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# Do crop diversity and livestock production improve smallholder intra-household dietary diversity, nutrition and sustainable food production? Empirical evidence from Pakistan

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Crop diversification and livestock production is an important strategy to enhance nutrition, sustainable food production, and improve food security, especially at the smallholder household level. However, existing evidences are mixed and there are limited information about the relationship among agriculture crops, household income diversification (HID), and household dietary diversity (HDD) among smallholder farmers in developing country setting like Pakistan. Therefore, this study aims to understand the role of crop diversification (CD) on HDD, nutrition, and sustainable agriculture and food production in the context of smallholder households in Punjab, Pakistan. The study employed ordered probit regression and cross-sectional data from 450 households collected using 24-h recall method. Regression results indicate that crop diversity and intra-household dietary diversity are positively associated across adults, adolescents, and children in all the study districts. Moreover, annual income, key crops grown by the household and family education are also the significant drivers of dietary diversity. Greater travel distance between markets was the most crucial factor in all regions which significantly affect dietary diversity. The overall research findings indicated that crop diversification and livestock production in the selected areas is significantly contributing to improve nutrition and sustainable food production. Therefore this study recommends for promoting crop diversification and livestock production for sustainable agricultural development and improving nutrition in the context of developing countries like Pakistan.

KEYWORDS

**crop diversity, food security, sustainable food production, income diversity, Pakistan, livestock production**

## 1. Introduction

Imbalanced diets and a lack of economic access to nutritious food are undoubtedly major reasons for malnutrition (Adjimoti and Kwadzo, 2018; Appiah-Twumasi and Asale, 2022). Almost 75% of the world's populations suffer from various forms of malnutrition, such as obesity, anemia, and stunting in developing countries. According to the United Nations report 2020, ~155 million small children are stunted, nearly 52 million children are wasted,

and nearly 2 billion people are vitamin deficient (Akhtar, 2016; United Nations, 2020). Every year, ∼40.2% of children in Pakistan are stunted, and 37.8% of men are anemic (National Nutrition Survey, 2018; Soofi et al., 2022). The prevalence of malnutrition has decreased in Pakistan during the past decade; however, the problem persists, particularly in the rural areas (Asim and Nawaz, 2018; Mahmood et al., 2020; Jamil et al., 2021a). Malnutrition is a pervasive problem affecting people of various ages, genders, socioeconomic standings, and geographic locations. However, it is rampant among the poor in rural areas, where childhood stunting and anemia are more prevalent than in urban areas (Abbas et al., 2020; Usman and Callo-Concha, 2021).

In Pakistan, most people directly attain food from agricultural crops and livestock. In the past few decades, rural areas in Pakistan have begun to experience significant shifts in agricultural practices and revenue streams. Due to limited resources, low income, and subsistence farming, the farm diversification of households has declined (Saqib et al., 2018; Fahad and Wang, 2020). Simultaneously, family members of farming households are quitting the business, expanding the breadth of economic opportunities for rural families in Pakistan (Usman et al., 2016; Drucza and Peveri, 2018; Khan et al., 2020). Currently, 70% of Pakistan's average farm family's income comes from the agriculture sector (Peerzado et al., 2019; Jamil et al., 2021b). At this time, it is unknown how these changes affect family nutrition. In light of ongoing changes, however, it is vital to comprehend these implications so that they can inform efforts to eliminate rural malnutrition in Pakistan.

Previous research has demonstrated the positive relationships between household income, crop diversity, and dietary diversity; this is noteworthy in light of recent variations in crop patterns and sources of income in Pakistani agriculture systems (Munir et al., 2015; Akhtar, 2016). Farm household who cultivate new crop varieties have access to higher household incomes as well as sustainable food production (Sibhatu and Qaim, 2018; Habtemariam et al., 2021). Although it has been demonstrated that rising income increases dietary diversity, very little research has been conducted to investigate the relationship between income diversity (ID) and dietary diversity (DD) among smallholder agriculture farmers in Pakistan (Jones, 2017; Koppmair et al., 2017; Passarelli et al., 2018). It is crucial to comprehend this link since farmers in developing countries rapidly diversify their revenue sources (Davis et al., 2014, 2017; Suberu et al., 2015; Gecho, 2017). Agriculture farmers who cultivate a wider variety of crops provide their families with sustainable food and a higher standard of living (Putra et al., 2020; Iqbal et al., 2021; Yaqoob et al., 2022). Therefore, it is important to understand the relationship among income diversification (ID) and dietary diversity (DD) among smallholder agriculture farmers in developing countries like Pakistan.

This study explored the relationship among crop diversity (CD, HHI, and HDD) among three Pakistani south Punjab districts undergoing distinct livelihood transitions: Layyah, Bhakkar, and Khushab. Consequently, farmers in Layyah and Bhakkar have shifted their focus to producing a wide variety of high-value crops, such as wheat, mung beans, gram, and sugarcane. In contrast, the farmers of Khushab are experts at cultivating wheat and pulses, Pakistan's most important food crops. In addition, these locations offer very low infrastructure compared to the bulk of farming areas in Pakistan, making it difficult for farm families to diversify their income sources through employment or business ownership. Layyah, Bhakkar, and Khushab are excellent case studies for examining the association among CD, household income diversity (HID), and smallholder farmer household dietary diversity (HDD) because they each represent distinctive livelihood transition pathways for smallholder farmer households in south Punjab, Pakistan, with still-high malnutrition rates. Particularly, we explore the following question: How do crop and household income diversity (CD and HHI) influence the DD of women, men, children, and adolescents among smallholder agricultural farmers in south Punjab districts (Layyah, Bhakkar, and Khushab)? How closely does dietary diversity (DD) at the individual level (male, female, adolescent, and child) associate with the following agricultural and socioeconomic factors?

This study links crop diversification and household income in Pakistani rural communities. In spite of the cross-sectional data, we scrutinize the relationship between CD, HID, and HDD. The main contribution of this study is to understand how crop specialization can increase HID as well as influence HDD. As big as it is, this transformation spreads across Pakistan as rural populations become increasingly connected to markets (Hirani, 2012; Khan et al., 2016; Shahid et al., 2022). Pakistan has one of the highest rates of malnutrition in the world (Doocy et al., 2018). Moreover, no research has been undertaken in south Punjab, Pakistan, correlating CD and HDD. This study's findings have been used to develop strategies and food policy efforts to promote dietary diversity in severely malnourished regions like Pakistan.

In this research, CD was found to be associated with DD in adults (males, females, and adolescents) in both districts (Layyah and Bhakkar) and children in district Khushab. In all districts, dietary diversity scores (DDSs) have positively correlated with family education, crop diversification, and travel distance to markets; however, in Layyah and Bhakkar, cash crops and annual income were the most important determinants. The dwellings of farmers in Layyah, Bhakkar, and Khushab were randomly sampled using a suitable scientific technique (Section Material and methods). Section Results and discussion describes the findings and the principal statistical analyses that elaborate on the regression results and also contains comprehensive information on farming systems in all districts. In Section Discussion, we highlight the fundamental limitations of this approach, along with our key findings and their significance in light of the preceding literature. The primary conclusions and policy implications of increasing food diversity among Pakistani smallholder farmers are in Section Conclusion.

## 2. Materials and methods

### 2.1. Study location and sampling methodology

This study based on survey data, we chose three districts in south Punjab, Pakistan (Layyah, Bhakkar, and Khushab) as shown in Figure 1, to compare their crop, farm, and income diversity to that of other states. Using secondary data from the Pakistan census on agricultural output, livestock ownership, economic output, and family education, we were able to find ideal locations along this gradient. Specifically, we based our index on

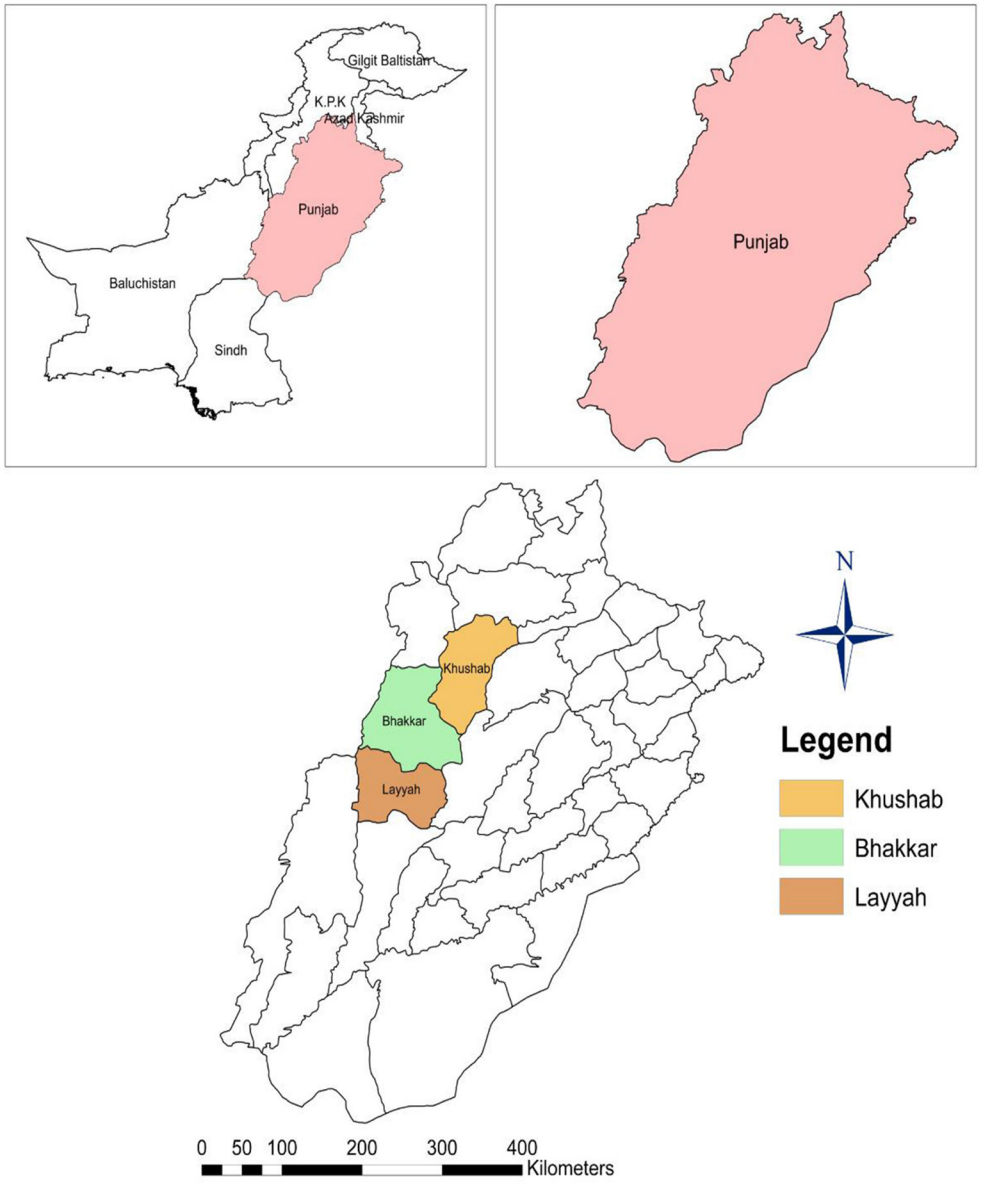


FIGURE 1
A map of Punjab, districts for this study in Pakistan.

Singh and Benbi (2016) and Singh et al. (2020) "Farming Intensity Index." To measure the degree to which agricultural variety differs from one location to another, we calculated the CDI for each district. The crop diversity (measured by the crop diversity index), farm diversity (measured by per capita of poultry and livestock), agriculture farm income (measured by total agriculture planted crop area as a percentage of total agriculture land), and family education were used to create an index to capture changes in income diversity (e.g., rural literacy).

We followed the same methods to elect union councils in all three of these districts: Layyah, Bhakkar, and Khushab. We chose three groups of villages rather than individual villages within each union council because secondary data at the level of separate villages was unavailable. We chose the villages at random from the union council. Each union council consisted of two or three adjoining villages. Approximately seven to nine farmer households were randomly selected from each village group using systematic random sampling. Our study included only farms with at least one adult male, one adult female, and one child or adolescent present. We limited our research to agricultural households because we were interested in the correlation between crop diversity and farmers' food diversity. While some of these farming households depend entirely on agriculture for their income, others have more diverse sources of income. Individuals who do not live in rural areas or often travel to cities for work or study are not treated as well in large conglomerate households as those who live in rural areas. A sample of farm households was randomly selected to conduct research in their homes. One adult male (head of household, >18 years), one adult female (primary food preparer, >18 years), one adolescent (>5 and 18 years), and one child (5 years), regardless

of gender, are randomly selected for each family. Each family's children and adolescents present at home during the survey were randomly selected. Participants included 2,672 people from 450 families from three states.

## 2.2. Data collection

Each adult male, adult female, adolescent, and child population was assigned a particular survey schedule, which was used to compile the data collected. Five-person teams surveyed each district between April and June 2020. One adult male, one adult female, and one child or adolescent from each family provided information on agricultural output, farm-related activities, sources of income, demographics, and food intake (recall period 24-h). We did not have an exact schedule for visiting the numerous villages; instead, we surveyed a particular settlement whenever farmer household members had free time. The fact that small village markets were not open 7 days a week could have impacted the 24-h recall procedures as shown in Figure 2.

## 2.3. Metrics constructed

The explanations and calculations of the metrics used in our research are provided below.

### 2.3.1. Crop diversity index (CDI)

Each farmer household that participated in the survey had their crop diversification index (CDI) determined using the formula (1-H)as the H represents the (HHI) Hirschman-Herfindahl index, which is determined as follows:

$$H = \sum_{i=1}^{N} Si^2$$

In the above equation the N represent the total number of crops during the period of 2019–20, the $S_i$signifies a percentage of the i-th crop area and (1-H), values indicate greater crop diversity (Singh and Benbi, 2016). The crop diversity index (CDI) is determined using whole crops grown throughout year.

### 2.3.2. Income diversification index (IDI)

The 1-H formula has used to calculate the Income Diversification Index (IDI), which represents the household income proportion that comes from the sources of agricultural and non-agricultural activities such as non-crop activities, crop production, dairy, poultry, beekeeping, and business. The majority of IDIs were found in the wealthiest communities. We believe it is more accurate to ask farmers what percentage because of their income comes from each source instead of asking for their total revenue. Most farmers do not keep records of their income and spending because their non-farming income. This conclusion is the outcome of extensive fieldwork.

### 2.3.3. Family education index (FEI)

The family education index (FEI) was determined in this study by aggregating the educational attainment of every adult as well as adolescent dwelling on the farm, then dividing this figure by the total number of adults. We chose the average education of all men, women and adolescents residing in each farmer's household, rather than highest level of education among them because, in our experience, the family's dietary habits are influenced by the food choices made by all of its members, not just the household's head.

### 2.3.4. Adults and adolescents dietary diversity score

The 10 food groups defined by FAO (2016), as representing the nutritional sufficiency of female diets were employed to assess the dietary diversity DD of men, women, and adolescents (Khan et al., 2019; Baxter et al., 2022). The food groups in the Minimum Dietary Diversity for Women were used to represent males and adolescents that are no validated dietary diversity indicators (MDD-W). This indicator has been used to evaluate the variety of different foods consumed by men, women, girls and adolescent in the selected area. In this study the first food group contains the grains, tubers, roots and plantains, similarly the second food group contains lentils, pulses, peas and beans. The third food group contains the different agriculture crops seeds and nuts. The fourth food group have different dairy and livestock products. The fifth food group

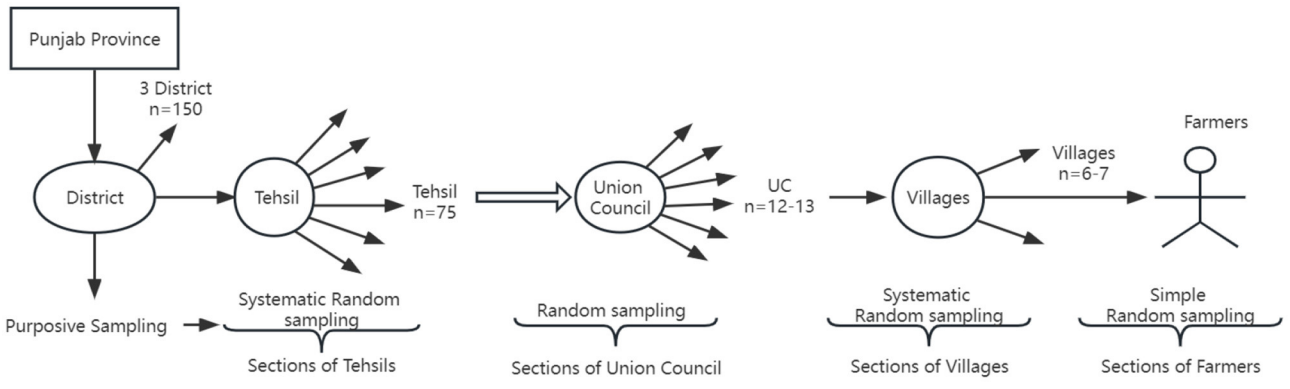


FIGURE 2
Sampling framework showing number of smallholders farmers each districts, tehsil and union council.

contains the fish, meat and poultry. The six food group has different animal's eggs. The seventh food group contains the different seasonal vegetables as the eighth food groups has seasonal fruits. The ninth and tenth food groups contains the others vegetables and fruits. The respondents are assigned (DDS) ranging from 0 to 10.

### 2.3.5. Children dietary diversity score

The World Health Organization (WHO) used a slightly different formula to calculate DDS for children compared to adults, considering seven rather than 10 dietary groups (WHO, 2008). The following are the seven classes: Cereals, tubers, and roots are brought in first, followed by legumes and nuts, dairy, meat, fish, and poultry, then eggs, and finally, the remaining fruits and vegetables. The DDS evaluates each child on a continuous scale ranging from 0 to 7. The DDSs could determine a child's consumption of the four World Health Organization-recommended essential nutrients (2008).

## 2.4. Framework to examine associations

Using regression analysis, association among the crops, income, and socioeconomic characteristics were assessed. Based on review of literatures, the following factors hypothesized to affect the outcome variable and accordingly included as independent variables in the regression analysis.

### 2.4.1. Crop diversity index (CDI)

The crop diversification index is a vital indicator in this study to examine, as there is an increasing number of farm households in Pakistan (Ahmed et al., 2017). According to Islam et al. (2018) and Singh et al. (2020) crop diversity and DD has significant relationship.

### 2.4.2. Crop and livestock groups

In this study the crop group also very important. We investigate the different pulses, vegetables, and cash crops that are associated with dietary diversity DD. Previous research has demonstrated an association between the cultivation of cash crops (Asaleye et al., 2020), vegetables (Balali et al., 2020), and pulses (Naik and Nagadevara, 2020). Livestock production in Pakistan is a major industry. Each year, Pakistan exports over 4.5 million tons of quality halal meat to places like the Middle East, Malaysia and Indonesia. Pakistan is the world's fifth largest producer of eggs and the fourth largest producer of milk.

### 2.4.3. Income diversification index (IDI) and annual per capita income

Many Pakistani agricultural households are transitioning toward more diversified assortment of income sources, which is emphasized (Kanwal et al., 2016; Batool et al., 2017; Iqbal et al., 2021; Habib et al., 2022). Previous research has indicated that more diverse income portfolio effect food security and nutrition at home; therefore, we examined link between IDI and dietary diversity (Milajerdi et al., 2018; Onah et al., 2022). Previous research (Warren et al., 2015; Larson et al., 2019; Singh et al., 2020; Mehraban and Ickowitz, 2021) have shown a positive correlation between higher income and dietary diversity.

### 2.4.4. Family education index (FEI)

In our regressions, we use the household education level as a control variable because it has been shown in previous research (Worku et al., 2017; Blackstone and Sanghvi, 2018; Gebrie and Dessie, 2021; Sambo et al., 2022) to be a significant predictor of dietary diversity.

### 2.4.5. Distance traveled to food markets (Kms)

The distance from agriculture farms to market place also very important in this study. According to previous studies the market access has significant impact on DD (Islam et al., 2018; Gupta et al., 2020; Usman and Callo-Concha, 2021; Usman and Haile, 2022). To do this, we attempted to incorporate market access as a control variable. As a proxy for farmers' access to markets, we examined the average distance farmers traveled to purchase fresh produce.

## 2.5. Statistical models

Initially, we compiled descriptive statistics for each district and state to determine the range of values for each of our variables across the various research sites. We used a series of regression, and the correlations between dietary diversity, socioeconomic factors, and crop and income diversification have been conducted. All continuous variables were averaged and normalized. As our outcome variables are count and ordered in nature, we have used ordered Probit as main regression and Poisson regression was used as a robustness check to verify all results. Poisson regression results are placed in the Supplementary Tables. All statistical calculations were performed using Stata 14 software including the ordered Probit and Poisson regression model.

An ordered probit model is used when the data are naturally ordered. In other words, it used when the outcome variable is a discrete variable which takes on values that reflect the natural order of things (i.e., the outcome variable is in some sense ordered). Ordered Probit Model is a model in which the dependent variable takes on only two levels (a binary variable) or three levels. It is like the linear regression model but with replacement of normal or Gaussian distribution with the beta distribution. In an ordered probit model, the linear probability model for the mean depends on the value of the dependent variable. Ordered Probit regression uses a latent variable that must be ordered. The ordered probit model is a multivariate extension of the unconditional or standard probit model. It extends the standard probit model to situations in which the dependent variable is a set of ordered categorical outcomes. The ordered probit model used when the dependent variable is qualitative, the individual categories of which are ordered. Alternately, the dependent variable can be quantitative and book-end category values used to indicate the upper and lower limits of the dependent variable.

We categorize the DD into three categories: 0, 1, DDS4 and 2, where 0 is the lowest category of dietary diversity. The food consumption categories are represented by an ordered variable Y that assumes the discrete ordered values of 0, 1 and 2. The ordered probit model for Y (conditional on explanatory variables X) can be derived from a latent variable model. Assume that the latent variable $Y^*$ is determined by $Y^* = X\beta + \epsilon$, where X is a vector of household's and community characteristics entering the equation and $\epsilon$ refers to the error term, which we assume is normally distributed across observations. However, $Y^*$, the probability to consume from a particular food group, is latent variable and unobserved. Given that we observe Y, the intra-household's dietary diversity status, the observed aspects of a dietary diversity status can be written as (Rammohan et al., 2019):

$$Y = \begin{cases} 0 \text{ if only 2 food groups are consumed} \\ 1 \text{ if 3 food groups are consumed} \\ 2 \text{ if 4 food groups are consumed} \\ 3 \text{ if 5 or more food groups are consumed} \end{cases}$$

and each of these categories is a discrete category of the dependent variable, which can be explained by the same set of explanatory variables including household and community characteristics as well as key explanatory variables including crop and income diversity.

# 3. Results and discussion

## 3.1. Results of individual dietary diversity scores

Table 1 compares the results of DDS in all selected areas. According to the findings, the district of Layyah has higher average dietary diversity scores as compared to the districts of Bhakkar and Khushab. According to the results across all districts, we consider the standard cut-offs for dietary diversity, and only one-third of children (men: 50%; women: 55%; adolescents: 57%; children: 43) attained the required minimum score for dietary diversity. The results also indicated that in district Bhakkar, only 43–50% of men, women, adolescents, and children attained minimum dietary diversity scores. In addition, in the district Khushab, 50–57% of men, women, and adolescents and 43% of children meet the dietary diversity scores, while in the Layyah district, 64% of men, women, and adolescents and 38% of the children achieve the required dietary diversity scores, respectively. So due to more crop diversification, the district Layyah achieved a higher DDS as compared to the districts Bhakkar and Khushab.

Table 1 shows that all of the males, females, and teens who were surveyed in the different districts ate grains, white roots and tubers, and plantains. In Layyah, over three-fourths of men, women, and adolescents consumed pulses, beans, peas, and lentils, whereas in other districts, the corresponding percentage was substantially lower. Among farmer households in all districts, dairy products were equally popular. However, 8–10% of the respondents in each district consumed nuts, meat, and eggs. In comparison to the other districts, Bhakkar and Khushab, only 20–24% of Layyah's men, women, and adolescents consumed dark-green leafy vegetables.

TABLE 1 Results of average (DDS), across farmer households in Layyah, Bhakkar, and Khushab (24-h recall) in percentage.

| Factor/variables | Layyah | Bhakkar | Khushab | Total |
|---|---|---|---|---|
| **Average dietary diversity score** | | | | |
| Men | 10.8 | 9.8 | 9.2 | 9.9 |
| Women | 10.6 | 9.1 | 9.1 | 9.6 |
| Adolescents | 9.5 | 9.1 | 9.2 | 9.3 |
| Children | 4.5 | 4.4 | 4.6 | 4.5 |
| **Individuals fulfilling the dietary diversification cut-off (percent)** | | | | |
| Men | 64 | 43 | 44 | 50 |
| Women | 64 | 50 | 50 | 55 |
| Adolescents | 55 | 54 | 61 | 57 |
| Children | 38 | 51 | 41 | 43 |
| **Food groups: men, consumed %** | | | | |
| FG1: Grains, white roots and tubers, and plantains | 284 | 283 | 269 | 278 |
| FG2: Beans, pulses, lentils, and peas | 102 | 90 | 99 | 97 |
| FG3: Nuts and seeds | 61 | 17 | 21 | 33 |
| FG4: Livestock product (Dairy) | 183 | 177 | 143 | 167 |
| FG5: Fish, poultry, and meat | 34 | 25 | 30 | 29 |
| FG6: Eggs | 11 | 9 | 4 | 8 |
| FG7: Dark green leafy vegetables | 171 | 167 | 146 | 161 |
| FG8: Others and vegetables fruits | 50 | 33 | 43 | 42 |
| FG9: Other vegetables | 99 | 95 | 93 | 96 |
| FG10: Other fruits | 87 | 90 | 79 | 85 |
| **Food groups: women, consumed %** | | | | |
| FG1: Grains, white roots and tubers, and plantains | 241 | 233 | 231 | 235 |
| FG2: Beans, pulses, lentils, and peas | 134 | 117 | 129 | 127 |
| FG3: Nuts and seeds | 43 | 13 | 19 | 25 |
| FG4: Dairy | 194 | 188 | 158 | 180 |
| FG5: Fish, poultry, and meat | 26 | 18 | 29 | 24 |
| FG6: Eggs | 2 | 1 | 3 | 2 |
| FG7: Dark green leafy vegetables | 167 | 147 | 129 | 148 |
| FG8: Other vitamin a-rich fruits and vegetables | 48 | 13 | 17 | 26 |
| FG9: Other vegetables | 135 | 117 | 112 | 121 |
| FG10: Other fruits | 76 | 70 | 85 | 77 |
| **Food groups: adolescents, consumed %** | | | | |
| FG1: Grains, white roots and tubers, and plantains | 204 | 208 | 197 | 203 |

*(Continued)*

TABLE 1 (Continued)

| Factor/variables | Layyah | Bhakkar | Khushab | Total |
|---|---|---|---|---|
| FG2: Beans, pulses, lentils, and peas | 67 | 60 | 76 | 68 |
| FG3: Nuts and seeds | 30 | 16 | 20 | 22 |
| FG4: Livestock product (Dairy) | 195 | 194 | 171 | 187 |
| FG5: Fish, poultry, and meat | 43 | 34 | 37 | 38 |
| FG6: Eggs | 12 | 9 | 15 | 12 |
| FG7: Dark green leafy vegetables | 156 | 143 | 129 | 143 |
| FG8: Other Vitamin A-rich fruits and vegetables | 73 | 67 | 70 | 70 |
| FG9: Other vegetables | 86 | 102 | 108 | 99 |
| FG10: other fruits | 93 | 85 | 99 | 92 |
| Food groups: children, consumed % | | | | |
| FG1: Grains, white roots, and tubers, and plantains | 121 | 124 | 134 | 126 |
| FG2: legumes and nuts | 36 | 63 | 60 | 53 |
| FG3: Livestock product (Dairy) | 172 | 160 | 166 | 166 |
| FG4: flesh food (fish, poultry, and meat) | 11 | 19 | 18 | 16 |
| FG5: Eggs | 3 | 5 | 2 | 3 |
| FG6: Other Vitamin A-rich fruits and vegetables | 60 | 32 | 43 | 45 |
| FG7: other fruits and vegetables | 53 | 44 | 40 | 46 |

Nearly two-fourths of men, women, and adolescents in Layyah consumed vitamin-A-rich fruits and vegetables. In contrast, in other districts, only one-third of individuals ate this food group. In districts Bhakkar and Khushab, a significantly higher percentage of men, women, and adolescents reported consuming other vegetables than in district Layyah. The fruit consumption proportion was similar in all communities among men, women, and adolescents. Regarding the components of children's diets, 85–90% of children consumed dairy items, grains, roots, and tubers across the districts. Children ate more legumes and nuts in Bhakkar and Khushab than in Layyah district. In district Layyah, ∼68% of children's diets included fruits and vegetables, compared to only 50–53% of children in districts Bhakkar and Khushab. However, 2–3 percent of children in all districts consumed flesh and eggs. It is essential to remember that respondent households were randomly selected without stratifying across vegetarian and non-vegetarian families.

## 3.2. Results of men's dietary diversity

Although income diversity had no association with men's dietary diversity in both Bhakkar and Khushab regions, it was significantly associated in the Layyah (p 0.01) (Table 2), respondents growing more crops (i.e., with more crop diversity) in a given year had a higher dietary diversity score in all districts (p 0.05), annual income and farming experience were important drivers of men's DDS in Layyah (p 0.05), considering main crop groups, respondent's households iAll regressions were run with poisson regression as a robustness check (Table 1). In Layyah, the results remained similar across all variables except the local market in the village, which became insignificant with Poisson regression. In the district Bhakkar, the significance level became smaller for pulses, vegetables, and fruit crops (p 0.001). With Poisson regression in district Bhakkar, the local market in the village became insignificant. In Khushab, the results remained similar across all the variables except farm size, which became negligible with Poisson regression.

## 3.3. Results of women's dietary diversity

Table 3 represents the results of dietary diversity among women and socioeconomic factors. The finding of the study indicated that higher crop diversity had more relationship with women's dietary diversity in Khushab ($p < 0.001$), whereas not associated with Layyah and Bhakkar women's DDS. Growing cash crops ($p < 0.001$) was associated with higher women's DDs in the Layyah and Bhakkar districts, but there is no association of cash crops with women's DDS in the Khushab district. Farming experience, family size, farm size, and distance travel to food markets ($p < 0.05$) was significantly associated with women's dietary diversity in district Layyah. In contrast, the farming experience was significantly associated with women's DDS in Bhakkar though the significance level was low ($p < 0.10$). Distance from the city and the main road ($p < 0.001$) were significantly associated with women's DDS in district Khushab. These regressions were run with Poisson regression as a robustness check (Table 2), and results remained similar across all variables in district Layyah. In Bhakkar, all the variables were significant with a low level ($p < 0.05$). In Khushab, the variables' results were the same, whereas the farming experience was highly effective ($p < 0.01$).

## 3.4. Results of adolescents dietary diversity

Table 4 represents the results of dietary diversity among adolescent and socioeconomic factors. The finding of the study inducted the significant ($p < 0.05$) association between the diversity of crops grown in the Khushab district and the variety of the adolescents' diets. The relationship between adolescent DDS and the output of cash crops and pulses was significant ($p < 0.05$) ($p < 0.01$). Adolescents in Khushab who grew their own fruits and vegetables had significant association with dietary diversity score ($p < 0.05$). Adolescents from Bhakkar household with higher annual incomes and those who did travel as far to purchase food in Layyah had higher dietary diversity. In addition, there was no correlation between adolescents' educational achievement and their dietary diversity in either district. Poisson regression was employed to evaluate the stability of the results. Poisson regression showed the

TABLE 2 Results of dietary diversity among men as assessed by an analysis of agricultural and socioeconomic factors.

| Variables | Layyah marginal effects | | | | Bhakkar marginal effects | | | | Khushab marginal effects | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX |
| Age | 0.0241 (0.278) | −0.0076 (0.275) | 0.0014 (0.304) | 0.0061 (0.276) | 0.0096 (0.613) | −0033 (0.613) | 0.0006 (0.624) | 0.0026 (0.612) | −0.0178 (0.439) | 0.0064 (0.434) | −0.0012 (0.460) | −0.0051 (0.432) |
| Farming experience | 0.0382 (0.035)** | −0.0120 (0.028) | 0.0023 (0.070) | 0.0097 (0.030) | −0.0068 (0.725) | 0.0023 (0.725) | −0.0004 (0.731) | −0.0019 (0.724) | 0.0122 (0.602) | −0.0044 (0.600) | 0.0008 (0.611) | 0.0035 (0.599) |
| Family size | −0.1815 (0.031)** | 0.0572 (0.025) | −0.0111 (0.076) | −0.0461 (0.025) | 0.0377 (0.628) | −0.0132 (0.628) | 0.0026 (0.633) | 0.0105 (0.628) | −0.1187 (0.095)* | 0.0431 (0.088) | −0.0084 (0.128) | −0.0346 (0.092) |
| Farm size | −0.0406 (0.037)** | 0.0128 (0.032) | −0.0024 (0.088) | −0.0103 (0.032) | −0.0138 (0.636) | 0.0048 (0.635) | −0.0009 (0.642) | −0.0038 (635) | −0.022 (0.043)** | 0.0080 (0.038) | −0.0015 (0.071) | −0.0064 (0.044) |
| Family Structure 1. Single 2. joint | −0.0717 (0.741) | 0.0226 (0.740) | −0.0043 (0.744) | −0.0182 (0.740) | 0.0036 (0.987) | −0.0012 (0.987) | 0.0002 (0.987) | 0.0010 (0.987) | −0.1909 (0.354) | 0.0686 (0.351) | −0.0133 (0.368) | −0.0552 (0.354) |
| Distance from city | −0.0043 (0.902) | 0.0013 (0.902) | −0.0002 (0.902) | −0.0011 (0.902) | −0.0835 (0.092)* | 0.0292 (0.041) | −0.0059 (0.209) | −0.0233 (0.036) | −0.0256 (0.616) | 0.0092 (0.615) | −0.0017 (0.617) | −0.0074 (0.615) |
| Distance from the main road | −0.0540 (0.510) | 0.0170 (0.510) | −0.0033 (0.518) | −0.0137 (0.510) | −0.0219 (0.783) | 0.0076 (0.783) | −0.0015 (0.782) | −0.0061 (0.783) | −0.317 (0.002)*** | 0.1139 (0.001) | −0.0221 (0.016) | −0.0917 (0.001) |
| Distance from input/output market | −0.0842 (0.004)*** | 0.0265 (0.002) | −0.0051 (0.011) | −0.0214 (0.004) | 0.0472 (0.410) | −0.0165 (0.409) | 0.0033 (0.446) | 0.0132 (0.404) | 0.0500 (0.018)** | −0.0179 (0.031) | 0.0035 (0.43) | 0.0144 (0.029) |
| Local market in the village | −0.6813 (0.062)* | 0.2149 (0.060) | −0.0416 (0.114) | −0.1732 (0.060) | −4.117 (0.000)*** | 1.4431 (0.000) | −0.2914 (0.003) | −1.1517 (0.000) | 0.3907 (0.063)* | 1.443 (0.000) | −0.2914 (0.003) | −1.1517 (0.000) |
| Drinkable water is available within 60 min walk | 0.4860 (0.444) | −0.1533 (0.442) | 0.0297 (0.459) | 0.1235 (0.442) | −0.1334 (0.795) | 0.0467 (0.794) | −0.0094 (0.793) | −0.0373 (0.795) | −0.3583 (0.448) | 0.1287 (0.446) | −0.0250 (0.453) | −0.1036 (0.448) |
| Road to village 1.Yes, 2. No. | 0.4438 (0.163) | −0.1400 (0.158) | 0.0271 (0.187) | 0.1128 (0.162) | 0.5312 (0.285) | −0.1862 (0.283) | 0.0376 (0.318) | 0.1486 (0.282) | −0.425 (0.303) | 0.1526 (0.298) | −0.0297 (0.305) | −0.1229 (0.304) |
| Crop diversity Index | 4.9801 (0.043)** | −1.5709 (0.040) | 0.3047 (0.063) | 1.2661 (0.046) | 0.3346 (0.055)** | −2.1173 (0.073) | 0.0376 (0.141) | 0.0936 (0.41) | −0.5340 (0.049)** | 0.2816 (0.009) | −0.0548 (0.024) | −0.2268 (0.019) |
| Income diversity Index | −2.9442 (0.005***) | 0.9287 (0.003) | −0.1801 (0.033) | −0.7485 (0.003) | 0.0964 (0.907) | −0.0338 (0.907) | 0.0068 (0.908) | 0.0269 (0.907) | 0.9796 (0.239) | −0.3519 (0.232) | 0.0685 (0.253) | 0.2834 (0.237) |
| Family education index | −0.1375 (0.848) | 0.0433 (0.848) | −0.0084 (0.849) | −0.0349 (0.848) | 1.0206 (0.154) | −0.3577 (0.149) | 0.0722 (0.201) | 0.2855 (0.149) | 0.6723 (0.248) | −0.2415 (0.248) | 0.0470 (0.270) | 0.1945 (0.252) |
| Cash crop group | 0.0652 (0.036)** | −0.02005 (0.033) | 0.0039 (0.078) | 0.0165 (0.035) | 0.01851 (0.289) | −0.0064 (0.281) | 0.0013 (0.306) | 0.0051 (0.283) | −0.0162 (0.437) | 0.0058 (0.433) | −0.0011 (0.449) | −0.0047 (0.433) |
| Pulses crop group | −0.0320 (0.529) | 0.0101 (0.528) | −0.0019 (0.535) | −0.0081 (0.529) | −0.1108 (0.016)** | 0.0388 (0.015) | −0.0078 (0.040) | −0.0310 (0.019) | 0.0133 (0.792) | −0.0048 (0.792) | 0.0009 (0.789) | 0.0038 (0.793) |
| Vegetables and fruits groups | 0.045027 (0.528) | −0.0142 (0.528) | 0.0027 (0.543) | 0.0114 (0.527) | −0.1400 (0.019)** | 0.0490 (0.012) | −0.0099 (0.035) | −0.0391 (0.017) | −0.0675 (0.258) | 0.0242 (0.250) | −0.0047 (0.266) | −0.0195 (0.257) |
| LR chi2 (17) Prob >chi2 Log-likelihood | 51.19 0.0000 −134.34725 | | | | 16.83 0.0000 −145.269 | | | | 21.50 0.0895 −149.875 | | | |

Age calculated in Years, Farming experience in Years, Farm size in Acres, Distance in Km. Significance code: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.





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TABLE 3 Results of dietary diversity among women as assessed by an analysis of agricultural and socioeconomic factors.

| Variables | Layyah marginal effects | | | | Bhakkar marginal effects | | | | Khushab marginal effects | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX |
| Age | 0.0279 (0.221) | −0.0086 (217) | 0.0016 (0.258) | 0.0069 (0.216) | −0.0380 (0.077)* | 0.0138 (0.069) | −0.0026 (0.106) | −0.0111 (0.075) | −0.0070 (0.740) | 0.0025 (0.740) | −0.0009 (0.740) | −0.0015 (0.741) |
| Farming experience | 0.036 (0.035)** | −0.0114 (0.030) | 0.0021 (0.071) | 0.0092 (0.032) | 0.0381 (0.063)* | −0.0138 (0.056) | 0.0026 (0.098) | 0.0111 (0.060) | 0.0126 (0.564) | −0.0046 (0.563) | 0.0017 (0.565) | 0.0028 (0.564) |
| Family size | −0.212 (0.010)*** | 0.0656 (0.007) | −0.0125 (0.043) | −0.0531 (0.008) | −0.0020 (0.979) | 0.0007 (0.979) | −0.0001 (0.979) | −0.0005 (0.979) | −0.0453 (0.520) | 0.0164 (0.518) | −0.0063 (0.516) | −0.0101 (0.523) |
| Farm size | −0.043 (0.024)** | 0.0134 (0.020) | −0.0025 (0.069) | −0.0108 (0.020) | 0.0140 (0.604) | −0.0051 (0.604) | 0.0009 (0.601) | 0.0041 (0.606) | 0.0655 (0.766) | −0.0238 (0.766) | 0.0092 (0.766) | 0.0146 (0.766) |
| Family structure 1single 2. joint | −0.153 (0.463) | 0.0475 (0.461) | −0.0091 (0.475) | −0.0384 (0.461) | 0.1348 (0.510) | −0.0491 (0.509) | 0.0095 (0.508) | 0.0395 (0.513) | 0.0428 (0.006)*** | −0.015 (0.003) | 0.006 (0.007) | 0.009 (0.007) |
| Distance from city | −0.001 (0.967) | 0.0005 (0.967) | −0.0001 (0.967) | −0.0004 (0.967) | 0.0232 (0.591) | −0.0084 (0.591) | 0.0016 (0.591) | 0.0068 (0.592) | −0.092 (0.010)*** | 0.033 (0.008) | −0.012 (0.016) | −0.020 (0.013) |
| Distance from the main road | −0.073 (0.365) | 0.0226 (0.363) | −0.0043 (0.390) | −0.0183 (0.363) | 0.1395 (0.057)** | −0.0508 (0.052) | 0.0098 (0.087) | 0.0409 (0.057) | 0.0431 (0.621) | −0.015 (0.620) | 0.006 (0.625) | 0.009 (0.619) |
| Distance from input/output market | −0.087 (0.004)*** | 0.0271 (0.004) | −0.0052 (0.016) | −0.0219 (0.004) | −0.0192 (0.665) | 0.0069 (0.665) | −0.0013 (0.665) | −0.0056 (0.665) | 0.0667 (0.083)* | −0.024 (0.081) | 0.009 (0.092) | 0.014 (0.091) |
| Local market in the village | −0.070 (0.089)* | 0.2190 (0.083) | −0.0419 (0.136) | −0.1771 (0.084) | −0.3617 (0.426) | 0.1317 (0.424) | −0.0255 (0.437) | −0.1061 (0.425) | 0.354 (0.313) | −0.129 (0.309) | 0.049 (0.328) | 0.079 (0.306) |
| Drinkable water is available within 60 min walk | 0.462 (0.440) | −0.1431 (0.438) | 0.0274 (0.453) | 0.1157 (0.438) | −0.3142 (0.508) | 0.1144 (0.508) | −0.0222 (0.437) | −0.1061 (0.425) | 0.0661 (0.910) | −0.024 (0.910) | 0.009 (0.910) | 0.014 (0.911) |
| Road to village 1.Yes, 2. No. | 0.586 (0.067)* | −0.1816 (0.060) | 0.0347 (0.096) | 0.1468 (0.065) | 0.3309 (0.442) | −0.1205 (0.439) | 0.0234 (0.451) | 0.0971 (0.441) | 0.4356 (0.352) | −0.158 (0.350) | 0.061 (0.346) | 0.097 (0.359) |
| Crop diversity index | 5.079 (0.108) | −1.5733 (0.101) | 0.3011 (0.134) | 1.2722 (0.106) | 2.6458 (0.520) | −0.9639 (0.520) | 0.1872 (0.511) | 0.7767 (0.524) | 9.047 (0.003)*** | −3.291 (0.001) | 1.272 (0.003) | 2.018 (0.004) |
| Income diversity Index | −2.321 (0.040)** | 0.7189 (0.035) | −0.1376 (0.083) | −0.5813 (0.037) | −1.1455 (0.121) | 0.4173 (0.116) | −0.0810 (0.176) | −0.3362 (0.115) | 0.3161 (0.668) | −0.115 (0.667) | 0.044 (0.668) | 0.070 (0.668) |
| Family education index | 0.133 (0.845) | −0.0413 (0.845) | 0.0079 (0.846) | 0.0334 (0.845) | 0.5127 (0.483) | −0.1867 (0.481) | 0.0362 (0.504) | 0.1505 (0.479) | 0.2896 (0.673) | −0.105 (0.672) | 0.040 (0.670) | 0.064 (0.674) |
| Cash crop group | 0.077 (0.035)** | −0.0241 (0.029) | 0.0046 (0.067) | 0.0195 (0.033) | 0.0466 (0.009)*** | −0.0169 (0.006) | 0.0033 (0.029) | 0.0136 (0.009) | 0.0100 (0.565) | −0.0003 (0.564) | 0.001 (0.559) | 0.002 (0.569) |
| Pulses crop group | −0.013 (0.803) | 0.0040 (0.803) | −0.0007 (0.802) | −0.0033 (0.803) | −0.0451 (0.322) | 0.0164 (0.320) | −0.0031 (0.359) | −0.0132 (0.317) | 0.0432 (0.404) | −0.015 (0.402) | 0.004 (0.400) | 0.009 (0.410) |
| Vegetables and fruits groups | 0.065 (0.323) | −0.0202 (0.320) | 0.0038 (0.351) | 0.0163 (0.319) | −0.0155 (0.769) | 0.0056 (0.769) | −0.0010 (0.768) | −0.0045 (0.769) | −0.076 (0.180) | 0.027 (0.175) | −0.010 (0.178) | −0.016 (0.187) |
| LR chi2 (17) Prob>chi2 Log–likelihood | 52.97 0.0000 −132.84 | | | | 21.45 0.2070 −150.1594 | | | | 21.14 0.2201 −141.2929 | | | |

Significance code: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.





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TABLE 4 Results of dietary diversity among adolescent as assessed by an analysis of agricultural and socioeconomic factors.

| Variables | Layyah marginal effects | | | | Bhakkar marginal effects | | | | Khushab marginal effects | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX |
| Age | 0.0473 (0.039)** | −0.0160 (0.033) | 0.0032 (0.076) | 0.0128 (0.036) | 0.0027 (0.897) | −0.0008 (0.897) | −0.0000 (0.906) | 0.0008 (0.897) | 0.0238 (0.265) | −0.0079 (0.259) | 0.0003 (0.563) | 0.0076 (0.263) |
| Farming experience | −0.0090 (0.584) | −0.0030 (0.584) | 0.0006 (0.588) | 0.0024 (0.584) | 0.0071 (0.722) | −0.0022 (0.722) | −0.0000 (0.810) | 0.0023 (0.722) | −0.0311 (0.168) | 0.0104 (0.161) | −0.0004 (0.552) | −0.0099 (0.164) |
| Family size | 0.0063 (0.935) | −0.0021 (0.935) | 0.0004 (0.935) | 0.0001 (0.935) | −0.0145 (0.863) | 0.0046 (0.863) | 0.0000 (0.881) | −0.0046 (0.863) | 0.1145 (0.105) | −0.0382 (0.104) | 0.0017 (0.557) | 0.0364 (0.102) |
| Farm size | 0.0363 (0.061)* | −0.0123 (0.055) | 0.0025 (0.113) | 0.0098 (0.055) | −0.0080 (0.793) | 0.0025 (0.792) | 0.0000 (0.842) | −0.0026 (0.792) | −0.0282 (0.896) | 0.0094 (0.896) | −0.0017 (0.903) | −0.0090 (0.895) |
| Family Structure 1. single 2. joint | 0.1379 (0.508) | −0.0468 (0.506) | 0.0095 (0.514) | 0.0372 (0.507) | 0.0788 (0.709) | −0.0250 (0.709) | −0.0004 (0.807) | 0.0254 (0.709) | 0.0294 (0.074)* | −0.0098 (0.063) | 0.0004 (0.546) | 0.0093 (0.063) |
| Distance from city | −0.0068 (0.857) | 0.0023 (0.857) | −0.0004 (0.857) | −0.0018 (0.857) | −0.0096 (0.830) | 0.0030 (0.830) | 0.0000 (0.858) | −0.0031 (0.830) | −0.0314 (0.448) | 0.0105 (0.445) | −0.0004 (0.625) | −0.0100 (0.445) |
| Distance from the main road | −0.2283 (0.005)*** | 0.0775 (0.003) | −0.0158 (0.022) | −0.0616 (0.004) | 0.1398 (0.090)* | −0.0444 (0.084) | −0.0007 (0.753) | 0.0452 (0.084) | −0.0135 (0.879) | 0.0045 (0.879) | −0.0002 (0.883) | −0.0043 (0.879) |
| Distance from input/output market | 0.0088 (0.755) | −0.0030 (0.755) | 0.0006 (0.755) | 0.0023 (0.755) | 0.0643 (0.166) | −0.0204 (0.161) | −0.0003 (0.754) | 0.0208 (0.160) | 0.0494 (0.243) | −0.0165 (0.237) | 0.0007 (0.571) | 0.0157 (0.238) |
| Local market in the village | 0.8936 (0.037)** | −0.3036 (0.031) | 0.0621 (0.067) | 0.2415 (0.035) | −0.9510 (0.089)* | 0.3021 (0.086) | 0.0051 (0.747) | −0.307 (0.082) | −0.0104 (0.980) | 0.0035 (0.980) | −0.0001 (0.980) | −0.0033 (0.980) |
| Drinkable water is available within 60 min walk | 1.2734 (0.072)** | −0.4326 (0.064) | 0.0621 (0.089) | 0.3441 (0.071) | −0.2934 (0.544) | 0.0932 (0.543) | 0.0015 (0.779) | −0.3073 (0.543) | −0.6616 (0.084)* | 0.2209 (0.077) | −0.0102 (0.528) | −0.2106 (0.083) |
| Road to village 1.Yes, 2. No. | 0.5621 (0.060)** | −0.1909 (0.052) | 0.039 (0.087) | 0.1519 (0.058) | −0.1084 (0.821) | 0.0344 (0.821) | 0.0005 (0.850) | −0.0350 (0.820) | 0.1005 (0.824) | −0.0335 (0.824) | 0.0015 (0.830) | 0.0320 (0.824) |
| Crop diversity index | −0.6310 (0.810) | 0.2144 (0.810) | −0.0438 (0.810) | −0.1705 (0.810) | −2.774 (0.567) | 0.8814 (0.565) | 0.0151 (0.782) | −0.8965 (0.566) | 5.853 (0.049)** | −1.954 (0.043) | 0.0910 (0.60) | 1.863 (0.042) |
| Income diversity index | 1.3152 (0.208) | −0.4468 (0.204) | 0.0914 (0.229) | 0.3554 (0.208) | −1.483 (0.066)** | 0.4712 (0.061) | 0.0080 (0.749) | −0.4793 (0.059) | 0.1888 (0.813) | −0.0630 (0.813) | 0.0029 (0.829) | 0.0601 (0.812) |
| Family education index | 0.1475 (0.832) | −0.0501 (0.832) | 0.0102 (0.833) | 0.0398 (0.832) | 0.6063 (0.602) | −0.1926 (0.602) | −0.0033 (0.784) | 0.1959 (0.601) | 0.6269 (0.315) | −0.2093 (0.314) | 0.0097 (0.577) | 0.1996 (0.317) |
| Cash crop group | −0.0306 (0.342) | 0.0104 (0.339) | −0.0021 (0.363) | −0.0082 (0.339) | −0.0375 (0.034)** | 0.0119 (0.029) | 0.0002 (0.752) | −0.0121 (0.029) | −0.0094 (0.551) | 0.0031 (0.549) | −0.0001 (0.656) | −0.0030 (0.550) |
| Pulses crop group | −0.0633 (0.227) | 0.0215 (0.222) | −0.0044 (0.250) | −0.0171 (0.225) | 0.1682 (0.002)*** | −0.0534 (0.001) | −0.0009 (0.749) | 0.0543 (0.001) | 0.0439 (0.394) | −0.0146 (0.391) | 0.0006 (0.605) | 0.0139 (0.392) |
| Vegetables and fruits groups | −0.0405 (0.533) | 0.0137 (0.532) | −0.0028 (0.540) | −0.0109 (0.532) | 0.1050 (0.076)* | −0.0349 (0.069) | 0.0030 (0.227) | 0.0319 (0.071) | −0.1132 (0.053)** | 0.0378 (0.046) | −0.0017 (0.542) | −0.0361 (0.046) |
| LR chi2 (17) Prob>chi2 Log–likelihood | 33.79 0.0089 −141.792 | | | | 36.36 0.0041 −144.275 | | | | 29.49 0.0303 −152.7064 | | | |

Significance code: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.





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same results regardless of the variable in Layyah, with the exception of age and farm size, where the significant threshold decreased ($p < 0.10$). With the exception of cash crops ($p < 0.10$) and vegetables and fruits ($p < 0.10$), the level of significance remained constant in Bhakkar. In the Khushab district, each component is of similar importance.

## 3.5. Results of children dietary diversity

There was a link between the prevalence of child DDS in Layyah and the diversity of crops grown in respondents' households (Table 5). Most developmental delays among adolescents in the Layyah district correlated with the production of cash crops and pulses ($p < 0.01$). Children in the Layyah district who lived further from the city, the central road, and the marketplaces were more likely to have DDS. In neither district is exposure to farming or family education associated with children's DDS rates. Poisson regression was also applied to each of these additional regressions as a robustness test. Despite the higher significant values for crop diversification and cash crops in Layyah, the results were consistent and independent of the variable. In Bhakkar, agricultural diversification and family education are closely connected with child DDS, thereby contributing additional stability. Adolescent DDS testing in the district of Khushab indicated a substantial correlation with agricultural diversification.

## 3.6. Factor importance

The significance of all agricultural and socioeconomic factors that operate independently of one another and the dietary diversity of men, women, adolescents, and children was evaluated (DDS). The diversity of crops grown in a region impacts the variety of foods available to men and women in a specific location. In every area, the average annual income and the distance to food markets were the most critical factors for male and female DDS. Crop diversification, yearly revenue, and travel time to markets were the three most influential factors affecting men's and women's DDS in all regions. Due to adolescent DDS, agricultural diversification and cash crops were necessary for Layyah and Bhakkar. The correlation between adolescent DDS and annual income was the strongest across all locales. In all aspects, adolescents with DDS were less constrained than their adult counterparts by factors such as distance to food markets and annual income. The significant variable plots for child DDS appear significantly different than those for men, women, and adolescents. Among adults of all ages and adolescents, crop diversity (CD) remained one of the most significant characteristics of DDS. Children in Layyah and Khushab ranked crop diversity as the first and third most important factors in dietary diversity, respectively. Cash crops, pulses, and annual income were the primary causes of district Layyah's child DDS being illuminated. However, in Bhakkar and Khushab, the same factors remained significant, such as the distance to the market, the composition of households, the availability of fresh vegetables, etc.

# 4. Discussion

To examine the relationship between farmers' income, crop diversification, and the variety of foods they consume, we analyzed primary data from 450 farmer families. We are exploring this relationship to better understand how recent agricultural developments, such as the diversification of farmers' income sources and the increase in crop specialization, have affected the diets of Pakistani farm families. In this study, the association between farmers' diets and their ability to produce many sources of income (as indicated by the crop diversity index, or CDI) was investigated (measured by the income diversity index, or IDI). Our research indicates a high association between crop diversification and dietary diversity among adults (men, women, and adolescents) and children in the Layyah and Bhakkar districts and the Khushab region. Thus, the nutrition of the children of Khushab was determined primarily and secondarily by the variety of available crops. Even though IDI was the second-most crucial factor in explaining variation in child DDS in Layyah and Bhakkar, we could not detect a statistically significant correlation between IDI and individual DDS across districts. Even though our data are cross-sectional and only examine the associations between crop and income diversity and dietary diversity over a single time step, our analysis has important implications for understanding how crop specialization and increased income diversity may affect family food variation. Our data indicate that crop specialization may be connected with a reduction in Pakistan's dietary diversity among farm households.

Consistent with prior studies, we identified a strong positive correlation between CDI and DDS at the district level (Dabo et al., 2013; Singh et al., 2020; Dereje et al., 2021; Derso et al., 2021; Mengistu et al., 2021; Azupogo et al., 2023). There is empirical support for a beneficial link between crop diversity and dietary diversity, which two distinct mechanisms may mediate: (1) by providing a farmer's household with a variety of food groups to consume and (2) by providing a variety of crops that can be sold to the market to generate income that is used to purchase a wider variety of foods from markets (Achterbosch et al., 2014; Hill and Vigneri, 2014; Ntakyo and van den Berg, 2019; Baker et al., 2020; Soukand et al., 2020).

As demonstrated by our research, both routes are involved in the link between crop diversity and individual dietary diversity. This study explored the association between farming various crops to fully comprehend how a higher CDI can improve nutritional diversity through the consumption and income pathway (cash crops, pulses, vegetables, and fruits). The prevalence of DDS is higher among adults, children, and adolescents in Layyah and Khushab, where the pulse population is growing. Farming households consumed more pulses than non-farming households in Bhakkar, where overall consumption was lower than in Layyah and Khushab (Table 1). Considering the potential impact of CDI on dietary diversity through growing income, for example, in Layyah, producing cash crops was related to a more diverse diet for men and adults, whereas Bhakkar and Khushab were associated with a more varied diet for all members of a farming household. Notably, the CDI of cash crop producers was much greater than that of other farmers. Similar results were found in Indonesia, Kenya, Ethiopia,

TABLE 5 Dietary diversity among children as assessed by an analysis of agricultural and socioeconomic factors.

| Variables | Layyah marginal effects | | | | Bhakkar marginal effects | | | | Khushab marginal effects | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX | Coefficients | Prob (Y = 0/X) dY/dX | Prob (Y = 1/X) dY/dX | Prob (Y = 2/X) dY/dX |
| Age | −0.0826 (0.005)*** | 0.0179 (0.002) | −0.0151 (0.005) | −0.0028 (0.030) | 0.0303 (0.281) | −0.0080 (0.275) | 0.0067 (0.275) | 0.0012 (0.341) | 0.0236 (0.241) | −0.0088 (0.233) | 0.0007 (0.287) | 0.0081 (0.237) |
| Farming experience | −0.0063 (0.799) | 0.0013 (0.799) | −0.0011 (0.798) | −0.0002 (0.807) | −0.0172 (0.511) | 0.0045 (0.509) | −0.0038 (0.508) | −0.0007 (0.532) | −0.0143 (0.485) | 0.0053 (0.482) | −0.0004 (0.495) | −0.0049 (0.484) |
| Family size | 0.2539 (0.022)** | −0.0551 (0.017) | 0.0464 (0.013) | 0.0086 (0.138) | −0.1180 (0.206) | 0.0311 (0.199) | −0.0263 (0.199) | −0.0047 (0.281) | −0.0150 (0.852) | 0.0056 (0.852) | −0.0005 (0.851) | −0.0051 (0.852) |
| Farm size | −0.1303 (0.000)*** | 0.0283 (0.000) | −0.0238 (0.000) | −0.0044 (0.067) | 0.0948 (0.083) | −0.0250 (0.077) | 0.0211 (0.079) | 0.0038 (0.179) | 0.0542 (0.799) | −0.0203 (0.799) | 0.0016 (0.799) | 0.0186 (0.799) |
| Family structure 1.single 2. joint | −0.6735 (0.023)** | 0.1462 (0.019) | −0.1231 (0.024) | −0.0230 (0.069) | 0.8324 (0.003)*** | −0.2196 (0.001) | 0.1858 (0.002) | 0.0338 (0.085) | 0.0265 (0.078)* | −0.0099 (0.072) | 0.0008 (0.135) | 0.0091 (0.080) |
| Distance from city | 0.1248 (0.005)*** | −0.0271 (0.003) | 0.0228 (0.002) | 0.0042 (0.100) | 0.0397 (0.585) | −0.0104 (0.584) | 0.0088 (0.584) | 0.0016 (0.598) | 0.0259 (0.574) | −0.0097 (0.573) | 0.0008 (0.592) | 0.0089 (0.573) |
| Distance from the main road | −0.4368 (0.003)*** | 0.0948 (0.001) | −0.0798 (0.001) | −0.0149 (0.053) | −0.0017 (0.985) | 0.0004 (0.985) | −0.0003 (0.985) | −0.0000 (0.985) | 0.1337 (0.178) | −0.0500 (0.170) | 0.0041 (0.268) | 0.0459 (0.172) |
| Distance from input/output market | 0.8728 (0.013)** | −0.0189 (0.011) | 0.0159 (0.014) | 0.0029 (0.060) | −0.0851 (0.247) | 0.0224 (0.243) | −0.0190 (0.243) | −0.0034 (0.312) | −0.0392 (0.397) | 0.0146 (0.395) | −0.0012 (0.932) | −0.0138 (0.931) |
| Local market in the village | −2.1223 (0.000)*** | 0.4607 (0.000) | −0.3881 (0.000) | −0.0726 (0.050) | −0.2283 (0.676) | 0.0602 (0.676) | −0.0509 (0.675) | −0.0092 (0.683) | −0.0402 (0.931) | 0.0150 (0.931) | −0.0012 (0.932) | −0.0138 (0.931) |
| Drinkable water is available within 60 min walk | −0.2951 (0.613) | 0.0640 (0.611) | −0.0539 (0.611) | −0.0100 (0.618) | −0.6331 (0.235) | 0.1670 (0.229) | −0.1413 (0.230) | −0.0257 (0.300) | 0.2397 (0.521) | −0.0897 (0.519) | 0.0074 (0.545) | 0.0823 (0.519) |
| Road to village 1.Yes, 2. No. | 0.7841 (0.045)** | −0.1702 (0.042) | 0.1434 (0.041) | 0.0268 (0.137) | 0.4590 (0.433) | −0.1211 (0.430) | 0.1024 (0.430) | 0.01864 (0.462) | −0.1049 (0.790) | 0.0392 (0.790) | −0.0032 (0.792) | −0.0360 (0.790) |
| Crop diversity index | −0.5124 (0.073)* | 0.1112 (0.075) | −0.0937 (0.062) | −0.0175 (0.077) | 11.440 (0.168) | −3.0187 (0.163) | 2.5540 (0.165) | 0.4647 (0.247) | 6.157 (0.024)** | −2.305 (0.019) | 0.1905 (0.119) | 2.114 (0.022) |
| Income diversity index | −3.1958 (0.010)** | 0.6937 (0.007) | −0.5844 (0.013) | −0.1093 (0.038) | −0.1415 (0.082)* | 0.0373 (0.075) | −0.0315 (0.080) | −0.0057 (0.079) | 0.2092 (0.788) | −0783 (0.788) | 0.0064 (0.789) | 0.0718 (0.788) |
| Family education index | 1.1866 (0.139) | −0.2576 (0.129) | 0.2170 (0.137) | 0.0405 (0.171) | −2.9892 (0.865) | 0.7887 (0.858) | −0.6673 (0.860) | −0.1214 (0.859) | −0.4772 (0.455) | 0.1786 (0.453) | −0.0147 (0.503) | −0.1638 (0.451) |
| Cash crop group | 0.1465 (0.005)*** | −0.0304 (0.004) | 0.0256 (0.003) | 0.0048 (0.090) | −0.0079 (0.710) | 0.0021 (0.709) | −0.0017 (0.709) | −0.0003 (0.716) | −0.0203 (0.224) | 0.0076 (0.218) | −0.0006 (0.266) | −0.0070 (0.224) |
| Pulses crop group | 0.1465 (0.036)** | −0.0318 (0.039) | 0.0268 (0.032) | 0.0050 (0.172) | 0.0745 (0.262) | −0.0196 (0.258) | 0.0166 (0.261) | 0.0030 (0.314) | −0.0017 (0.973) | 0.0006 (0.973) | −0.0000 (0.973) | −0.0005 (0.973) |
| Vegetables and fruits groups | −0.0830 (0.306) | 0.0180 (0.309) | −0.0151 (0.318) | −0.0028 (0.310) | 0.1324 (0.073)* | −0.0349 (0.065) | 0.0295 (0.067) | 0.0053 (0.169) | −0.0653 (0.252) | 0.0244 (0.244) | −0.0020 (0.336) | −0.0224 (0.243) |
| LR chi2 (17) Prob>chi2 Log–likelihood | 56.20 0.0000 −66.839 | | | | 30.17 0.0251 −80.3042 | | | | 13.84 0.6786 −149.1097 | | | |

Significance code: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.





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and Malawi (Ochieng et al., 2016; Shahbaz et al., 2017; Dessie et al., 2019; Williams et al., 2020). According to these findings, farmers who cultivate various crops and have strong ties to the markets where those crops are marketed may contribute to dietary diversity in rural Pakistan.

Considering the significance of other factors in our study, family education was significant in the districts. Previous studies have suggested that higher levels of education, particularly maternal education (Reinbott et al., 2016; Jones, 2017; Kuchenbecker et al., 2017; Luna-González and Sørensen, 2018; Murendo et al., 2018), have a positive effect on farmer households' dietary diversity.

Cash crop income has the most significant impact on DDS for children, but annual per capita income has the most significant effect on adults (PCAI). These findings demonstrate the importance of the income-to-nutrition relationship in fostering dietary diversity among farming households. The distance traveled by family members to reach food markets (DFM) was one of the most important determinants of each member's DDS, with greater DFM (distance to food markets) accessibility being associated with a higher DDS. This conclusion contradicts logic but is consistent with other research (such as Mbwana et al., 2016). It may accurately reflect that families who consume various foods must sometimes travel further to do so. In our experience, local village markets provide a limited selection of items from each food group. Individuals interested in unusual foods such as dark green leafy vegetables and vitamin A-rich vegetables and fruits may have to travel a considerable distance. Based on these findings, we hypothesize that increasing family education, higher farm revenues, and larger local village markets may contribute to a greater variety of foods consumed by farmer households.

According to the survey, one of the most pervasive instances of gender discrimination occurs in the food allotment industry (Choudhury et al., 2019; Gupta et al., 2019; Bonis-Profumo et al., 2021; Mengistu et al., 2021). Even among family members, women's DDS tends to be lower than men's, as evidenced by our findings (Table 1), which are consistent with those of other studies (Gitagia et al., 2019). Multiple factors may be at play here. First, in rural Pakistan, the male household head is frequently the primary source of income, providing him greater control over the available cash and maybe allowing him to purchase and consume a wider variety of meals (Hoek et al., 2021). Second, because rural Pakistani women are more likely to be vegetarians than men, they would have fewer food options. Women consume less meat and egg products than men, as shown in Table 1. To better understand the underlying causes of the gender imbalance, we analyzed the characteristics related to disparities in DDS between men and women residing in the same household. Increases in the educational attainment of farmer households could minimize the gender disparity in Pakistan's dietary diversity. We discovered that female DDS was more significant than male DDS in FEI. In addition, a shorter DFM has been associated with a larger DDS in females than males. We discovered no statistically substantial DDS differences between male and female adolescents and children. The analysis of adult DDS compared individuals within the same family, whereas the current study examined males and females from particular households, reducing statistical power.

Our work has various limits as well as potential future opportunities. Then, using the MDD-W (Minimum Dietary Variety for Women) food groups, we assessed the dietary diversity of males and adolescents (FAO, 2016). There are presently no food group guidelines for men or adolescents, and we encourage future research to investigate whether the food categories for MDD women are suitable for the dietary variability of males and adolescents. Second, we do not employ panel data to assess changes in agriculture over time within the same farmer households; instead, our results are based on cross-sectional observational data. Therefore, our results are only correlative and not causal. An additional longitudinal study on the same farming households is required to determine the cause-and-effect relationship between crop and income diversity and household dietary diversity.

Third, we have lost sight of the proportion of our food that comes from farms instead of supermarkets. The trade-off is that we better understand the consumption and revenue channels through which increased crop variety leads to a more diverse diet among farmer households. We randomly surveyed localities to account for the likelihood of neighboring daily local markets. Even if the nutritional type is likely to be more significant in the days after the establishment of a local market, our results may be skewed in regions where markets are not constantly open. We could not include a dummy variable for market presence due to a lack of information regarding the days on which local markets were open (i.e., whether a specific monthly or weekly market was available on the day of the survey). We do not believe that the fact that we randomly picked locations for our surveys based on a market's proximity affected the reliability of our findings. Future research should take this new variable into account. Due to cost and time constraints, the survey design only included a small number of teenagers or children from each farmer's household; therefore, their numbers were lower than those of adult (male and female) respondents. Although the data size for child regressions was considerably smaller than that for adult regressions, our regressions were able to find the correlations between CDI and distance traveled to the markets that exhibited the most vital connections with DDS for other family members (male, female, and adolescent). We acknowledge the possibility that the sensitivity of these regressions was insufficient to detect the effects of additional factors with smaller effect sizes. We could not obtain seasonal agricultural and nutritional data due to a lack of time and resources (such as during the monsoon and winter). Seventh, it was not always straightforward to determine, for instance, why CDI was associated with child and adolescent DDS in Layyah but not in Bhakkar and Khushab. Future research would benefit from speaking more with farmers to appreciate the context of these results properly. Lastly, we would like to emphasize that just three locations in Pakistan were selected for this case study, as each represents a distinct agricultural transition. Rather than generalizing our findings to other regions, we wish to highlight the potential effects of two different agricultural transition approaches on dietary diversity. Future research should focus on the several Pakistani states whose variation stretches along a gradient to comprehend the causal linkages between diversification routes and nutritional diversity.

Our findings indicate that adults in Layyah and Bhakkar and adolescents and children in Khushab consumed a more diverse diet with greater crop diversification. Our research reveals that when crop diversity is high, farmer households with more diverse diets

are more likely to be permitted to vary their meals. Although the variation in Layyah's dietary diversity has been influenced by her income diversity, we could not detect a correlation between the two. According to our data, diversifying farmers' revenue sources may have a minimal effect on households' diversity of foods consumed. We find that greater dietary diversity is associated with higher income production among farmer households in the states, whether through crop sales, increased cash crop yields, or paid professional activities. The education level of the household's head, the extent to which farmers are connected to the market, and the family's annual income are significant drivers of the variety of foods consumed. Future programmes that enhance the variety of foods consumed by farmer households cannot utilize a one-size-fits-all approach, as the essential factors vary between homes and locations. It demonstrates complicated connections between dietary diversity among farmers, socioeconomic indicators, and crop and revenue diversification.

## 5. Conclusion

This study examined the income, crop diversification, livestock production and food diversity of 450 farmer households in Layyah, Bhakkar, and Khushab in Pakistan. Because rising crop specialization and revenue diversification may reduce the nutritional diversity of farmer households, we set out to learn more about this potential relationship. Adults, adolescents, and children in Layyah, Bhakkar, and Khushab exhibit a statistically significant positive correlation between crop diversification and DDS. According to this knowledge, Pakistan's food diversity and livestock production decrease if farmers focus on fewer crops. The development of DDS in males, females, and adolescents was most strongly influenced by educational attainment and family financial stability. The distance to food markets, the household's education level, and the crops farmed were the essential factors in deciding how each individual's DDS was explained. According to our findings, having a more diverse diet may be a viable strategy for increasing economic output. This will allow to boost farmer's income through selling food, cultivating cash crops, livestock production and other subsistence activities. Diversifying crops and building more diversified local food markets may be more beneficial to boosting farmer households' dietary diversity. Several factors, including the socioeconomic status of the farmer, the state of the market, and the types of crops they cultivate, can substantially impact the nutrition of a farmer's family. We conclude that dietary diversity and livestock production among farmer households in rural area of Pakistan is beneficial for sustainable production, food security, nutrition and farmer's livelihoods.

According to the overall finding, the following policy is suggested regarding crop diversity and livestock production in Pakistan: Crop diversity in agriculture applies to both the public and private sectors. The public sector can improve household nutrition, food production, and sustainable agriculture production through the development of crop diversity and livestock production in rural areas of Pakistan. The government should provide an enabling environment and subsidies to smallholder farmers in the rural areas of Pakistan. Pakistan must prepare a national policy to ensure the conservation of food security and national resources and to improve the agriculture performance in the rural areas of Pakistan.

### 5.1. Limitation and future research

There are several limitations in this study. This empirical research only addresses the crop diversity and livestock production to smallholder intra-household dietary diversity, nutrition and sustainable food production, in the rural area of south Punjab, Pakistan. The future studies should consider other parameters and include some other social demographic characteristics with new results in other developing areas around the world.

## Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

## Author contributions

MW, AHMSI, and MHR reviewed the literature, proposed the research model, and conceptualized and designed the study. XL conducted the literature search, preceded with the data extraction process, and involved in the development of the manuscript. MW, IJ, and QA conducted the statistical analysis and revised the manuscript critically for important content. XL, AHMSI, and IJ revised the whole manuscript according to the comments of the reviewer and rechecked the relevant data of the manuscript. XL and ME put forward many constructive suggestions on promoting the revision of the manuscript and supervised the entire writing process of the manuscript. All authors have equal contribution and approved the final manuscript to be published.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2023.1143774/full#supplementary-material

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