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RESEARCH ARTICLE

Crop diversification for resilient farming: Determinants, challenges and policy implications for smallholder agriculture

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Abstract

Crop diversification is a critical approach to minimizing risks from climatic variability, income instability and nutrition insecurity in cereal-based systems. In Odisha, overdependence on paddy, fragmented landholdings, inadequate irrigation and frequent climatic shocks render diversification indispensable for sustainable agriculture. The current research explores the factors influencing farmers' willingness to adopt crop diversification and identifies the major constraints hindering its spread in Odisha. A multi-stage sampling design was used to select 220 farm households from districts representing contrasting levels of cropping intensity. Data covering the period 2021–2024 were collected through structured surveys and secondary sources. The analysis employed Principal Component Analysis (PCA) to derive key socio-economic dimensions, Probit regression (PR) to estimate the adoption probability and the Garrett ranking to rank the constraints. Five major dimensions - land and income capital, demographic experience, market and institutional access, labour and finance and household labour reserve - were extracted through PCA, explaining a cumulative variance of 77.86 % . Probit regression revealed that land ownership, farm income and extension visits significantly increased the probability of diversification, whereas age, paddy yield, market access and credit access decreased the probability. Garrett ranking identified the most important hurdles as lacking market intelligence (rank I; score 66.05), excessive transportation costs (rank II; 60.76) and expensive labour (rank III; 55.08), followed by pest occurrence (rank IV; 53.12), malpractices by middlemen (rank V; 49.60) and poor irrigation (rank VII; 44.58). The results confirm that resource endowments (owned land and farm income), institutional support (extension services) and infrastructural development (market access and transport costs) strongly influence crop diversification. The study illustrates the need for targeted interventions, including improved market intelligence, accessible credit, decentralized infrastructure and the promotion of climate-resilient crops, to advance diversification, enhance farmer incomes and strengthen food and nutrition security, in alignment with the Sustainable Development Goals.

Keywords: agro-climatic resilience; crop diversification; nutritional security; probit regression; sustainability

Introduction

Crop diversification is a strategic approach that involves growing multiple crop types within a production system rather than relying on a single predominant crop. It's commonly seen as a shifting from low-value traditional crops (generally cereal-dominated monoculture crops - paddy, maize etc) to more high-value ones (vegetables: brinjal, tomato, okra, chilli, cucurbits; pulses: green gram and black gram; oilseeds: groundnut, mustard, sesame; fruits: banana, papaya, mango; spices and condiments: turmeric, ginger; commercial crops: sugarcane, floriculture crops: marigold) and is an important avenue for agricultural advancement. By enhancing adaptability to unforeseen events (climate shocks such as cyclones (e.g., cyclone Yaas, cyclone Fani-type events common in Odisha), heavy unseasonal rains during harvesting, Prolonged dry spells/ drought stress, pest and disease outbreaks), it promotes self-reliance and sustainability in agriculture (1). Ecologically, diversification helps prevent soil erosion, salinization, pest and disease infestations and environmental contamination, while maintaining soil fertility and diversity (2, 3). It economically creates alternative sources of income for farmers, enabling them to adapt to changing market demands. For marginal and small farmers, diversification enhances income opportunities and access to niche markets and value chains outside conventional subsistence farming (4, 5).

As a fundamental element of sustainable agriculture, crop diversification involves having "multiple sources of production" at farm and spatial levels (6). It also supports various Sustainable Development Goals (SDGs). Diversification promotes food and nutrition security (SDG 2) and health and well-being (SDG 3) through balanced diets. By stabilizing and even increasing farm incomes, it helps reduce poverty (SDG 1). Environmentally, it promotes soil conservation and biodiversity (SDG 15) as well as increased climate change resilience (SDG 13). The inclusion of the SDGs is crucial, as they provide a clear framework for evaluating how crop diversification supports economic, nutritional and ecological goals and are justified because crop diversification inherently aligns with global priorities on poverty reduction, food security and climate resilience. Indian evidence suggests that households transitioning to high-value crops have reduced poverty risk, particularly for smallholders, with substantial improvements in economic well-being (7, 8).

In Odisha, rural economies remain dominated by agriculture, but structural weaknesses arise from the dominance of paddy monocropping. Heavy dependency on rain, along with vulnerability to cyclones, floods and droughts, leads to yield volatility, food insecurity and income variability, particularly among marginal and small farmers. Extensive areas of rice-fallow are not cultivated during the dry season because of poor irrigation, poor soil moisture, unavailability of short-duration pulse crops and oilseeds, overgrazing by animals and out-migrating labour (9-11). Thus, diversification becomes imperative under such circumstances. Climate-resilient crops such as millets (e.g., finger millet and pearl millet) and pulses (e.g., green gram and black gram) with low input requirements offer viable alternatives for input-poor farmers (12). Diversification reduces malnutrition by improving dietary diversity. Staple cereal-based diets often lead to hidden hunger, in which calorie intake is adequate but micronutrient requirements are not met. Incorporating pulses, vegetables, fruits and millets can provide balanced nutrition that is rich in protein, vitamins and minerals, especially significant in rural Odisha (13).

At the policy level, India must strengthen policies and initiatives promoting sustainable and healthy agricultural diversification. This calls for the establishment of conducive conditions for private sector involvement, particularly by youth entrepreneurs, to generate efficient and inclusive value chains that connect farmers to markets and safeguard environmental sustainability (14-16). As food demand rises and threats to food security grow (17), India must target not just higher rice yields in the monsoon but also use rice-fallow land to cultivate diverse pulse crops and oilseeds during the post-monsoon season.

This research seeks to identify the determinants of farmers' willingness to adopt crop diversification in Odisha. In addition, the findings are expected to identify and prioritize the major problems and constraints hindering adoption. The study aims to provide policymakers, development agencies and researchers with evidence based insights to design targeted interventions that not only promote crop diversification but also address the structural and institutional barriers farmers face. Ultimately, the study contributes to strategies to enhance smallholder resilience, improve rural livelihoods and advance agricultural sustainability, in line with the SDGs. Based on these objectives, the study hypotheses that farmers diversify when the perceived economic benefits and risk-reduction advantages outweigh the security provided by staple-crop specialization.

Materials and Methods

Study area and sampling design

A multi-stage random sampling method was used to select participants for the study. In the first stage, two districts were purposively identified on the basis of cropping intensity to capture contrasting agricultural situations within the state: Cuttack, which reported the highest cropping intensity and Sundargarh, which recorded the lowest. At the second stage, blocks within each district were stratified by cropping intensity: one group comprised blocks with intensity above the district average and the other, below. One block was drawn from each group through probability proportional to size (PPS) sampling to provide an unbiased representation on different levels of agricultural intensity. In the third stage, two villages from each selected block were randomly selected using PPS, thereby strengthening the representativeness of the sample. Based on Farm information and advisory center (FIAC) and district agriculture office records, the sampling frame comprised 112 farm households in the selected block of Cuttack and 108 households in the corresponding block of Sundargarh, from which a total of 220 farmers were ultimately selected as the final sample (Fig. 1) (18).

Data collection

Primary and secondary data were meticulously gathered to successfully fulfil the objectives of the study. The primary data were collected directly from the sample farmers using a pre-tested, structured questionnaire, prepared according to the research objectives to ensure relevance and the precision of responses. The primary data recorded for the research study pertained to the agricultural years from 2021-22 to 2023-24. Secondary information was compiled from a variety of sources, including project reports from the FIAC in selected districts, reports from the Directorate of Economics and Statistics (Government of Odisha) and relevant academic publications.

Statistical Analysis

Principal component analysis (PCA)

Principal Component Analysis was utilized to minimize redundancy between explanatory variables like landholding, income, market access and extension services, which tended to be highly correlated. PCA transforms correlated variables into a smaller set of uncorrelated components that capture most of the dataset's variance (19). The eigenvalue (λ) associated with each component was computed as:

$$AX = \lambda X \qquad \text{(Eqn. 1)}$$

Where A is the covariance matrix, X is the eigenvector and λ represents the variance explained by each component. Components with eigenvalues exceeding 1 (Kaiser's criterion) were retained and the cumulative variance was used to assess adequacy:

$$Cumulative\ variance = \frac{\sum_{j=1}^{k} \lambda_i}{\sum_{j=1}^{p} \lambda_i} X100 \qquad \text{(Eqn. 2)}$$

Where k = number of retained components and p = total number of variables. The resulting principal components highlighted the dominant dimensions, including land and income factors, demographic attributes, market and institutional support and access to labour and credit. These extracted components were subsequently incorporated into the PR to quantify their influence on the likelihood of crop diversification.

Determinants of adoption of crop diversification: Probit regression model

To determine the determinants of farmers' decision to undertake crop diversification (Table 1), a PR model was used. Within this context, the dependent variable was dichotomous, coded as 1 if the farmer had adopted diversification (Herfindahl Index (HI) < 0.7) and 0 otherwise. The general specification of the Probit model is:

The Probit model:

$$P(Y = 1 \mid X) = \Phi(\beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_k X_k) \qquad \text{(Eqn. 3)}$$

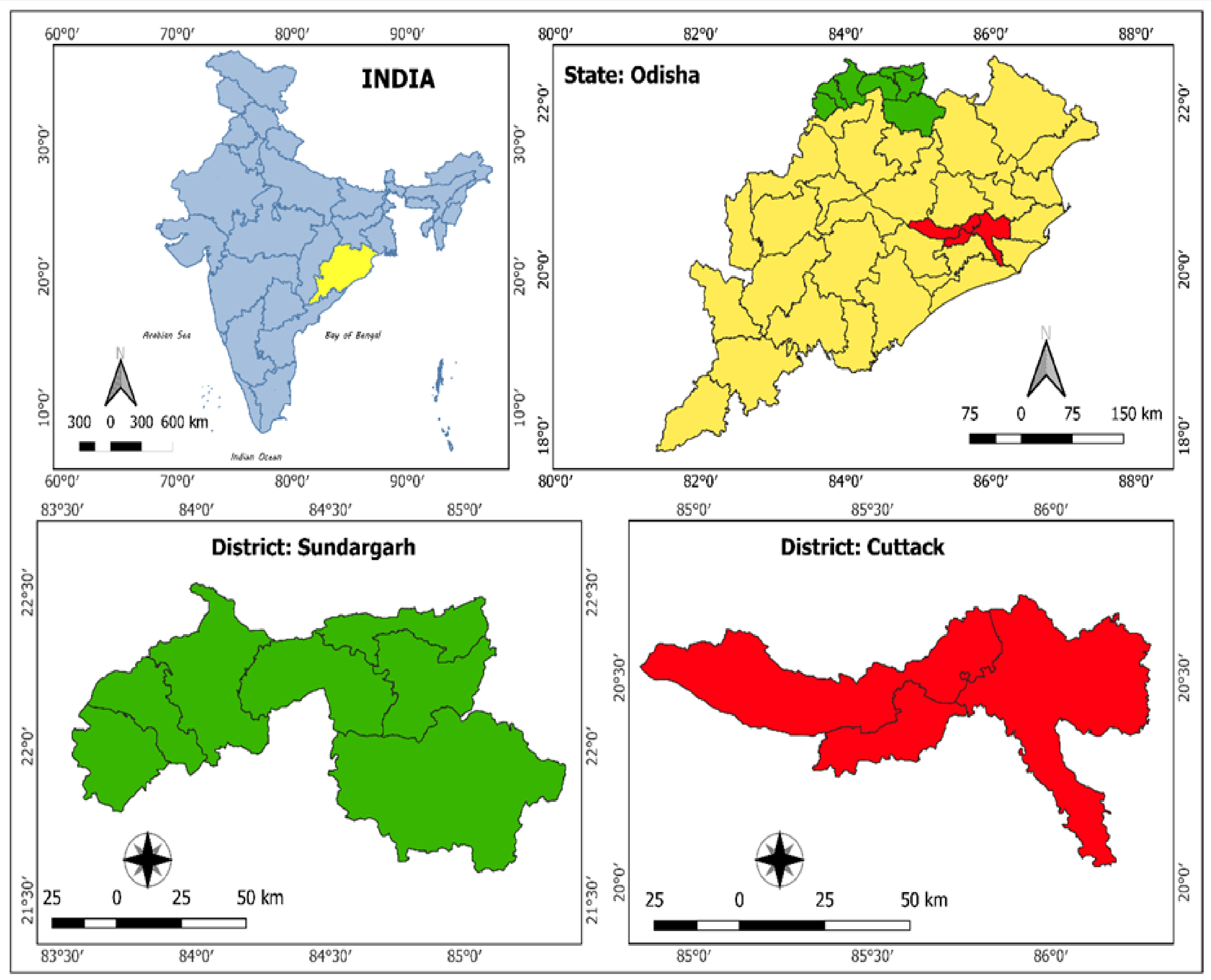

Fig.1. Diagrammatic depiction of the location of the study area.

*Study area generated using QGIS Geographic Information System, Version 3.44“Solothurn.”

Table 1. Detailed explanation of the explanatory variables employed in the Probit model

Variables	Code	Description	Measurement
		Dependent Variable	
Crop Diversification		Whether the farmer is going for Crop Diversification or not?	1 = Yes 0 = No
		Independent Variable	
Owned Land	X_1	Operational farm area owned by the farmer.	Quantitative variable (in Acre (Ac))
Age	X_2	Age of the farmer.	Quantitative variable (in years): 18–34 (young); 35–54 (Middle–aged); 55 and above (old–aged)
Farming Experience	X_3	Total number of years in farming activities.	Quantitative variable (in numbers)
Education	X_4	Level of education.	Primary/ Senior Secondary/ Higher Secondary/ Graduation
Size of the farm family	X_5	Is a family nuclear or joint?	Quantitative variable (in numbers)
Farm income	X_6	Total income from various crops.	Quantitative variable (Rs/year)
Yield of paddy	X_7	Total amount of paddy harvested from the cultivated land.	Quantitative variable (in kg/acre)
Labour availability	X_8	Availability of hired labour.	Dummy (1 = Yes, 0 = No)
Access to credit	X_9	Easy availability of credit from various financial institutions.	Dummy (1 = Yes, 0 = No)
Access to market	X_{10}	Availability of market facilities (buying and selling of farm produce).	Dummy (1 = Yes, 0 = No)
Frequency of extension visits	X_{11}	Timely training and inspection of extension personnel.	Dummy (1 = Yes, 0 = No)

Where, P(Y=1lX) is probability that a farmer adopts crop diversification; Φ is cumulative distribution function of the standard normal distribution, β_0's intercept (i = 1 to k); βi, coefficients to be estimated; X_i explanatory variables (e.g., landholding, income, age, education, market access, credit access, extension visits).

Pseudo R-square is a statistical measure that quantifies the goodness-of-fit of a Probit model. The log-likelihood of a model is compared to that of a model that includes merely a constant.

$$\ln L(\beta) = \sum_{i=1}^{n}[Y_i \ln \Phi(X_i\beta) + (1 - Y_i)\ln(1 - \Phi(X_i\beta))]$$ (Eqn. 4)

Goodness of fit was assessed using the pseudo-R^2 and percentage of correctly predicted outcomes. To improve interpretability, marginal effects were computed, which estimate the change in the likelihood of diversification per one-unit change in an explanatory variable. Marginal effects were calculated as average marginal effects (AME), providing an interpretable measure of the change in diversification probability averaged across all sample households:

$$\frac{\partial P(Y=1|X)}{\partial x_j} = \phi(X\beta)\beta j$$ (Eqn. 5)

In this context, ϕ refers to the probability density function associated with a standard normal distribution. This allowed the estimation of the magnitude and direction of influence of each socio-economic and institutional factor on the likelihood of crop diversification.

Garrett ranking

This technique was employed to identify and rank the constraints farmers face in adopting crop diversification (20). Respondents assigned ranks to various constraints, which were then converted into per cent positions expressed by the formula:

$$\text{Per cent position} = \frac{100 \times (R_{ij} - 0.5)}{N_j}$$ (Eqn. 6)

Where R_{ij} is the rank assigned to the i_{th} factor by the j_{th} respondent and Nj represents the total number of factors rated by the j_{th} respondent. The rank values were converted to percentile positions, then to Garrett scores using the conversion table. The average score for each constraint was calculated as: R_{ij}= The rank assigned to i_{th} factor by j_{th} individual.

$$\text{Mean Score for Factor i} = \frac{\sum_{j=1}^{n} S_{ij}}{n}$$ (Eqn. 7)

Where S_{ij} is the Garrett score for the i_{th} factor given by the j_{th} respondent and n is the total number of respondents. The constraints were organised by mean score, from highest to lowest, thereby identifying the most critical issues hampering diversification, such as a lack of market intelligence, high transportation costs and labour scarcity.

Results and Discussion

Principal component analysis

In Fig. 2A and 2B, supplementary Fig. 1 and supplementary Table 1A, 1B, the loading plot highlights the contribution of variables to the principal components. For Principal Component 1 (PC1), socio-economic factors such as Family Size (X_5),

Principal component analysis was applied to reduce multicollinearity among explanatory variables and to identify the principal socio-economic dimensions underlying crop diversification adoption. In Fig. 2A and 2 B and in supplementary Table 1, the eigenvalue distribution showed that the first five components had eigenvalues greater than 1, consistent with Kaiser's criterion and together explained 77.86 % of the cumulative variance. A cumulative variance of 77.86 % is considered satisfactory for socio-economic datasets, as such data typically involve complex, interrelated variables and capturing over 70 % of the total variance is widely accepted as indicating a strong and reliable dimensional representation. In particular, PC1 accounted for 23.56 % of the variance, followed by PC2 (19.77 %), PC3 (13.32 %), PC4 (12.05 %) and PC5 (9.16 %), suggesting that these five components are sufficient to capture most of the variability in the data set.

The pattern of loading indicated clear thematic orientations. PC1 was highly correlated with owned land (32.47 %), farm income (28.93 %) and paddy yield (26.77 %), indicating a "land and income capital" factor. PC2, led by age (36.35 %) and years of farming (35.64 %), expressed a "demographic and experiential" factor. PC3, as indicated by access to market (52.96 %) and frequency of extension visits (19.09 %), indicated a "market and institutional support" factor. PC4, characterized by the availability of labour (24.71 %) and credit access (20.09 %), was a "labour and financial access" dimension. Lastly, PC5, with a high loading for family size (85.21 %), reflected a "household labour reserve" dimension.

The grouping was supported by the correlation matrix (Fig. 2C), with farm yield and income strongly correlated with landholding, but education exerting greater influence in subsequent components as a secondary determinant of adoption. Collectively, the analysis underscores that access to credit, market connectivity and labour availability, in conjunction with demographic characteristics, are the primary socio-economic drivers of crop diversification adoption. These components were subsequently incorporated into the PR to quantify their marginal effects on the likelihood of adoption.

Determinants of crop diversification

A PR framework was used to identify and quantify the major variables influencing farmers' decisions to adopt crop diversification. In the model framework, eleven explanatory (independent) variables and one dependent variable were included to represent the multi-faceted nature of farmers' decision-making. The HI was used as a proxy for crop diversification and served as the dependent variable in the model. For operational purposes, the dependent variable was dichotomized to take binary outcomes: farmers practising crop diversification were coded as '1' and those who did not diversify were coded as '0'. More specifically, farmers with a HI score below 0.7 were assigned a value of '1', as lower HI scores indicate greater diversification. On the other hand, farmers with an HI of 0.7 or higher were assigned the value '0' for a comparatively less diversified or specialized cropping pattern. The threshold of HI < 0.7 is widely used to distinguish diversified from specialized farming systems, as values above 0.7 indicate a high concentration in one or two crops, while values below 0.7 reflect meaningful dispersion across multiple crops. Prior studies on crop diversification in India and other developing regions have similarly used HI cut-offs of 0.6-0.75 to classify diversification intensity, making 0.7 a consistent and defensible operational benchmark.

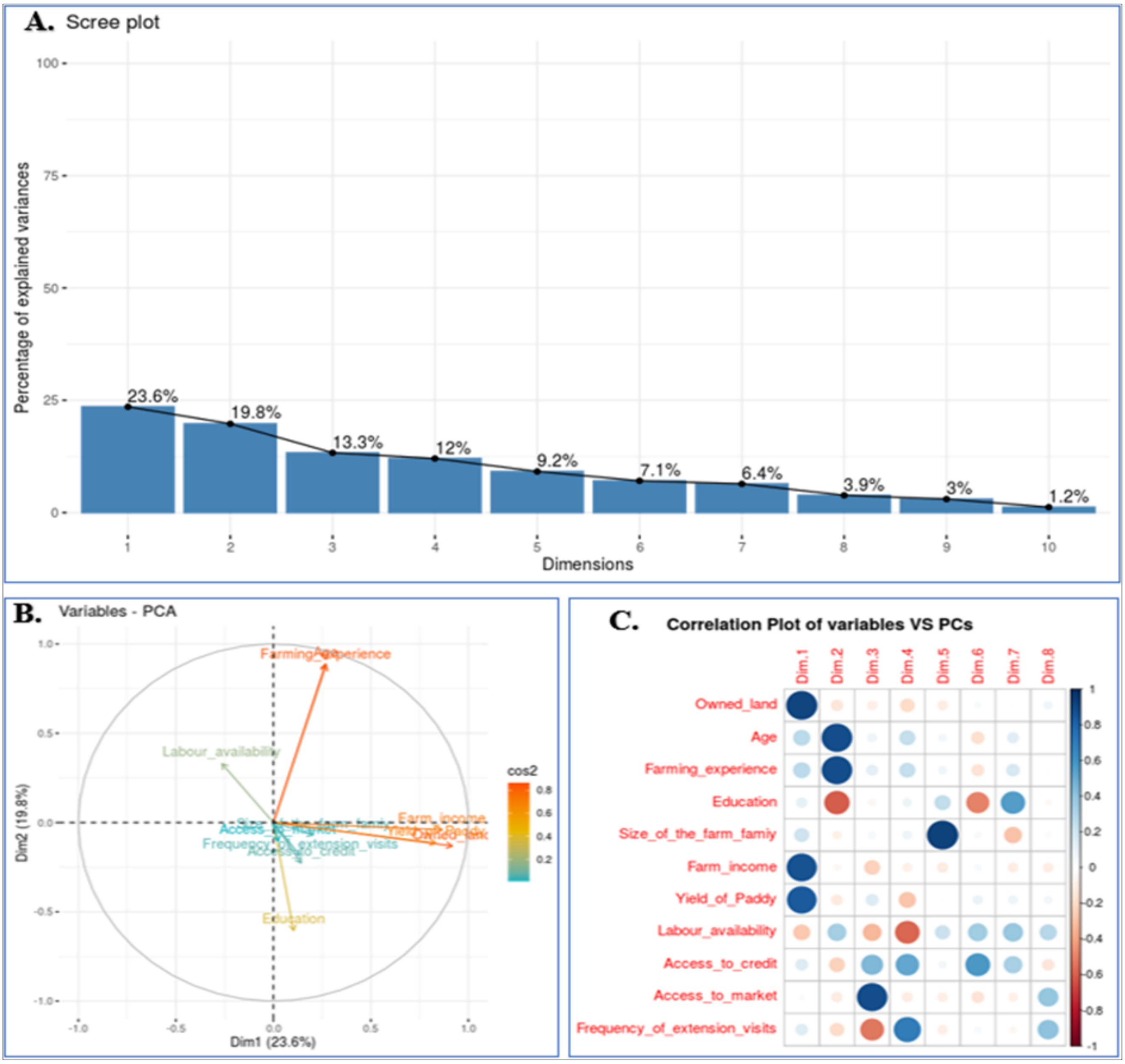

Fig. 2. Principal component analysis result.

(A) **Scree Plot:** Illustrates the variation accounted for by each primary component, facilitating component selection;

(B) **Variable Contributions:** Emphasizes the impact of variables on primary components;

(C) **Correlation Matrix:** Illustrates the interrelationships among variables and their correspondence with primary components.

It is important to note that the estimated coefficients in the Probit model presented in Table 2 do not directly quantify the level of crop diversification. The signs of the coefficients are significant, as they indicate the direction of the effect of the explanatory variables on the likelihood of diversification. A positive coefficient signifies that an increase in the corresponding independent variable enhances the likelihood of crop diversification. In contrast, a negative coefficient indicates a reduction in the chance of diversification with an increase in the explanatory variable.

Additional interpretability of the estimates was achieved by computing marginal effects, which provide a quantitative measure of the change in the probability of crop diversification for a one-unit change in an independent variable, while other variables remain constant. The marginal effect of the variable owned land was estimated at 0.478, indicating that a 1-unit increase in owned land increases the probability of taking up crop diversification by about 47.8 %.

Variables such as owned land, farm income and the number of extension visits were found to be positively and statistically significantly associated with the probability of crop diversification. This shows that high land ownership, higher income levels and more frequent agricultural extension visits increase the probability of diversification. In contrast, variables such as farmers' age, paddy yield, access to credit and access to markets were identified as negatively and significantly affecting diversification. This suggests that young farmers, who have low dependence on paddy yields and good proximity to financial institutions and markets, are more likely to go for crop diversification.

These results concur with the earlier empirical findings from the Kangra district of Himachal Pradesh, which demonstrated that economic determinants (e.g., size of farm, availability of farm machinery, tenancy contracts and income streams) as well as social determinants (e.g., household size, age and education level of the household head) play a significant role in influencing farmers' crop

Table 2. Determinants of crop diversification

Variables	Estimates	Marginal effect
Intercept	7.835**(0.0027)	–
Owned land (X_1)	0.4789** (0.006)	0.04 (0.066)
Age (X_2)	-0.1802* (0.05)	-0.015 (0.11)
Farming experience (X_3)	0.1673 (0.06)	0.013
Education(X_4)	0.025 (0.93)	0.002
Size of the farm family (X_5)	−0.108 (0.399)	−0.009
Farm income (X_6)	0.000057** (<0.001)	0.000004 (<0.001)
Yield of Paddy (X_7)	-0.0004** (<0.001)	-0.00003 (0.003)
Labour availability (X_8)	0.6892 (0.387)	0.05
Access to credit(X_9)	-1.77** (0.001)	-0.14
Access to market (X_{10})	0.8256	0.068
Frequency of extension visits (X_{11})	1.157**	0.096 (0.01)
Pseudo R^2	0.63	

Values mentioned in parentheses represent *p*–value.

Pseudo R^2= 0.710, AIC= 88.8 % correctly predicted=96;

**, * represent significance levels of 5 % and 1 %, respectively.

diversification decisions significantly (21). The current findings support this evidence, thereby strengthening the argument that crop diversification is a function of socio-economic and infrastructural determinants. Similar observations reported are mentioned in Table 3.

Constraints faced by sample farmers

The Garrett ranking analysis prioritized the major constraints limiting crop diversification among sample farmers. In Table 4, results indicated that lack of market intelligence was the most serious problem, suggesting that farmers often operate without adequate information on prices and demand trends. This was followed by high transportation costs and rising labour expenses, which reduced profitability and discouraged diversification. Insect and disease infestations, malpractices by intermediaries and low land productivity were also identified as major problems. Barriers such as insufficient irrigation, credit constraints and a lack of quality seeds further hindered adoption, especially among smallholders. Though ranked lowest, stray animal and monkey menace remained localized, yet a persistent challenge.

All in all, the report highlights that both institutional issues e.g., poor market linkages and access to finance and infrastructure shortfalls e.g., transport and irrigation are core hindrances. Addressing these issues through improved market information systems, affordable credit and strengthened rural infrastructure would create a more enabling environment for crop diversification. Similar observations were reported, highlighting that input-related barriers and knowledge gaps significantly hinder farmers' capacity to diversify (22). This finding is consistent with earlier research that identified scarcity of quality irrigation water as the most important physical constraint to diversification (23).

Table 3. Factors affecting farmers' adoption of crop diversification

Domain	Determinants	Effect on Diversification	References
Farmer Characteristics	Gender	Mixed influence depending on socio–cultural norms.	(24, 25)
	Age	Older farmers are more likely to diversify.	(26, 27)
	Education	Higher education increases diversification; literacy effects vary.	(28–32)
Household Characteristics	Size of the family	Larger households encourage diversification due to more labour availability.	(24, 26, 27, 33)
	Family income	Higher income enables the adoption of diverse crops.	(34–36)
Farm Resources	Landholding size	Larger landholdings positively influence diversification.	(24, 26)
	Livestock ownership	Encourages integrated and diversified systems.	(35, 37)
	Fixed assets/technology	Resource constraints may limit diversification.	(38, 39)
Institutional & Territorial Factors	Farm location and cultivation intensity	Location and land–use intensity shape crop choices.	(25, 34)
	Access to credit and advisory services	Greater access facilitates diversification.	(26, 37, 40)
	Infrastructure and markets	Better infrastructure supports diversification opportunities.	(25, 39)
Environmental Conditions	Climatic variability	Farmers diversify to manage risks from uncertain weather.	(32,35)

Table 4. Constraints faced by sample farms

Sl. No.	Particulars	Total score	Average score	Rank
1	Non–availability of the desired quality seed	8946	40.66	IX
2	Lack of irrigation facility	9808	44.58	VII
3	Problems of insect and disease	11687	53.12	IV
4	Costly labour	12117	55.08	III
5	High transportation charges	13367	60.76	II
6	Lack of market intelligence	14531	66.05	I
7	Stray animals and monkey menace	8751	39.78	X
8	Malpractices by middlemen	10911	49.60	V
9	Low land	10228	46.49	VI
10	Access to credit	9514	43.25	VIII

Policy implications

The implications highlight the urgent need for targeted policies to fast-track crop diversification in Odisha and similar agro-ecological contexts. At first, diversification plans were to be anchored in climate resilience, with increased focus on the development of pulse crops, oilseeds and millets in rice-fallow areas through incentives, guaranteed procurement and location-specific varietal development. Rebalancing subsidy patterns away from input-intensive cereals towards diversified production would provide greater economic returns to farmers in adopting more resilient and sustainable options. Another key area is the creation of effective market and value chain linkage. Efficient farmer-producer organisations, cooperatives and decentralised processing facilities can strengthen collective bargaining power, minimise post-harvest losses and ensure equitable returns for non-cereal commodities. Besides, digital innovations hold transformational potential: mobile-based advisories, live weather and pest alerts and AI-enabled crop planning tools can close information gaps and enable evidence-based decision-making for smallholders.

Investment in decentralized storage facilities, grading and cold chains is also a key enabler of diversification. This will protect perishable crops and bring them into formal markets. Nutritionally, crop diversification policies need to be coordinated with public food programs such as the public distribution system (PDS), mid-day meal schemes and community nutrition initiatives to simultaneously improve income security and dietary diversity. Lastly, risk management structures need to be redesigned; crop insurance products need to be developed that can insure diversified crop portfolios and offer premium subsidies for farmers growing climate-resilient crops. Together, these actions would not only reduce over-reliance on paddy monoculture but also provide long-term food, income and nutrition security for risk-prone farming systems.

Conclusion

This research identifies crop diversification as a key avenue for enhancing resilience, food and nutrition security and income stability for smallholder farmers in Odisha. The findings indicate that farm income, landholding size and extension services significantly affect diversification, whereas institutional and infrastructural limitations such as poor credit, limited market access and labour costs hinder its implementation. Institutional and infrastructural impediments remain major challenges requiring targeted interventions.

Beyond the regional context, the results have broader global relevance. With global warming heightening production risks and monoculture systems challenging biodiversity and overall soil health, diversification in crops is a global approach to insulate farming systems from shocks. By supporting climate-resilient crops like pulses, oilseeds and millets, diversification can help mitigate greenhouse gas emissions, improve resource use efficiency and address the global issue of hidden hunger through nutrient-dense diets. Furthermore, the enhancement of the agricultural value chain and farmer-producer networks aligns with the global effort to develop inclusive and sustainable agri-food systems.

Integrating crop diversification policies with international frameworks such as Sustainable Development Goals - specifically SDG 1 (No Poverty), SDG 2 (Zero Hunger) and SDG 13 (Climate Action) - underscores its potential scalability and multidimensional benefits. Therefore, promoting diversification in smallholder systems not only addresses local risk factors but also aligns with international priorities in sustainable agriculture, climate resilience and nutrition-sensitive food systems.

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Authors' contributions

AP and SP were involved in the preparation of the original draft, conceptualization, methodology, investigation, visualization, validation, software, formal analysis and editing. SNM provided supervision, resources, methodology and reviewing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The Authors do not have any conflicts of interest to declare.

Ethical issues: The study protocol, designed as a socio-economic investigation involving farmer participants, was reviewed and approved by the Research Ethics-cum-Advisory Committee of the College of Agriculture, Odisha University of

Agriculture and Technology, Bhubaneswar, Odisha, India. Informed consent was obtained from all participants before their inclusion in the survey. Each participant was clearly briefed about the objectives of the study, the voluntary nature of their participation and the assurance of confidentiality. Only individuals who provided verbal and/or written consent were enrolled in the study.

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

During the preparation of this work, the author used Quillbot to improve language clarity and correct grammatical errors. After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

1. Nayak CR, Kumar CR. Crop diversification in Odisha: an analysis based on panel data. Agric Econ Res Rev. 2019;32:67-80. https://doi.org/10.5958/0974-0279.2019.00006.5
2. Barman A, Saha P, Patel S, Bera A. Crop Diversification an Effective Strategy for Sustainable Agriculture Development. Sustainable Crop Production - Recent Advances. IntechOpen; 2022. https://doi.org/10.5772/intechopen.102635
3. Shibani G, Mehta G, Samriti. Determinants of crop diversification: a case study of farm households in Himachal Pradesh. Indian J Econ Dev. 2023;19(4):847-54. https://doi.org/10.35716/IJED-23326
4. Anuja AR, Shivaswamy GP, Ray M, Singh KN. Pattern of crop diversification and its implications on undernutrition in India. Curr Sci. 2022;122(10):1154-60. https://doi.org/10.18520/cs/v122/i10/1154-1160
5. Pattanaik S, Sarangi K, Mishra SN, Dash A, Priyadarshini A. A study on prevalence of predominant integrated farming systems in coastal Odisha. Biol Forum Int J. 2022;14(4a):729-32.
6. International Panel of Experts on Sustainable Food Systems (IPES-Food). From uniformity to diversity: a paradigm shift from industrial agriculture to diversified agroecological systems. 2016.
7. United Nations. Transforming our world: the 2030 agenda for sustainable development. New York: UN; 2015.
8. Food and Agriculture Organization. The state of food and agriculture: moving forward on food loss and waste reduction. Rome: FAO; 2019.
9. Singh T, Satapathy BS. Intensification of pulses and oilseeds in rice fallows. Indian Farming. 2019;69(10):31-4.
10. Pasupalak S, et al. Strategies for pulse production in rice fallows of Odisha. Bhubaneswar: Orissa University of Agriculture and Technology; 2016.
11. Abraham M, Pingali P. Shortage of pulses in India: understanding how markets incentivize supply response. J Agribus Dev Emerg Econ. 2021;11:411-34. https://doi.org/10.1108/JADEE-11-2017-0128
12. Pattanaik S, Priyadarshini A. Millets: super food for nutrition security and livelihood improvement. In: Pradhan J, Sahoo JP, Samal KC, Dash M, editors. Millets and other potential crops: ensuring climate resilience & nutritional security. London: CRC Press, Taylor & Francis; 2024. p. 11-22. https://doi.org/10.1201/9781003531937-2
13. Neogi S, Ghosh BK. Evaluation of crop diversification on Indian farming practices: a panel regression approach. 2022;14(24):1-18. https://doi.org/10.3390/su142416861
14. Paroda R. Crop diversification for sustainable agriculture. Ecol Econ Soc. 2022;5(1):15-21. https://doi.org/10.37773/ees.v5i1.611
15. Nayak CR. Crop diversification and land productivity in Odisha: role of rural infrastructure. Pragati J Indian Econ. 2015;2(2):1-18. https://doi.org/10.17492/pragati.v2i2.8613
16. Nayak CR, Kumar CR. Crop diversification in Odisha: an empirical assessment. In: Swain M, Nayak CR, editors. Agrarian distress and farmer's suicide in India. New Delhi: S.K. Book Agency; 2018. p. 164-78.
17. Organisation for Economic Co-operation and Development (OECD). Table A.6.2 - Rice projections: consumption, per capita. OECD-FAO Agricultural Outlook 2015. Paris: OECD Publishing; 2015.
18. QGIS Development Team. QGIS Geographic Information System. Version 3.44 "Solothurn". QGIS Association; 2025.
19. Gopinath K, et al. grapesAgri1: collection of Shiny apps for data analysis in agriculture. J Open Source Softw. 2021;6(63):3437. https://doi.org/10.21105/joss.03437
20. Garrett HE, Woodworth RS. Statistics in psychology and education. Bombay: Vakils, Feffer and Simons; 1969. p. 329.
21. Mahajan G. Crop diversification: an empirical analysis of Kangra farm of Himachal Pradesh. Agric Econ Rev. 2004;17:199-217.
22. Mohanty AK, Lepcha B, Kumar A. Constraints analysis in adoption of vegetable production technologies for livelihood perspective of tribal farmers in North Sikkim. Indian Res J Ext Educ. 2013;13(2):51-6.
23. Singh R, Dogra A, Sarker A, Saxena A, Singh B. Technology gap, constraint analysis and improved production technologies for yield enhancement of barley (Hordeum vulgare) and chickpea (Cicer arietinum) under arid conditions of Rajasthan. Indian J Agric Sci. 2018;88(2):109-15. https://doi.org/10.56093/ijas.v88i2.79207
24. Aribi F, Sghaier M. Determinants and strategies of farmers' adaptation to climate change: the case of Medenine Governorate, Tunisia. Agrofor Int J. 2020;5:122-9. https://doi.org/10.7251/AGRENG2002124A
25. Mazzocchi C, Orsi L, Ferrazzi G, Corsi S. The dimensions of agricultural diversification: a spatial analysis of Italian municipalities. Rural Sociol. 2020;85:316-45. https://doi.org/10.1111/ruso.12291
26. Dembele B, Bett HK, Kariuki IM, LeBars M, Ouko KO. Factors influencing crop diversification strategies among smallholder farmers in cotton production zone in Mali. Adv Agric Sci. 2018;6:1-16.
27. Anuja AR, Kumar A, Saroj S, Singh KN. The impact of crop diversification towards high-value crops on economic welfare of agricultural households in Eastern India. Curr Sci. 2020;118:1575-82. https://doi.org/10.18520/cs/v118/i10/1575-1582
28. Cramer JS. Logit models from economics and other fields. Cambridge: Cambridge University Press; 2003. https://doi.org/10.1017/CBO9780511615412
29. Hosmer DW, Lemeshow S. Applied logistic regression. New York: John Wiley & Sons; 2000. https://doi.org/10.1002/0471722146
30. Hoo ZH, Candlish J, Teare D. What is an ROC curve? Emerg Med J. 2017;34:357-9. https://doi.org/10.1136/emermed-2017-206735
31. Wojewodzic T, Jezowit-Jurek M, Rachwał P. Remuneration for labour on agricultural commodity farms in the Małopolska and Pogórze macroregion. Problemy Drobnych Gospodarstw Rolnych. 2015;73-87. https://doi.org/10.15576/PDGR/2015.1.73
32. George GP, Sharma HO. Determinants of crop diversification in Kerala: a temporal analysis. J Trop Agric. 2020;58:99-106.
33. Bansal H, Sharma S, Kumar R, Singh A. The factors influencing and various technological and socio-economic constraints for crop diversification in Haryana. Econ Aff. 2020;65:409-13. https://doi.org/10.46852/0424-2513.3.2020.13
34. Rehima M, Belay K, Dawit A, Rashid S. Factors affecting farmers' crops diversification: evidence from SNNPR, Ethiopia. Int J Agric Sci. 2013;3:558-65.
35. Makate C, Wang R, Makate M, Mango N. Crop diversification and livelihoods of smallholder farmers in Zimbabwe: adaptive management for environmental change. Springerplus. 2016;5

(1):1135. https://doi.org/10.1186/s40064-016-2802-4

36. Mithiya D, Mandal K, Datta L. Trend, pattern and determinants of crop diversification of smallholders in West Bengal: a district-wise panel data analysis. J Dev Agric Econ. 2018;10(4):110-21. https://doi.org/10.5897/JDAE2018.0921

37. Nayak DK. Changing cropping pattern, agricultural diversification and productivity in Odisha: a district-wise study. Agric Econ Res Rev. 2016;29(1):93-104. https://doi.org/10.5958/0974-0279.2016.00022.7

38. Kumar CR. Crop diversification and its determinants: a comparative study between Cuttack and Kandhamal districts of Odisha, India. J Glob Resour. 2020;6. https://doi.org/10.46587/JGR.2020.v06i02.007

39. Mulwa CK, Visser M. Farm diversification as an adaptation strategy to climatic shocks and implications for food security in northern Namibia. World Dev. 2020;129:104906. https://doi.org/10.1016/j.worlddev.2020.104906

40. Dries L, Pascucci S, Gardebroek C. Diversification in Italian farm systems: are farmers using interlinked strategies? New Medit. 2012;4:7-15.

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