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Remoteness, Farm Production, and Dietary Diversity in Nepal

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Notices

ABSTRACT

This paper explores the relationship between agriculture, dietary diversity, and market access in Nepal, testing the complex causal chains involved, and the nuanced connections between production diversity and dietary diversity among smallholder farmers. While diversifying farm production could enhance dietary diversity, the case of Nepal indicates a varied and context-specific relationship. Market access emerges as a crucial factor, often exerting a more significant impact on smallholder farm households than production diversity. Access to markets not only influences economic viability but also contributes directly to food and nutrition security, offering a practical solution to address dietary needs. Focusing on Nepal's diverse terrain, the study analyzes the interplay of remoteness, market access, irrigation availability, and complementary inputs in shaping farmers' decisions, providing valuable insights into sustainable agricultural strategies for improved dietary outcomes in low- and middle-income countries.

Keywords: South Asia, Nepal, Production diversity, Diets, Energy access, Irrigation

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Introduction

As the primary source of food and livelihood in low- and middle-income countries, agriculture plays a pivotal role in shaping nutritional outcomes (Pinstrup-Andersen, 2007) for a majority of the world's population. However, the relationship between agriculture and nutrition is complex, with lengthy and complex causal chains linking the two (Webb & Kennedy, 2014). In the most underdeveloped agricultural settings characterized by inefficient markets, smallholder farmers often consume a significant portion of their own produce, and limited market access may prompt farmers to diversify their agricultural production to mitigate potential dietary deficiencies. In these settings where production and consumption decisions are inseparable, increasing the variety of crops grown and livestock species is often seen as an effective strategy to enhance household dietary diversity. (Fanzo et al., 2013; Jones et al., 2014; Powell et al., 2015; Jones, 2017).

While the notion that diversifying farm production can improve dietary diversity in subsistence farming households is compelling, empirical research reveals a complex and varied relationship between these two factors. Smallholder farmers are neither strictly subsistence-focused nor entirely market-driven. Despite their subsistence-orientation, they frequently engage in market transactions, for purchase of inputs, but also for the sale of surplus produce and for their own sustenance needs. So, whether production diversity leads to dietary diversity, often depends on specific regional and local contexts; the relationship is not always straightforward (Snapp & Fisher, 2015; Sibhatu et al., 2015; Hirvonen & Hoddinott, 2017; Koppmair et al., 2017). A comprehensive review by Sibhatu and Qaim (2018) notes that fewer than 20 percent of studies find consistently positive and significant associations between production and dietary diversity among smallholders. Furthermore, the incremental benefit of production diversity on dietary diversity, though present, is limited in scale, indicating that a substantial increase in crop or livestock species is essential to bring about any meaningful enhancement in dietary diversity.

Recent literature has shifted focus to emphasize the crucial role of market access in influencing dietary diversity (Remans et al., 2015). Many of the same studies investigating the link between production and dietary diversity underscore that market access can significantly impact smallholder farm households, more so than production diversity. The economic viability of crops produced is a crucial factor in the practicality of diverse production. Sibhatu et al. (2015) argue that the income derived from specialized and economically viable crops can sometimes outweigh the benefits of diversification. In such instances, encouraging smallholder farmers to increase crop diversity could inadvertently jeopardize their competitive advantage and potential earnings. This is corroborated by Kissoly et al. (2018), who found that farm production diversity plays a lesser role in the dietary diversity of rural farm households when agro-ecological conditions are favorable, and market access is robust.

Moreover, access to markets can directly contribute to food and nutrition security by increasing the availability and variety of micronutrient-rich foods (Sibhatu et al., 2015; Abay & Hirvonen, 2017; Stifel & Minten, 2017; Usman & Haile, 2019). This can partially substitute the need for smallholder farmers to diversify their own food crop production as a means to achieving a varied household diet. Markets, in essence, provide a direct route to a diverse range of foods far exceeding what any single household can produce, thereby offering a practical solution to meet the dietary needs of smallholder farm households (Bellon et al., 2016).

Finally, in many low- and middle-income countries, the feasibility of diversifying production beyond mere subsistence is often constrained by factors such as small size of landholdings, limited access to technology, mechanization and information, and the challenges posed by local market connectivity and agro-climatic and soil biophysical characteristics (Hirvonen & Hoddinott, 2017).

In this paper, we study the relative importance of market access versus production diversity as a means for accessing diverse and nutritious diets in the context of Nepal. Diverse, healthy diets are crucial for improving nutritional outcomes (Graham et al., 2007), and a large proportion of the world's population is chronically undernourished because of a lack of access to affordable food (Bai et al., 2021). In countries like Nepal, diets tend to be cereal-heavy, with poor nutritive value and lacking in essential micronutrients like iron and zinc, which has exacerbated the incidence of malnutrition (Central Bureau of Statistics, 2011). Subpar nutrition during early childhood can hinder cognitive and physical growth, potentially compromising future educational outcomes (Alderman et al., 2006; Glewwe et al., 2001). The case of Nepal is especially interesting due to the diversity of terrain over a relatively small area. Over a brief span, Nepal's landscape transitions from the fertile Gangetic plains, ideal for agriculture, to the barren expanses of the Himalayan mountains. This rapid change in altitude has wide ranging implications for what can be grown on the land, what inputs are available to farmers, how extensive and accessible markets are, and whether nutritious diets are affordable and accessible.

We contribute to the literature examining the relationship between farm production diversity and household dietary diversity by looking at the factors influencing farmers' decisions to adopt either diversified or specialized farming strategies in Nepal. Our paper addresses critical gaps in the literature by not only analyzing the direct relationship between farm diversity and dietary diversity, but also highlights how this relationship is mediated by market access, irrigation availability and the availability of other complimentary inputs. Furthermore, we provide a comparative analysis of common trends and associations within, and across, two demographically and ecologically distinct regions of Nepal – the plains (Terai) and the mid-hills – each with their unique social structures, agricultural practices, and cultural traditions.

1. The role of markets shaping Nepal's farming and diets

In the context of Nepal, the relationship between household remoteness, farm production diversity, and household diets is particularly intriguing for two reasons: the nation's diverse geography and its strategic location adjacent to India, and its dependence on India for a majority of agricultural input needs. Nepal's varied topography, climate, and soil types contribute to its agroecological variety, ranging from the fertile plains of the Terai to the rugged terrains of the mid-hills and mountains. This leads to significant agricultural heterogeneity, with farming systems adapted to specific altitudes and regions (Shrestha, 1992). While the Terai region favors commercial agriculture like rice-wheat based systems of the larger Indo-Gangetic plains, producing most of the country's marketed surplus, the mid-hills largely function on a subsistence level, with greater reliance on livestock and forestry. Due to smaller, fragmented land holdings and logistical constraints that hinder economies of scale, farmers in the mid-hills rely more on basic, self-sustaining farming methods.

Secondly, the Terai's proximity to the Indian border significantly influences market access and participation for farmers in this area. The well-developed transport network in the Terai, linking major towns in Nepal to India, facilitates exchange of labor, inputs, technology, output, and information. Further, the Trade and Transit Treaty between Nepal and India enhances market access by allowing most exports from Nepal to enter India duty-free, while imports from India enjoy reduced duties. This preferential market access is vital for Nepal, which relies heavily on foreign food supply, primarily from India (Food and Agriculture Organization of the United Nations & United Nations World Food Programme, 2007). In addition, this network is instrumental in promoting mechanization in the bordering Terai districts, providing farmers with access to new farming tools and technology, and facilitating the flow of goods and services. This, in turn, enables farmers to improve their farming practices, sell their produce more easily, and access a variety of products and services they need (Gauchan & Shrestha, 2017).

Proximity to India also impacts the availability and affordability of inputs such as seeds, fertilizers, and pesticides, which in turn directly influences crop yields and the types of crops cultivated. In regions where farmers have easy access to quality inputs, they can optimize agricultural practices, leading to increased productivity and yields, and consequently higher income. This, in turn, is a pathway to enhance the nutritional diversity of local diets. A prime example is access to irrigation technology. In Nepal, the intricate connection between irrigation and diets underscores the role of water management in shaping food security and nutritional outcomes. The country's diverse topography requires tailored irrigation systems to support agriculture. Effective irrigation enhances crop yields by providing a reliable water supply, allowing farmers to cultivate a variety of crops throughout the year. In regions where irrigation is prevalent, such as the Terai plains, farmers can grow staples like rice and wheat, potentially alongside a diverse range of vegetables and fruits. Moreover, the consistent water supply facilitates the cultivation of high-value and cash crops, contributing not only to food security but also to economic well-being. Conversely, in areas with limited access to irrigation such as the mid-hills, dependency on rain-fed agriculture prevails, making crops vulnerable to climatic uncertainties. This can result in periodic food shortages, affecting the nutritional diversity of diets. Efforts to expand and improve irrigation infrastructure in Nepal can thus be seen as vital steps toward ensuring a stable and diverse food supply, ultimately enhancing the nutritional well-being of its population.

Ultimately, agriculture and agricultural markets are intricately linked to dietary habits in rural Nepal, shaping the food choices and nutritional well-being of its residents. Despite the agricultural richness, challenges persist in rural Nepal, such as limited access to modern farming techniques, irrigation facilities, and market opportunities. These challenges often hinder the maximization of agricultural productivity and the cultivation of a broader array of crops. As a result, dietary choices in some areas can be constrained, leading to over-reliance on traditional staples.

2. Materials and Methods

2.1. Data

The data used in this study comes from a farm household survey conducted in February 2023 in Nepal, as part of CGIAR's Nexus Gains Initiative. CGIAR is a global agricultural innovation network that unites organizations engaged in research for a food-secure future. Nexus Gains is one of CGIAR's research initiatives with the primary objective to enhance synergies across water, energy, food, and ecosystems in specific transboundary river basins. It focuses on advancing research capabilities, strengthening systems thinking, and equipping stakeholders with the necessary analytical tools and training to drive research that informs development. One of the primary goals of this initiative is to address the underlying environmental, social and policy conditions that facilitate access to affordable, nutritious diets. By targeting these factors, the initiative strives to make healthy food options more accessible and affordable.

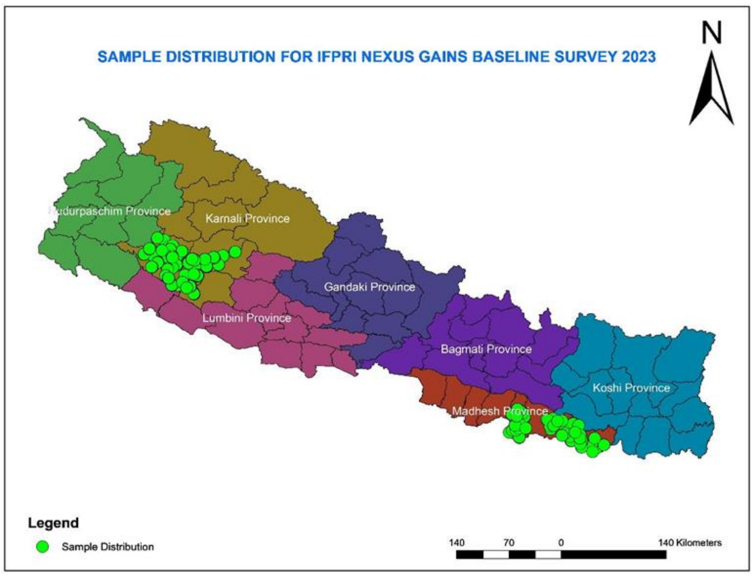
Inter Disciplinary Analysts (IDA) conducted the survey, covering two provinces and six districts, with an equal representation from the Terai and Mid-hills region of Nepal. The survey's sampling frame was obtained from the Central Bureau of Statistics (CBS) of the Government of Nepal, based on data from the 2011 National Population and Housing Census. Household selection was based on a multi-stage probability sampling design, wherein the first step, three districts from each province were selected, ensuring parity in sample sizes across provinces. In each district, a sampling frame was constructed, enumerating all urban and rural municipalities, along with their wards and population sizes. Employing a probability proportional to size approach, 42 wards from each province were selected, resulting in a total of 84 wards in our sample. In the second step, 12 households per ward were selected randomly. Each selected household was administered two separate surveys – one to a male respondent and other to a female respondent.

Interviews captured a wide array of information, including details on demographics, socio-economic status, agricultural practices, and food consumption patterns. Primary agricultural decision-makers, typically informed on land details, cropping pattern, and crop economics, answered questions on agricultural decision-making. Women, central to managing household resources, were administered detailed modules on household demographics, asset ownership, access to basic services, and homestead farming. Dietary intake was gauged using the Diet Quality

Questionnaire (DQ-Q), a standardized tool for recalling food consumption over the previous 24 hours from both genders.

Supplementary to the household data, IDA conducted a community-level survey, gathering information on the demographic makeup of villages, availability of government services, and market accessibility, among other information. In total, 1008 farm households were surveyed. Out of this total, we excluded those that had missing data for relevant variables, leaving 998 households.

Figure 1: Location of the study areas and sampled households.



Source: Created by the author using survey data and shapefiles of Nepal.

2.2.Measurement of household dietary diversity

In this study, we used the Food Group Diversity Score (FGDS) to evaluate household dietary quality. The FGDS, which incorporates ten distinct food groups, serves as a measure for the diversity of food consumed within a specified timeframe, typically 24 hours, based on the count of consumed food groups (World Health Organization, 2021). We focused on women’s FGDS to reflect household dietary diversity, acknowledging that the Minimum Dietary Diversity for Women (MDD-W), from which the FGDS is derived, is an internationally recognized marker for evaluating micronutrient adequacy for women of reproductive age. This selection is supported by substantial evidence, including a recent study by Arimond M et al. (2021), which demonstrated a positive correlation between women’s FGDS and micronutrient adequacy across various demographic groups in China, and Mexico. Given that women are often the nutritional gatekeepers in households, their dietary diversity is a critical measure of the overall nutritional quality available to the household, especially children who are directly impacted by the maternal diet. Therefore, we propose that FGDS of women is a robust proxy for household dietary diversity, offering a more detailed reflection of household nutrition than the FGDS of men.

The FGDS was calculated using individual food consumption data collected from surveyed households. Respondents were asked to list all food items consumed in the past 24 hours, which were then categorized into predefined food groups. Food groups considered were: (1) grains, white roots, and tubers; (2) pulses; (3) nuts and seeds; (4) dairy; (5) meat, poultry, and fish; (6) eggs; (7) dark green leafy vegetables; (8) other vitamin A-rich fruits and vegetables; (9) other vegetables; (10) other fruits. A binary score of '1' for consumption and '0' for non-consumption was assigned to each food group, and the FGDS was then calculated by summing these scores, yielding a range of 0 to 10, with higher scores indicating greater dietary diversity.

2.3.Measurement of farm production diversity

We collected detailed information on farmers' agricultural production over the past 12 months, revealing distinct cropping patterns across regions. In Terai, there is a pronounced emphasis on paddy cultivation during the monsoon season. Most households cultivate it, either as a single crop or through multiple plantings. While intercropping occurs, it's less common, with a modest presence of other crops like wheat, pigeon pea, and various vegetables. Mid-hills display more diverse agricultural practices. Paddy, often intercropped with maize, is a prevalent cultivation choice. Maize, also a key crop, is grown both alone and alongside paddy, with additionally intercropping combinations including finger millet, cowpeas, and various vegetables. Winter season farming trends show wheat as the primary crop in both regions. Farmers in the Mid-hills either cultivate wheat alone or intercrop it with other staples like barley, potatoes, and oilseeds. The region also reveals multi-cropping strategies, with up to five different crops being grown simultaneously. In Terai too, wheat remains prevalent but is less often intercropped, suggesting that it might serve as a cash crop or a staple food source. During summer, a significant portion of farmers in Nepal's regions do not engage in crop cultivation, with 65% in the Pahad region and 92% in the Tarai region reporting no agricultural activity. This pattern suggests significant seasonal influences on farming practices. Despite a substantial number of farmers in the Pahad region not growing crops during this period, those who do exhibit a diverse cropping pattern centered around maize. Contrastingly, the Terai region, which has an even higher percentage of non-cultivating farmers, displays less crop diversity in the summer, with a focus on fewer crop types like maize and sugarcane.

In the main analysis, we define production diversity as a combination of two main types of agricultural activities: farming and livestock rearing. We look at the diversity of these activities over the course of a year, rather than at a single point in time, and use a simple, unweighted count measure of the number of crops and livestock species produced on the farm over the past 12 months. In a set of robustness checks, we use two alternative measures to examine whether this influences the results significantly. First, we use the crop species count, which is an unweighted count of the number of crop species cultivated on the farm. Second, we use the Simpson index, which captures both the richness and evenness of a farm's crop composition. The index is defined as $SI = 1 - \sum_{i=1}^{n} P_i^2$, where P_i is proportionate area of ith crop by the ith household. The index ranges from 0 to 1, where a higher value indicates greater crop diversity.

2.4.Measurement of physical remoteness

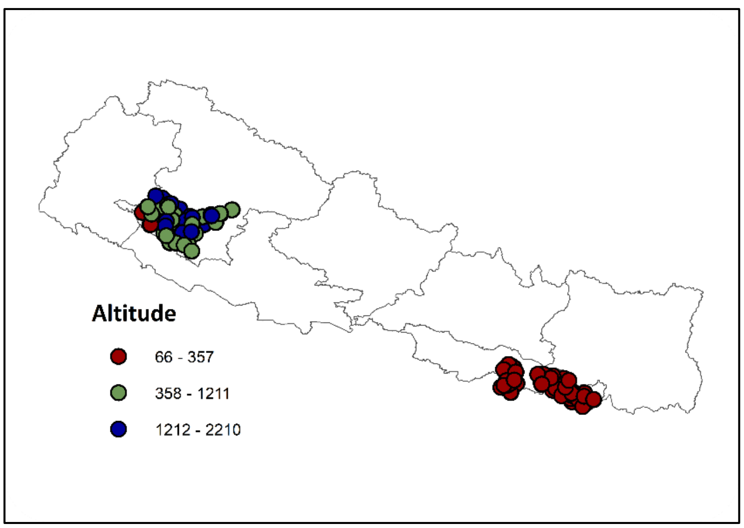
As a proxy for physical remoteness, the study used the elevation of households' residence. The rationale hinges on the understanding that geographical elevation often correlates with remoteness and accessibility, both of which are key determinants of market access in regions like Nepal. Nepal's varied topography, where elevation can be a significant barrier to market connectivity, highlights this relationship (Banick & Kawasoe, 2019). Poor road infrastructure and longer travel times remains a significant barrier to Nepal's shift from predominantly subsistence farming to more diverse and commercial agricultural systems. This issue is especially acute in the country's hilly and mountainous regions, where challenging landscapes and low road density limit access to markets (Asian Development Bank, 2009). In contrast, lower elevations, typically found in the plains like the Terai region, often benefit from more developed transportation networks and closer proximity to market centers. Furthermore, elevation as a proxy is supported by empirical evidence linking geographic elevation to market accessibility and agricultural practices. Studies have shown that elevation can influence the type of crops grown, agricultural yields, and farmers' decisions to engage in market-oriented production versus subsistence farming (Shilpi & Fafchamps, 2002).

To accurately measure elevation, GPS coordinates of the households were recorded during the survey. Subsequently, the Shuttle Radar Topography Mission (SRTM) Digital Elevation Model

(DEM) was utilized to retrieve elevation values for each household based on their latitude and longitude coordinates. The use of SRTM DEM ensures precise and reliable elevation data, crucial for this study's analysis.

In the main part of the analysis, we use elevation data to approximate market access. For robustness checks, we use an alternative indicator of physical remoteness: distance of households from the closest entry point on the India-Nepal border. This measure is relevant given the significant trade between Nepal and India, especially along the border. Nepalese villages near the border benefit from easier access to agricultural products from India, like seeds, fertilizers, and farm machinery, impacting their farming practices and market participation. Additionally, India is Nepal's primary source of food imports, with most items entering through this border. The distances were calculated using the Google Distance Matrix API, measuring the on-road distance from households to the nearest border entry point.

Figure 2: Households' elevation above mean sea level (in meters).



Source: Created by the author using survey data and shapefiles of Nepal.

2.5.Measurement of irrigation, farm machinery, and energy access

Irrigation, farm machinery, and access to cleaner energy sources for cooking are integral in enhancing productivity, both on the farm and within households. For instance, irrigation, especially small-scale systems, is increasingly recognized in securing food and livelihoods. Empirical studies highlight its potential to significantly increase agricultural yields and income while reducing crop losses due to water scarcity, thereby primarily benefiting smallholder farmers (Xie et al., 2014; Lipton et al., 2003). Moreover, irrigation often leads to enhanced market participation. Notable interventions such as the introduction of tubewells and treadle pumps in regions like sub-Saharan Africa have substantially raised commercialization rates of irrigated crops and returns per hectare, illustrating how irrigation can drive market-oriented production and increase agricultural income (Burney & Naylor, 2012; Mangisoni, 2008; Nkonya et al., 2011). Similarly, in Nepal, the mechanization of agriculture is undergoing a transformative shift, evidenced by a significant uptick in the use of modern farming equipment. This change is primarily attributed to the tangible benefits perceived by farmers, including considerable savings in time, resources, and labor, indicating a broader transition towards more efficient and sustainable farming practices (Gauchan & Shrestha, 2017). In terms of household productivity, access to cleaner energy sources for cooking plays a pivotal role. The transition to modern energy sources like LPG and electricity not only streamlines household time management but also enhances the quality of life.

To analyze the role of these variables for dietary diversity, we construct three variables. First, for irrigation access, we identified farmers who own or use irrigation assets like tubewells, borewells, and pumps, including those who lease or buy water. This led to a binary variable, distinguishing between farmers with any form of irrigation access and those without, effectively capturing the availability of irrigation resources in the agricultural households surveyed. Second, the use of farm machinery was assessed through a multiple correspondence analysis based on detailed survey data on the use of various manual and mechanized farming tools. The first-dimension score from this analysis was used as a proxy for the level of mechanization, thus quantifying the extent of agricultural technology usage on a continuous scale. Third, for energy sources used in cooking, we classified households based on their primary cooking energy sources into three categories: households using exclusively unclean sources, those transitioning to clean sources (using a mix of both), and those using exclusively clean sources.

3. Empirical Strategy

Our empirical goal is to measure observed correlation in the available data, focusing on two main objectives: firstly, to investigate the effect of farm production diversity on household dietary diversity; and secondly, to assess the role of markets and other relevant factors in shaping this relationship. We utilize three sets of linear regression models to empirically assess these dynamics. At the core of our analysis is the hypothesis that, *ceteris paribus*, farmers increase the diversity of their agricultural production to improve the dietary diversity of their households. However, this general premise is tested in the context of varying geographical characteristics that significantly influence farming practices.

Geography plays a critical role in agricultural decisions. In regions where remoteness is less pronounced, typically characterized by better market access and more developed transportation facilities, we observe a trend towards reduced agricultural production diversity. This shift is driven by the economic incentives of crop specialization, where farmers focus on certain crops that promise higher market value and profitability. Such a strategy is particularly rational in areas proximate to markets where these crops are in higher demand, potentially leading to increased farmer incomes. This additional income can then be used to purchase a wider range of nutritious foods, contributing to dietary diversity (Jones et al., 2014). In contrast, in areas with higher levels of remoteness, where access to markets is more challenging, agricultural practices differ markedly. In these isolated and hilly regions, diversification in agricultural production becomes not just beneficial but often essential for enhancing dietary diversity.

We define our primary model specifically to examine the direct correlation between farm production diversity and household dietary diversity, excluding all other covariates. To do this, we use regression models of the following form:

$$HDD_i = \alpha_0 + \alpha_1 PD_i + \varepsilon_i \qquad [1]$$

where HDD_i is the dietary diversity score of farm household i and PD_i is production diversity in farm household i, which is a simple count of crop and livestock species produced on a farm. ε_i is a random error term, and α_0 and α_1 are coefficients to be estimated, with a particular interest in the estimate for α_1. A significant positive coefficient for α_1 would suggest that higher production diversity is correlated with higher dietary diversity, as is commonly assumed.

In the extended model, we adjust to include a variable indicative of household remoteness to examine how varying degrees of remoteness, as measured by household elevation, affect the relationship between production diversity and dietary diversity. This is based on our hypothesis that this, along with production diversity, influences dietary diversity. We do this by estimating the model for the pooled sample, and then separately for sub-samples from each of the two regions. This approach allows us to verify if the impact of production diversity on dietary diversity diminishes in areas with better access to markets due to less pronounced remoteness. To account for potential confounding factors that might affect this relationship, we introduce additional controls: farm size and commercialization, livestock income, agricultural information access, kitchen gardens, household size, household wealth, age, education, and sex of household head, and household caste. The specification for the regression model is as follows:

$$HDD_i = \alpha_0 + \alpha_1 PD_i + \alpha_2 HR_i + \alpha_3 \boldsymbol{C}_i + \varepsilon_i \qquad [2]$$

where HDD_i and PD_i continue to represent dietary diversity and production diversity, respectively, and HR_i represents household remoteness measured by the elevation of households' residence above mean sea level. $\boldsymbol{C}_i$ represents the vector of socioeconomic, agricultural, and demographic control variables mentioned above, and α_3 is the vector of coefficients associated with these controls.

To substantiate our findings, we further extend the model in equation 2 by including interaction terms. This enhancement allows for a more nuanced exploration of how geographical remoteness plays a moderating role in the relationship between farm production diversity and household diets. We hypothesize that the impact of farm production diversity on dietary diversity is more pronounced in remote areas compared to regions with enhanced market access and infrastructure. Additionally, we posit that the influence of household wealth on dietary diversity may vary depending on geographic location, with its effect being stronger in areas with better market access which allows for the purchase of a variety of food. To examine these moderating effects, we introduce interaction terms between household remoteness and both farm production diversity and household wealth.

Finally, beyond production diversity and household remoteness, we also assess the impact of irrigation availability, farm machinery access, and cleaner cooking energy sources. Recognizing their importance, we treat access to irrigation and farm machinery as mediating variables that directly influence agricultural production, thereby affecting both market participation and income, which in turn shapes dietary outcomes. For example, improved irrigation and machinery can lead to more consistent and diversified farming, enabling farmers to either diversify or specialize according to market demands. Additionally, we explore the subtle yet significant role of cleaner cooking energy. While its primary impact lies in enhancing household diets through better food preparation methods, it indirectly supports the agriculture-nutrition link by optimizing household time management, thereby freeing up time for agricultural activities and market engagement. To analyze the role of these variables, we further extend this model as follows:

$$HDD_i = \alpha_0 + \alpha_1 PD_i + \alpha_2 HR_i + \alpha_3 \boldsymbol{X}_i + \alpha_4 \boldsymbol{C}_i + \varepsilon_i \qquad [3]$$

where $\boldsymbol{X}_i$ represents a vector of variables indicating irrigation availability, farm machinery access, and the type of energy sources used for cooking.

In all models, we employ robust standard errors to address any concerns of heteroscedasticity. We also control for regional fixed effects to account for potential heterogeneity arising out of unobserved socioeconomic and cultural differences that could otherwise confound our analysis.

Table 1: Descriptive statistics for key variables.

Variable	Description	Pooled	Mid-Hills	Terai	Diff.
Household dietary diversity	Food group diversity score – 10 groups	4.60 (1.54)	4.43 (1.60)	4.77 (1.45)	-0.34***
Farm production diversity					
Production diversity	Total unweighted count of crop and livestock species on the farm	6.54 (3.24)	7.63 (3.30)	5.44 (2.76)	2.19***
Crop species count	Total unweighted count of crop species on the farm	4.95 (3.05)	6.05 (3.12)	3.85 (2.55)	2.20***
Simpson index	Simpson index of crop diversity	0.64 (0.18)	0.72 (0.14)	0.56 (0.17)	0.16***
Physical remoteness / Market access					
Remoteness	Elevation of households' residence (100 meters)	6.13 (5.86)	11.22 (4.10)	1.04 (0.27)	10.18***
Border distance	Households' distance to nearest India-Nepal border entry (10 km)	9.41 (7.50)	16.32 (3.86)	2.50 (1.44)	13.82***
Agricultural characteristics					
Size of farm	Household's farm size in acres	1.53 (1.98)	1.05 (0.83)	2.02 (2.59)	-0.96***
Commercialization ratio	Proportion of crops sold in the market	0.14 (0.24)	0.09 (0.19)	0.20 (0.27)	-0.10***
Livestock income	Livestock income per household member (1000 NPRs)	6.36 (12.56)	6.94 (14.05)	5.79 (10.85)	1.15
Agricultural info. access	Households' agricultural information access: Yes = 1	0.75 (0.43)	0.84 (0.37)	0.66 (0.48)	0.18***
Kitchen garden	Households' possession	0.89	0.95	0.84	0.11***

	of kitchen garden: Yes = 1	(0.31)	(0.22)	(0.37)	
Sociodemographic characteristics					
Size of household	Number of individuals in household	5.04 (2.42)	4.34 (1.75)	5.74 (2.77)	-1.40***
Wealth index	Household asset wealth index	-0.00 (3.06)	-2.63 (1.75)	2.63 (1.33)	-5.27***
Age of head	Age of household head in years	53.18 (12.85)	51.59 (13.64)	54.78 (11.79)	-3.20***
Education					
Low	No formal education	0.40 (0.49)	0.38 (0.49)	0.42 (0.49)	-0.05
Medium	Completed some formal education	0.57 (0.50)	0.60 (0.49)	0.54 (0.50)	0.06*
High	Graduate and above	0.03 (0.17)	0.02 (0.15)	0.04 (0.19)	-0.01
Caste					
Dalit	Marginalized group	0.18 (0.38)	0.20 (0.40)	0.16 (0.37)	0.04
Janjati	Indigenous or tribal group	0.22 (0.42)	0.13 (0.34)	0.31 (0.46)	-0.18***
Other	Non-indigenous, non-tribal, or non-Dalit	0.21 (0.41)	0.02 (0.13)	0.41 (0.49)	-0.39***
Upper	Higher social status group	0.38 (0.49)	0.65 (0.48)	0.12 (0.32)	0.54***
Female-headed household	Household head gender: Female = 1	0.07 (0.25)	0.05 (0.21)	0.08 (0.27)	-0.03**
Irrigation, mechanization, and energy use					
Irrigation access	Irrigation access in household: Yes = 1	0.46 (0.50)	0.08 (0.27)	0.84 (0.37)	-0.76***
Farm-tech usage score	Household farm technology usage composite score	0.00 (1.00)	-0.91 (0.42)	0.91 (0.42)	-1.82***
Energy source for cooking					
Unclean	Household only uses unclean energy sources for cooking	0.51 (0.50)	0.66 (0.47)	0.36 (0.48)	0.30***
Transitioning	Household uses a mix of unclean and clean energy sources	0.48 (0.50)	0.33 (0.47)	0.62 (0.49)	-0.29***
Clean	Household only uses clean energy sources for cooking	0.01 (0.10)	0.00 (0.06)	0.02 (0.13)	-0.01*

Observations	998	449	449

Mean values are shown with SDs in parentheses.

4. Results

4.1. Characteristics of Sample

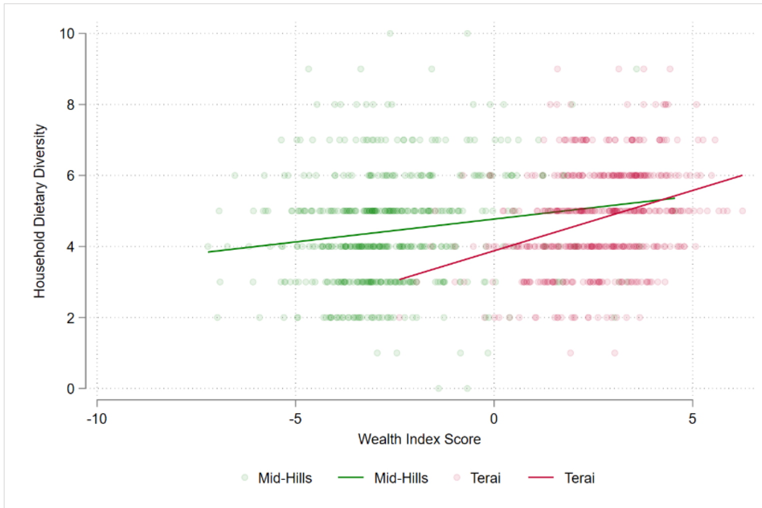
Table 1 presents the descriptive statistics for the variables used in the analysis. Household dietary diversity score shows that on average, households consumed 4.6 types of food groups during the 24 hours prior to the survey. Approximately half of the households consumed fewer than five food groups; only 11 percent consumed more than 6 food groups. Predominantly consumed food groups include cereals, pulses, dark green leafy vegetables, other vegetables, and dairy products, with cereals almost universally consumed. In contrast, the intake of meats, fruits, and other nutrient-rich foods like vitamin-A dense vegetables, eggs, nuts, and seeds is markedly lower, as detailed in Table 2. These patterns point to a moderate level of dietary diversity among the sampled farm households.

Table 2: Aggregation of food groups access by farm households.

Food groups	Percent
Grains, white roots and tubers, and plantains	100
Pulses (beans, peas, and lentils)	75
Dark green leafy vegetables	75
Other vegetables	71
Dairy	63
Meat, poultry, and fish	25
Other fruits	25
Other vitamin A-rich fruits and vegetables	13
Eggs	9
Nuts and seeds	6

Comparing outcomes across the two regions that make up the sample of our study, one finds that households in the Terai region demonstrate a generally higher dietary diversity compared to those in the Mid-hills (p-value < 0.01). Wealth appears to be a crucial determinant in this aspect. Figure 3 shows a positive correlation between households' wealth and dietary diversity across both regions. This is consistent with the expectation that dietary diversity should increase with income. Notably, in the Terai region, this correlation is pronounced, suggesting that increased wealth allows for greater access to diverse food groups. By contrast, this relationship is weaker in the Mid-hills, suggesting the presence of other influential factors shaping food choices, which could play a more significant role in dietary decisions in this region than mere economic well-being.

Figure 3: Wealth and dietary diversity among farm households in Nepal.



The rest of the variables serve as covariates in our regression model. Farm size averages 1.5 acres across the sample. However, there is a notable variance in farm sizes and other socio-economic characteristics both within and across regions. Production diversity also shows considerable variation. For instance, farmers in the Terai region demonstrate lower production diversity, producing on average only 5.4 species, in contrast to their counterparts in the Mid-hills, where an average of 7.6 different crops and livestock species are produced on each farm. Computation of Simpson index, which captures both the richness and evenness of a farm's crop composition, also shows considerable variation in crop diversity, revealing that crop diversity is notably higher in the Mid-hills (p-value < 0.01). This is an interesting contrast given the higher dietary diversity in the Terai region and indicates that higher production diversity may not directly translate to diverse diets.

To examine how closely agricultural characteristics correspond to wealth, Table 3 reports a variety of agricultural characteristics across wealth quintiles. We find that the wealthier quintiles have larger farms and exhibit higher commercialization ratios, suggesting increased market participation. They also use more irrigation and agricultural technology. Differences in livestock income across the income gradient are less distinct. While the overall farm commercialization within our sample is relatively low, its relationship with household wealth and the ensuing impact on dietary diversity remains a point of interest. Broadly speaking, the relationship between wealth and farm commercialization is complex and reciprocal. While stable market prices and other constant factors imply that increased commercialization directly contributes to household wealth, the reverse is also true. Wealthier households generally have greater access to resources and are more capable of investing in agricultural technology and practices that boost commercialization. Through simple observation alone, it's challenging to identify the causal mechanisms that link wealth and farm commercialization. In examining the link between farm commercialization and dietary diversity, we find a weak positive correlation in the Terai and virtually no connection in the Mid-hills. This contrast with the stronger association between wealth and diet suggests that commercialization's impact on dietary diversity may be limited within our sample. Nevertheless, even this limited degree of commercialization among some farmers in our sample is relevant and noteworthy.

Table 3: Agricultural characteristics by income quintile.

	Lowest	Low	Middle	High	Highest
Production diversity	7.76	7.50	6.10	5.54	5.77
Crop species count	6.11	5.88	4.69	3.93	4.14
Simpson index	0.73	0.70	0.63	0.56	0.57
Size of farm	0.91	1.16	1.23	1.62	2.76
Commercialization ratio	0.09	0.10	0.12	0.20	0.21
Livestock income	5.55	5.72	8.05	6.55	5.95
Agricultural info. access	0.80	0.82	0.68	0.70	0.73
Kitchen garden	0.94	0.96	0.85	0.83	0.89
Irrigation access	0.04	0.04	0.52	0.76	0.92
Farm-tech usage score	-1.03	-0.90	0.17	0.86	0.91

In terms of households' remoteness, we find a stark contrast across regions. Elevations stretch from roughly 66 meters above sea level in the Terai plains to well over 2,200 meters above sea level in the Mid-hills. This variation highlights the differing levels of remoteness, with the Terai plains being less remote due to more accessible terrain implying better market access. This is partially reflected in the agricultural practices of these regions. For instance, in the Terai, 56 percent of households reported selling some of their crop produce in the last year, compared to only 32 percent in the more remote Mid-hills. Despite the relatively better connectivity in the Terai, the overall rate of farm commercialization is still moderate.

Overall, a quick look at the inter-region comparison shows that the farms in the Terai are more specialized in production yet exhibit higher dietary diversity, implying that specialization and lower production diversity do not necessarily correlate with reduced dietary variety, especially when households have the means to purchase diverse foods from the market. These relations are analyzed in more detail in the following.

4.2.Linking farm production diversity with household dietary diversity

We now turn to the results of the regression models explained in Equation (1), which posit household dietary diversity as dependent and farm production diversity as independent variables. Table 4 shows results of the regression analysis which utilizes production diversity score as an indicator of farm production diversity. Across the pooled sample and within each of the two regions of Nepal – Terai and Mid-hills – we observe a positive correlation between production diversity and dietary diversity. This finding aligns with the expectation that smallholder farmers, who often consume a significant portion of their own produce, benefit from a diverse production in terms of dietary outcomes. However, it is noteworthy that the magnitude of this effect, while positive, is modest. Specifically, the introduction of an additional crop or livestock species is associated with only a 0.05 increment in the variety of food groups consumed.

The magnitude of this effect varies by region. In the Mid-hills, where average production diversity is already relatively high, the coefficients are smaller, suggesting that any additional increase in farm diversity might have a limited incremental benefit to dietary diversity. In the Terai region, the association between production diversity and dietary diversity is more pronounced, likely a reflection of the lower baseline level of production diversity in this area. Many farmers across the pooled sample focus on cultivating staple crops like paddy and wheat, either as a single crop or through repeated plantings, suggesting a focus on these crops due to their economic importance or suitability to the region's agroecological conditions. However, the instances of intercropping are fewer in the Terai region, which could be indicative of the region's reliance on fewer crop types or a higher prevalence of mono-cropping practices. Thus, the observed enhancement in dietary diversity in the Terai seems to be driven more by income generation from marketable crops, overall household wealth, and superior market access, rather than by increased production diversity per se. Further analysis, as presented in Tables A1-2, examines these relationships using crop species count and Simpson index as alternative measures of farm diversity. We find that the positive association between farm diversity and dietary diversity holds for crop species count but doesn't hold for Simpson index.

Table 4: Association between production diversity and dietary diversity in smallholder farm households across Nepal's Terai and Mid-hills region.

	Pooled	Mid-hills	Terai
Production diversity	0.050***	0.042*	0.062***
	(0.016)	(0.023)	(0.022)
Observations	998	499	499
R-squared	0.022	0.007	0.014

*The dependent variable in all models is the dietary diversity score of households, including 10 food groups. Models were estimated using Ordinary Least Squares. Coefficient estimates are shown with robust SEs in parentheses. The pooled data model was estimated with region fixed effects. *** p<0.01, ** p<0.05, * p<0.1*

4.3. The role of physical remoteness

We now analyze how the effect of farm production diversity on household dietary diversity changes when we augment our regression model to incorporate a variable indicative of the household's remoteness. In addition, we include a vector of other relevant sociodemographic variables. The results, outlined in Table 5, use household elevation as a proxy for remoteness. The estimated coefficient is negative in the pooled sample, suggesting that households situated in more remote, higher-altitude locations tend to exhibit lower dietary diversity. Improved market access, characterized by easier access and fewer physical or geographical barriers, commonly found in lower elevation areas, is likely to lead to higher dietary diversity.

Interestingly, the impact of farm production diversity on dietary diversity remains robust and significant even when considering these geographical nuances. The comparison of the effect sizes in the model indicates that a decrease in elevation by 22 meters has an equivalent positive effect on dietary diversity as the addition of one crop or livestock species to farm production. While caution is necessary in interpreting these effect sizes, they underscore the critical role of access to markets, as influenced by geographical location, in shaping dietary patterns.

In our extended analysis, detailed in Table A3, we further explore the relationship between farm diversity and dietary diversity using two alternative measures of farm diversity: crop species count and the Simpson index. This analysis yields mixed results. While the crop species count shows a positive association with dietary diversity, aligning with our initial findings, the results for the Simpson index do not indicate a significant correlation, suggesting a more nuanced interaction under this measure of farm diversity.

Table 5: Association between production diversity, household remoteness, and dietary diversity in smallholder farm households across Nepal's Terai and Mid-hills region.

	Pooled	Mid-hills	Terai
Production diversity	0.034**	0.051**	0.009
	(0.016)	(0.022)	(0.023)
Remoteness	-0.155**	-0.169**	-0.029
	(0.078)	(0.083)	(1.912)
Remoteness squared	0.005	0.006	-0.104
	(0.003)	(0.004)	(0.833)
Commercialization ratio	0.403**	0.215	0.591**
	(0.201)	(0.328)	(0.248)
Livestock income	0.009**	0.007	0.016***
	(0.004)	(0.005)	(0.006)
Wealth Index	0.141***	0.056	0.309***
	(0.040)	(0.047)	(0.055)
Size of farm	0.066***	0.012	0.052**
	(0.021)	(0.087)	(0.022)
Agricultural info. access	0.348***	0.722***	-0.070
	(0.107)	(0.177)	(0.131)
Controls	✓	✓	✓
Observations	998	499	499
R-squared	0.123	0.178	0.182

*The dependent variable in all models is the dietary diversity score of households, encompassing 10 distinct food groups. Remoteness denotes the relative isolation of households, measured by their residence's elevation above mean sea level (in 100-meter increments), serving as a key indicator of market access. The models were estimated using Ordinary Least Squares, and the coefficient estimates are shown with robust SEs in parentheses. The pooled data model was estimated with region fixed effects. Controls include household size, caste, and age, gender, and education level of the household head, and households' possession of kitchen gardens. See Table A4 for full results. *** p<0.01, ** p<0.05, * p<0.1*

We further examined how the level of remoteness affects the significance of farm production diversity in influencing dietary diversity. This investigation involved reanalyzing the models for the two distinct regions in our study – Terai and Mid-hills. The results, as presented in the latter part of Table 5, support our hypothesis that in less remote areas, like the Terai region, the impact of farm production diversity on dietary diversity becomes less significant.

In addition to elevation, we also considered the geographic distance to the nearest India-Nepal border entry point as an alternative measure of remoteness. This objective metric, without the survey errors usually common in self-reported data, provided consistent negative effects, reinforcing the idea that improving physical access to markets, whether through reduced travel distance, time, or cost, is a key factor in enhancing dietary diversity (table not shown).

The model in Table 5 also investigates the impact of actual market participation on household dietary diversity. To assess this, we use two specific measures. The first measure is farm commercialization, quantified by the ratio of the total quantity of crops sold to the total quantity produced. The second measure is the per capita income accrued in the past year from the sale of livestock or livestock products. Analysis reveals a positive correlation between both measures and dietary diversity. Specifically, for every 1 percent increase in farm produce sold in the market, there is an associated 0.4 percent rise in dietary diversity. Similarly, increased income from livestock sales is correlated with enhanced dietary diversity. However, it's important to note that while these aspects of market participation positively influence dietary diversity, their impact is relatively modest. Thus, achieving significant improvements in dietary diversity would necessitate a considerable increase in the level of household market participation.

4.4.Interactions between wealth, remoteness, and production diversity

The role of remoteness and its impact on shaping dietary outcomes can be more comprehensively assessed by introducing interaction terms in our regression models. This approach allows us to observe the moderating effect of remoteness on the relationship between farm production diversity and household dietary diversity. It further helps to substantiate our hypothesis that production diversity is more crucial in remote settings and diminishes in significance as market access, as reflected by lower levels of remoteness, increases. We include interactions between farm production diversity and remoteness and between household wealth and remoteness in separate regression models controlling for the same covariate as those included in non-interaction models.

Our results (shown in Table 6) indicate a significant increase in the importance of farm production diversity in contributing to household dietary diversity in more remote regions. This is confirmed by the significant and positive interaction term between remoteness and production diversity. In remote areas, where farms are often more reliant on subsistence farming due to limited access to markets, diversifying agricultural production becomes an essential strategy for enhancing dietary variety. The positive coefficient for the interaction between production diversity and elevation suggests that as the level of remoteness increases, so does the beneficial impact of production diversity on dietary diversity.

Interestingly, the analysis (refer to Table 6) shows a decrease in the positive impact of household wealth on dietary diversity in more remote areas. Wealthier households in these regions struggle to translate their economic resources into improved dietary diversity, primarily due to constrained access to diverse food markets. This outcome highlights the crucial role of market accessibility, or lack thereof in remote areas, in enabling wealth to translate into better dietary outcomes.

Table 6: Association between production diversity, household remoteness, wealth, and dietary diversity: OLS and Poisson regression analysis.

	Ordinary Least Squares		Poisson Regression	
	Model 1	Model 2	Model 3	Model 4
Production diversity	0.001	0.032**	-0.000	0.007**
	(0.024)	(0.016)	(0.005)	(0.003)
Remoteness	-0.207**	-0.185**	-0.046**	-0.039**
	(0.084)	(0.077)	(0.018)	(0.017)
Remoteness squared	0.006*	0.004	0.001*	0.001
	(0.003)	(0.003)	(0.001)	(0.001)
Commercialization ratio	0.440**	0.434**	0.099**	0.095**
	(0.202)	(0.201)	(0.042)	(0.042)
Livestock income	0.009**	0.010**	0.002**	0.002**
	(0.004)	(0.004)	(0.001)	(0.001)
Wealth index	0.145***	0.274***	0.032***	0.058***
	(0.040)	(0.053)	(0.008)	(0.011)
Size of farm	0.066***	0.057***	0.011***	0.009***
	(0.021)	(0.021)	(0.004)	(0.004)
Agricultural info. access	0.345***	0.313***	0.077***	0.071***
	(0.107)	(0.107)	(0.024)	(0.024)
<u>Model interactions</u>				
Production diversity X Remoteness	0.005*		0.001*	
	(0.003)		(0.001)	
Wealth index X Remoteness		-0.020***		-0.004***
		(0.006)		(0.001)
Controls	✓	✓	✓	✓
Observations	998	998	998	998
R-squared, Pseudo R2	0.125	0.132	0.016	0.017

*The dependent variable in all models is the dietary diversity score of households, encompassing 10 distinct food groups. Remoteness denotes the relative isolation of households, measured by their residence's elevation above mean sea level (in 100-meter increments), serving as a key indicator of market access. The models were estimated for the pooled sample and incorporate region fixed effects. Coefficient estimates are shown with robust SEs in parentheses. Controls include household size, caste, and age, gender, and education level of the household head, and households' possession of kitchen gardens. See Table A4 for full results. *** p<0.01, ** p<0.05, * p<0.1*

4.5. The role of irrigation, farm machinery, and energy access

In our analysis, we also examine how factors like irrigation availability, farm machinery access, and the use of cleaner energy sources for cooking influence dietary patterns. Despite the known benefits of irrigation and farm machinery in increasing agricultural yields, improving market participation, facilitating a transition towards more efficient farming practices, their impact on dietary diversity is more nuanced than expected (as shown in Table 7). We observe that access to irrigation, contrary to our initial hypothesis, did not demonstrate a statistically significant correlation with dietary diversity in our sample. This outcome implies that while irrigation may increase crop yields and diversify agricultural practices, its effect on dietary diversity is possibly mediated by an increase in agricultural income. However, given the low level of farm commercialization in our sample and the tendency for most produce to be consumed rather than sold, the expected income effect from improved productivity does not seem to significantly alter dietary diversity.

Similarly, the utilization of farm machinery, as measured by a farm technology usage score, failed to demonstrate a direct, significant impact on dietary diversity. This suggests that, although mechanization can enhance agricultural efficiency and yield, its influence on diet is likely indirect and less substantial than anticipated. This could be attributed to the subsistence-focused nature of the farms in our study and a diminished role of the income pathway in influencing diet.

Interestingly, the type of energy source used for cooking emerged as a significant factor associated with dietary diversity. Households transitioning to cleaner energy sources for cooking, such as LPG and electricity, showed a notable increase in dietary diversity. This improvement can be attributed to several direct and indirect pathways. Directly, the availability of a reliable cooking energy source reduces time spent on fuel collection, thereby freeing up time for childcare and feeding, and allowing households to invest more time in preparing diverse and nutritious meals.

Additionally, cleaner energy sources contribute to safer food preparation methods, thus lowering the risk of foodborne illnesses (Bervoets et al., 2018). Indirectly, it enhances agricultural productivity and market participation by freeing up time for these activities. This shift particularly impacts women, who traditionally manage cooking tasks, allowing them greater involvement in farming and market activities. Furthermore, using cleaner energy sources often leads to economic savings by reducing expenditure on traditional fuels. These savings might be redirected towards purchasing a wider variety of foods, indirectly linking energy access to dietary diversity. Improved energy access also influences labor distribution within households, with potential benefits for agricultural decisions and nutritional outcomes. Importantly, the use of cleaner cooking methods significantly reduces indoor air pollution, leading to better health conditions for household members.

Table 7: Association between production diversity, household remoteness, agriculture and household inputs (irrigation, farm machinery, energy) and dietary diversity in smallholder farm households across Nepal's Terai and Mid-hills region.

	Pooled	Mid-hills	Terai
Production diversity	0.034**	0.049**	0.014
	(0.016)	(0.022)	(0.022)
Remoteness	-0.171**	-0.178**	-0.276
	(0.079)	(0.083)	(1.971)
Remoteness squared	0.006*	0.006*	-0.023
	(0.003)	(0.004)	(0.864)
Commercialization ratio	0.428**	0.386	0.577**
	(0.202)	(0.344)	(0.250)
Livestock income	0.009**	0.007	0.016***
	(0.004)	(0.005)	(0.006)
Wealth Index	0.079*	0.009	0.248***
	(0.046)	(0.056)	(0.060)
Size of farm	0.068***	0.015	0.054**
	(0.022)	(0.087)	(0.022)
Agricultural info. access	0.335***	0.662***	-0.066
	(0.107)	(0.176)	(0.131)
Irrigation access	0.080	-0.184	0.117
	(0.148)	(0.233)	(0.197)
Farm-tech usage score	0.021	0.072	-0.087
	(0.117)	(0.183)	(0.158)
Energy source for cooking			

Transitioning	0.375***	0.378**	0.343***
	(0.112)	(0.185)	(0.132)
Clean	0.927*	0.573	0.748
	(0.479)	(0.438)	(0.576)
Controls	✓	✓	✓
Observations	998	499	499
R-squared	0.134	0.187	0.194

*The dependent variable in all models is the dietary diversity score of households, encompassing 10 distinct food groups. Remoteness denotes the relative isolation of households, measured by their residence's elevation above mean sea level (in 100-meter increments), serving as a key indicator of market access. The models were estimated using Ordinary Least Squares, and the coefficient estimates are shown with robust SEs in parentheses. The pooled data model was estimated with region fixed effects. Controls include household size, caste, and age, gender, and education level of the household head, and households' possession of kitchen gardens. See Table A4 for full results. *** p<0.01, ** p<0.05, * p<0.1*

5. Discussion and conclusion

In this paper, we examine the influence of farm production diversity, physical remoteness as a proxy for market access, and factors such as irrigation and farm machinery access on dietary diversity in Nepal. Our results show that farm production diversity is positively associated with dietary diversity. However, the effect is relatively small, particularly in cases where farms, like those in the Mid-hills, already have a high level of inherent diversity in their production of multiple crops and livestock species.

We also show that farmers' ability to access and participate in food markets positively influences the variety in their household diets. Notably, when we specifically account for these factors, market access appears to be more influential than the diversity of farm production. This is particularly clear in our sub-sample analysis, where the initial positive link between production and dietary diversity, observed in both the primary and extended models, weakens, and becomes negligible in areas with better market connectivity, such as the Terai plains. This suggests that market accessibility plays a significant role in dietary diversity, even in subsistence-oriented settings like rural Nepal. Contrary to conventional beliefs that associate higher diversity in farm production directly with improved dietary outcomes, our findings indicate that in regions with adequate market access, dietary diversity depends less on farm production variety and more on the capacity to engage with these markets. However, this trend is less pronounced in places like the Mid-hills, where geographical challenges restrict market access, highlighting the importance of production diversity in such settings.

Further, our examination of the relationship between household wealth and market access uncovers an intriguing pattern: the typically positive effect of wealth on dietary diversity gradually diminishes in areas with limited market access. This trend is especially noticeable in isolated, high-altitude regions, where the ability of wealthier households to use their financial resources to achieve a varied diet is considerably constrained by the lack of accessible and varied food markets. This diminished role of wealth in remote areas further emphasizes the critical role of markets in enabling financial resources to effectively contribute to dietary diversity.

Our analysis about irrigation and farm machinery access also provides a few new perspectives on their role in dietary diversity. While these factors are essential for agricultural productivity, their direct impact on dietary outcomes appears limited. This may be due to two primary factors: firstly, the restricted availability of resources like irrigation, which is as low as 7 percent in the Mid-hills, and secondly, the current low level of farm commercialization in our study group. Nevertheless, considering the positive association between farm commercialization and household diets, these factors have the potential to improve diets significantly if they are integrated into a pathway that links them with income through farm commercialization.

In conclusion, our study suggests that while promoting production diversity can be beneficial in some situations, it should not be the sole focus for improving dietary diversity, particularly in areas where market influences are stronger. The findings highlight the need for comprehensive strategies that consider local institutional aspects and promote both market accessibility and farm productivity improvements, including the diffusion of irrigation and farm machinery, to enhance dietary diversity in rural Nepal. These efforts should target not only main towns but also remote regions like the Mid-hills, aiming to facilitate income generation and better diets for smallholder farmers.

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Appendix

Table A1: Association between crop species count and dietary diversity in smallholder farm households across Nepal's Terai and Mid-hills region.

	Pooled	Mid-hills	Terai
Crop species count	0.065***	0.078***	0.045**
	(0.016)	(0.023)	(0.022)
Observations	998	499	499
R-squared	0.027	0.023	0.006

*The dependent variable in all models is the dietary diversity score of households, including 10 food groups. Models were estimated using Ordinary Least Squares. Coefficient estimates are shown with robust SEs in parentheses. The pooled data model was estimated with region fixed effects. *** p<0.01, ** p<0.05, * p<0.1*

Table A2: Association between Simpson index and dietary diversity in smallholder farm households across Nepal's Terai and Mid-hills region.

	Pooled	Mid-hills	Terai
Simpson index	0.468	0.740	0.279
	(0.378)	(0.780)	(0.356)
Observations	998	499	499
R-squared	0.015	0.004	0.001

*The dependent variable in all models is the dietary diversity score of households, including 10 food groups. Models were estimated using Ordinary Least Squares. Coefficient estimates are shown with robust SEs in parentheses. The pooled data model was estimated with region fixed effects. *** p<0.01, ** p<0.05, * p<0.1*

Table A3: Association between crop species count / Simpson index, household remoteness, and dietary diversity in smallholder farm households across Nepal's Terai and Mid-hills region.

	Crop Species Count			Simpson Index		
	Pooled	Mid-hills	Terai	Pooled	Mid-hills	Terai
Crop species count	0.051***	0.079***	-0.003			
	(0.017)	(0.023)	(0.024)			
Simpson index				0.341	0.681	-0.124
				(0.352)	(0.662)	(0.347)
Remoteness	-0.166**	-0.184**	0.050	-0.142*	-0.159*	0.143
	(0.078)	(0.083)	(1.910)	(0.077)	(0.083)	(1.946)
Remoteness squared	0.006*	0.006*	-0.138	0.005	0.005	-0.183
	(0.003)	(0.004)	(0.831)	(0.003)	(0.004)	(0.852)
Commercialization ratio	0.405**	0.284	0.608**	0.447**	0.198	0.602**
	(0.201)	(0.328)	(0.247)	(0.201)	(0.332)	(0.241)
Livestock income	0.010**	0.008	0.016***	0.010**	0.008	0.016***
	(0.004)	(0.005)	(0.006)	(0.004)	(0.005)	(0.006)
Wealth Index	0.138***	0.054	0.310***	0.140***	0.055	0.311***
	(0.040)	(0.047)	(0.055)	(0.040)	(0.047)	(0.055)
Size of farm	0.064***	-0.003	0.053**	0.071***	0.047	0.053**
	(0.020)	(0.086)	(0.023)	(0.023)	(0.086)	(0.022)
Agricultural info. access	0.342***	0.718***	-0.069	0.351***	0.725***	-0.071
	(0.107)	(0.174)	(0.131)	(0.107)	(0.177)	(0.131)
Kitchen garden	-0.207	-1.515***	0.437**	-0.196	-1.577***	0.436**
	(0.183)	(0.360)	(0.186)	(0.185)	(0.375)	(0.185)
Female-headed household	0.574**	0.862*	0.366	0.539**	0.819*	0.365
	(0.251)	(0.496)	(0.230)	(0.248)	(0.484)	(0.229)
Age of household head	0.005	0.003	0.003	0.005	0.004	0.003
	(0.004)	(0.005)	(0.006)	(0.004)	(0.005)	(0.006)
Education (Base: Low)						
Medium education	0.075	-0.017	0.206	0.089	0.026	0.208
	(0.108)	(0.161)	(0.140)	(0.110)	(0.162)	(0.140)
High education	0.692**	0.619	0.584	0.725**	0.750	0.581

	(0.330)	(0.485)	(0.396)	(0.335)	(0.518)	(0.396)
Caste (Base: Dalit)						
Janjati group	0.459***	0.564**	0.031	0.475***	0.566**	0.030
	(0.159)	(0.250)	(0.214)	(0.160)	(0.252)	(0.214)
Other caste	0.157	1.767***	-0.323	0.153	1.648***	-0.323
	(0.169)	(0.456)	(0.204)	(0.169)	(0.454)	(0.204)
Upper caste	0.121	0.305*	-0.323	0.130	0.300*	-0.328
	(0.147)	(0.174)	(0.252)	(0.147)	(0.175)	(0.251)
Household size	0.000	0.012	-0.039*	-0.003	0.008	-0.039*
	(0.021)	(0.039)	(0.023)	(0.021)	(0.039)	(0.023)
Observations	998	499	499	998	499	499
R-squared	0.127	0.189	0.181	0.120	0.172	0.181

*The dependent variable in all models is the dietary diversity score of households, encompassing 10 distinct food groups. Remoteness denotes the relative isolation of households, measured by their residence's elevation above mean sea level (in 100-meter increments), serving as a key indicator of market access. Columns 1-3 pertain to crop species count, representing a simple unweighted count of different crop species produced on the farm. Conversely, columns 4-6 measure production diversity using the Simpson index, a metric assessing the diversity of crop species. The models were estimated using Ordinary Least Squares, and the coefficient estimates are shown with robust SEs in parentheses. The pooled data model was estimated with region fixed effects. *** p<0.01, ** p<0.05, * p<0.1*

Table A4: Factors influencing dietary diversity in smallholder farm households in Nepal (pooled sample).

	Model 1	Model 2	Model 3	Model 4
Production diversity	0.034**	0.001	0.032**	0.034**
	(0.016)	(0.024)	(0.016)	(0.016)
Remoteness	-0.155**	-0.207**	-0.185**	-0.171**
	(0.078)	(0.084)	(0.077)	(0.079)
Remoteness squared	0.005	0.006*	0.004	0.006*
	(0.003)	(0.003)	(0.003)	(0.003)
Commercialization ratio	0.403**	0.440**	0.434**	0.428**
	(0.201)	(0.202)	(0.201)	(0.202)
Livestock income	0.009**	0.009**	0.010**	0.009**

	(0.004)	(0.004)	(0.004)	(0.004)
Wealth Index	0.141***	0.145***	0.274***	0.079*
	(0.040)	(0.040)	(0.053)	(0.046)
Size of farm	0.066***	0.066***	0.057***	0.068***
	(0.021)	(0.021)	(0.021)	(0.022)
Agricultural info. access	0.348***	0.345***	0.313***	0.335***
	(0.107)	(0.107)	(0.107)	(0.107)
Kitchen garden	-0.223	-0.193	-0.238	-0.209
	(0.185)	(0.187)	(0.185)	(0.188)
Female-headed household	0.561**	0.567**	0.618**	0.525**
	(0.251)	(0.252)	(0.245)	(0.251)
Age of household head	0.005	0.004	0.004	0.004
	(0.004)	(0.004)	(0.004)	(0.004)
Education (Base: Low)				
Medium education	0.080	0.070	0.101	0.050
	(0.109)	(0.109)	(0.108)	(0.108)
High education	0.710**	0.679**	0.685**	0.636*
	(0.333)	(0.330)	(0.337)	(0.339)
Caste (Base: Dalit)				
Janjati group	0.462***	0.479***	0.456***	0.432***
	(0.160)	(0.160)	(0.159)	(0.160)
Other caste	0.157	0.164	0.121	0.119
	(0.169)	(0.169)	(0.168)	(0.170)
Upper caste	0.121	0.131	0.129	0.077
	(0.148)	(0.147)	(0.148)	(0.148)
Household size	-0.004	-0.006	-0.016	0.012
	(0.020)	(0.020)	(0.021)	(0.022)
Model interactions				
Production diversity X		0.005*		

Remoteness				
		(0.003)		
Wealth index X Remoteness			-0.020***	
			(0.006)	
Irrigation, farm machinery, and energy access				
Irrigation access				0.080
				(0.148)
Farm-tech usage score				0.021
				(0.117)
Energy source for cooking				
Transitioning				0.375***
				(0.112)
Clean				0.927*
				(0.479)
Observations	998	998	998	998
R-squared	0.123	0.125	0.132	0.134

*The dependent variable in all models is the dietary diversity score of households, encompassing 10 distinct food groups. Remoteness denotes the relative isolation of households, measured by their residence's elevation above mean sea level (in 100-meter increments), serving as a key indicator of market access. The models were estimated for the pooled sample using Ordinary Least Squares, incorporating region fixed effects. Coefficient estimates are shown with robust SEs in parentheses. *** p<0.01, ** p<0.05, * p<0.1*

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