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EDITED BY

Umer Farrukh,
Government College Women University
Sialkot, Pakistan

REVIEWED BY

Hatice Türkten,
Ondokuz Mayıs University, Türkiye
Qamar Ali,
Virtual University of Pakistan, Pakistan

*CORRESPONDENCE

Muhammad Arshad
✉ muhammad.arshad@zalf.de

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Linking sustainable food systems and dietary diversity among agricultural communities: an ESG-based analysis

Sihan Chen¹, Abida Hafeez² and Muhammad Arshad^{3*}

¹Faculty of Social Science and Law, University of Bristol Business School, University of Bristol, Bristol, United Kingdom, ²Department of Economics, Division of Management and Administrative Sciences, University of Education, Lahore, Pakistan, ³Leibniz Centre for Agricultural Landscape Research (ZALF), Müncheberg, Germany

Background: Food and nutritional security are pivotal for sustainable development in developing countries. Dietary diversity is an essential aspect of food and nutritional security. Sustainable food systems play a significant role in achieving food and nutrition security. In this context, the Environmental, Social, and Governance (ESG) framework is a comprehensive approach to transitioning to sustainable food systems and climate resilience. However, scant empirical evidence exists on the link between particular ESG-compatible practices of farmers and their diet diversity in developing countries. ESG in agriculture drives sustainable food production by promoting environmental responsibility, social equity, and transparent governance.

Objectives: Therefore, the core objective of this study was to link ESG in agriculture to the diet diversity of farmers in Pakistan.

Methodology: Data collected from 435 farmers through multistage purposive and random sampling techniques were analyzed using binary probit regression and propensity score matching.

Results: The Simpson index showed an average diet diversity score of 0.74, and cereals were the main source of calorie provision to the agricultural households. Furthermore, farmers with large families consumed less diverse foods than those with small families. The findings also revealed that the ESG dimensions significantly affect the dietary diversity of agricultural households. In the environmental dimension, farmers adopting more sustainable farm practices were likely to have higher dietary diversity than those with less sustainable farm practices. In the social dimension, nutritional knowledge and women's empowerment were significantly associated with household dietary diversity. Governance is also positively related to the dietary diversity of agricultural households. The propensity score matching results revealed that the adoption of a greater number of sustainable practices at the farm level results in better dietary diversity than those farmers with the adoption of a lower number of sustainable farming practices.

Conclusion: Therefore, agricultural policies should incorporate ESG-aligned strategies to improve dietary diversity in farming communities in developing countries.

KEYWORDS

sustainable food systems, food and nutrition security, diet diversity, women empowerment, sustainable agriculture

Introduction

Food and nutritional security are central to sustainable development in developing economies. Food security has four dimensions (availability, access, utilization, and stability) (Gordillo and Jeronimo, 2013). However, the scope of food security has expanded beyond caloric sufficiency to include nutritional adequacy (Ritchie et al., 2018). Nutritional security focuses on the continuous availability of diverse, safe, and nutrient-rich foods that meet nutritional needs and promote active and healthy lifestyles. Persistent undernutrition and micronutrient deficiencies, particularly in women and children in developing countries, indicate precarious nutritional security despite improvements in agricultural productivity (Kiani et al., 2022). Structural problems such as poverty, gender inequality, and environmental degradation add to the problem of nutritional inadequacy among rural communities, especially smallholder farmers residing in developing nations (Woodhill et al., 2022).

Dietary diversity has become one of the main indicators of nutritional quality and healthy diets. It indicates the number of various food categories consumed by a person during a given time and is commonly considered a proxy for the sufficiency of micronutrients (Ma et al., 2023). Research has provided constant information indicating that a more diverse diet is linked to health benefits, a lower risk of undernourishment, and increased productivity. However, rural diets in developing countries contain high amounts of cereals and low amounts of fruits, vegetables, legumes, dairy, and animal-source foods (Elolu et al., 2023; Hassaan et al., 2024). The effect of this lower dietary diversity is the prevalence of micronutrient deficiencies, such as iron, zinc, and vitamin A deficiencies, in developing countries. In 2022, more than 720 million individuals worldwide were food insecure, most of whom lived in developing nations (FAO IFAD UNICEF WFP WHO, 2023). Moreover, even where people have enough food in terms of caloric needs, many people suffer from hidden hunger, showing a lack of essential vitamins and minerals due to a lack of dietary diversity in daily diets (Muthayya et al., 2013).

The situation is more serious in Pakistan. Although the country has good food production capabilities as an agricultural economy, it has persistently experienced high levels of food insecurity and malnutrition (Government of Pakistan, 2019). The report shows a stunting prevalence of more than 36.9%, wasting of 17.7%, and underweight of 40.2% among children below the age of five (UNICEF, 2019). Anemia among women of reproductive age is still at a very worrying rate (Ali, 2021). These statistics represent both insufficient food consumption and food quality. Nutritional insecurity is also increased due to economic inequalities, inflation, gender inequality, poor maternal health, and regional inequalities (Baxter et al., 2022). In addition, pandemics such as floods and droughts caused by climate change devastate food production and distribution outputs and exacerbate the situation in fragile groups (World Bank, 2021). Being both a source of food and nutritionally concerned households, smallholder farmers, who are a significant component of the rural poor, must cope with the so-called dual challenge (Giller et al., 2021). Therefore, the issue of food and nutritional insecurity in Pakistan needs to be addressed through an integrated response that includes building a resilient food system, inclusive access to it, and provision of nutritional adequacy and dietary diversity to various sectors of the population.

Sustainable food systems are necessary for global environmental sustainability and health. Sustainable food systems provide everyone with food in a manner that does not undermine the economic, social, and environmental dimensions of sustainability (FAO, 2018). Dietary diversity is at the center of a sustainable food system because sustainable agricultural activities do not only affect food availability and determine its variety and nutritional status. Crop diversification, agroecological farming, integrated crop-livestock production systems, and decreased reliance on man-made inputs conserve the environment and promote the growth of food resources (Fanzo et al., 2021). This production diversity increases the chances of household-level diverse diets that are directly connected to better micronutrient consumption and less malnutrition (Jones, 2017). Therefore, the shift to sustainable food systems is an important opportunity to benefit dietary diversity and, consequently, nutrition and health outcomes, especially at the household level of smallholder farms in developing countries.

In this context, the Environmental, Social, and Governance (ESG) framework is a comprehensive approach to transitioning toward sustainable food systems and climate resilience. Previously applied in investment and corporate governance, ESG principles are gradually being implemented in agriculture to view sustainability in farming. The environmental component consists of crop diversification, less chemical input, water conservation, and agroecological farming (Haq et al., 2021). The social aspect focuses on equity, gender inclusion, social community involvement, and knowledge exchange (Rasool et al., 2023). The concept of governance relates to open policies, institutional patronage, market access, and certification procedures that inform sustainable agricultural practices. In Pakistan, ESG-related agricultural activities, including regenerative farming and green energy use, are increasingly observed, although the trend has not yet been comprehensively reviewed from an ESG perspective.

Agriculture plays a central role in striving for economic stability by employing more than one-third of the Pakistani workforce and with a significant (22.9%) share in the gross domestic product of the country (GOP, 2025). The majority of the Pakistani population resides in rural areas, and the rural community is mainly dependent on agriculture for food security. Thus, the sustainable agriculture sector is pivotal for ensuring food security and sustainable economic growth. However, the agriculture sector is endangered by climate change, which has had catastrophic effects on this sector in recent times (Haq et al., 2021).

Therefore, there is a strong theoretical and empirical basis for linking ESG-aligned sustainable agricultural practices to improvements in dietary diversity. Ecologically, incorporated cropping and animal systems enrich the supply and access to nutrient-rich foods (Hammad et al., 2024; Hassaan et al., 2024). Species-level variation in diets, that is, nutritional biodiversity, improves the index with micronutrients and decreases the reliance on a minimal number of staple crops (Fanzo et al., 2021). ESG creates an inclusive food system at the social level by educating and providing individuals with technical assistance to help farmers adapt to nutrition-sensitive interventions (Rasool et al., 2023). Governance mechanisms, including good market connections, extension services, and input subsidies, contribute to the use of such practices and make them sustainable. To better understand the connection between ESG-oriented agricultural practices and subsequent improvements in household diet diversity (DD) in Pakistan, there is a lack of research on its treatment.

Despite the fact that dietary diversity assessments have been dominated by women and children, very little has been done to evaluate the dietary patterns of entire households, especially mature males who are farmers and are considered representatives and major decision-makers in the agricultural sector. Second, scant empirical evidence exists on the linkage between particular ESG-compatible practices of farmers and household DD. Therefore, this study aims to fill this gap by creating a link between ESG in agriculture and dietary diversity. The objectives of this study are as follows:

1. To estimate the DD of agricultural households
2. To estimate the share of different food groups in daily calorie intake of agricultural households
3. To link ESG in agriculture to the DD of the agricultural households

The potential beneficiaries of this study include agricultural policymakers, researchers, NGOs, farming communities, investors in sustainable agriculture, and public health authorities, particularly in developing countries.

Review of literature

ESG is a concept that is continuously growing among researchers worldwide. Although ESG does not appear in micro-level nutritional research, the ESG framework greatly intersects with sustainable farming systems and the DD of farm families. The three dimensions of ESG allow us to examine how environmentally oriented farm practices, social arrangements, and governance mechanisms jointly determine DD of farm families. Recent studies emphasize that sustainable farming systems are crucial to achieve not only sustainable development in agriculture but also food security.

The environmental dimension of ESG is closely linked to sustainable farming systems, focusing on climate change adaptation, efficient use of resources, and biodiversity. Farm production diversity is considered one of the best and most sustainable farm practices linked to DD. Mastura et al. (2023) used the panel data and determined the positive impact of farm diversification on DD. Akerele and Shittu (2017) also endorsed the positive impact of food production diversity on DD in Nigeria. These findings indicate that DD is increased by diversified food production, either in the form of direct food intake or through increased income from selling surplus farm products. The adoption of climate-smart farm practices, such as planting date adjustments, adoption of drought-tolerant varieties, harvesting rainwater, remaining up to date with weather information, and adoption of solar at farm, extends this logic by indicating how environmental-oriented farm practices play their role in developing sustainable and resilient food production systems. Haq et al. (2021) used the cross-sectional data of total 196 rural families and determined that the high adoption of climate smart farm practices significantly improve the food security by enhancing nutritional intakes and food diversity. Similarly, Omotoso and Omotayo (2025) determined the positive role of adopting climate-smart farm practices among 480 rural households in enhancing their DD and food security.

The second dimension of ESG, Social (S), focuses on women empowerment, remains up to date with nutritional knowledge, and human capital. These elements are highly recognized for their

contributions to sustainable food production systems and the DD framework. WE continuously acknowledge the need to strengthen the agriculture-nutrition pathway. Huang et al. (2023) determined the mitigating impact of WE on DD based on the data of 1,199 rural households. They described that WE significantly mitigated the side effects of low farm production diversity of DD. Kihui and Amuakwa-Mensah (2021) examined the gender disparities regarding market access and the households' DD. They determined that although the market access of men and women enhances the DD, the impact of women's market access on DD was almost double that of men. Shahbaz et al. (2022) and Kassie et al. (2020) analyzed how WE and their innovativeness affect the adoption of sustainable farm practices, which further improve the DD of rural families.

The third dimension of ESG, governance (G), indicates the incentives, allocation of resources, and development of rules regarding farm production and agricultural markets. Therefore, governance has a strong link with sustainable farm production systems in shaping the DD of farm families. Qureshi et al. (2015) analyzed the diverse range of policies regarding demand, access and supply, and they determined that the policies significantly affect the food security. They described that food security policies strongly enhance food security when a country chooses a context-specific policy instrument. Sibhatu et al. (2022) determined that a productivity promotion program for smallholders in Zambia significantly enhanced DD. They indicated that the smallholder support program improved their DD by 3%. Similarly, Pienaaah et al. (2024) demonstrated the positive impact of food demonstrations and home gardening on the DD of families.

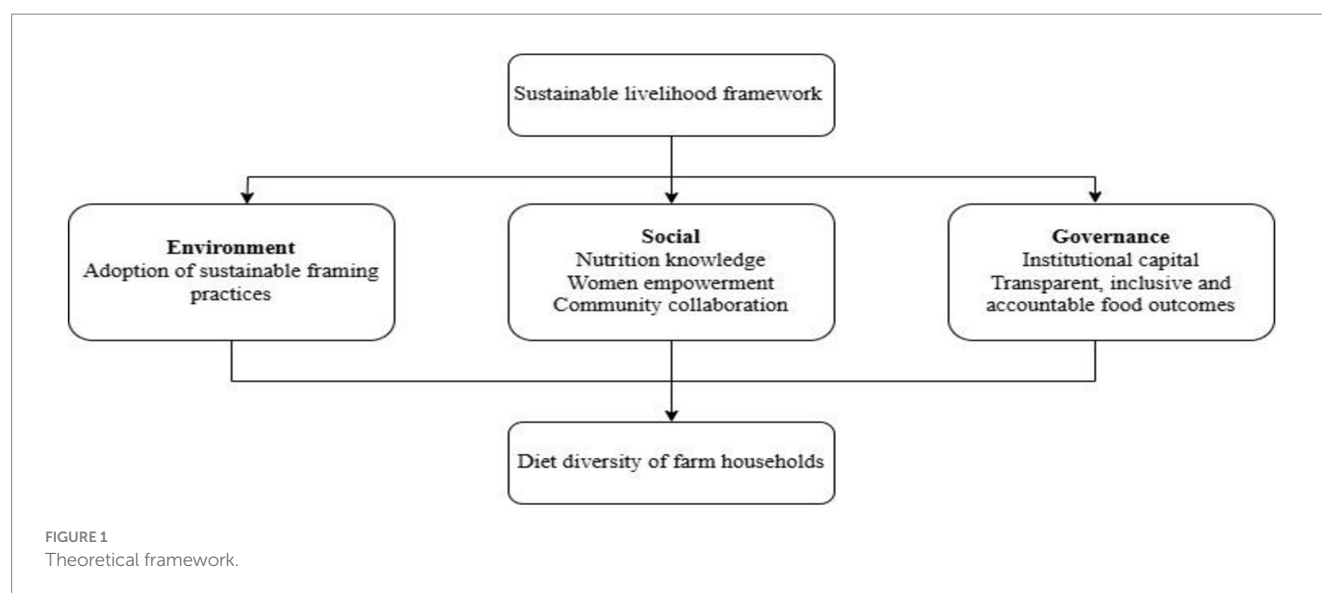
Theoretical framework

The Sustainable Livelihoods Framework (SLF) (DFID, 1999; Scoones, 1998) provides a theoretical framework for this study. The SLF emphasizes how farm households leverage various forms of capital, such as natural, human, social, and institutional capital, to improve their food security and well-being. Therefore, the environmental (E) dimension of ESG, which is measured by the adoption of sustainable farming practices, contributes to the natural capital. This natural capital leads to the availability and accessibility of diverse food sources in the region. The social (S) dimension of this study strengthens social and human capital through NK, WE, and CCI. This enables farm families to make better food-related decisions. Governance (G) indicates institutional capital, which enables families to achieve transparent food and nutrition outcomes. Therefore, these elements of the SLF indicate an integrated conceptual understanding of how ESG influences the DD of farm families. Figure 1 also shows the theoretical framework of the study.

Materials and methods

Study area

Punjab is the most populous province of Pakistan with more than half of country's population living in this province. Of this population, approximately 63 percent live in rural areas, and the remaining 37% reside in urban areas (Pakistan Bureau of Statistics, 2023). This shows the agrarian character of the province and makes it an important



region to explore the idea of rural development and sustainability in terms of agriculture and nutrition. Punjab is also a key contributor to Pakistan's national GDP, with agriculture as one of its main sectors (Planning and Development Board Punjab, 2023). The province contributes more than one-third of the national wheat and rice production. Thus, the province is also referred to as the Pakistan breadbasket (Pakistan Ministry of National Food Security and Research, 2023). In addition, there are more than 6.6 million agricultural families in Punjab. The majority of them are small farmers with little land and other resources (Punjab Agriculture Department, 2023).

Malnutrition is a highly prevalent issue despite agricultural prosperity in the province. Food insecurity is a severe issue in the Punjab province. The co-existence of food abundance and nutrition insecurity represents an intricate failure of the food system in the province. Thus, Punjab is an appropriate study area for research on DD, food and nutrition security, and the challenge of sustainable food systems. Furthermore, many farming policies aim to enhance livelihoods and food security in rural Punjab (Government of Punjab, 2023). These dynamics make Punjab an interesting and worthwhile research field for people conducting research in the area of food, agriculture, and nutrition.

Study questionnaire and data collection

This study used multistage purposive and random sampling techniques to collect data from agricultural households. In the first step, Punjab province was selected purposefully because of its prominent role in national domestic output and agricultural production. Punjab is divided into different agro-climatic zones and in second step, four of them (mix cropping, cotton mix cropping, maize-wheat mix cropping, rice-wheat) were chosen to promote diversity and representativeness. One district from each selected agroecological zone was selected based on its agricultural significance. In the fourth step, two counties (local tehsils) were randomly selected from each chosen district. From each county, four villages were selected in consultation with the local agriculture department, giving

a total of 32 villages. Households in each village were sampled using a simple random sampling method. Proportionate sampling was used to select approximately 13–14 farm households in each village, giving a total sample size of 435 in this study.

Primary data were collected using a structured, pre-tested questionnaire. This was designed based on the relevant literature and adapted to the local context. The questionnaire was translated into Urdu to make it comprehensible to the local population. It contained a broad set of questions, such as household socioeconomic profiles, dietary intakes, and ESG-related questions. It was pilot-tested to determine the clarity and reliability of the instrument prior to the final survey. A team of well-experienced enumerators conducted face-to-face interviews using the local language. Each respondent provided verbal informed consent for the study. The study purpose was explained by the enumerators before the interview was conducted to maintain privacy and comply with the ethics of research principles. When households did not respond, they were randomly replaced by households from the same village.

The survey questionnaire was prepared by taking assistance from the prior relevant literature. The study used two step process to ensure the reliability and validity of the survey questionnaire. In the first step, three subject specialists (one associate professor and two professors) were consulted, and the questions were thoroughly revised and rearranged to ensure face validity. In the second step, a pilot survey was conducted with the study households to ensure the content validity of the survey questionnaire. The data collected from 24 farmers during the pre-testing were not utilized in the final analysis due to significant changes in the final survey questionnaire.

Diet diversity

DD was the main variable, which was estimated using the Simpson index. This index indicates both DD and the nutritional adequacy of households (Nguyen and Winters, 2011; Ruel, 2003). DD indicates the quality of diet and consumption of different food items across or within different food groups. These food groups contain different food items that provide the necessary nutrients for human

growth. Households in rural areas consumed different food items, but their consumption varied across households. In Pakistan, there are six different food groups that categorize the food items consumed by households. These food groups are (i) cereals, (ii) vegetables, (iii) fruits, (iv) milk and milk products, (v) meat and pulses, and (vi) fats and oils (FAO and GoP, 2018). The consumption of food items from different food groups indicates DD. Therefore, farm households that consume food items from all six food groups are characterized by a high DD. To apply the Simpson index, we used the calorie share of each food group to calculate the DD of agricultural households. The following formula was used:

$$DD = 1 - \sum_{g=1}^n P_i^2$$

where DD indicates diet diversity, P_i shows calories share of the i th food group, n is the total food group, and g indicates food groups from 1 to 6. This resulted in the DD index, and its value varied between 0 and 1. Values near 1 indicate a higher DD, while values near 0 indicate a low DD among agricultural households. To estimate the calorie intake from each food group, we converted the food items consumed from any food group into calories using the composite food table index prepared by the Government of Pakistan and the Food and Agricultural Organization (FAO and GoP, 2001).

Statistical and econometric analysis

First, the demographic characteristics and ESG aspects of agricultural households were assessed using descriptive statistics. To examine the impact of demographic characteristics and ESG aspects on the DD of agricultural households, we applied a binary probit model. For this purpose, agricultural households were divided in two categories (high and low dietary diversity groups). Of the households, 66% were highly diet-diversified and 34% were low-diversified. The numeric values were assigned to them; the high diet-diversified households were assigned 1, and low diet-diversified households were assigned 0. It generates a dependent variable with two categories, which justifies the application of the binary probit model. The binary probit model estimates the probability of a family having a highly diversified diet. This model assumes that the observed dependent variable Y can be 1 if and only if its underlying continuous latent variable Y^* takes on a positive value (Washington et al., 2011).

$$Y = \begin{cases} 1, & \text{if } Y^* \geq \text{average DD score} \\ 0, & \text{Otherwise} \end{cases}$$

Where,

$$Y^* = X\beta + \varepsilon, \text{ with } \varepsilon \sim N(0,1)$$

Where Y indicates the respondents' family categories belonging to highly diet-diversified households, X shows the vector of independent variables, β indicates the vector of measurable unknown parameters for the latent variable Y^* , and ε is the error term. By

indicating two outcomes as 1 and 2, the cumulative probabilities of outcome 1 occurring for households n can be specified as follows:

$$P_n(1) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{(\beta_1 X_{1n} - \beta_2 X_{2n})/\sigma} e^{-\frac{1}{2}w^2} dw,$$

Where, σ indicates the standard deviation used to rescale the normally distributed random variables into the standard normal distribution. Therefore, the cumulative probability for the binary case is specified as follows:

$$P_n(1) = \varphi(\beta_1 X_{1n} - \beta_2 X_{2n})/\sigma$$

where φ indicates the cumulative distribution function of the standard normal distribution. To apply the probit model, the unknown parameters were estimated using the maximum likelihood method. The variables with multicollinearity were removed from the probit analysis. Moreover, propensity score matching was used to link the intensity of sustainable farming practices at the farm level with the dietary diversity of rural households.

As we have a categorical dependent variable in 0 and 1 forms, the probit model was particularly suitable for this study. The categorical form of households offers an estimation of the probability of achieving a high DD in the presence of ESG dimensions and other household characteristics. Moreover, propensity score matching enabled us to determine causal inference by reducing selection bias. This method offers a robust estimation of the average treatment effect of adopting sustainable farming practices on DD by controlling for possible confounders. Therefore, both the probit model and propensity score matching complement each other and improve the analytical analysis.

Results and discussion

Demographic characteristics provide important information about the background of the respondents and their capabilities to diversify their diet and adopt certain sustainable farm practices (Haq et al., 2023). Table 1 presents the demographic characteristics of agricultural households. The respondents were almost 44 years old and had nearly 9 years of schooling. The reason may be that education level of people living in rural area is lower than those living urban

TABLE 1 Demographic characteristics of agricultural households.

Characteristics (units)	Mean	Std. deviation
Age (years)	43.70	14.47
Farming experience (years)	25.42	8.44
Education (years)	8.90	4.78
Family size (members)	7.30	4.47
Family income (PKR, million)	0.93	0.36
Agricultural land size (hectares)	2.92	0.85
Agricultural labor force (persons)	2.16	0.78
Market distance (kilometers)	11.93	5.98

areas. The average farming experience of the agricultural households was more than 25 years. This result shows that the respondents had abundant farming experience and had spent more than half of their lives in farming fields. The average family size was more than 7 family members, and their average family income was 0.930 million annually. Large family sizes normally prevail in rural areas of Pakistan because of the joint family system (Shahbaz et al., 2020). The mean agricultural land size was 2.93 hectares. The reasons for this small farm size may be that a large majority of farming households own less than five hectares of land in the country. On average, more than two persons from each rural family were engaged in farming activities. A plausible reason for this may be that agriculture is not the main source of food production but also a source of livelihood for more than one-third of the country's population.

Environment, social and governance aspects in agricultural households

ESG among farmers indicates how strongly they are integrating all three aspects of farming to optimize their farm productivity. As every action taken by a farmer ultimately affects their farm production, which ultimately affect their daily diet.

Figure 2 presents the sustainable farm practices that are broadly adopted by farmers in this locality. These strategies indicate how seriously farmers consider the environment when producing different farm products. Moreover, the adoption of sustainable farming practices enhances the resilience of food production systems and lowers carbon emissions (Nkumulwa and Pauline, 2021). The first strategy is to cultivate drought-tolerant varieties, which is one of the most important strategies according to the weather conditions in the study area. The harsh weather conditions in the study area necessitate the adoption of drought-resistant varieties to stabilize farm production under the threat of climate change. Only 63.68% of respondents reported a preference for drought-resistant varieties. Farmers reported rainwater crop diversification strategies that overcome the problem of land infertility. However, slightly more than half of the farmers practiced crop diversification. Shahbaz et al. (2020) also determined

crop diversification is one of the effective sustainable farm practices in to maintain land nutrients and fertility. The third most adopted strategy by farmers was shifting planting techniques. This is a common strategy adopted in other parts of the province, but almost two-thirds of the respondents were changing the planting dates of their farm crops to lower the impact of the harsh climate. The most widely used strategies among farmers were diversifying their income sources, and four-fifths of the farmers diversified their income sources. Diversifying income sources generates extra income, which assists farmers in improving their diet by improving their purchasing capacity and production capabilities at the farm. The adoption of renewable energy sources, such as solar panels, has also been implemented at the farm level to obtain electricity for running tubewells or lights at the farm. However, this strategy is not common among farmers, and slightly more than one-third of farmers have adopted solar energy as a farm energy source. To achieve sustainable farming, the adoption of sustainable farming practices is crucial, as it enables farm managers to utilize their farm resources more efficiently, leading to stable farm productivity while contributing to a sustainable environment (Alotaibi et al., 2025). The efficient use of natural resources and the adoption of sustainable farming practices generate an integrated and sustainable food production system that fosters environmental stewardship.

Table 2 indicates the social and governance dimensions of ESG, and three different aspects of social groups were assessed. The first aspect of the social dimension is nutrition knowledge (NK), and an average score of 2.90 with a standard deviation of 1.07 indicates that farmers have medium-level knowledge of nutrition, with great variation in responses among respondents. This implies that there were both types of farmers with high or low NK. Among the four different items used for measuring NK, NK3-having education or training on nutrition had the lowest mode value compared to the other three items. This indicates that most respondents strongly disagreed with this statement. The highest average score of 3.16 indicates that farmers had a good level of knowledge of a balanced diet. The farmers were not well informed about the different food groups, as NK4 had an average value of 2.64.

Women empowerment (WE) greatly contributes to the social sustainability of farming systems (Ventura et al., 2021). Considering

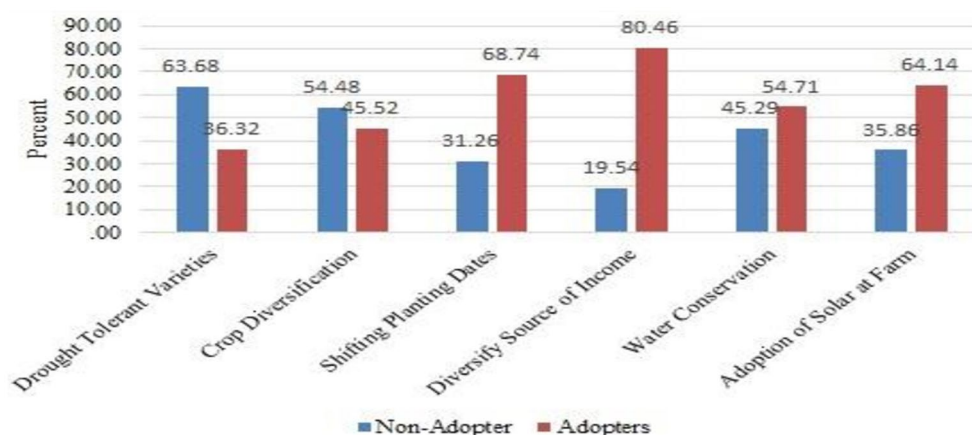


FIGURE 2
Sustainable farm practices.

TABLE 2 Social and governance aspects of ESG.

Dimensions/statements	Mode	Mean	Std. Deviation
Social dimension			
Nutrition knowledge (NK)		2.90	1.07
Understanding what constitutes a healthy diet-NK1	4	2.95	1.37
Balanced diet knowledge-NK2	4	3.16	1.38
Having education/training on nutrition-NK3	1	2.84	1.57
Information of different food groups-NK4	2	2.64	1.19
Women empowerment (WE)		2.81	0.83
Making farming decision-WE1	3	2.88	1.23
Owning agricultural resources like land/livestock-WE2	3	2.89	1.21
Visiting the market independently-WE3	3	2.84	1.11
Member of community group-WE4	1	1.44	1.10
Having a say in food purchasing decision-WE5	3	3.68	1.34
Community collaboration and impact (CCI)		2.60	0.84
Sharing farming knowledge and practices to improve productivity-CCI1	3	2.54	1.08
Collaboration with neighbor regarding healthy diet practices-CCI2	2	2.62	1.09
Sharing food or resources within community-CCI3	3	2.70	1.13
Community members work together to improve food accessibility and availability-CCI4	2	2.56	1.29
Governance (GO)		3.24	0.95
Fair and transparent governmental food/farming programs-GO1	3	3.13	1.24
Knowing where/how to register complaints about food/agriculture services-GO2	3	3.35	1.19
Trust on local agricultural support services-GO3	3	3.35	1.25
Having access to information about food/agriculture policies-GO4	4	3.29	1.31
Locally governmental food or nutritional programs-GO5	3	3.07	1.28

WE, the second aspect of the social dimension, the overall score of WE were very low (2.81), which indicates that women were not greatly empowered in the study area. WE4 indicates that women's involvement in the community as community members is very weak. The average equal to 3 for WE% only describes women making purchasing decisions regarding food items in the study area. The average response value of 2.84 for WE3 highlights that women visit the market, but it is not commonly practiced in the study area. The average of WE1 and WE2 is almost the same, which indicates that respondents have shown slight disagreement with the items. This implies that women have a mild lack of autonomy in making farming decisions and visiting markets independently. This may signify some social and cultural barriers in the study area that limit the mobility and resource ownership of women. Hou (2011) also described the low decision-making power of women in Pakistan, and Adeel and Yeh (2018) highlighted high level of women's immobility compared to men in Pakistan.

The third aspect of the social dimension is community collaboration and impact (CCI). The overall average score of 2.60 indicates that this aspect of the social dimension is very weak in the study area, as most of the respondents were neutral. Although the respondents indicated a neutral response to CCI3, their responses had great diversity due to the high standard deviation. This implies that there were households that shared food or resources with neighbors to improve their food diversity. The low average and mode values of sharing knowledge of framing practices-CCI1, collaboration with

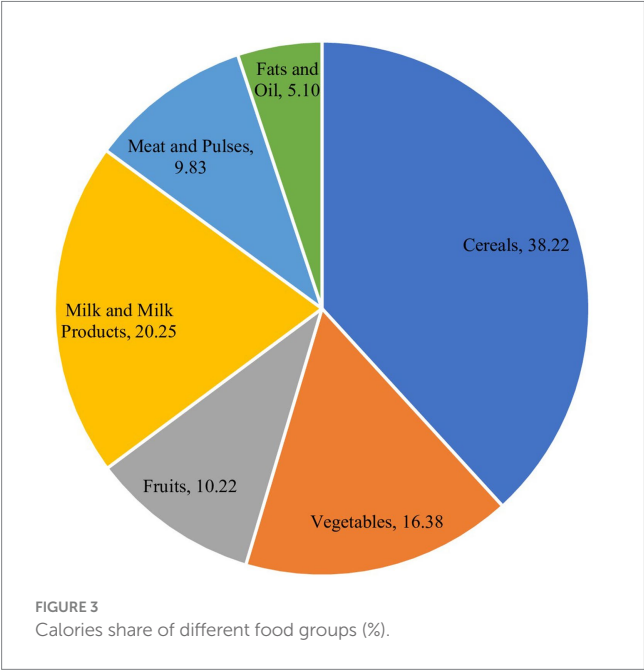
neighbor-CCI2, and working together to improve food accessibility and availability-CCI4 indicate that the majority of the students indicated neutral or disagree response. This indicates that the CCI was not strong among the respondents.

The overall average score 3.24 of for governance (GO) indicates that respondents had slightly above the neutral point perception regarding the governance system. The lowest average 3.07 of for GO5 describes that respondents had a neutral perception of the implementation of governmental food or nutritional programs at the local level. This indicates uncertainty or mixed perceptions among respondents. Similar response observed for GO1, GO2 and GO3 were slightly above 3 (neutral status).

Share of different food groups in daily dietary intake

The calorie shares of the six food groups are presented in Figure 3. The findings indicate that the agricultural households were primarily consuming calories from cereals. It comprised 38.22% of the total calories consumed. The second major calorie-providing food group was milk and milk products, which comprised 20.25% of total calorie intake. The total share of calories from vegetables and fruits was approximately one-fourth of the total calories, which also indicates a good level of consumption of vegetables and fruits. This may be because agricultural households prefer to grow their own vegetables

along with some fruit plants on their farms for home consumption. The fats and oil group provided almost 5% of the total calories. Among all food groups, [Geng et al. \(2022\)](#) determined that cereals are the major food group contributing to energy intake in Pakistan. Our findings are similar to those of [Haq et al. \(2021\)](#) regarding the share of cereals but contradict those of vegetables and fruits.



Dietary diversity of agricultural households

[Figure 4](#) presents the DD scores of all agricultural households. The average DD score of the agricultural households was 0.74, indicating a moderate level of DD. The DD scores of the households ranged from 0.55 to 0.80. These findings show great diversity in the DD scores of agricultural households.

Impact of ESG on diet diversity of agricultural households

[Table 3](#) indicates the findings of binary probit regression, which shows that the model was statistically significant as the chi-square value of 528.66 was significant at the 1% level of significance. The findings revealed that only family income and family size from the demographic characteristics of farmers significantly affected their DD. High family income and small family size increased the probability of diverse DD. The insignificant coefficients of age and education indicate that age and education of the head of the household do not strongly affect improving DD in the locality. The findings indicate that family income and family size are crucial determinants of DD. A high family income typically enables households to have greater access to a variety of nutritious foods, while a large family size affects the DD within the household by impacting the distribution of resources and food choices. Our findings are consistent with those of [Kartikasari et al. \(2024\)](#). They also determined the positive impact of family income on DD. They demonstrated that households with higher family income are more likely to have diverse and nutritious food. Households with

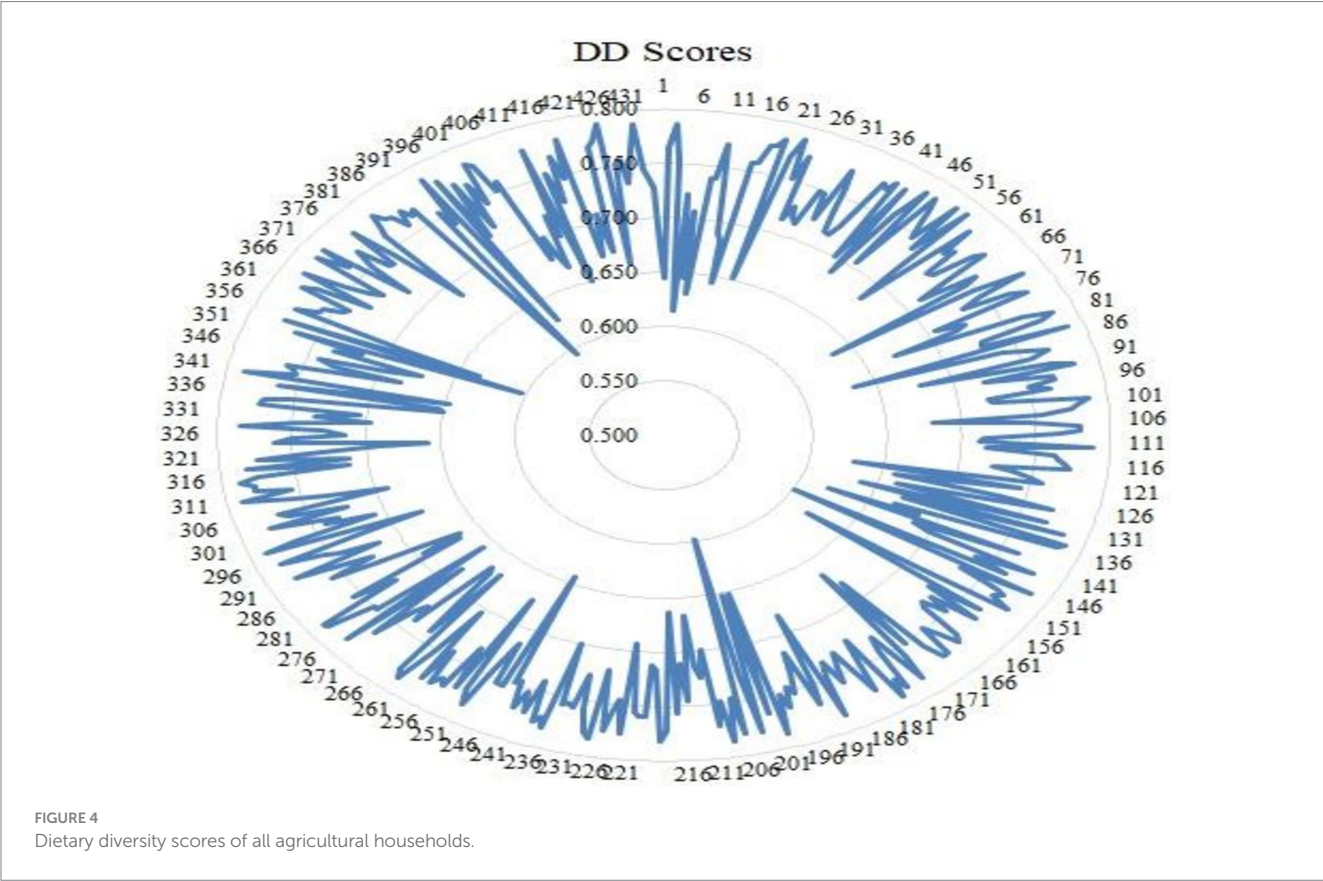


TABLE 3 Impact of ESG on dietary diversity of agricultural households.

Variables	Indicators	Coef.	St. err.	t-value
Demographic characteristics	Family income	0.438**	0.194	2.26
	Age	−0.02	0.023	−0.89
	Education	0.011	0.059	0.18
	Family size	−0.201*	0.119	−1.68
ESG dimensions				
Environment	Sustainable farm practices	0.246*	0.146	1.68
Social	Nutrition knowledge	5.262***	1.241	4.24
	Women empowerment	1.156**	0.584	1.98
	Community collaboration and impact	0.339	0.369	0.92
Governance	Likert scale statements	0.496*	0.29	1.71
	Constant	−19.172	4.102	−4.67

Chi-square = 528.66; Prob > chi2 = 0.000; Pseudo r-squared = 0.852. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

low income often face limited food choices, resulting in an inadequate DD. Households with large family sizes lead to high competition for resources, which may negatively affect DD. Utami (2023) found that the family size equal to five or greater are more likely to have inadequate DD. They demonstrated that food distribution among more family members may dilute the variety of food available to each member.

The environmental aspect of agricultural households based on the adoption of sustainable farm practices significantly improves the DD of agricultural households. This implies that the adoption of effective sustainable farm practices substantially contributes to the DD of households by improving farm productivity. Therefore, the findings reveal that the adoption of sustainable farm practices strongly contributes to the DD of households in rural areas. For example, a study in Zambia and Zimbabwe highlighted that households adopting sustainable practices reported improved DD due to increased farm production (Ngoma et al., 2023). Similarly, in Punjab, Pakistan, rural households adopting climate-smart farming practices exhibited high diversity in food and calorie intakes (Haq et al., 2021). This indicates a clear association between sustainable farming practices and the dietary outcomes.

Among the three aspects of the social dimension, the findings indicate that NK and WE both significantly affect DD, while CCI has no effect on the DD of households. This implies that households with high nutrition knowledge and high female empowerment were more likely to have a diverse diet. NK and WE are critical pathways that affect DD and nutritional outcomes. Our findings are consistent with those of Ahmed et al. (2020) and Yimer and Tadesse (2016). For example, studies in South Asia highlight that interventions targeting the social aspects of households substantially improve DD. For instance, Ahmed et al. (2020) in Bangladesh described that NK strongly affects DD, and in Ethiopia, NK was found to reduce child stunting, highlighting its crucial role in improving child nutrition (Melesse, 2020). Moreover, Melesse (2020) and Yimer and Tadesse (2016) also indicated that WE in farming decisions and economic resources improved nutrition.

Similarly, governance also has a strong impact on DD, implying that when governance-related factors are improved, households are more likely to consume a diverse diet. The findings regarding GO indicate its crucial role in improving the DD of farm households, particularly within the ESG framework. This indicates that an effective

GO can substantially improve food systems by integrating local knowledge and aligning policies, thereby improving diet sustainability. This outcome confirms that ESG is an important aspect of improving the DD of agricultural households. Alam et al. (2023) described that access to information systems strongly influences the DD of households, which directly indicates how GO can contribute to DD by establishing an effective information system. Moreover, del Valle et al. (2022) stated that coherent policies across sectors can facilitate access to diverse foods, and they confirmed that effective food governance strongly affects DD.

Linking sustainable farm practices with dietary diversity of households

Sustainable farming practices are crucial for the food and nutrition security of agricultural households. Therefore, farming communities are adopting different sustainable practices at the farm level to overcome climatic vulnerabilities and ensure food security of their households. The farmers were categorized based on their adoption levels of different sustainable farming practices. The farmers adopting all six sustainable farming practices were categorized as full adopters, and those adopting any single sustainable farming practice were included in the solo adopter group. Farmers with four to five sustainable practices on their farms were considered multiple adopters, and those adopting only two to three practices were termed partial adopters.

The propensity score matching results revealed that the adoption of a greater number of sustainable practices at the farm level results in better DD than the adoption of a lower number of sustainable farming practices. For example, full adopter farmers had 0.14 and 0.10 higher dietary diversity than partial and solo adopters, respectively. Similarly, multiple adopters had 0.09 higher dietary diversity than single adopters (Table 4). This may be because the implementation of additional sustainable agricultural practices improves DD by stimulating the overall resilience and output of the farms. The result is an increased availability of a greater variety of foods consumed in the household. Those living in rural areas, where families are

TABLE 4 Propensity score matching results.

Adoption status		Average difference
Full adopter	Multiple adopter	0.07* (0.02)
0.78	0.71	
Full adopter	Partial adopter	0.10** (0.04)
0.78	0.68	
Full adopter	Solo adopter	0.13** (0.05)
0.78	0.65	
Multiple adopter	Partial adopter	0.05 (0.04)
0.75	0.67	
Multiple adopter	Solo adopter	0.09** (0.04)
0.75	0.66	
Partial adopter	Solo adopter	0.02 (0.07)
0.67	0.66	

*, and ** shows significance level at 1 and 5%, respectively. The values in the parentheses are standard errors.

commonly dependent on their own production, this kind of diversity on the farm has a direct reflection of a more diverse and healthier diet. These results align with those of [Haq et al. \(2021\)](#) and [Teklewold et al. \(2019\)](#), who also reported that farmers with a higher number of farm practices at the farm level have a higher daily dietary intake than those with a lower number of farm practices.

Conclusion

DD among agricultural households in rural areas is a major challenge under continuously changing climatic conditions, social structures, and government circumstances. Therefore, the core objective of this study was to link ESG in agriculture to the DD of farmers in Pakistan. A total of 435 agricultural households were selected for direct face-to-face interviews through multistage purposive and random sampling techniques from four agro-climatic zones of Punjab, Pakistan. The study used binary probit model to link ESG aspects with dietary diversity of agricultural households. Moreover, the Simpson diversity index was used to estimate the DD of agricultural households. The overall average DD score of the farmers was 0.74, which indicates that agricultural households had a good DD level. Among the six food groups, cereals had the largest share of total calories consumed. The findings of the binary probit model revealed that households with high income and small family size were more likely to have a high DD. Similarly, the findings indicated a significant impact of ESG dimensions on the DD of the agricultural households. This implies that the adoption of sustainable farming practices, high NK, WE, and accessible and transparent GO have a strong positive impact on DD. Moreover, a high GO leads to more equitable service delivery, which contributes to improved DD. The results also revealed that the adoption of a greater number of sustainable practices at the farm level results in better dietary diversity than those farmers with the adoption of a lower number of sustainable farming practices. Thus, promoting environmental sustainability, social inclusion, and good governance is crucial for enhancing food and nutrition security in the country.

Based on the study findings, following policies are recommended to improve dietary diversity and sustainable agricultural practices. National and local governments must ensure fair and targeted subsidies and cash transfer programs to low-income and marginalized rural families to improve their dietary diversity. Farmers should be encouraged to increase environmentally oriented farm practices through rewards, training, and demonstrations. To foster the adoption of sustainable farm practices and improve DD, farmers practicing environmentally friendly farm practices must be linked with separate premium markets to increase their profitability and adoption. To enhance NK, nutritional literacy programs should be integrated into agricultural extension services and local community health centers to raise awareness among rural households about the importance of DD. To empower women, their access to agricultural resources must be increased by making credit and farm inputs more accessible. Moreover, nutrition-oriented education must be incorporated into community women's groups to improve the mental health and dietary choices of women in rural families. For good governance, transparency and fair distribution of food and agricultural programs must be ensured. Similarly, grievance redressal mechanisms and the implementation of food policies at the local level must be functional, visible, and accessible to all. The government must launch a digital system to avoid favoritism and improve the monitoring of welfare programs. Moreover, investment in developing rural infrastructure and storage facilities must be increased to lower post-harvest losses. Similarly, agricultural policies must be aligned with national nutritional goals by encouraging and supporting diversified farming systems.

The study has following limitations which also must be kept in mind while generalizing the findings of the study. This study used cross-sectional data, which may not fully indicate the causal relationship between variables. Future studies should focus on longitudinal or panel data to examine reliable cause-and-effect relationships. Further, this study was conducted in Punjab province and did not consider geographical differences present country. Therefore, there is a potential for further studies with wider geographical distribution including all provinces of the country. Moreover, cultural variations may also influence the ESG and DD pathways; for this purpose, future studies may consider cultural variation as one of the most important elements of DD.

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.

Ethics statement

The studies involving humans were approved by University of Education Lahore, Pakistan. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SC: Conceptualization, Writing – review & editing, Investigation, Methodology, Visualization, Software, Writing – original draft. AH: Writing – review & editing, Conceptualization, Writing – original draft, Project administration, Data curation. MA: Resources, Writing – review & editing, Funding acquisition, Writing – original draft, Visualization, Supervision.

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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.2025.1660246/full#supplementary-material>

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