to quantifying species diversity (Fedor and Zvaríková 2019). Included in our application of SSR in addition to vegetables and fruits are cereals, legumes, roots, and tubers.

Furthermore, we analyzed diversity in seed management practices in terms of three types of market orientation and related socio-economic relationships: self-saving seed (no market orientation, no need for cash, high degree of autonomy), exchanging seed (no market orientation, seed used as "cash," some social networking), and purchasing seed commercially from an agro-dealer, company, or on the market (market orientation, cash needed, some social networking).

To assess dietary diversity, we utilized the Diet Quality Questionnaire (DQQ), a standardized tool to calculate indicators of dietary adequacy. These include the Global Dietary Recommendation (GDR) Score, the Non-communicable Disease (NCD) Protect Score (Global Diet Quality Project 2024; Herforth et al. 2020), and Dietary Species Richness Score (DSR) (Fedor and Zvaríková 2019; Lachat et al. 2018). The GDR Score ranges from 0 to 18 and indicates adherence to global dietary recommendations, focusing on dietary factors protective against NCDs. A higher score suggests better compliance with these recommendations (Global Diet Quality Project 2024; Herforth et al. 2020). The NCD Protect Score measures the consumption of nine healthy food groups (0–9): whole grains, pulses, nuts, and seeds, vitamin A-rich vegetables, dark green leafy vegetables, other vegetables, vitamin A-rich

fruits, citrus fruits, and other fruits. A higher score indicates a diet that includes more health-promoting foods.

DSR is a dietary biodiversity indicator that measures the diversity of food intake. It is calculated as the count of different plant or animal species consumed by a household (Fedor and Zvaríková 2019). Species-level data are used to calculate it. When a specific species cannot be identified, the genus is recorded with the suffix "sp" (e.g., all bananas can be recorded as *Musa sp*). Ambiguities in scientific species names are resolved using databases such as *The Plant List* (www.theplantlist.org.) and the *Species 2000 & ITIS Catalogue of Life* (www.catalogueoflife.org/col). For mixed food preparations where species-level identification is not possible (approximately 0.1% of the cases), at least one primary ingredient is used to calculate the species richness for that food group. Different parts of plant or animal species are counted as one, and no minimum quantity is required to include a species in the biodiversity indices (Lachat et al. 2018).

Data analysis

Quantitative data were analyzed using the R program v4.3.3. Descriptive statistical methods were applied, and results were presented as frequencies, proportions, mean values, and standard deviations.

To identify factors associated with agrobiodiversity and dietary diversity outcomes, we used generalized linear models (GLMs) with a Poisson distribution, implemented via the glm function in R. Poisson Regression is a statistical method used to model count data, which consists of non-negative integer values representing the number of times an event occurs (Wu and Little 2011). Model selection was based on the Akaike Information Criterion (AIC), allowing for stepwise comparison of multivariate models (Beaujean and Grant 2016). Explanatory variables included total cultivated area category, vegetable production area category, location (Sa Pa vs. Mai Son), ethnicity (Kinh, Thai, Hmong, and Dao), household size, education level of the household head, group membership (VCG or DHC), and vegetable sales.

To ensure valid inferences and avoid multicollinearity, we calculated Variance Inflation Factors (VIFs), retaining only variables with VIF < 5. Final models were chosen based on the lowest AIC. Adjusted Poisson regression models were used to estimate incidence rate ratios (IRRs = exp(β)) and their 95% confidence intervals (CIs), using the broom package. Model representativeness was evaluated with adjusted R^2, and goodness-of-fit was assessed via the chi-squared test from the performance package ($p > 0.05$ indicating acceptable fit).

To reduce bias in data collection and improve representativeness across ethnic and landholding groups, the number of participants by ethnic groups (Hmong, Dao, Thai, and Kinh) was more or less similar. Along with that,

households within the same ethnic group generally had similar landholding sizes. In the analysis phase, we allocated balanced households into land size categories. In addition, we adjusted these variables to control potential confounding. Furthermore, we conducted sensitivity checks to confirm that the model estimates were robust to variations in ethnic or land size representation.

Results

Household demographic characteristics

Table 2 presents the characteristics of households participating in the study by location. The proportion of Dao households (37.4%) was slightly higher compared to other ethnic groups. Nearly half of the households (47.1%) were located in Ngu Chi Son commune, Sa Pa town. The majority (approximately 70%) consist of medium-sized households with 4–6 members. Most household heads had primary school education or below (51.2%), with a slightly higher prevalence in Sa Pa (53.7%) compared to Mai Son (48.9%). A significant majority of households were members of Diet Health Clubs (DHCs) (72.4%), with a higher participation rate observed in Mai Son (81.5%) than in Sa Pa (62.2%), which is largely due to the higher number of DHCs in Mai Son (4 vs 3). About one-quarter of households (27.6%) belong to VCGs, with prevalence in Sa Pa (37.8%) compared to Mai Son (18.5%), reflecting a relatively stronger interest in vegetable production that has grown in Sa Pa than in Mai Son. Additionally, nearly half of the households

Table 2. Household demographic characteristics by district.

	District		
Indicators	Mai Son (n = 92)	Sa Pa (n = 82)	Overall (n = 174)
Ethnicity (%)			
Thai	63.0	0.0	33.3
Hmong	36.9	20.7	29.3
Dao	0.0	79.3	37.4
Commune (%)			
Co Noi	57.6	0.0	30.5
Chieng Chan	42.4	0.0	22.4
Ngu Chi Son	0.0	100.0	47.1
Household size (%)			
Small (up to 3 members)	12.0	6.1	9.2
Medium (4–6 members)	72.8	65.9	69.5
Large (6+ member)	15.2	28.1	21.3
Educational level of household head (%)			
Primary school & below	48.9	53.7	51.2
Secondary school	14.1	22.0	17.8
High school & above	37.0	24.4	31.0
Member of the group (%)			
DHCs	81.5	62.2	72.4
VCGs	18.5	37.8	27.6
Sold vegetables (%)	27.2	63.4	44.3

reported selling vegetables during the last cropping season, with this activity more than twice as common in Sa Pa (63.4%) than in Mai Son (27.2%).

Land area and use

Per capita cultivated land area was distinguished into three classes: less than 1 ha, between 1 and 2 ha, and more than 2 ha. Under these conditions, farmers with more than 2 ha of cultivated land are considered "large" landholders. The total cultivated land area by the households in the two sites was typically small to very small (between 1–2 ha and less than 1 ha), with the majority of households (66.1%) cultivating less than 1 ha (Table 3). This proportion was higher in Sa Pa (85.4%), among Dao households (84.6%), and slightly higher among DHC members (66.9%). With regard to vegetable production area per household (which is the area primarily cultivated with vegetables, sometimes intercropped with fruit trees), the distinction was based on extremely small areas of less than 100 m^2 (or less than a parcel of 10 × 10 m) (36.8% of all households), between 100 and 1000 m^2 (27.6%); and "large" areas of more than 1,000 m^2 (35.6%). Large vegetable cultivation areas (>1,000+ m^2) were more common in Mai Son (47.8%; more than double that of Sa Pa), among Thai households (56.9%), and among VCG members (65.9%). Extremely, small vegetable cultivation areas (below 100 m^2) were more prevalent in Sa Pa (40.2%), among Hmong households (62.8%), and within DHC members (44.6%).

Agrobiodiversity

Crop species diversity

Regarding staple crops, around 87% of farming households produced ordinary maize, 40% glutinous (sticky) maize, 49% ordinary rice, and 55% sticky rice. Households in Mai Son predominantly grow ordinary maize (82%), while ordinary rice is the most common crop (94%) in Sa Pa. In terms of vegetable production, approximately 91% produced pumpkin, 47% chayote, 45% French bean, and 38% Hmong cucumber. About fruits, over 50% produced longan (all in Mai Son), 44% had mango (primarily in Mai Son), more than 47% grew plum (roughly 74% in Mai Son and 82% in Sa Pa), and 37.4% peach (mainly in Sa Pa) (Appendix 1).

On average, each household cultivates approximately 17 (±6) different crop species, with the Hmong group cultivating the fewest crops (14 ± 6) and the Thai group cultivating the most (19 ± 8) in the last 3 months before the survey was carried out (Table 4). With regard to vegetables, each household grew an average of nearly 10 (±4) species, with the Hmong group cultivating the fewest (8 ± 3). Each household cultivated an average of 3 (±2) fruit species, with Mai Son growing more types than Sa Pa (5 vs. 2), the Thai group growing more

Table 3. Per capita land areas and areas allocated to vegetable production in the last season by location, ethnicity, and farmer group membership.

	District		Ethnicity			Group		
Indicator	Mai Son (n = 92)	Sa Pa (n = 82)	Thai (n = 58)	Dao (n = 65)	Hmong (n = 51)	DHC (n = 130)	VCG (n = 44)	Overall (n=174)
Total cultivated land area category (%)								
Less than 1 ha	48.9	85.4	51.7	84.6	58.8	66.9	63.6	66.1
1–2 ha	28.3	8.5	29.3	7.7	21.6	18.5	20.5	19.0
More than 2 ha	22.8	6.1	19.0	7.7	19.6	14.6	15.9	14.9
Vegetable production land area category (%)								
Less than 100 m^2	33.7	40.2	17.2	33.9	62.8	44.6	13.6	36.8
100–999 m^2	18.5	37.8	25.9	38.5	15.7	30.0	20.5	27.6
More than 1000 m^2	47.8	22.0	56.9	27.7	21.6	25.4	65.9	35.6

Table 4. Average species richness related to food crops by district, ethnicity, and farmer group (standard deviation).

	District		Ethnicity			Group		
Indicator	Mai Son (n = 92)	Sa Pa (n = 82)	Thai (n = 58)	Dao (n = 65)	Hmong (n = 51)	DHC (n = 130)	VCG (n = 44)	Overall (n = 174)
Crop species richness	17.2 (7.3)	16.5 (4.1)	18.8 (7.5)	17.1 (3.9)	14.3 (5.5)	17.0 (6.5)	16.6 (4.2)	16.9 (6.0)
Vegetable species richness	9.3 (4.5)	9.9 (2.6)	10.2 (4.6)	10.3 (2.5)	8.0 (3.4)	9.6 (3.9)	9.6 (3.0)	9.6 (3.7)
Fruit species richness	4.8 (2.3)	1.7 (1.3)	5.3 (2.2)	1.8 (1.3)	3.0 (2.2)	3.4 (2.6)	3.0 (1.8)	3.3 (2.4)
Staple species richness	2.6 (1.4)	4.0 (1.6)	3.0 (1.4)	4.1 (1.6)	2.6 (1.5)	3.3 (1.7)	3.3 (1.3)	3.3 (1.6)

types than the Hmong and Dao groups (5 vs. 3 and 2), and DHCs cultivating more types than VCGs (4 vs. 3). In terms of staples, each household grew an average of about 3 (±2) species, while Sa Pa (4 ± 2) and the Dao group (4 ± 2) have the highest number of staple crops.

Vegetable seed management practices

Table 5 provides an overview of household seed management practices for vegetable production. In the last season, on average, households self-saved seeds for nearly six varieties of vegetables (6 ± 3), purchased seeds for approximately two varieties (2 ± 2), and exchanged seeds for one variety (1 ± 1). Self-saving was more prominent among households in Sa Pa (6 ± 2), the Dao ethnic group (7 ± 2), and members of DHCs (6 ± 3). Households in Mai Son (2 ± 2), the Thai ethnic group (3 ± 2), and members of VCGs (2 ± 2) were more likely to purchase vegetable seeds for production.

Socio-economic differentiation and agrobiodiversity

Table 6 highlights the associations between cultivation area, ethnic group, and participation in agricultural groups, with agrobiodiversity indices, including Crop Species Richness (CSR), Vegetable Species Richness (VSR), Fruit Species Richness (FSR), and Staple Species Richness (SSR). Households with a cultivation area greater than 2 ha demonstrated 17% higher CSR ($p = 0.04$) and 33% higher FSR ($p = 0.03$) compared to those with less than 1 ha. Households with a vegetable cultivation area larger than 1000 m^2 reported 22% higher CSR ($p = 0.01$), 31% higher VSR ($p = 0.00$), and 31% higher FSR ($p = 0.00$) than those with less than 100 m^2, respectively. It seems that households with larger cultivated areas are generally better positioned to cultivate a wider range of crops. As a result, their farms tend to exhibit higher levels of agrobiodiversity compared to those households with smaller cultivated areas.

Ethnic group differences were evident, with Dao households showing 26% higher CSR ($p = 0.04$), 22% higher VSR ($p = 0.03$), and 88% higher FSR ($p = 0.03$) compared to Hmong households in Sa Pa. Thai households in Mai Son also exhibited even greater species richness than the Hmong households, with CSR and FSR being 28% ($p = 0.03$), 386% ($p = 0.00$) higher, respectively. Hmong households in Mai Son had an FSR that was 353% higher ($p = 0.00$) than that among Hmong households in Sa Pa but the SSR was 46% lower ($p = 0.00$). Ethnic differences in agrobiodiversity indices may stem from variations in farming practices, market access, and topographic conditions. For instance, the Hmong people in Sa Pa often engage in self-sufficient agriculture and tend to cultivate more beans and legumes for year-round consumption compared to other ethnic groups. In contrast, the Dao people, who live

Table 5. Average number of seed varieties accessed by households from different sources by district, ethnicity, and farmer group (standard deviation).

	District		Ethnicity			Group		
Indicator	Mai Son (n = 92)	Sa Pa (n = 82)	Thai (n = 58)	Dao (n = 65)	Hmong (n = 51)	DHC (n = 130)	VCG (n = 44)	Overall (n = 174)
Number of seed varieties by self-saving	5.3 (4.0)	6.3 (2.0)	5.5 (4.4)	6.5 (2.0)	5.0 (2.7)	6.0 (3.3)	5.0 (2.9)	5.7 (3.2)
Number of seed varieties from purchase	2.3 (1.9)	0.8 (0.9)	2.9 (1.9)	0.9 (0.9)	0.8 (1.2)	1.3 (1.5)	2.3 (2.0)	1.6 (1.7)
Number of seed varieties from exchange/sharing	0.8 (1.2)	0.1 (0.5)	0.8 (1.2)	0.1 (0.4)	0.5 (1.0)	0.5 (1.0)	0.3 (0.8)	0.5 (1.0)

Table 6. Multivariate Poisson regression of factors associated with agrobiodiversity indices among households in northern Vietnam.

Variable	CSR Exp(β)	VSR Exp(β)	FSR Exp(β)	SSR Exp(β)
Intercept	13.77***	6.58***	2.80***	3.37***
Cultivated land area				
Less than 1 ha	1	1	1	1
1–2 ha	0.96	0.97	0.97	0.96
More than 2 ha	1.17*	1.16	1.33*	1.19
Vegetable production area				
Less than 100 m^2	1	1	1	.
100–999 m^2	1.07	1.16	1.08	.
More than 1000 m^2	1.22**	1.31***	1.31**	.
Location*Ethnicity				
Hmong – Sa Pa	1	1	1	1
Dao – Sa Pa	1.26*	1.22*	1.88*	1.13
Hmong – Mai Son	0.95	0.89	3.53***	0.54***
Thai – Mai Son	1.28*	1.13	4.86***	0.75
Group				
VCG	.	1	.	1
DHC	.	1.17*	.	1.11
Sold vegetables				
No	.	.	1	.
Yes	0.87*	.	0.76*	.
Adjusted R^2	*0.32*	*0.29*	*0.68*	*0.31*
P value of Goodness-of-Fit Test	*0.29*	*0.38*	*0.06*	*0.99*

Variables of significance ***p ≤ 0.001, ** p ≤ 0.01, and * p ≤ 0.05.
CSR: Crop Species Richness; VSR: Vegetable Species Richness; FSR: Fruit Species Richness (FSR); SSR: Staple Species Richness.

closer to the town and have greater access to markets, grow a wider range of vegetables to meet the demands of buyers and tourists. Meanwhile, the Thai and Hmong communities in Mai Son, where both tropical and temperate fruit trees thrive, cultivate more diverse fruit varieties than their counterparts in Sa Pa, where only temperate fruits are suitable for cultivation

Participation in agricultural groups and vegetable marketing also influenced species richness. Households involved in DHCs reported 17% higher VSR ($p = 0.05$) compared to those in VCGs. In contrast, households engaged in vegetable sales had 13% lower CSR ($p = 0.03$) and 24% lower FSR ($p = 0.02$) compared to those not involved in selling vegetables.

Socio-economic differentiation and seed management

Table 7 illustrates the relationship between total cultivated area, vegetable production area, ethnicity, location, farmer group participation, education, and sales of vegetables and seed management in terms of self-saved and purchased seeds of vegetable varieties. Households with vegetable production areas of at least 1000 m^2 self-stored approximately 52% more vegetable variety seeds than those with vegetable production areas under 100 m^2 ($p = 0.00$). Dao households and households participating in DHCs self-saved 47%

Table 7. Multivariate Poisson regression of factors associated with seed management (saved and purchased) among households in northern Vietnam.

Variable	Number of seed variety from saving Exp(β)	Number of seed variety from purchasing Exp(β)
Intercept	3. 90***	3.45***
Cultivated land area		
Less than 1 ha	.	1
1–2 ha	.	0.84
More than 2 ha	.	1.30*
Vegetable production area		
Less than 100 m^2	1	.
100–999 m^2	1.18	.
More than 1000 m^2	1.52***	.
Location*Ethnicity		
Hmong – Sa Pa	1	1
Dao – Sa Pa	1.47**	2.12
Hmong – Mai Son	0.84	4.72***
Thai – Mai Son	1.03	8.24***
Group		
VCG	1	.
DHC	1.28*	.
Education level of household head		
Primary and below	.	1
Secondary	.	0.92
High school and above	.	0.66*
Sold vegetables		
No	1	1
Yes	0.75**	1.62**
Adjusted R^2	*0.31*	*0.51*
P value of Goodness-of-Fit Test	*0.43*	*0.39*

Variables of significance ***$p \leq 0.001$, ** $p \leq 0.01$, and * $p \leq 0.05$.

more ($p = 0.01$) and 28% more ($p = 0.03$) vegetable seeds, respectively, compared to Hmong – Sa Pa households and those in VCGs. Households engaged in selling vegetables, self-stored 25% fewer vegetable variety seeds than households not selling vegetables ($p = 0.01$).

With regard to seeds of vegetable varieties purchased, households with total cultivation areas exceeding 2 ha purchased 30% (p = 0.05) more types of vegetable varieties than those with cultivation areas below 1 ha. Hmong and Thai households in Mai Son purchased 372% (p = 0.00), 724% (p = 0.00) more types of vegetable varieties than Hmong households in Sa Pa, respectively. Households that sold vegetables purchased 62% (p = 0.01) more vegetable variety seeds than those not selling. Households where the head had a high-school education or higher purchased 34% fewer vegetable seeds compared to households where the head had a primary school education or below (p = 0.05).

Socio-economic differentiation, agrobiodiversity, and diet quality

Table 8 indicates the relationship between household agrobiodiversity and diet quality indicators. An increase of one fruit species grown by the households was associated with increases of 3% in the GDR ($p = 0.04$), 5% in the NCD-protect

Table 8. Multivariate Poisson regression of factors associated with GDR, NCD protect score, and DSR among households in northern Vietnam.

Variable	GDR Exp(β)	NCD protect score Exp(β)	DSR Exp(β)
Intercept	8.1***	1.95*	10.11***
CSR	.	.	1.00
VSR	.	.	1.01
FSR	1.03*	1.05*	1.04*
SSR	.	.	0.93***
Vegetable production area			
Below 100 m^2	.	1	1
100–999 m^2	.	1.50***	1.41***
1000^+ m^2	.	1.47***	1.46***
Location*Ethnicity			
Hmong – Sa Pa	.	.	1
Dao – Sa Pa	.	.	1.12
Hmong – Mai Son			1.06
Thai – Mai Son	.	.	1.04
Household size			
Large	.	.	1
Medium	.	.	0.82***
Small	.	.	0.63***
Group			
VCG	1	.	.
DHC	1.06	.	.
Education level of household head			
Primary and below	1	.	1
Secondary	1.10	.	1.07
High school and above	1.01	.	1.18*
Sold vegetables			
No	1	.	.
Yes	1.04	.	.
Adjusted R^2	*0.31*	*0.35*	*0.44*
P value of Goodness-of-Fit Test	*0.93*	*0.98*	*0.31*

Variables of significance ***p ≤ 0.001, ** p ≤ 0.01, and * p ≤ 0.05.
GDR: Global Dietary Recommendation Score; Non-communicable Disease (NCD) Protect Score; DSR: Dietary Species Richness Score.

score ($p = 0.02$), and 4% in the DSR ($p = 0.03$). In contrast, the addition of one staple crop was associated with a 7% reduction in the DSR ($p = 0.00$). An increase in vegetable crops was not associated with any significant improvement in diet quality indicators. Vegetable production area was correlated with dietary quality. Households cultivating vegetables in areas of 100–900 m^2 and more than 1000 m^2 had NCD-protect scores that were higher by 50% ($p = 0.00$) and 47% ($p = 0.00$), respectively, compared to households with areas under 100 m^2. Households with vegetable areas of 100–999 m^2, and at least 1000 m^2 exhibited DSR scores that are 41% higher ($p = 0.00$), and 46% higher ($p = 0.00$), respectively, than those with less than 100 m^2 of vegetable area.

Large households with six or more members had a DSR 18% (p = 0.00), and 37% (p = 0.00) higher than medium, and small households respectively. Similarly, households with heads with a high school education or higher exhibited 18% greater DSR (p = 0.05) compared to those with heads having a lower education endowment (i.e., primary school education or less).

Discussion

In Vietnam, the backbone of the agriculture sector is small landholder farmers, as reflected by an average farmland size of just 0.85 ha (Asian Development Bank 2015). There is a difference in terms of landholding between the two study sites, with Sa Pa more aligned to national statistics, having more small landholders (85.4% with less than 1 ha of cultivated land), while in Mai Son, land tenure includes 48.9% of small landholders. These findings point to relatively limited land tenure differentiation and a certain degree of commonly felt land pressure in Sa Pa, while in Mai Son there is a more marked land tenure differentiation and somewhat less land pressure felt. Our findings confirm the higher land endowment and more commercial orientation of farmers in Mai Son.

With regard to vegetable production and marketing, a higher proportion of households in Sa Pa participates in vegetable marketing compared to Mai Son (63.4% vs. 27.2%), although Mai Son has a higher percentage of farmers with relatively large, cultivated vegetables area (almost 50% of households with more than 1,000 m^2 compared to 22% for Sa Pa). The higher proportion of farmers engaged in sales in Sa Pa is likely because, in this area, most farmers, despite growing vegetables primarily for home consumption, regularly sell the surplus to local markets. This is most likely driven by the strong demand for fresh vegetables in and around tourist rich Sa Pa city. Farmers in Mai Son tend to be more commercially oriented and specialized, often focusing on crops other than vegetables like fruit, and growing vegetables largely for home consumption.

Seed management practices seem to confirm this. In Sa Pa, local households primarily rely on own-saved seeds. Besides the strong focus on home consumption, this could be due to the poorly developed vegetable seed market in the region (limited availability, high prices, and poor quality), and unreliable seed imported from China, as our own field research in the Sa Pa region found (Nguyen et al. Forthcoming). In Mai Son, a similar prevalence of own-saved was found, which is not surprising as fewer households here engage in vegetable marketing than in Sa Pa. Another factor is the different capacity building experiences of the members of the two types of farmer groups. Members of DHCs have been trained in maintaining diversity and saving seed, while members of VCGs have received training in group production and marketing. This might explain why the former are more likely to use own-saved seeds than the latter.

Crop diversity is remarkably high across the two sites, with households cultivating an average of 17 different crop species. The highest diversity was found for vegetables (10), with no major differences across the two districts. Conversely, in Mai Son, considerably more diversity is found for fruit species and less diversity for staple species, compared to Sa Pa. Some differences

among ethnic groups emerge. The Hmong group cultivates the lowest number of crops (14) and the Thai group the highest (19), with the Dao in-between (17). These findings are aligned with what has been reported in previous studies which suggest that the Hmong maintains the lowest crop diversity among other ethnic groups inhabiting the same geographical areas (Nguyen et al. 2023). Only for fruit crops, the Hmong do not rank last, but this is associated with the location of Mai Son where the production and marketing of diverse fruit species is an important economic activity for the Hmong, whereas for the Hmong in Sa Pa (with low diversity) it is not so important.

The agrobiodiversity richness in vegetable (VSR) and fruit species (FSR) are the leading factors in determining the overall crop diversity (CSR) that the household manages. Our findings indicate that the vegetable production area is the main driver of VSR, with farmers allocating larger areas to these crops reporting considerably more diversity than farmers with smaller vegetable areas. Production area is also an important determinant of FSR, as large farms tend to maintain higher diversity. Furthermore, higher FSR is associated with relatively large vegetable areas, and this is likely due to the nature of the production systems in these provinces, where often fruit trees are intercropped in vegetable areas, including the home garden (Naziri et al. Forthcoming). Besides, the size of the production area, location was a key factor affecting the level of diversity maintained, in particular, for fruit. Mai Son is considerably richer in fruit diversity, and being located there appears to be the main driver of FSR. This is not surprising as the production of a wide range of fruit crops is a critical farming activity and a major source of income in this district, which benefits from a milder climate (Son La PSO 2023). To a lesser extent, being located in Sa Pa is associated with high vegetable diversity (VSR), though only for Dao. For fruit crops, the Hmong manages less diversity compared to the Dao in Sa Pa and Thai in Mai Son. Two additional factors can partially explain agrobiodiversity richness. First, in the case of vegetables, farmers belonging to Diet Heath Clubs report considerably more diversity, which can be explained by an outcome of the efforts to promote more diverse food production, especially vegetables among the women members (Swaans and Nabuuma 2023). Second, being engaged in selling vegetables affects negatively fruit diversity, suggesting a decrease in intercropping as farms specialize in vegetable production for the market.

High VSR is frequently associated with the cultivation of various indigenous vegetables for which farmers primarily rely more on own-saved seeds. Factors determining vegetable seed management practices at the study sites are consistent with this. Managing large vegetable production areas, belonging to the Dao ethnic group in Sa Pa, and being a DHC member, are the three key determinants of both VSR and seed saving. Furthermore, having a larger vegetable area might be associated with overall enhanced capacity and experience in vegetable production and diversity, including seed multiplication and

post-harvest handling practices. Factors suggesting an overall stronger commercial orientation in farming are key drivers of seed purchase. These include managing a larger farm, being located in Mai Son, and selling vegetables. The latter also explains less seed saving because, as seed purchase is a major cost in vegetable production, this factor could also be associated with higher capital available to the farmer to cover this expense.

We explored how the level of agrobiodiversity managed by a household, their farm assets and characteristics contribute to healthier and more diverse diets. Surprisingly, a high level of VSR was not associated with more diverse diets, for any of the indicators explored. Rather, managing a larger vegetable production area seems to have a very high explanatory power for the diversity of the diet in terms of food groups (NCD-Protect) and food items (DSR). However, it is important to make a distinction between these two indices. In the case of NCD-Protect, a large vegetable area is likely more important than managing high diversity of vegetable species (VCR) in the field as this index focuses on food groups in which many vegetables are lumped together in the same consumption category. Conversely, DSR focuses on the diversity of species consumed. In this case, we would have expected to find a higher explanatory power of VCR. Findings of other studies can guide us to interpret this result. Nguyen et al. (2023) conducted a study on the same site and found healthier and more diverse diets in Mai Son compared to Sa Pa (based on NCD-Protect, DSR), although the average consumption of vegetables was significantly lower. A possible explanation is that, in more commercially oriented settings, the economic mechanisms at play, such as income generation from large-scale market production, become more important for achieving a diverse diet (DSR). In these contexts, the ability to purchase a variety of foods through increased income may play a more critical role than cultivating a diversity of vegetables for direct consumption. This is consistent with Tacconi et al. (2023), who noted that households managing larger farms improve their diet primarily by increasing their engagement in off-farm activities and markets. The findings from Nguyen et al. (2023) seem to confirm this, as they report much higher consumption of fruit, eggs, dairy, and other animal-based foods in Mai Son than in Sa Pa.

Managing high agrobiodiversity richness of fruit (FSR) contributes to increased intake of diverse food items (DSR) in line with findings by Tacconi et al. (2023), although these authors found that this effect decreases with the increase in farm size. The opposite was found for staple crops, most probably due to the overall limited diversity found on the farms for these crops. Two additional factors contribute to higher DSR: smaller household size and higher level of education of the household head. These findings are not unexpected when the key drivers of a healthy and diverse diet are often revenue and wealth (Tacconi et al. 2023), with larger households being more likely to generate off-farm income, and education being a common indicator

of improvement in people's livelihoods (for a study on education and livelihoods in Northwest Vietnam, see Tran et al. 2020). All factors that were found contributing to a more diverse diet, namely, larger vegetable production area, higher FSR, lower SSR, few very small households, and higher education were more apparent in Mai Son and, all together, might explain the healthier and more diverse diets which can be found in this district, compared to Sa Pa.

Conclusions

In this study, we built on the previous results of our research for development activities in northern Vietnam, under the [deleted] initiative, to improve smallholder livelihoods through improved vegetable farming. Although overall, participating farmers assessed the results of the different activities as positive, there was no clear understanding of which farmers benefitted in which ways, and what the reason or reasons for this was/were. One of the important findings is that there is a difference in terms of landholding between the two study sites, with Sa Pa more aligned to national statistics, having more small landholders, combined with very small percentages of intermediate landholders and larger landholders, while in Mai Son land tenure is less skewed and with larger numbers of intermediate and larger landholders.

The differences between each site and across sites are important to consider from the start of planning activities as land size is a crucial resource that heavily impacts farming options and livelihood pathways. We found that cultivating a larger vegetable land area goes hand in hand with higher vegetable diversity, for example. However, a small land holding does not equate no or little market participation, as the Sa Pa data for vegetable marketing indicates. Additional value-chain development activities, for example, catering to the growing agrotourism sector (e.g., the rise of homestays) or low-cost organic certification of certain vegetable crops (e.g., through Participatory Guarantee System), therefore, could be of strong interest to Sa Pa farmers and could contribute to conservation and sustainable use of agrobiodiversity.

In our previous work, we did not investigate these factors very systematically, which could have contributed to designing more tailor-made intervention options for different farmer groups, but the new analysis has made us more aware of the need for this. The new analysis helps to deepen our knowledge about the influence of socio-economic differentiation on livelihood development pathways in more ways.

Our findings indicate that ethnic groups and locations also matter in farming options and pathways. Crop diversity is remarkably high in both sites and among the three ethnic groups, notably when considering the high prevalence of extremely small crop areas, but there are differences among the ethnic groups, with the Hmong overall having the lowest and the Thai the highest levels of diversity, excluding staple crops. The Hmong in Sa Pa did not practice

much vegetable seed saving compared to the other groups there. These findings are important to consider when designing activities that concern (increasing or changing) crop and tree conservation or diversification strategies, which should be based and built on existing differences and not on the same blueprint strategy for everyone.

For example, the interest in and need for a crop community seed bank are likely to be highest among the groups with the lowest level of diversity overall (even more so if diversity is declining, which is occurring across Vietnam), while a community seed bank specializing in tree crops could be the most appealing for the group with the lowest tree diversity. To enlarge access to more diversity and increase seed availability, the Hmong in Sa Pa might benefit most from a community seed bank. All farmers in Sa Pa, more broadly speaking, would reap benefits from a community seed bank, which, apart from conservation efforts, specializes in quality seed production, given the overall situation of a poorly functioning seed market. The same applies to farmers in both districts belonging to the three ethnic groups with extremely small vegetable cultivation areas. In addition, a community seed bank can be an effective mechanism to build or strengthen a culture of seed sharing among households at the commune level and beyond, contributing to more seed security overall.

We obtained another important insight by exploring if the level of agrobiodiversity managed by a household, their farm assets and characteristics contribute to healthier and more diverse diets. We found that a high level of VSR is not associated with more diverse diets, for any of the indicators explored. What is associated is managing a larger vegetable production area, which allows revenue generation through marketing, which in turn allows purchasing food. These findings suggest that policy interventions need to be based on sound analysis of (dietary) species richness to better capture how changes in agrobiodiversity affect diets.

This raises the question of what the most effective strategies are for improving diets for farmers, with different farming assets, practices, and marketing opportunities (influenced by location). Here as well, new value chain development activities for any of the crops/trees cultivated on the farm currently or for new crop/tree species to be added could be beneficial to create more income generation opportunities. DHCs could directly benefit from this. Awareness raising and educating farmers about healthy diets can be important for ensuring that more diversity is maintained in the farm, and VCGs could directly benefit from this. Participants in DHCs that were exposed to the benefits of and supported in growing different vegetable species and varieties serve as a good example. However, this doesn't necessarily translate automatically into a healthier and diverse diet, which often requires access and consumption of food items that can be purchased from the market.

This study provides critical insights into the relationship between agrobiodiversity and dietary diversity among three ethnic groups in upland Northwest

Vietnam. The application of rigorous statistical models to assess socio-economic differentiation and its interaction with agrobiodiversity and dietary diversity indicators yields robust empirical evidence that advances our understanding of these complex interrelationships. The inclusion of multiple ethnic groups further augments the cultural relevance and applicability of the results, contributing substantively to the broader literature on agriculture – nutrition linkages.

Notwithstanding its strengths, the study has several limitations that merit consideration. Although the sample size ($n = 181$) is appropriate given resource constraints and is representative of the study area, it may restrict the generalizability of the findings to other contexts. Additionally, the food environment is not given much thought in the study, which mainly concentrates on agrobiodiversity and dietary diversity. Despite these constraints, the findings could inform policy interventions aimed at improving dietary diversity and food security in similar settings. Future research should seek to incorporate a more comprehensive assessment of food environments and consider additional socio-cultural factors.

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Appendix 1: The top five crops cultivated per crop type, by district (2023)

Crop name	Mai Son ($n = 92$), %	Sa Pa ($n = 82$), %	Overall ($n = 174$), %
Staples			
Maize	81.5	92.7	86.8
Maize (glutinous)	22.8	58.5	39.7
Rice	–	93.9	48.9
Glutinous rice	56.5	53.7	55.2
French bean	46.7	45.1	46.0
Long bean	22.8	–	–
Vegetables			
Pumpkin	87.0	95.1	90.8
Hmong mustard	70.7	75.6	73.0
Sauropus (sweet leaf)	51.1	–	–
Chili	46.7	58.5	52.3
Chayote	–	72.0	46.6
Hmong cucumber	–	70.7	–
French bean	46.7	–	46.0
Fruits			
Plum	44.6	50.0	47.1
Longan	89.1	–	47.1
Peach	–	69.5	37.4
Mango	82.6	–	43.7
Banana	53.3	12.2	33.9
Jackfruit	34.8	–	–
Pear	–	26.8	–
Wampee (wampi)	–	6.1	–