Pattern of crop diversification and its implications on undernutrition in India

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The present study explores the pattern and extent of food-crop diversification and its implications on nutritional indicators in India using district-level data for the most recent period. It relied on data from land-use statistics and the National Family Health Survey 2015–16. We estimated the Simpson index for food-crop diversification and undernutrition index for nutritional status. The association of crop diversification and nutritional status was analysed employing bivariate copula function. The findings show striking regional differences in the extent of food-crop diversification and nutritional outcomes. The results of the copula function indicate a significant inverse relationship between crop diversification and undernutrition.

Keywords: Bivariate copula, crop diversification, land use, nutritional status, undernutrition index.

IN India, at the policy level, there is a substantial shift in focus from enhancing food production to promoting farmers' welfare and nutritional security[1]. Diversion, degradation and the continuous fragmentation of agricultural landholdings along with climatic variability and associated risks highlight the need to device alternative strategies for increasing the prospects of farming as an occupation, especially for small and marginal farmers. Enhancing farmers' income by 2022 is a major goal and diversification towards high-value crops is one of the important strategies suggested within agriculture[2]. India has tremendous potential for crop diversification and making farming a sustainable and profitable economic activity[3].

The sustainable development goals (SDGs) have set specific targets aimed at ending poverty, protecting the planet and ensuring prosperity for all by 2030. SDG2 focuses on a global commitment to tackle undernutrition and hunger. It also recognizes the need to promote sustainable agriculture for achieving food security and improved nutrition[4]. The SDG India index suggests that the country's performance towards SGD2 was not satisfactory[5]. Undernutrition among children and adult populations in India is still high[6].

Crop diversification refers to a shift from the regional dominance of one crop to the regional production of several crops. In India, the degree of diversification exhibits large disparities among different regions[7]. Diversification of crops enhances the cropping intensity and productivity growth[8]. Diversification towards more remunerative crops such as fruits, vegetables, plantation crops, etc. can enhance farmers' income security and risk-bearing ability[9–18]. An inverse relationship between the degree of diversification and the likelihood of being poor has been empirically established, and this is specifically true for smallholders[19–22]. Crop diversification also helps reduce the vulnerability of small farmers towards climate change[23].

Diversification among food crops is also important from a nutritional point of view. The literature suggests a direct effect of crop diversification on food availability and nutrition[24–27]. Diverse production systems focusing on horticultural crops increase food security and reduce anaemia[28].

However, the literature emphasizing the empirical relationship between the effects of crop diversification and nutritional status in India is limited. In this study, using district-level data, we assess the relationship between diversification within food crops and the nutritional status in India.

Data and methodology

We explored the relationship between the extent of food crop diversification and undernutrition. The study has covered 21 major Indian states, viz. Andhra Pradesh, Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Karnataka, Kerala, Jammu and Kashmir, Jharkhand, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Telangana, Uttarakhand, Uttar Pradesh and West Bengal. The diversification and nutrition indices were estimated for 549 districts across the states. These states together contribute to about 97% of the total population[29] and more than 90% of gross cropped area to the agriculture sector in India. The food crops group includes cereals and millets, pulses, fruits and vegetables, sugar, spices and condiments, and oilseeds. The area under food crops was considered for estimation of diversification index based on the assumption of its major influence on the nutritional outcomes.

Crop diversification index

The data used for the estimation of district-wise food crop diversification index were collected from the land-use

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District-wise diversification indices were estimated for the 21 major states considering the area under food crops. We estimated crop diversification index using the triennium average of food crops area ending for the year 2015–16, as the recent National Family Health Survey IV (NFHS IV) data used for the estimation of undernutrition index were available for the year 2015–16. District-level indices were estimated due to limitations in the availability of the production and consumption database at the household level.

Simpson index of crop diversification (Sd) was used to assess the degree of crop diversification. The index was estimated using the following formula

$$\mathrm{Sd} = 1 - \sum_{i=1}^{n} p_i^2, \tag{1}$$

where p_i is the proportion of the ith crop/crop sector in the gross cropped area. The diversification index ranged between 0 and 1, with higher values indicating a high degree of crop diversification.

Normalized undernutrition index

We estimated the normalized undernutrition index using data from the district fact sheets of the NFHS IV, 2015–16, following the methodology given by Gulati *et al.*[30]. The index provided a broad perspective on the relative status of the major Indian states in terms of undernutrition.

The percentage of wasted, stunted and underweight children (under the age of 5 years), and the percentage of thin men and women (whose body mass index is less than 18.5 kg/m^2 in the age group of 15–49 years) and anaemic women (in the age group of 15–49 years) were used for the construction of the index. Indicators of child undernutrition included the percentage of underweight, wasted and stunted children. Underweight estimates the weight for a specific age and those children with a ratio below two standard deviations from the average fall under this category. Stunting, which is an indicator of the long-term impact of undernutrition, measures growth retardation in terms of height for age. Wasting, an indicator of current nutrition status, measures the weight for height based on similar standards.

Normalization of the indicators was performed using the formula

$$\text{Normalization indicator} = \frac{\text{Actual values} - \text{minimum value}}{\text{Maximum value} - \text{minimum value}}. \tag{2}$$

Normalizations add robustness to the calculated index values and render them scale-free[30]. Undernutrition indices were calculated as a simple average of the normalized child and adult nutrition indicators, and enable comparison of the performance of the districts in terms of their nutritional outcomes. The undernutrition index ranged from 0 to 100, with higher values indicating a higher extent of undernutrition.

Bivariate copula function

We employed bivariate copula function using conditional distribution of the undernutrition index based on the conditional value of the diversification index[31–34]. Bivariate copulas explain the extent of dependence between two random variables. The present study estimates the conditional distribution of the undernutrition index (random variable Y), given the conditional value of the food crop diversification index (random variable X). Suppose $F_X(x)$ and $F_Y(y)$ represent marginal distribution functions of these variables. The joint distribution function of $F_{X,Y}(x, y)$ according to copula functions can be estimated as

$$F_{X,Y}(x, y) = C[F_X(x), F_Y(y)], \tag{3}$$

where C is the bivariate copula, a cumulative distribution function for a bivariate distribution. For each set of data, we have fitted six copula families, viz. Gaussian, Student t, Clayton, Gumbel, Frank and Joe. To select the best-suited copula function for simulation of the conditional distribution, we employed minimum Akaike's information criterion (AIC) and Bayesian's information criterion (BIC), and the largest log-likelihood value. For observations x_i and y_i ($i = 1, 2, \ldots, n$), the log-likelihood, AIC and BIC of a bivariate copula family C with parameter(s) θ are defined as

$$\text{log-likelihood} = \sum_{i=1}^{n} \ln[C(F_X(x_i), F_Y(y_i)/\theta)],$$

$$\mathrm{AIC} = -2\sum_{i=1}^{n} \ln[C(F_X(x_i), F_Y(y_i)/\theta)] + 2k,$$

$$\mathrm{BIC} = -2\sum_{i=1}^{n} \ln[C(F_X(x_i), F_Y(y_i)/\theta)] + \ln(n)k,$$

where $k = 1$ for one-parameter copulas family and $k = 2$ for two-parameter copulas family.

The joint density function can be written as

$$f_{X,Y}(x, y) = f_X(x) f_Y(y) C_{12}[F_X(x), F_Y(y)], \tag{4}$$

where

$$C_{12}[F_X(x), F_Y(y)] = \frac{\partial}{\partial[F_X(x)]}\frac{\partial}{\partial[F_Y(y)]} C[F_X(x), F_Y(y)].$$

The conditional distribution function of $Y/X = x$ can be written as

$$F_{Y/X}(y/x) = C_1[F_X(x), F_Y(y)], \tag{5}$$

where

$$C_1[F_X(x), F_Y(y)] = \frac{\partial}{\partial[F_X(x)]} C[F_X(x), F_Y(y)].$$

Utilizing eq. (5) the conditional distribution of Y (undernutrition index) can be simulated for given values of X (diversification index). This analysis was done employing the 'VineCopula' package of R software.

Cluster analysis

Using the 'cluster' package of R software, we also performed hierarchical clustering for grouping the districts and states of India based on the estimated values of the undernutrition index.

Results and discussion

Crop diversification index

Figure 1 depicts the district-wise spatial dimensions in the extent of diversification among food crops in India for TE 2015–16. We have four clusters of districts based on the degree of crop diversification among food crops: (i) districts with low levels of food crop diversification (Simpson index range: 0.00–0.20), (ii) districts with medium level of diversification (0.20–0.40), (iii) districts with high level of diversification (0.40–0.60) and (iv) districts with very high level of diversification (0.60 and above). The districts with low to medium degree of food crop diversification were mainly spread over the northern (Punjab, Haryana, Jammu and Kashmir, Uttar Pradesh and Uttarakhand), eastern (Bihar and Odisha) and central states (Chhattisgarh and Jharkhand). Districts with diversification index above 0.60 (very high level) were concentrated in the southern states of Karnataka, Tamil Nadu, Kerala and the central state of Madhya Pradesh.

Of the total 549 districts, the cluster of low-level food crop diversification had 88 districts with a mean index value of 0.12. The second group had 138 districts with medium extent of diversification (average diversification index of 0.30). The third and fourth clusters with high (187 districts) and very high (136 districts) degrees of diversification had mean index values of 0.51 and 0.67 respectively.

The extent of diversification within food crops was low in the northern region, especially in Punjab and Haryana, as more than 90% of the area of food crop cultivation in these states was under wheat and rice. Specialization towards paddy and wheat cultivation adversely affected the agricultural sustainability of the region by the degradation of natural resources[35,36]. About 80% of the gross cultivated area in Odisha and Bihar was under cereals and millets, indicating low level of diversification in the region. The southern region exhibited higher degree of diversification within the food crops. Rice, maize, pulses, oilseeds, and fruits and vegetables were the major crops cultivated in this region.

Undernutrition index

Figure 2 portrays the clustering of major states based on the undernutrition index. This dendrogram represents the hierarchal relationship between the states under consideration using the clustering approach. The results obtained from cluster analysis indicate that the 21 states can be grouped into three distinct groups (low, medium and high performing states) based on the extent of undernutrition.

The low performing states in terms of nutritional outcomes include Jharkhand, Bihar, Gujarat, Madhya Pradesh, Odisha, Maharashtra, West Bengal, Uttar Pradesh, Chhattisgarh and Rajasthan. The mean value of the undernutrition index was 34.27 for the first group. Jharkhand, Bihar and Madhya Pradesh fared the worst in the nutrition status as evident from the index values (39.17, 36.98 and 36.22 respectively). Assam, Andhra Pradesh, Haryana, Karnataka and Telangana constituted the second cluster (medium performing states) with an average undernutrition index value of 28.25. The third cluster consisted of

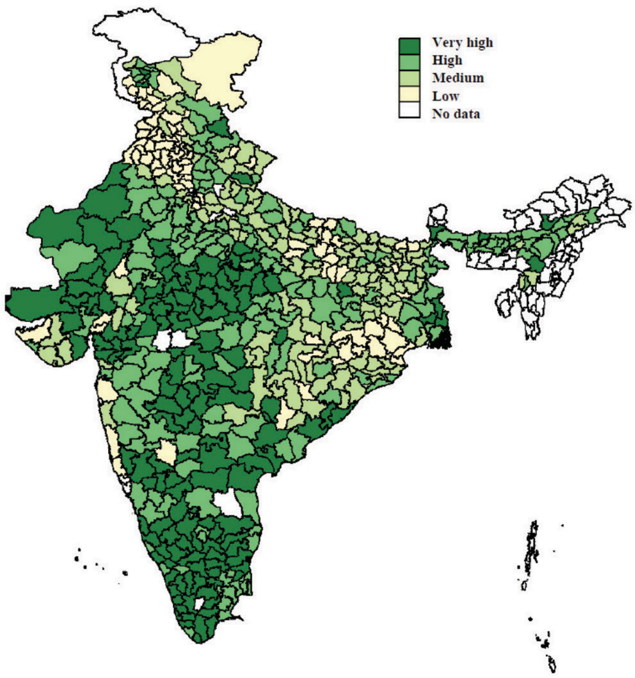

Figure 1. District-wise diversification index for food crops 2015–16.

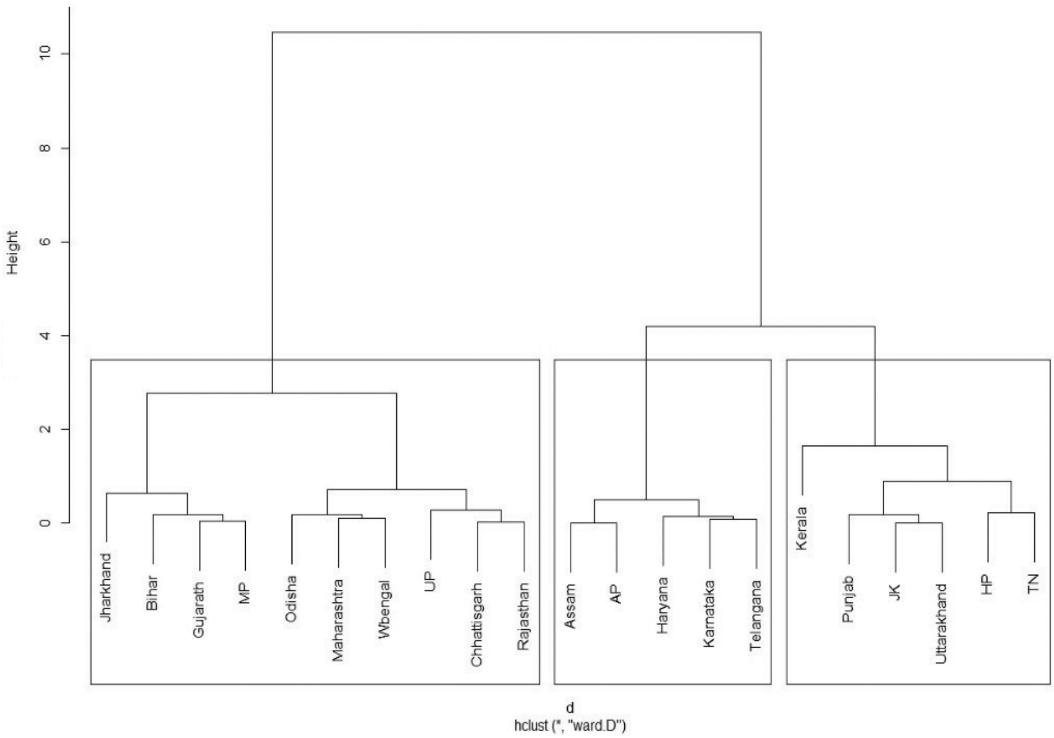

Figure 2. Cluster dendrogram of states based on undernutrition index.

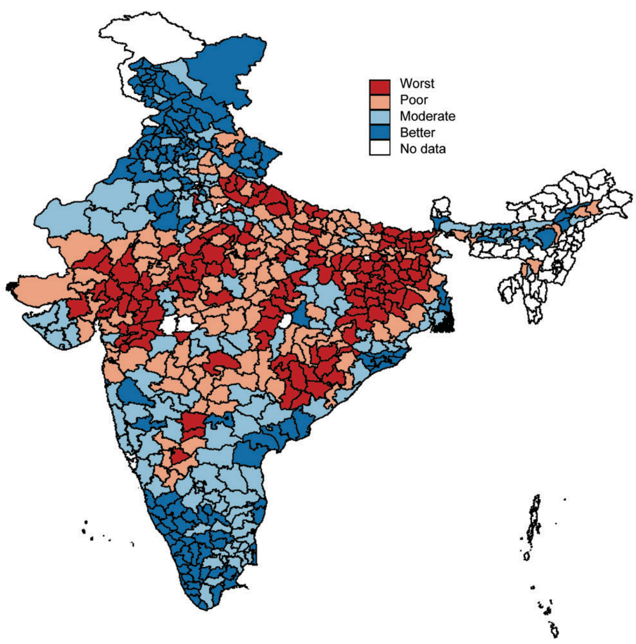

Figure 3. District-wise undernutrition index 2015–16.

six states (high performing states), viz. Kerala, Punjab, Jammu and Kashmir, Uttrakhand, Himachal Pradesh and Tamil Nadu. The mean undernutrition index was 22.43 for the third group which was much lower compared to the low-performing group. Kerala ranked the best with an index value of 16.26.

Figure 3 shows the status of undernutrition across the Indian districts. We observed four clusters of districts: (i) better performing districts having undernutrition index below 26; (ii) moderate performing districts having undernutrition index in the range 26–31; (iii) poorly performing districts having undernutrition index in the range 31–36; and (iv) worst performing districts with undernutrition index above 36.

Of the total 549 districts, the better performing cluster had 134 districts with an average undernutrition index of 22.04. The second moderate performing cluster had 137 districts with a mean index value of 28.52. The third cluster (poor performing districts) which accounted for about 23% of the total sample districts, had an average undernutrition index value of 33.42. The fourth worst-performing cluster had 152 districts with an average index value of 39.15.

The better performing districts were mainly located in the southern states of Kerala, Tamil Nadu, and Andhra Pradesh, and the hill states of Himachal Pradesh, Uttrakhand, Jammu and Kashmir, and Punjab. Kerala, Tamil Nadu, Punjab, Himachal Pradesh, and Jammu and Kashmir were high-income states[37]. Districts of Punjab, and Jammu and Kashmir exhibited simultaneous existence of low food crop diversification, but improved nutritional status. This could be explained by the higher income status of these states. The worst performing districts in terms of nutritional outcomes were spread over the eastern, central and western states.

Table 1. Effect of crop diversification on undernutrition index using copula method

Copula	Gaussian copula	Student's *t* copula	Clayton copula	Gumbel copula	Frank copula
Parameter	–0.03*	Par1: –0.04* Par2: 8.14*	–0.12*	–1.05*	–0.39*
Log-likelihood	0.07	1.46	1.07	1.53	0.55
Akaike's information criterion	1.86	1.07	1.13	0.94	1.41
Bayesian's information criterion	6.17	5.69	5.87	5.24	5.92

*Significant at 5% level of significance.

Table 2. Simulation of conditional distribution of undernutrition index based on conditional value of diversification index

Conditional value of diversification index	Probability of undernutrition index >30	Probability of undernutrition index >35
0.05	0.66	0.38
0.25	0.61	0.34
0.50	0.56	0.29
0.75	0.49	0.24
0.98	0.44	0.18

Crop diversification and undernutrition: bivariate copula function

In this study, among the six fitted bivariate functions, based on AIC, BIC and log-likelihood values, Gumbel copula was found best for the considered datasets (Table 1). From the fitted function, simulation of conditional distribution of the undernutrition index for divergent values of diversification index 0.05, 0.25, 0.50, 0.75 and 0.98 were generated. Further, for each simulated dataset, the probability of an undernutrition index of more than 30 and 35 was computed. About 43% of the districts had an undernutrition index value above 30 and about 32% above 35. We hypothesize that the degree of food crop diversification has a negative influence on the undernutrition status of the respective districts.

Table 2 represents the probability values. The results indicate a strong negative influence of the extent of crop diversification on the undernutrition status in a district. Also, the probability of having an undernutrition index value higher than 35 is significantly reduced at a higher degree of diversification among food crops. Therefore, the results indicate that a higher degree of crop diversification among food crops could reduce the probability of undernutrition. This could be attributed to the enhanced availability and affordability of food crops in the more diversified districts. Though several other factors influence the nutritional outcome of a region, agriculture is the prime sector influencing the production and consumption of nutritious food[38]. According to Gulati *et al.*[30], indicators of the level of agricultural performance or income have a strong and significant negative relationship with indices of undernutrition among adults and children. Crop diversification can directly influence the access, variety and affordability of a diverse diet[27,39]. It is positively correlated with the household-level food consumption by improving the quantity and variety of food[40,41]. Lack of a diverse diet leads to an increase in the proportion of malnourished people[42]. Higher crop diversification also increases the resilience of households to short-term agricultural shocks[43].

Conclusion

Using district-level land-use statistics data, we analysed the status of food crop diversification in India for TE 2015–16. We also analysed the empirical relationship between food crop diversification and nutritional status using spatially disaggregated district-level data and employing bivariate copula function. The following conclusions can be drawn from this study. Striking differences are evident in the degree of food crop diversification and nutritional outcomes across districts. There exists a strong negative relationship between food crop diversification and undernutrition status of the districts. A higher degree of diversification within food crops can significantly reduce the probability of undernutrition.

These findings have some specific policy implications for bridging regional disparities in nutritional outcomes in India. Promoting diversification among food crops can improve the nutritional outcomes of districts showing underperformance. There is a need to focus on crop neutral policies regarding price support, access to inputs and other infrastructure, value-chains and market linkages favouring diversified food systems. Parallel efforts should be made to address the lacunae associated with resource-use efficiency, sustainability, market logistics, regional demand–supply gap and the income demands of farmers.

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