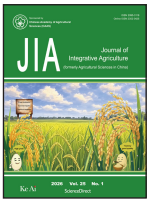
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RESEARCH ARTICLE

Pathways to improved food and nutrition security: The role of farm production diversity in household dietary outcomes in rural areas of Pakistan

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Highlights

- Farm production diversity significantly enhances household dietary diversity in rural Pakistan, primarily through the own-farm consumption pathway.
- Each additional crop or livestock species cultivated increases household dietary diversity, with own-farm production demonstrating stronger effects than market purchases.
- Gender, education, and access to mobile phones influence dietary outcomes, underscoring the importance of social and technological factors alongside agricultural diversity.

Abstract

Malnutrition remains a significant global challenge, particularly in developing countries. Policymakers have increasingly focused on improving household food security and nutrition through farm production diversity (FPD). While research indicates that FPD correlates positively with reduced malnutrition, other studies emphasize the importance of market access for improved nutritional outcomes. However, this evidence varies by region and remains inconsistent. To address this knowledge gap, this study analyzed survey data from 450 smallholder farmers in Punjab, Pakistan, using regression models to examine the relationship between FPD and dietary diversity, as well as the underlying impact pathways. The findings demonstrate that FPD significantly correlates with increased household dietary diversity score (HDDS). FPD influences dietary diversification through both own-farm production and market food consumption pathways, with the own-farm production pathway showing greater impact. The increase in food expenditure through own-farm production yielded a marginal return of 8% in household dietary diversity compared to 5.3% through marketing. Gender differences emerged as significant, with male-headed households showing relatively lower dietary diversity. These findings have substantial implications for countries with smallholder farming systems, providing valuable insights for the formation of agricultural policies, resource optimization, and rural development initiatives.

Keywords: food security, nutrition security, FPD, HHDS, smallholder farmers

1. Introduction

Providing enough food for household consumption (food security) and food quality (nutrition security) has always been a problem in both developing and developed countries (Herforth *et al.* 2022; Wijerathna-Yapa and Pathirana 2022). Ending hunger is a primary target of the United Nations Sustainable Development Goals, yet more than 800 million people continue to suffer from chronic hunger (Asim *et al.* 2015; Sekabira and Nalunga 2020). The poor distribution of food is a primary cause of hunger and is closely correlated with income. As a result, food markets have marginalized poor households due to income disparities within society (Ahmed *et al.* 2017; Jamil *et al.* 2021).

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Unfortunately, income inequality is increasing in some countries, and this increasing level of income inequality also enhances poverty, hunger, and malnutrition. Therefore, farm production diversity (FPD) is a vital strategy for enhancing dietary diversity, household food security, and nutrition security. For the last few decades, Pakistan's government has introduced new policies for farmers to identify specific crops and livestock to grow or raise to ensure that FPD is a crucial pathway for securing household food consumption (Ahmed *et al.* 2017; Jerzak and Śmiglak-Krajewska 2020; Wudil *et al.* 2022).

Thus, those policies have, to some extent, influenced the diversity of household farm production, household nutrition, and, consequently, dietary diversity. A complex interrelationship of agriculture (FPD), food security (quantities of food consumed), and nutrition (diet quality) needs to be understood to ensure household nutrition security (Ahmed *et al.* 2017; Muthini *et al.* 2020; Usman and Callo-Concha 2021).

Recognizing the impact of malnutrition on human welfare and economic development, Pakistan's government has established policies to ensure household nutrition security. Through its agricultural sector strategy and investment plan, the government has emphasized the use of technologies to improve household food security, income, and nutritional levels. The government promoted diverse agricultural production, including cotton, maize, rice, beans, potatoes, cattle, goats, poultry, citrus, vegetables, and bananas (Hashmi *et al.* 2021; Jamil *et al.* 2021). This agricultural diversity system aligns with the government's vision for 2030.

A significant research gap exists in understanding agricultural systems, particularly the relationship between FPD and dietary diversity. This gap is especially notable among smallholder farm households, which constitute the largest proportion of chronically hungry populations. Several studies (Qaim *et al.* 2016; Pawlak and Kołodziejczak 2020) demonstrate that market access has greater significance than FPD in enhancing dietary diversity (defined as the number of different food groups consumed over a given period, serving as an indicator of diet quality and nutritional adequacy). However, this evidence may not be applicable to certain regions of Pakistan, characterized by smallholder farmers with limited market infrastructure and unequal income distribution. Other research (Chegere and Stage 2020; Habtemariam *et al.* 2021) highlights the importance of FPD for dietary diversity, although the evidence remains inconclusive. Empirical research examining the interrelationship between FPD and nutrition (quality and quantity) is limited, insufficient, and disconnected. While agriculture and nutrition security are crucial for eliminating severe hunger and malnutrition, developing relationships within an integrated framework remains a strategic research priority.

Currently, no empirical relationship between FPD and dietary diversity in Pakistan has been established using survey or national representative data. This study addresses this research gap through two primary questions: First, what is the effect of farm production on household dietary diversity? Second, how do farm-generated income and food security pathways through market access compare, and which pathway is more effective in increasing household dietary diversity score (HDDS) through FPD?

1.1. Conceptual framework

Households fulfill their consumption requirements primarily through farm production or market purchases. Through diversification practices, households cultivate a variety of crops and raise different livestock species on their farms. This approach enables households to consume their produce and products while generating income through sales. Consequently, two primary consumption pathways emerge: consumption from on-farm sources and consumption through market access. In this study, 'the own farm produces consumption pathway' refers to households obtaining consumable goods, such as plant or animal species, directly from agricultural farms.

Conversely, "the consumption pathway based on market access" describes how households acquire consumable goods through market channels. This includes purchasing unprocessed food items from local markets for home preparation, obtaining pre-cooked meals from dining establishments, and utilizing alternative methods of food acquisition. The study proposes a hypothesis suggesting a positive correlation between FPD and household food security (HFS), which influences the HDDS. This relationship manifests through the FPD system, enabling households to obtain food through two distinct channels: the farm food security (FFS) pathway, where food is acquired directly from farms, and the market food security (MFS) pathway, where farm income facilitates market purchases. These linkages are illustrated in Fig. 1.

Our hypothesis suggests that households with greater FPD demonstrate improved food security and achieve a higher HDDS. Furthermore, households with diversified agricultural production have more opportunities for marketing their agricultural products. This diversification reduces risks associated with single-market dependence and enhances overall income. Subsequently, these households can procure more food items from markets and improve their HDDS. The analysis assumes that self-managed FFS contributes more significantly to dietary diversity than MFS.

It is essential to note that contextual and household-specific characteristics influence this relationship. The hypotheses address these factors and indicate their directional influence through arrows in the conceptual framework. The positioning of these attributes within the framework reflects their expected influence on remaining linkages. A greater distance from markets presents challenges regarding market access and negatively impacts market consumption. However, increased distance from markets often correlates with remoteness, potentially allowing for more land to be used for agricultural purposes and encouraging self-sufficiency for local consumption. In many households, while male household heads generate income, they typically do not participate in meal planning and nutritional decisions, which can potentially negatively affect HDDS. Conversely, factors promoting knowledge acquisition, such as mobile phones, education, and the age of the household head, are expected to enhance HDDS through improved nutrition education. Wealth factors, including land size, are anticipated to positively affect HDDS by providing more farming area. Household size exhibits dual

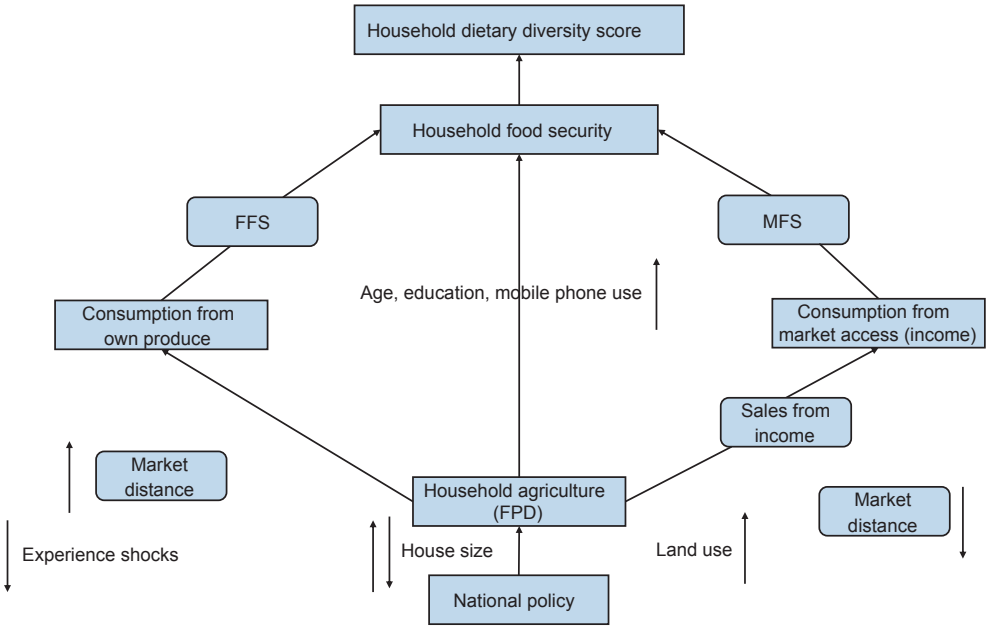


Fig. 1 Conceptual framework of farm production diversity (FPD) and household dietary diversity score (HDDS). FFS refers to food security achieved by consuming produce from farms; MFS refers to food security *via* consumption from the market (income, on and off-farm).

effects: working-age members or adult children can contribute to farm labor or income generation, positively impacting HDDS. However, households with numerous dependents, particularly young children or elderly members, face increased burdens. External shocks, including droughts, floods, or the death or prolonged illness of the household head, typically compromise a household's ability to access adequate food, adversely affecting HDDS.

1.2. Food quality differences

While both own-farm production and market-based food purchases contribute to household dietary diversity, significant nutritional quality differences exist between these sources. Homegrown food typically comprises fresh, minimally processed ingredients, retaining higher levels of essential micronutrients, including vitamins, minerals, and fiber. However, homegrown food diversity is constrained by land availability, seasonal variations, and farming capacity. Market-purchased food offers access to a broader range of food groups, including processed and fortified products that enhance dietary adequacy but may introduce higher levels of sugar, fat, and preservatives. Understanding these quality distinctions is crucial, as exclusive reliance on own-farm food may not ensure optimal nutritional intake, while excessive market dependence can lead to dietary imbalances. Future research should incorporate food quality indicators alongside dietary diversity measures to provide more comprehensive assessments of nutrition security.

2. Data and methods

2.1. Measurement of FPD and household food and nutrition security

A household biodiversity index (HBI) was calculated based on FPD (Habtemariam *et al.* 2021). The HBI counts all crops and livestock raised on a farm. Previously, studies have used the HBI to measure FPD (Jones *et al.* 2014; Sekabira and Nalunga 2020; Habtemariam *et al.* 2021). The current household production diversity (HPD) index relies on a simple count of crop and livestock species present on a farm. However, this approach does not fully capture the dietary relevance of different food sources. To enhance the index, we refined it by incorporating a dietary-weighted HPD score, which assigns greater weight to food groups that contribute more significantly to household dietary diversity. Specifically, food groups were categorized based on nutritional value, frequency of household consumption, and market availability. This adjustment ensures the appropriate consideration of staple food crops (e.g., cereals, legumes) and high-nutrient foods (e.g., fruits, vegetables, dairy products, and protein sources) rather than treating all species equally. A similar methodology has been used in prior studies on farm production and nutrition linkages (Ecker 2018; Sibhatu and Qaim 2018). This refined approach enhances the interpretability of the HPD index by aligning it more closely with dietary intake patterns rather than mere species diversity. During the computation of the HBI, crop species cultivated for food consumption or generating income were considered. A numerical value of 1 was assigned to each crop and livestock species. The HBI was calculated by summing the values of the CBI and LBI indices. CBI quantifies the diversity of crops grown in a given area. It is crucial for assessing food system resilience, climate adaptation, and dietary diversity; while LBI measures the diversity of livestock species and breeds in a farming system. It helps maintain genetic resources, ensures resilience to diseases, and supports sustainable livestock production, which is used to measure FPD. These equations

from (1) to (3) represent given formulae:

$$\sum_{n=1}^{K}\text{Crop species}_i=\text{CBI}_i \quad (1)$$

$$\sum_{n=1}^{J}\text{Livestock species}_i=\text{LBI}_i \quad (2)$$

$$\text{CBI}_i+\text{LBI}_i=\text{LBI}_i \quad (3)$$

For household *i*, crop species are numbered from 1 to *K*, while livestock species are numbered from 1 to *J*. The cultivated crops included a variety of agricultural products, such as bananas, beans, cabbage, chickpeas, cotton, peas, and a range of fruits and vegetables. The livestock species comprised all varieties of cattle and small ruminants present in the region.

The valuation of household food consumption from own-farm production utilized market-equivalent prices for each crop and livestock product. For each food item consumed from household farms, the prevailing local market price at the time of data collection was applied. This methodology ensures compatibility with market-purchased food expenditures and aligns with established research on farm production and dietary diversity (Kennedy *et al.* 2010; Leroy *et al*. 2015). The analysis incorporated seasonal price variations through district-level monthly price averages for primary food groups. For items lacking direct market equivalents (e.g., indigenous crops or livestock by-products), farmer-reported opportunity costs or comparable substitute market prices were utilized. This valuation approach provides a more precise assessment of the economic contribution of own-farm food consumption to household dietary diversity.

The HDDS serves as a key indicator of dietary diversity and nutritional adequacy by measuring the number of distinct food groups consumed within a household during a specified recall period. Following FAO (2010) guidelines, food items were categorized into 12 standards groups: cereals, roots and tubers, vegetables, fruits, meat, eggs, fish, legumes, dairy products, oils and fats, sweets, and condiments/spices. Households received scores ranging from 0 to 12, with higher scores indicating greater dietary diversity. The study employed a 24-h recall period, consistent with previous dietary diversity research in South Asia (Kennedy *et al.* 2010; Leroy *et al.* 2015).

The HDDS served as a metric for assessing the nutritional value of the food consumed within households, thus functioning as an indicator of household food security. However, it is crucial for these methodologies to accurately capture the relative attributes of foods, diets, and societal food practices (Leroy *et al.* 2015; Aleksandrowicz *et al.* 2016; Singh *et al.* 2020). Previous studies of dietary diversity used HDDS (Kennedy *et al.* 2010; McDonald *et al.* 2014; Zhang *et al.* 2020; Zhao *et al.* 2020; Kundu *et al.* 2021).

Household food insecurity assessment utilized a food security dummy variable, categorizing households as food secure (1) or food insecure (0). This categorization employed the Household Food Insecurity Access Scale (HFIAS), which evaluates food access sufficiency through nine standardized questions addressing food shortages, meal frequency reductions, and diet quality constraints (Gebreyesus *et al.* 215). Households reporting food shortages, reduced meal sizes, or meal skipping due to economic constraints were classified as food insecure. The food security threshold was established using a methodology consistent with previous Pakistan-focused studies (Ahmed *et al.* 2017; Hashmi *et al.* 2021).

2.2. Data used

This research utilizes survey data from the rain-fed region of Punjab Province, Pakistan. The surveys were conducted in May 2023 across three districts: Layyah, Bhakkar, and Khushab. Through a multi-stage sampling process, 450 smallholder farm households were selected. These smallholder farmers cultivate a variety of food, cash, and fodder crops specific to their regions, with some also engaging in livestock production. The selected regions feature smallholder farmers, particularly in remote areas, who face significant market failures that prevent the separation of farm production decisions from household consumption decisions. These areas experience water scarcity, land degradation, climate change, and food security challenges. The survey collected socioeconomic household data, including income sources, climate resilience on crops, and annual crop production. A 3-d recall period was implemented to gather information about household food consumption quantities, including foods received as gifts and those found in natural environments. Research by Hashmi *et al.* (2021) demonstrated that diverse food sources significantly enhance the dietary quality of rural smallholder households.

The study surveyed 450 respondents through a multi-stage systematic sampling technique. Prior to analysis, the surveys conducted in the rain-fed region of Punjab are described, as illustrated in Fig. 2. A standardized methodology was implemented across the study regions for selecting union councils in the three districts. Due to the limited accessibility of secondary data at the individual village level, the sampling approach focused on clusters of villages rather than single villages within each union council. Random selection was applied to choose villages from each union council, typically comprising two to three contiguous villages. Systematic random sampling was then employed within each selected village cluster to identify approximately seven to nine farming households per cluster. This methodology enabled the construction of a representative and robust sample while addressing data limitations at the village level. Subsequently, various indicators are explained to demonstrate FPD and household nutritious diets before introducing the statistical methodologies.

2.3. Empirical model on the effects of FPD and food and nutrition security

The following specifications were adopted for the regression models.

$$\text{FNSI}_{it}=x_0+x_1\text{FPD}_{it}+x_2T_t+\varepsilon_{it} \quad (4)$$

FNSI_{it} represents a food/nutrition security indicator (food security dummy or HDDS) of household *i* in year *t*. x_0 represents a constant. x_1 indicates the effect of farm production diversity (FPD_{it}). x_2 is a time-fixed effects parameter, *T* is the year identifier, and ε_{it} represents the error term. In this context, FPD was equivalent to HBI.

To estimate the impact of FPD on food security and dietary

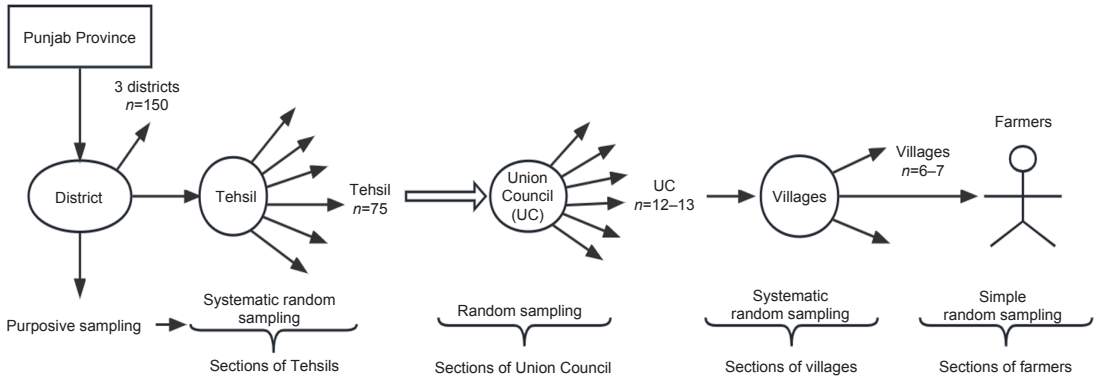


Fig. 2 Sampling framework of the study.

diversity using eq. (4), several methodological considerations must be addressed. In agricultural contexts, households make decisions about growing specific crops or livestock, potentially leading to endogeneity problems. These include correlation and causality issues across years, stemming from observed and unobserved heterogeneity bias. A critical consideration in examining the relationship between FPD and HDDS is potential endogeneity. This may emerge from reverse causality, as households with higher dietary diversity might adopt more diversified farming practices, resulting in biased estimates. Furthermore, unobserved heterogeneity factors (such as household preferences, farming expertise, or local food policies) could influence both FPD and HDDS, creating omitted variable bias. To address these methodological challenges, instrumental variable (IV) regression is employed, utilizing district-level climate variability (rainfall deviation) and agricultural extension service access as instruments for FPD. Rainfall deviations affect farm production decisions but are unlikely to directly influence HDDS beyond their impact on FPD. Similarly, agricultural extension access influences crop diversification without directly affecting household dietary patterns. These instruments meet the relevance and exclusion criteria essential for valid IV estimation. The integration of these econometric approaches enhances result validity and provides more reliable estimates of FPD's impact on dietary diversity.

The analysis employs both fixed effects (FE) and random effects (RE) models to examine the relationship between FPD and HDDS. The FE model accounts for time-invariant unobserved heterogeneity, ensuring that household-specific characteristics (including cultural food preferences, soil quality, farming techniques) do not bias the results. However, the FE model cannot estimate the effects of time-invariant variables, such as geographic characteristics. The RE model assumes unobserved heterogeneity is uncorrelated with explanatory variables, enabling more efficient estimation of time-invariant variables. The Hausman specification test determines the more appropriate model choice. A statistically significant test result indicates that the FE model provides consistent estimates, while a non-significant result supports the RE model's efficiency.

Eq. (4) was analyzed using both RE, which captures variation among observed time-variant and time-invariant covariates of farm households, and FE, controlling for unmeasured heterogeneity parameters. Recent studies have applied these advanced econometric techniques involving FE and RE specifications to analyze FPD dietary diversity. The Hausman test statistic indicated a superior fit for the FE specification, which was subsequently employed for impact analysis. In cases of non-significance, the RE specification was interpreted. This analytical approach represents a novel contribution, particularly in the Pakistani context, where smallholder farms are the predominant type.

2.4. Impact of FPD pathways on dietary diversity (nutrition)

Following Ecker (2018), Ceballos *et al.* (2020) and Singh *et al.* (2020), eq. (5) was developed to model the impact pathways of FPD on $HDDS_{it}$ through modification of the original equation. Eq. (4) was adjusted in two ways: first, by controlling for the market food security pathway (MFS_{it}) and farm food security pathway (FFS_{it}); second, by incorporating additional covariates, including household, farm, and contextual attributes (X_{it}).

$$HDDS_{it}=\alpha_0+\alpha_1 FPD_{it}+\alpha_2 FFS_{it}+\alpha_3 MFS_{it}+\alpha_4 X_{it}+\alpha_5 T_t+\varepsilon_{it2} \quad (5)$$

In the given context, α_0 represents a constant term, α_1 denotes the effect of FPD on HDDS while controlling for other variables, α_2 signifies the influence of self-sustained food security on HDDS, α_3 represents the impact of market-based food security on HDDS, and α_4 represents the coefficients for household characteristics, X_{it}, which affect HDDS. The parameter α_5 represents time-fixed effects, the variable T serves as a year identifier, and ε_{it2} denotes the error term. Eq. (5) was estimated using both random and fixed effects, consistent with the methodology employed in previous studies (Islam 2020; Nandi *et al.* 2021).

3. Results

3.1. Descriptive results

According to Table 1, the household average consumption of food groups was 8.4. The mean value demonstrated a range of 11, indicating relatively limited dispersion from the central tendency. Households cultivated and raised an average

of eleven different species of crops and livestock on their agricultural farms. Regarding food security, approximately 24% of households demonstrated food security based on data from the three districts. Quantitative analysis revealed that daily per capita consumption through market transactions was approximately double the consumption derived from individual farm production.

The explanatory variable's mean values appear in the middle of Table 1. The sample primarily comprised rural areas (87%) and was predominantly headed by males (85%). The proportion of male-headed households showed a consistent decline across districts. Mobile phone usage was prevalent, with 67% of participants reporting device usage, showing an upward trend across districts. Households averaged seven members, with size consistently increasing across districts. The average land ownership was 5 acres, showing a consistent decline across districts. Household heads possessed modest educational backgrounds, averaging six years of schooling at the middle level.

Additionally, household heads averaged 46 years of age. The average distance between households and the nearest market was 12 km, indicating some households' remote locations. Approximately 47% of households experienced adverse events, including droughts, floods, severe illnesses, and deaths. However, the frequency of these shocks demonstrated a gradual decline across districts.

3.2. Empirical results

FPD directly impacts household food and nutrition security Table 2 presents regression model results examining the relationship between FPD and household food and nutrition security and HDDS. Logistic regression models were employed to analyze factors influencing food security, as demonstrated in models (1) and (2). The Hausman test statistic produced a positive result, directing interpretation toward these two models.

The probability of household food security decreased with increased FPD. However, the direct negative effects were not significant, which contradicted the initial hypothesis. It is noteworthy that the food security dummy variable exhibited bias toward food insecurity, as only approximately 24% of the sample demonstrated food security. The analysis revealed a statistically significant relationship between FPD and food security, measured by daily household food consumption per capita in PKR. The Hausman test produced a statistically significant result, leading to the interpretation of the fixed effects model (4). The findings demonstrated a positive association between increased FPD and improved HDDS, which emerged as a significant outcome. The introduction of a single species of crops or livestock into household agricultural practices correlated with an approximate 0.04-unit increase in the consumption of different food groups, suggesting a 0.5% increase relative to the sample mean of 7.6 food groups. These results indicate a positive relationship between policies aimed at increasing food production and dietary diversity in Pakistan.

Nutritional impacts of the diversification of agricultural production among households To analyze impact pathways, this study employed a systematic approach that comprehensively evaluated these pathways and related household characteristics. The results of this analysis are presented in Table 3. The interpretation focused on the FE models. The results from the second model, which examined

Table 1 Explanation of the independent variables and dependent variables

Variable[1)]	District Layyah (mean & Std. Dev)	District Bhakkar (mean & Std. Dev)	District Khushab (mean & Std. Dev)	Pooled sample
Household dietary diversity score (HHDS)	8.52 (2.43)	8.44 (2.47)	8.55 (2.34)	8.41 (2.36)
HHs with food security (percentage)	22.88 (42.31)	26.22 (42.76)	22.45 (41.73)	23.46 (42.61)
Poverty line based on utility-weighted CPI (PKR)	1,445.23 (182.21)	1,521.01 (187.48)	1,681.61 (183.40)	1,549.28 (184.36)
Farm production diversity, FPD (biodiversity index)	12.30 (5.66)	11.31 (5.01)	12.46 (4.64)	12.34 (5.36)
Explanatory variables				
Nearest market distance (km)	11.41 (4.34)	13.56 (5.24)	13.33 (5.11)	12.77 (4.90)
The location of HH was rural (percentage)	27.76 (45.65)	24.52 (43.57)	22.39 (41.25)	24.89 (43.49)
Male gender of HH head (percentage)	89.74 (65.86)	82.67 (58.11)	83.47 (58.45)	85.29 (60.81)
Household size (persons)	7.43 (3.45)	8.23 (3.87)	6. 37 (3.46)	7.34 (3.59)
HH family structure (1. Single; 2. Joint)	1.05 (0.17)	1.04 (0.17)	1.02 (0.17)	1.03 (0.17)
Education of HH head (years)	6.43 (5.18)	6.35 (5.03)	6.11 (4.98)	6.30 (5.06)
HH head used mobile phones (percentage)	54.46 (51.24)	58.58 (51.68)	64.75 (50.63)	59.26 (51.18)
Age of the HH head (years)	46.64 (16.23)	47.64 (16.74)	46.12 (16.11)	46.80 (16.36)
HH experienced shocks (percentage)	61.18 (49.67)	45.12 (50.46)	36.58 (48.82)	47.62 (49.65)
Land size (acres)	5.63 (6.56)	5.36 (5.85)	4.83 (5.01)	5.27 (5.81)
HH farming experience (years)	12.23 (5.42)	10.54 (5.11)	10.01 (4.79)	10.93 (5.11)
Pathways analysis variables				
Household food consumption (PKR) per capita daily	2,136.21 (1,834.12)	2,311.23 (1,925.24)	2,445.56 (2,214.21)	2,297.66 (1,991.19)
Household food consumption (PKR) per capita daily (*via* markets) (a proxy for MFS)	1,324.47 (1,745.34)	1,421.23 (1,769.12)	1,626.47 (1,849.21)	1,457.39 (1,787.89)
Household food consumption (PKR) per capita daily *via* farm production (a proxy for FFS)	621.45 (437.81)	589.19 (412.39)	679.74 (493.48)	630.12 (447.89)

[1)] HH, household; CPI, consumer price index; PKR, Pakistani Rupees; MFS, market food security pathway; FFS, farm food security pathway.
Sources: author's calculation from HH data.

Table 2 Food security associated with farm production diversity (FPD)

Variables	Food security as a dummy[1)]		HHDS (12 food groups)[1)]	
	RE (1)	FE(2)	RE (3)	FE (4)
FPD (biodiversity index)	0.025*** (0.008)	–0.012 (0.014)	0.039*** (0.007)	0.044*** (0.008)
District Layyah	0.328*** (0.036)	0.301*** (0.063)	–0.124*** (0.027)	–0.323*** (0.061)
District Bhakkar	0.038*** (0.063)	–0.012 (0.066)	0.047 (0.076)	0.067 (0.028)
District Khushab	0.041** (0.088)	0.121* (0.073)	0.025*** (0.089)	0.048*** (0.023)
Constant	–2.001*** (0.071)		6.112*** (0.054)	6.134*** (0.067)
Wald χ^2 value	65.45***		104.65***	
F-value		44.69***		26.45***
Hausman test value		29.14***		9.73**
N		450		

[1)] RE is random, and FE is fixed effects.
Standard errors in parentheses, ***, $P<0.01$; **, $P<0.05$; *, $P<0.1$.

the combined daily per capita food consumption/expenditure in PKR, demonstrated a positive correlation between FPD and the HDDS. Each additional species cultivated on the agricultural farms corresponded to an increase of 0.039 food groups in the overall dietary diversity. The coefficient of 0.039 in the present analysis represents a decrease from the coefficient of 0.044 in Table 2. Upon examining consumption through distinct pathways, specifically markets and household foods obtained from individual farms, the FPD coefficient maintained a consistent value of 0.039. These pathways significantly enhance food security through the promotion of dietary diversity. However, the two pathways demonstrated varying levels of impact on the HDDS.

Model (4) demonstrates a significant positive correlation between enhanced household food security, achieved through both market access and agricultural production, and increased dietary diversity within households. The findings indicate that a 1,000 Pakistani Rupee (PKR) increase in food security expenditure through MFS correlates with a 0.5 increase in household consumption of food groups, representing a 5.3 percent increase. Implementation of the farm production pathway with equivalent incremental expenditure resulted in a 0.6 increase in food consumption groups, corresponding to an 8 percent rise.

Across the six specifications, the HDDS coefficients showed decreased magnitude, while coefficients for daily market food consumption and own farm food consumption remained stable. These results demonstrate the resilience of both MFS and FFS pathways in promoting food security to achieve HDDS. However, the declining significance of FPD with HDDS suggests alternative mechanisms through which FPD influences HDDS. Mobile phone usage, educational attainment, and household head age emerged as crucial factors in knowledge acquisition and dissemination. Model (6) explained approximately 27 percent of dietary diversity variance.

Model (6) revealed additional variables affecting HDDS beyond FPD. Mobile phone usage correlated with a 0.32 increase in food group consumption, representing a 5.5 percentage point increase. The household head's age showed a positive correlation with HDDS, with each additional year correlating to a 0.01 increase in consumed food groups, equivalent to 0.13 percentage points. Educational levels demonstrated a positive correlation with HDDS, where each additional year of formal education correlated with a 0.05 increase in consumed food groups, representing 0.75 percentage points.

Distance from the nearest market showed a significant positive correlation with HDDS improvements. The analysis indicates that a one-kilometer increase correlates with a 0.01 increase in consumed food groups, representing 0.11 percentage points. Households experiencing specified shocks showed a 0.07 increase in food group consumption, equivalent to 1.1 percentage points. Household size increases correlated significantly with HDDS increases, with each additional member corresponding to a 0.29 increase in consumed food groups, representing 3.8 percentage points.

Model (6) further revealed gender's significant impact on HDDS. Male household headship correlated with lower HDDS, showing a 0.4 decrease in consumed food groups, equivalent to a 6.6 percentage point reduction. The specified districts demonstrated adverse effects on HDDS. Notably, wealth indicators, particularly land ownership, showed substantial positive effects on HDDS, with a one-acre increase correlating to a 0.002 increase in consumed food groups, representing a 0.03 percent increase.

4. Discussion

4.1. Discussion of the descriptive results

Previous studies reported average HHDS values for specific regions in Pakistan of 8.7 and 7.5, respectively (Ansari 2010). At the national level, De Jager *et al.* (2018) calculated Kenya's HDDS at 11.4 food groups, while Ethiopia's HDDS was 5.4 food groups. Our results demonstrate consistency with existing literature. Although our HDDS findings in Pakistan are comparable to studies from African countries, important structural differences exist in food systems, income levels, and market dynamics across regions. Pakistan's agricultural production relies predominantly on irrigated farming, with staple crops like wheat, rice, and pulses forming the foundation of household diets (Hashmi *et al.* 2021). In contrast, many African nations depend on rain-fed agriculture, which exhibits greater vulnerability to climate fluctuations, resulting in variable food availability (Ecker 2018). Moreover, household income disparities significantly influence dietary diversity. While low-income households in some African contexts often depend on food aid or informal

Table 3 Food security impact pathways of farm production diversity (FPD) on households

Explanatory variables[1)]	Household dietary diversity score (HHDS of 12 food groups)[2)]					
	RE (1)	FE (2)	RE (3)	FE (4)	RE (5)	FE (6)
FPD (biodiversity index)	0.048*** (0.006)	0.027*** (0.007)	0.062*** (0.006)	0.034*** (0.06)	0.022*** (0.007)	0.030*** (0.005)
Food consumption per capita daily (PKR)	0.0007*** (1.1×10^{-4})	0.0007*** (1.1×10^{-4})				
Food consumption per capita daily *via* markets (PKR)			0.0005*** (1.2×10^{-5})	0.0005*** (1.5×10^{-5})	0.0005*** (1.2×10^{-5})	0.0005*** (1.6×10^{-5})
Food consumption per capita daily *via* own production (PKR)			0.0006*** (2.5×10^{-5})	0.0007*** (2.4×10^{-5})	0.0007*** (2.6×10^{-5})	0.0007*** (3.2×10^{-5})
Use of mobile phone by household head (yes=1)					0.632*** (0.042)	0.324*** (0.056)
Market distance (km)					0.006** (0.003)	0.011** (0.004)
Size of the household					0.330*** (0.009)	0.271*** (0.031)
The family structure of the HH (1=single, 2=joint)					0.133** (0.053)	0.089*** (0.011)
HH head as a male gender (male=1)					–0.231*** (0.054)	–0.405*** (0.089)
HH head age (years)					0.002 (0.003)	0.012*** (0.003)
HH head education (years)					0.075*** (0.0070)	0.050*** (0.007)
Experienced shocks of the HH (yes=1)					0.113*** (0.021)	0.066* (0.048)
Size of the land (acres)					0.001 (0.001)	0.003* (0.002)
Farming experience of HH head (years)					0.024** (0.056)	0.089* (0.080)
District Layyah	–0.060*** (0.0231)	–0.327*** (0.0328)	–0.140*** (0.0245)	–0.337*** (0.0356)	–0.281*** (0.032)	–0.352*** (0.036)
District Bhakkar	–0.125*** (0.0321)	–0.044*** (0.0345)	–0.121*** (0.0345)	–0.132*** (0.0360)	–0.365*** (0.036)	–0.452*** (0.0430
District Khushab	–0.051*** (0.0121)	–0.0211*** (0.0125)	–0.034*** (0.0321)	–0.135*** (0.0311)	–0.151*** (0.044)	–0.211*** (0.051)
Constant	6.558*** (0.0454)	5.005*** (0.0542)	6.730*** (0.0565)	5.065*** (0.0661)	2.781*** (0.030)	2.312*** (0.133)
Wald χ^2 value	2,121.61***		1,345.64***		3,125.35***	
F-value		247.03***		142.12***		121.51***
Hausman test value		35.12***		49.35***		133.40***
R^2	0.209	0.302	0.140	0.165	0.415	0.272
N				450		

[1)] HH is known household, PKR is the abbreviation of Pakistani Rupees.
[2)] RE, random effects; FE, fixed effects.
Standard errors in parentheses: ***, $P<0.01$; **, $P<0.05$; *, $P<0.1$.

markets, Pakistan's food accessibility is shaped by market integration and government support programs (Ahmed *et al.* 2017). Cultural preferences also influence dietary patterns, with higher meat and dairy consumption in South Asia compared to predominantly cereal- and tuber-based diets in parts of Africa. These distinctions necessitate careful consideration when comparing HDDS across regions. A more nuanced approach must account for regional variations in agricultural systems, economic structures, and food access mechanisms. Future research would benefit from implementing standardized cross-country frameworks to better evaluate dietary diversity determinants across different socio-economic contexts. In Pakistan, the FPD metric exceeded the HDDS metric. Our analysis reveals that a one-unit increase in HPD corresponds to a 0.5% increase in HDDS, demonstrating the importance of farm diversification for household nutrition. This finding aligns with previous South Asian research, though magnitudes vary. Sibhatu and Qaim (2018) documented a 0.3% increase in HDDS per unit increase in production diversity in Ethiopia. Similarly, Ecker (2018) observed a 0.6% increase in HDDS among Ghanaian smallholder farmers, noting market integration's modifying effect. Studies within Pakistan have produced varied results. Ahmed *et al.* (2017) identified market access as more influential than production diversity for dietary outcomes, while Hashmi *et al.* (2021) emphasized own-farm production's greater impact in remote rural areas with limited market access. Our findings indicate that both own-farm production and market-based consumption pathways contribute to dietary diversity, with the farm pathway showing greater influence. These comparisons underscore the importance of considering local economic conditions, market infrastructure, and household characteristics when analyzing HPD's impact on dietary diversity. Further research should examine context-specific determinants, including

regional variations in dietary habits and food availability.

This indicates that Pakistan demonstrated higher crop and livestock species production, while households consumed a relatively lower food variety. This pattern can be attributed to substantial reliance on essential food items in Pakistan, primarily cereals, roots, and tubers. The significant variation in the (FPD) range may also reflect considerable differences in food species diversity within Pakistan (Ansari 2010). However, it is crucial to note that own farm production valuation uses farm prices, which are typically lower than market prices. Therefore, market-based consumption should not be determined from the data, as it holds greater significance than independent farm production.

Our findings indicate that FPD correlates positively with HDDS; however, this relationship does not necessarily indicate reduced staple food dependence. The FPD index employed here measures crop species diversity but does not explicitly differentiate between staple foods (e.g., wheat, rice) and nutrient-dense foods (e.g., fruits, vegetables, dairy). In Pakistan, staple foods like wheat and rice comprise a substantial portion of household diets, often providing more than 50% of total caloric intake (Hashmi *et al.* 2021). Even households with high FPD maintain dominant staple-derived energy proportions, suggesting farm diversification supplements rather than replaces staple food consumption. This corresponds with previous South Asian research, which indicates smallholder farmers prioritize staple crops for food security, while diversification primarily enhances micronutrient intake rather than reducing staple dependence (Ecker 2018; Sibhatu and Qaim 2018). Future research should consider an adjusted FPD score distinguishing between staple and non-staple food categories to better capture food reliance patterns. Furthermore, combining dietary recall data with farm production data would provide more comprehensive insights into how diversification affects both macronutrient and micronutrient intake in Pakistani households. The wide range of consumption values also indicates substantial variation in household consumption capacities (Phimmavong *et al.* 2019; Giller *et al.* 2021; Waarts *et al.* 2021).

The usage pattern of mobile phones in Pakistan demonstrated similarities to previous findings (Newton *et al.* 2021). The literature also documented a consistent growth in population size, potentially attributable to elevated fertility levels (De Jager *et al.* 2018; Rimmer *et al.* 2021). There is a possibility that land fragmentation is causing a reduction in land size (Ntihinyurwa *et al.* 2019). Several large-scale farmers were evident from the extensive range of land acres.

The official reports on annual precipitation between 2017 and 2018 indicate that either 2017 or 2018 showed the most minimal average rainfall (Iqbal and Athar 2018). The observed decline in the FPD, daily market consumption, consumption of own farm production, and HDDS variable can be attributed to the heavy reliance on rainfall for agricultural activities in the districts of Layyah, Bhakkar, and Khushab in Pakistan. The observed upward pattern of the food poverty line can be attributed to the associated rise in food prices (Cheteni *et al.* 2020; Waseem *et al.* 2023). The observed increase in the food security trend may be attributed to providing food aid or remittances, both of which have been identified as crucial sources of sustenance for improving household food security in Pakistan (Alam *et al.* 2020; Harris *et al.* 2020).

4.2. Discussion of the empirical results

The results presented in Table 3 demonstrate that farm production and markets function as consistent pathways for food security, illustrating the influence of farm diversity on household dietary diversity. The study's small coefficients reflect the relatively low value of the PKR, which served as the unit for per capita consumption measurement. Previous research has noted similar small-sized consumption coefficients in dietary diversity studies (Kihiu and Amuakwa-Mensah 2021; Hanley-Cook *et al.* 2023).

The consumption pathway for own-farm production demonstrated a stronger impact on HDDS compared to the market consumption pathway. Most households engaged in subsistence farming, producing food primarily for household consumption. Consequently, these households met their nutritional needs through direct farm consumption. While enhanced urbanization and improved market infrastructure would facilitate food security through market mechanisms, Pakistan's predominantly rural population (70%, as shown in Table 1) and underdeveloped market infrastructure made achieving dietary diversity more feasible through own farm production. Therefore, in Pakistan's context, improving dietary diversity showed stronger correlation with domestic farm production rather than market dependence. Previous studies in Pakistan have similarly concluded that domestically produced food constituted the majority of individual consumption (Singh *et al.* 2019; Devereux *et al.* 2020).

The study revealed significant associations between FPD and dietary diversity, particularly influenced by the household head's age, education level, and mobile phone usage. Mobile phone ownership among household heads influences dietary diversity through multiple channels, including income, access to information, and knowledge acquisition. Mobile technology has enhanced access to remittance services, enabling consistent consumption level maintenance. Additionally, mobile phones facilitate communication between individuals and their business or family networks, contributing to income stabilization and consumption management. Mobile applications have enhanced access to nutritional information and food composition data. These findings align with previous research demonstrating positive correlations between mobile phone (MP) usage and HDDS. As household heads age, they accumulate knowledge and expertise through social network interactions and experiences. This educational foundation provides essential nutritional knowledge, enabling dietary diversity enhancement (Appendix A). The results correspond with previous studies conducted in Malawi, Bangladesh, and Uganda (Datta and Njuguna 2009; Motbainor *et al.* 2016; Singh *et al.* 2020; Habtemariam *et al.* 2021). Education enhances HDDS through multiple mechanisms: increasing nutrition awareness, improving decision-making capacity, and enabling income generation and purchasing power. Better-educated household heads typically engage in higher-income employment sectors, including formal wage labor, skilled professions, and agribusiness, providing stable financial

resources for food consumption diversification (Ahmed *et al.* 2017; Wen *et al.* 2022). Educated households demonstrate greater market efficiency, leveraging price variations, improved food storage, and access to nutrient-rich processed foods. Research in Pakistan and South Asia indicates higher income elasticity of demand for non-staple foods among educated households, reflecting increased allocation to fruits, vegetables, and protein-rich foods (Ecker 2018; Sibhatu and Qaim 2018). The positive association between education and HDDS suggests both knowledge and economic capacity contribute to improved nutrition. Further research should examine the mediating role of income in the education-HDDS pathway to determine whether education's impact on dietary diversity primarily stems from income effects or behavioral changes in food choices (Leroy *et al.* 2015; Drammeh *et al.* 2019; Siddiqui *et al.* 2020; Singh *et al.* 2021).

The analysis revealed a positive correlation between remoteness and enhanced dietary diversity. Remote locations were associated with greater agricultural land availability, particularly among households dependent on subsistence farming within the sample. Previous research has established a positive correlation between market distance and Pakistan's HDDS (Kabir *et al.* 2022). The study's unexpected finding of a positive correlation between remoteness (measured as distance to the nearest market) and HDDS contrasts with previous research, which typically suggests that improved market access enhances dietary diversity through increased food availability and affordability (Ahmed *et al.* 2017; Ecker 2018). This finding may be attributed to remote households possessing larger landholdings, enabling greater on-farm food production and self-sufficiency. Households in isolated areas may rely more heavily on subsistence farming, resulting in higher on-farm consumption of diverse food products. Furthermore, reduced market dependency might decrease reliance on processed or store-bought staple foods, promoting dietary variety. A robustness check using interaction terms between remoteness and farm size (Appendix B) indicates that remoteness's positive effect on HDDS strengthens for households with larger farms, supporting the self-sufficiency hypothesis. However, the effect becomes negligible for smaller farms. These findings emphasize the context-dependent nature of market access and food security, suggesting that dietary diversity improvement policies should consider land availability, subsistence farming, and infrastructure development as crucial factors. Additional research could explore regional variations in the effects of remoteness, including transport accessibility and seasonal market fluctuations.

The occurrence of shocks was correlated with an increase in dietary diversity. During household-specific shocks, such as prolonged illnesses or the death of household heads, households relied on remittances from family members. During community or regional disturbances, such as floods or droughts, households typically received assistance from national, regional, or international sources. This assistance generally provided adequate quantities and high-quality food items, including nutritional supplements. This explains the positive correlation between shocks and dietary diversity. However, employing a panel design across three districts in Pakistan could enhance the reliability of results in capturing the annual situation. This approach could also reveal insights into the long-term effects of shocks on sampled households. The reliability of the remittance pathway during persistent shocks may exceed both national and international aid pathways. Research has demonstrated that remittances correlate with improved household food consumption (Cantrell *et al.* 2008; Datta and Njuguna 2009), while food aid remains an essential food source in Pakistan (Siddiqui *et al.* 2020).

The provision of labor for food production, through agricultural activities or wage employment, resulted in larger household sizes that increased food quantity and dietary variety. However, certain individuals, such as elderly people and children, may lack the capacity for physical labor while still requiring sustenance. This situation creates strain on food resources (Chai *et al.* 2021). The average age of our sample, as shown in Table 1, was 46 years, corresponding to the typical workforce entry age. Our findings align with previous studies identifying a positive correlation between household size and HDDS (Buheji *et al.* 2020; Liyanaarachchi *et al.* 2021). However, several studies have found an inverse relationship (Tammaru *et al.* 2020).

Traditionally, women have been responsible for overseeing dietary practices within households. However, the authority over income and decisions regarding food production and purchases has resided with primary decision-makers, predominantly male household heads. The lack of income control among secondary decision-makers often negatively affected dietary diversity, despite their responsibility for nutrition-related decisions. Our study findings align with recent empirical evidence indicating a negative correlation between male headship and HDDS (Buisman and García-Gómez 2015; Barlow *et al*. 2020; Gordon *et al.* 2020). Female-headed households arise from various factors, including natural and social circumstances, such as the death of husbands or marital dissolution through divorce.

Sample households were primarily subsistence-based (Motbainor *et al.* 2016); increases in land allowed for greater agricultural productivity, enabling farmers to cultivate more diverse crops and livestock species. This led to improved dietary diversity. The results align with our initial hypotheses and previous research findings (Sarlio-Lähteenkorva and Lahelma 2001; Tarasuk *et al.* 2015). The observed negative temporal effects may relate to increasing climate change implications or progressive food price increases. This study did not extensively examine climate change and food price impacts.

4.3. Robustness analysis

Additional tests were conducted to verify the reliability and validity of our primary empirical findings. Specifically, we examined FPD effects on two key variables: (1) food security and dietary diversity and (2) FPD influences on food security as measured by the HDDS. We performed a RE-estimation of our primary findings using alternative methodologies. The study employed a Mundlak (MK) approach, a common pseudo-fixed effects estimator, to reexamine FPD's influence on food security and HDDS. Additionally, we utilized a three-stage least squares (3SLS) approach to reevaluate the pathways through which food security impacts HDDS. The Mundlak approach selection was based on using the fixed

effects estimator in our primary findings. However, within our sample, households experienced headship changes due to deaths or divorces, causing fluctuations in typically stable variables like gender. Consequently, these variables remained included in the fixed effects estimator analysis.

Based on the Hausman test results supporting the FE estimator's suitability, we implemented a pseudo-fixed effects (MK) estimator for robustness analysis. The MK estimator incorporated mean values of covariates as additional explanatory variables to address potential biases from time-invariant unobserved heterogeneity (Kansiime *et al.* 2021). The FPD coefficients demonstrated consistency across both methods, yielding values of 0.033 in Table 3 and 0.036 in Appendix A. The system analysis employed a three-stage least squares approach, with results presented in Appendix C According to Appendix B, the findings reveal a statistically significant positive correlation between food markets, own-farm production, and HDDS, aligning with Table 3 results. Notably, the own-farm output pathway exhibited a stronger correlation with the HDDS, consistent with our findings in Table 3. Furthermore, the coefficients interpreted through the finite element method proved more conservative.

5. Conclusion

This study demonstrates a significant positive relationship between FPD and household food security and dietary diversity. The findings indicate FPD's crucial role in enhancing overall food security. The implementation of policies promoting food production and distribution (FPD) in Pakistan has shown meaningful improvements in food security. Specifically, the research reveals a positive and significant correlation between FPD and household dietary diversity in Pakistan. This impact manifests through farm production and market consumption pathways directly connected to food security. Households have demonstrated increased awareness of food production and consumption effects on dietary diversity through the farm production consumption pathway. The study identified additional pathways through which FPD influences household dietary diversity. Mobile phone technology has enhanced the information and knowledge pathway, complementing improvements in adult age and education. Gender-related factors significantly influence household dietary diversity levels, with male-led households showing lower dietary diversity compared to female-led households. This gender disparity stems from persistent male control over household incomes, whereas females typically maintain primary influence over food choices and feeding patterns.

The consistency of results across various analytical methodologies strengthens our confidence in the established impact associations. However, the study acknowledges the importance of incorporating more precise nutrition indicators, such as micronutrients, to better assess dietary quality improvements.

To represent the conclusion visually, we have replicated Fig. 1 and presented it as Fig. 3. This figure illustrates the comparison between our research findings and initial expectations, as depicted in Fig. 1. Our study uses green ink to indicate positive findings regarding household dietary diversity, while orange ink denotes negative findings. However, we maintain using black ink to represent prior expectations, thereby effectively illustrating both areas of agreement and divergence.

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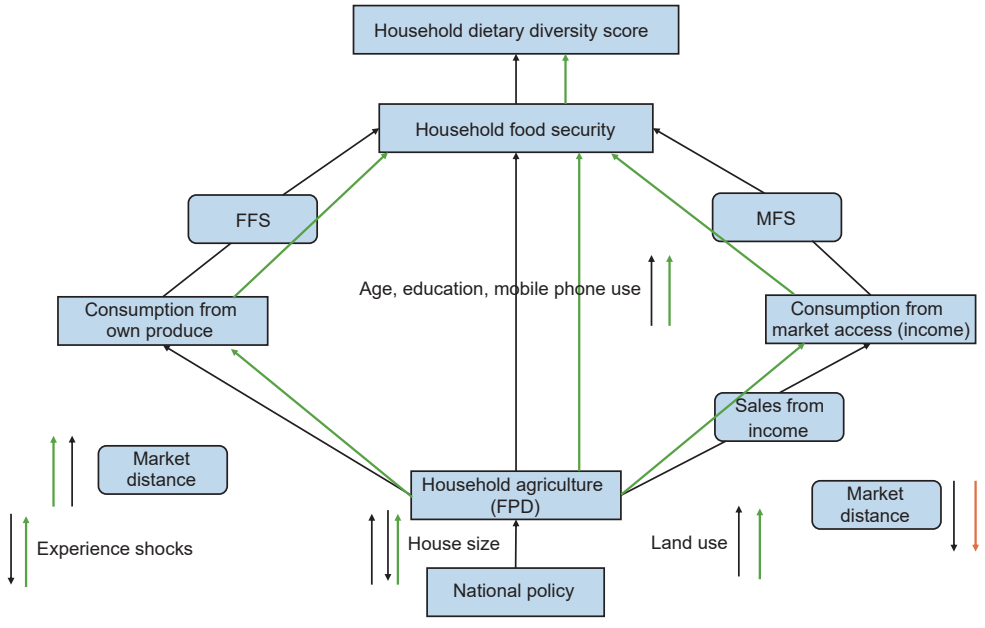


Fig. 3 Conceptual framework of household dietary diversity and farm production diversity (FPD). FFS refers to food security achieved by consuming produce from farms; MFS refers to food security *via* consumption from the market (income, on and off-farm).

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Declaration of competing interest

The authors declare that they have no conflict of interest.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT-5 to improve the readability of the article. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published artice.

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References

Ahmed U I, Ying L, Bashir M K, Abid M, Zulfiqar F. 2017. Status and determinants of small farming households' food security and role of market access in enhancing food security in rural Pakistan. *PLoS ONE*, **12**, e0185466.

Alam A, Chowdhury M, Dibley M J, Raynes-Greenow C. 2020. How can we improve the consumption of a nutritionally balanced maternal diet in rural Bangladesh? The key elements of the "balanced plate intervention. *International Journal of Environmental Research and Public Health*, **17**, 6289.

Aleksandrowicz L, Rosemary G, Joy E J M, Smith P, Haines A. 2016. The impacts of dietary change on greenhouse gas emissions, land use, water use, and health: A systematic review. *PLoS ONE*, **11**, e0165797.

Ansari N B. 2010. The role of household food insecurity, socioeconomic status, and dietary diversity as underlying determinants of undernutrition in Pakistani households. PhD thesis, University of California, Davis.

Asim M, Hussain M, Nadeem N, Ali A, Imran M A, Hussain M, Rashid M. 2015. Does credit play a role in increasing the yields of wheat and cotton: A case study of district Sahiwal. *Mediterranean Journal of Social Sciences*, **6**, 482.

Barlow P, Rachel L, Valerie T, Aaron R. 2020. Liberal trade policy and food insecurity across the income distribution: An observational analysis in 132 countries, 2014–17. *The Lancet Global Health*, **8**, 1090–1097.

Buheji M, da Costa Cunha K, Beka C, Mavrić B, do Carmo de Souza Y L, da Costa Silva S S, Hanafi M, Yein T C. 2020. The extent of COVID-19 pandemic socio-economic impact on global poverty. A global integrative multidisciplinary review. *American Journal of Economics*, **10**, 213–224.

Buisman L R, Pilar G G. 2015. Inequity in inpatient healthcare utilisation 10 years after apartheid. *Development Southern Africa*, **32**, 193–208.

Cantrell R A, Moses S, Karen M, Sibi L M, Sierra W, Chi B H, Bushimbwa T C, Levy J, Stringer E M, Mulenga L, Stringer J S A. 2008. A pilot study of food supplementation to improve adherence to antiretroviral therapy among food-insecure adults in Lusaka, Zambia. *Journal of Acquired Immune Deficiency Syndromes*, **49**, 190–195.

Ceballos F, Kannan S, Kramer B. 2020. Impacts of a national lockdown on smallholder farmers' income and food security: Empirical evidence from two states in India. *World Development*, **136**, 105069.

Chai J, Zhang X K, Lu Q Y, Zhang X J, Wang Y B. 2021. Research on imbalance between supply and demand in China's natural gas market under the double-track price system. *Energy Policy*, **155**, 112380.

Chegere M J, Jesper S. 2020. Agricultural production diversity, dietary diversity and nutritional status: Panel data evidence from Tanzania. *World Development*, **129**, 104856.

Cheteni P, Yohane K, Gisele M. 2020. Exploring food security and household dietary diversity in the Eastern Cape Province, South Africa. *Sustainability*, **12**, 1851.

Datta D, James N. 2009. Food security in HIV/AIDS response: Insights from Homa Bay, Kenya. *SAHARA-J: Journal of Social Aspects of HIV/AIDS*, **6**, 170–178.

Devereux S, Christophe B, John H. 2020. Conceptualizing COVID-19's impacts on household food security. *Food Security*, **12**, 769–772.

Drammeh W, Noor A H, Rohana A J. 2019. Determinants of household food insecurity and its association with child malnutrition in Sub-Saharan Africa: A review of the literature. *Current Research in Nutrition and Food Science*, **7**, 610–623.

Ecker O. 2018. Agricultural transformation and food and nutrition security in Ghana: Does farm production diversity (still) matter for household dietary diversity? *Food Policy*, **79**, 271–282.

FAO. 2010. Country Fact Sheet on Food and Agriculture Policy Trends, Pakistan. [2023-11-19]. www.fao.org/fileadmin/user_upload/emergencies/docs/pakistanfloods1yrbrochure.pdf.

Gebreyesus S H, Lunde T, Mariam D H, Woldehanna T, Lindtjørn B. 2015. Is the adapted Household Food Insecurity Access Scale (HFIAS) developed internationally to measure food insecurity valid in urban and rural households of Ethiopia? *BMC Nutrition*, **1**, 2.

Giller K E, Delaune T, Silva J V, Descheemaeker K, van de Ven G, Schut A G T, van Wijk M, Hammond J, Hochman Z, Taulya G, Chikowo R, Narayanan S, Kishore A, Bresciani F, Teixeira H M, Andersson J A, van Ittersum M K. 2021. The future of farming: Who will produce our food? *Food Security*, **13**, 1073–1099.

Gordon T, Frederik B, Josue M. 2020. Socio-economic inequalities in the multiple dimensions of access to healthcare: The case of South Africa. *BMC Public Health*, **20**, 1–13.

Habtemariam L T, Christoph G, Harry H, Stefan S. 2021. Farm production diversity and household dietary diversity: Panel data evidence from rural households in Tanzania. *Frontiers in Sustainable Food Systems*, **5**, 151.

Hanley-Cook G T, Daly A J, Remans R, Jones A D, Murray K A, Huybrechts I, Lachat C. 2023. Food biodiversity: Quantifying the unquantifiable in human diets. *Critical Reviews in Food Science and Nutrition*, **63**, 7837–7851.

Harris J, Depenbusch L, Pal A A, Nair R M, Ramasamy S. 2020. Food system disruption: Initial livelihood and dietary effects of COVID-19 on vegetable producers in India. *Food Security*, **12**, 841–851.

Hashmi S, Safdar N F, Zaheer S, Shafique K. 2021. Association between dietary diversity and food insecurity in urban households: A cross-sectional survey of various ethnic populations of Karachi, Pakistan. *Risk Management and Healthcare Policy*, **14**, 3025–3035.

Herforth A, Venkat A, Bai Y, Costlow L, Holleman C, Masters W A. 2022. Methodsand options to monitor the cost and affordability of a healthy diet globally. Background paper for the state of food security and nutrition in the world 2022. FAO Agricultural Development Economics Working Paper 22–03.

Iqbal M F, Athar H. 2018. Variability, trends, and teleconnections of observed precipitation over Pakistan. *Theoretical and Applied Climatology*, **134**, 613–632.

Islam M S. 2020. Do education and health influence economic growth and food security evidence from Bangladesh. *International Journal of Happiness and Development*, **6**, 59.

De Jager I, Giller K. E, Brouwer I D. 2018. Food and nutrient gaps in rural Northern Ghana: Does production of smallholder farming households support adoption of food-based dietary guidelines? *PLoS ONE*, **13**, e0204014.

Jamil I, Jun W, Mughal B, Raza M H, Imran M A, Waheed A. 2021. Does the adaptation of climate-smart agricultural practices increase farmers' resilience to climate change? *Environmental Science and Pollution Research*, **28**, 27238–27249.

Jamil I, Jun W, Mughal B, Waheed J, Hussain H, Waseem M. 2021. Agricultural innovation: A comparative analysis of economic

benefits gained by farmers under climate resilient and conventional agricultural practices. *Land Use Policy*, **108**, 105581.
Jerzak M A, Śmiglak-Krajewska M. 2020. Globalization of the market for vegetable protein feed and its impact on sustainable agricultural development and food security in EU countries illustrated by the example of Poland. *Sustainability*, **12**, 888.
Jones A D, Shrinivas A, Bezner-Kerr R. 2014. Farm production diversity is associated with greater household dietary diversity in Malawi: Findings from nationally representative data. *Food Policy*, **46**, 1–12.
Kabir M R, Halima O, Rahman N, Ghosh S, Islam M S, Rahman H. 2022. Linking farm production diversity to household dietary diversity controlling market access and agricultural technology usage: Evidence from Noakhali district, Bangladesh. *Heliyon*, **8**, e08755.
Kansiime M K, Tambo J A, Mugambi I, Bundi M, Kara A, Owuor C. 2021. COVID-19 implications on household income and food security in Kenya and Uganda: Findings from a rapid assessment. *World Development*, **137**, 105199.
Kennedy G, Berardo A, Papavero C, Horjus P, Ballard T, Dop M, Brouwer I D. 2010. Proxy measures of household food consumption for food security assessment and surveillance: Comparison of the household dietary diversity and food consumption scores. *Public Health Nutrition*, **13**, 2010–2018.
Kihiu E N, Amuakwa-Mensah F. 2021. Agricultural market access and dietary diversity in Kenya: Gender considerations towards improved household nutritional outcomes. *Food Policy*, **100**, 102004.
Kundu S, Al Banna M H, Sayeed A, Sultana M S, Brazendale K, Harris J, Khan M S I. 2021. Determinants of household food security and dietary diversity during the COVID-19 pandemic in Bangladesh. *Public Health Nutrition*, **24**, 1079–1087.
Leroy J L, Ruel M, Frongillo E A, Harris J, Ballard T J. 2015. Measuring the food access dimension of food security: A critical review and mapping of indicators. *Food and Nutrition Bulletin*, **36**, 167–195.
Liyanaarachchi G, Deshpande S, Weaven S. 2021. Market-oriented corporate digital responsibility to manage data vulnerability in online banking. *International Journal of Bank Marketing*, **39**, 571–591.
McDonald C M, McLean J, Kroeun H, Talukder A, Green T J. 2014. Household food insecurity and dietary diversity as correlates of maternal and child undernutrition in rural Cambodia. *European Journal of Clinical Nutrition*, **69**, 242–246.
Motbainor A, Worku A, Kumie A. 2016. Level and determinants of food insecurity in East and West Gojjam zones of Amhara Region, Ethiopia: A community based comparative cross-sectional study. *BMC Public Health*, **16**, 503.
Muthini D, Nzuma J, Qaim M. 2020. Subsistence production, markets, and dietary diversity in the Kenyan small farm sector. *Food Policy*, **97**, 101956.
Nandi R, Nedumaran S, Ravula P. 2021. The interplay between food market access and farm household dietary diversity in low and middle-income countries: A systematic review of literature. *Global Food Security*, **28**, 100484.
Newton R, Zhang W, Xian Z, McAdam B, Little D C. 2021. Intensification, regulation and diversification: The changing face of inland aquaculture in China. *Ambio*, **50**, 1739–1756.
Ntihinyurwa P D, de Vries W T, Chigbu U E, Dukwiyimpuhwe P A. 2019. The positive impacts of farm land fragmentation in Rwanda. *Land Use Policy*, **81**, 565–581.
Pawlak K, Kołodziejczak M. 2020. The role of agriculture in ensuring food security in developing countries: Considerations in the context of the problem of sustainable food production. *Sustainability*, **12**, 5488.
Phimmavong S, Maraseni T N, Keenan R J, Cockfield G. 2019. Financial returns from collaborative investment models of Eucalyptus agroforestry plantations in Lao PDR. *Land Use Policy*, **87**, 104060.
Qaim M, Sibhatu K, Krishna V. 2016. Market access and farm household dietary diversity. *International Journal of Rural Development*, **50**, 12–14.
Rimmer M A, Larson S, Lapong I, Purnomo A H, Pong-Masak P R, Swanepoel L, Paul N A. 2021. Seaweed aquaculture in Indonesia contributes to social and economic aspects of livelihoods and community wellbeing. *Sustainability*, **13**, 10946.
Sarlio-Lähteenkorva S, Lahelma E. 2001. Food insecurity is associated with past and present economic disadvantage and body mass index. *The Journal of Nutrition*, **131**, 2880–2884.
Sekabira H, Nalunga S. 2020. Farm production diversity: Is it important for dietary diversity? Panel data evidence from Uganda. *Sustainability*, **12**, 1028.
Sibhatu K T, Qaim M. 2018. Farm production diversity and dietary quality: linkages and measurement issues. *Food Security*, **10**, 47–59.
Siddiqui F, Salam R A, Lassi Z S, Das J K. 2020. The intertwined relationship between malnutrition and poverty. *Frontiers in Public Health*, **8**, 453.
Singh D R, Sunuwar D R, Shah S K, Sah L K, Karki K, Sah R K. 2021. Food insecurity during COVID-19 pandemic: A genuine concern for people from disadvantaged community and low-income families in Province 2 of Nepal. *PLoS ONE*, **16**, e0254954.
Singh J K, Acharya D, Gautam S, Adhikari M, Park J H, Yoo S J, Lee K. 2019. Socio-demographic and diet-related factors associated with insufficient fruit and vegetable consumption among adolescent girls in rural communities of Southern Nepal. *International Journal of Environmental Research and Public Health*, **16**, 2145.
Singh S, Jones A D, DeFries R S, Jain M. 2020. The association between crop and income diversity and farmer intra-household dietary diversity in India. *Food Security*, **12**, 369–390.
Tammaru T, Marcin C S, Aunap R, van Ham M, Janssen H. 2020. Relationship between income inequality and residential segregation of socioeconomic groups. *Regional Studies*, **54**, 450–461.
Tarasuk V, Cheng J, De Oliveira C, Dachner N, Gundersen C, Kurdyak P. 2015. Association between household food insecurity and annual health care costs. *Canadian Medical Association Journal*, **187**, 429–436.
Usman M A, Callo-Concha D. 2021. Does market access improve dietary diversity and food security? Evidence from Southwestern Ethiopian smallholder coffee producers. *Agricultural and Food Economics*, **9**, 18.
Waarts Y R, Janssen V, Aryeetey R, Onduru D, Heriyanto D, Aprillya S T, Ingram V J. 2021. Multiple pathways towards achieving a living income for different types of smallholder tree-crop commodity farmers. *Food Security*, **13**, 1467–1496.
Waseem M, Li X Y, Jamil I, Saiful Islam A H M, Abbas Q, Raza M H, Eliw M. 2023. Do crop diversity and livestock production improve smallholder intra-household dietary diversity, nutrition and sustainable food production? Empirical evidence from Pakistan. *Frontiers in Sustainable Food Systems*, **7**, 1143774.
Wen J, Hussain H, Waheed J, Ali W, Jamil I. 2022. Pathway toward environmental sustainability: Mediating role of corporate social responsibility in green human resource management practices in small and medium enterprises. *International Journal of Manpower*, **43**, 701–718.
Wijerathna-Yapa A, Pathirana R. 2022. Sustainable agro-food systems for addressing climate change and food security. *Agriculture*, **12**, 1554.
Wudil A H, Usman M, Rosak-Szyrocka J, Pilař L, Boye M. 2022. Reversing years for global food security: A review of the food security situation in Sub-Saharan Africa (SSA). *International Journal of Environmental Research and Public Health*, **19**, 14836.
Zhang J, Zhao A, Ke Y, Hu S, Ma Y, Zhang Y, Liu K. 2020. Dietary behaviors in the post-lockdown period and its effects on dietary diversity: The second stage of a nutrition survey in a longitudinal Chinese study in the COVID-19 era. *Nutrients*, **12**, 3269.
Zhao A, Li Z, Ke Y, Huo S, Ma Y, Zhang Y, Ren Z. 2020. Dietary diversity among Chinese residents during the COVID-19 outbreak and its associated factors. *Nutrients*, **12**, 1699.

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