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CURRENT TRENDS, INDICES AND CHALLENGES OF CROP DIVERSIFICATION: A REVIEW

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ABSTRACT

Crop diversification is increasingly recognized as a vital strategy for enhancing agricultural sustainability, farm income and resilience to climate variability. This study examines trends, indices and challenges of crop diversification using secondary data and existing literature. The results show a gradual shift from cereal dominated systems toward high value crops such as horticulture, oilseeds and plantation crops though rice and wheat continue to dominate in many irrigated regions. Diversification patterns vary widely across states, with rainfed regions generally exhibiting higher crop diversity than input intensive areas. Multiple indices including Simpson, Herfindahl–Hirschman, Entropy, Shannon and the Effective Number of Crop Species reveal that overall national crop diversity has remained relatively stable, while several states have experienced either increasing concentration or notable diversification. Despite its ecological and economic benefits, crop diversification faces constraints related to rainfed dependence, resource degradation, weak market linkages, limited access to quality seeds and policy bias toward staple cereals. The study highlights the need for region-specific and policy-supported diversification strategies to strengthen agricultural resilience and sustainability in India.
***Keywords* :** Crop Diversification, Sustainability, Agricultural resilience, Climate Change, Natural Resources.

Introduction

Crop diversification has become a critical strategy for strengthening agricultural sustainability, enhancing farm income, and improving resilience to climate variability in India's predominantly smallholder production system. The need for diversification has intensified due to the limitations of cereal-centric growth and the ecological stresses emerging from monoculture dominated systems, especially in states like Punjab and Haryana (Chand *et al.,* 2011). Monoculture has been widely developed in the last centuries in response to the increasing food demand, linked to the demographic explosion (Tilman *et al.*, 2001). Agricultural expansion and intensification are widely recognized as major drivers of habitat and biodiversity loss, soil and freshwater degradation, environmental pollution, and greenhouse gas emissions across the globe (Campbell *et al.,* 2017). All countries in the world have led to fast depletion of natural resources (Mallick and Lenka, 2006), It is necessary to make best use of available biophysical (mainly land and water) and human resources. It is necessary to diversify crops for reducing risks of yield, market and price of crops, degradation of natural resources and environment and attaining self-reliance in critical crop products, employment generation and earning foreign exchange. Agricultural diversification is the intentional addition of functional biodiversity to cropping systems at multiple spatial and temporal scales, and it aims at regenerating biotic interactions underpinning yield-supporting ecosystem services (Kremen *et al.,* 2012). It is defined by IPES-Food (2016) as a maintenance of "multiple source of production, and varying what is produced across farming landscapes (intercropping) and overtime (crop rotation)". Crop diversification is an alternate way for the substitutability, regeneration and conservation of natural resources to enhance key elements of biodiversity which reduce negative impacts on the environment without compromising crop yields (Bommarco *et al.,* 2013) and can have important implications for farmers' welfare, nutritional security and sustainability in agriculture.

National assessments show that diversification patterns vary widely across regions, with rainfed states often exhibiting higher diversity compared to irrigated, input-intensive areas (GOI, 2021). To understand these variations scientifically, several indices such as the Simpson Diversity Index (Simpson, 1949), Entropy Index (Theil, 1967), Herfindahl–Hirschman Index (Hirschman, 1964), and the Effective Number of Crop Species (Aguilar *et al.,* 2015) are commonly used to quantify the degree of crop diversification.

Despite its potential benefits, crop diversification in India continues to face multiple challenges, including inadequate irrigation, weak market linkages, limited availability of quality seeds, declining public investment, and a policy environment historically biased toward staple cereals (Birthal *et al.,* 2015 and Pingali, 2015). Addressing these constraints is essential to shift Indian agriculture toward a more diversified and climate-resilient production system. Therefore, examining current trends, the measurement of diversification indices and the underlying constraints provides an integrated understanding of the opportunities and limitations shaping India's crop diversification panorama.

Status of Crop Diversification in India

Timeframe of spatial and temporal patterns of crop diversification has been divided into six distinct phases as outlined by Chand and Parappurathu (2012):

1. The pre-green revolution period (PGR) from 1960-61 to 1968-69,
2. The early green revolution period (EGR) from 1968-69 to 1975-76,
3. The period of wider technology dissemination (WTD) from 1975-76 to 1988-89,
4. The period of diversification (DIV) from 1988-89 to 1995-96,
5. The post-reform period (PR) from 1995-96 to 2004-05 and
6. The period of recovery (REC) from 2004-05 to 2010-11.

With the exception of pulses and nutri-cereals (including coarse cereals), the area under nearly all of the major crops has grown throughout time. acknowledged as a new and significant category for guaranteed health coverage. Comparing the recovery era to the pregreen revolution period, the percentage of land under pulses and nutri-cereals has somewhat decreased. Fruits and vegetables are important commodities for both producers and consumers, as seen by a steady and notable growth in their percentage of GCA. Farmers have been encouraged to cultivate more fruits and vegetables due to the short-duration nature of these commodities and the increasing market demand for horticultural crops. More than one-third of the cropping pattern is still made up of rice and wheat. Over the past five to six decades, the proportion of nutri-cereals has significantly decreased. Over time, the area share of fruits and vegetables has increased, indicating that demand and production are focused on high-value products.

Changes in Crop Area from 1971–72 to 2017–18

A preliminary projection of crop diversification might be based on changes in the area of share of particular crops. Rice and wheat were the main crops grown in India. One of the drivers for growing traditional crops in India was the "green revolution," which aimed to address the country's severe food situation right away. Wheat and rice yields had reached record levels when the "green revolution" was successful.

However, in 2000, Indian agriculture saw yet another transformation. The areas with spices and horticulture crops had inevitably grown dramatically. Pertaining to other crops, farmers prioritized on horticulture crops and spices since they were in greater demand and earned higher profits than conventional crops.

Table 1. revealed that, changes in crop area of various crops over time as,

Rice: Crop area increased gradually from 37,758 to 44,904 thousand hectares in 2001-02, then slightly declined 43,774 thousand hectares in 2017-18.

Wheat: Continuous growth of crop area from 19,139 to 29,865 thousand hectares in 2011-12, thereafter remained stable at 29,651 thousand hectares in 2017-18.

Table 1 : Changes in crop area of various crops from 1971–72 to 2017–18

Crop/Year	1971-72	1981-82	1991-92	2001-02	2011-12	2017-18
Rice	37,758	40,708	42,649	44,904	44,006	43,774
Wheat	19,139	22,144	23,262	26,345	29,865	29,651
Other cereals	43,576	42,442	33,418	29,523	26,422	24,287
Pulses	22,151	23,840	34,948	22,008	24,462	29,813

Oilseed	17,125	18,908	25,886	22,636	26,308	24,508
Cotton seed	7800	8060	7661	9132	12178	12586
Sugarcane	2390	3193	3844	4412	5038	4737
Jute	820	830	880	870	810	690
Tea	357	384	421	510	579	577
Coffee	138	217	279	347	410	455
Spices	1395	1712	2005	2777	3448	3878
Total Horticultural Crops	-	-	12,903	16,270	23,694	25,433
(Neogi and Ghosh, 2022)						

Other cereals: Sharp decline from 43,576 to 24,287 thousand hectares in 2017-18.

Pulses: Crop area of pulses was fluctuated, reaching peak of around 34,948 in 1991-92, followed by a significant turnaround to 29,813 thousand hectares in 2017-18.

Oilseeds: Oilseeds crop area grew from 17,125 to 26,308 in 2011-12, then declining slightly to 24,508 thousand hectares in 2017-18.

Cotton seed: Crop area of cotton is gradual rise from 7,800 in 1971-72 to 12,586 thousand hectares in 2017-18.

Sugarcane: Sugarcane crop area expanded from 2,390 to 5,038 thousand hectares in 2011-12, then dropped to about 4,737 in 2017-18.

Jute: Jute crop area remained nearly stagnant up to 2011-12, then decreased from 820 to 690 thousand hectares in 2017-18.

Tea: Crop area of tea shows steady growth, increased from 357 thousand hectares in 1971-72 to 577 thousand hectares in 2017-18.

Coffee: Coffee crop area strongly raised from 138 thousand hectares in 1971-72 to 455 thousand hectares in 2017-18.

Spices: Notable expansion in crop area of spices from 1,395 thousand hectares to 3,878 thousand hectares in 2017-18.

Horticultural crops: Only data from 1991-1992 is provided for horticulture crop area shows rapid expansion from 12,903 thousand hectares in 1991-1992 to 25,433 thousand hectares in 2017-18.

Data indicates that crop area under rice and wheat remained largely stable with moderate growth, while other cereals experienced a sharp decline. In contrast, pulses, oilseeds, cotton, and horticultural crops recorded strong gains and plantation crops such as tea, coffee, and spices expanded steadily. Over the period from 1971-72 to 2017-18, the share of cash crops in India's gross cropped area nearly doubled rising from about 18% to 37%, reflecting significant changes in crop area allocations and a trend toward diversification.

Changes in food and Non-food Crop Area between Triennium Ending Average (TE) 2001 and TE 2016

1. Western Region (Rajasthan, Maharashtra, Gujarat)

The Western region shows a moderate decline in food crop area from 58.22% to 53.20% and a corresponding increase in non-food crops. Rajasthan and Maharashtra experienced noticeable shifts away from food crops, likely due to expansion of oilseeds, cotton and horticulture. Gujarat, however, remained almost stable, with only marginal changes. Overall, the region reflects a clear diversification toward commercial, non-food crops.

Table 2 : Region and State-wise Area Share of Food Crops and Non-food Crops in Gross Cultivated Area (%)

States or Regions	Food crops		Non-food crops	
	TE 2001	TE 2016	TE 2001	TE 2016
Rajasthan	62.31	59.28	37.69	40.72
Maharashtra	69.21	57.53	30.79	42.47
Gujarat	43.14	42.80	56.86	57.20
Western	*58.22*	*53.20*	*41.78*	*46.80*
Uttar Pradesh	92.12	91.20	7.88	8.80
Punjab	82.41	88.04	17.59	11.96
Haryana	73.30	70.79	26.70	29.21
Northern	*82.61*	*83.34*	*17.39*	*16.66*
Madhya Pradesh	66.19	64.79	33.81	35.21
Chhattisgarh	94.81	94.84	5.19	5.16
Central	*80.50*	*79.82*	*19.50*	*20.18*

Andhra Pradesh	67.87	65.39	32.13	34.61
Karnataka	72.63	75.39	27.37	24.61
Tamil Nadu	71.72	76.46	28.28	23.54
Kerala	44.59	37.85	55.41	62.15
Southern	*64.20*	*63.70*	*35.80*	*36.30*
Odisha	88.77	97.98	11.23	3.17
Bihar	95.53	96.36	4.47	3.64
West Bengal	84.42	83.18	15.58	16.82
Assam	81.31	79.72	18.69	20.28
Eastern	*87.51*	*89.31*	*12.49*	*10.98*
TE: Triennium Ending Averages; TE 2001 = 1999-2001, TE 2016 = 2014-2016				
(Rajesh *et al.,* 2021)				

2. Northern Region (Uttar Pradesh, Punjab, Haryana)

The Northern region remained largely stable, with food crop area edging up slightly (82.61% to 83.34%). Uttar Pradesh and Haryana showed minimal changes, indicating continued dominance of cereals, especially wheat and rice. Punjab, however, registered a rise in food crop share, reflecting its entrenched role in the rice–wheat system. Overall, the region retained its strong food-grain orientation.

3. Central Region (Madhya Pradesh, Chhattisgarh)

The Central region experienced only minor shifts, with food crop share decreasing slightly (80.50% to 79.82%). Madhya Pradesh diversified marginally toward non-food crops, while Chhattisgarh remained almost unchanged, maintaining a very high share of food crops. This suggests slow structural change in cropping patterns, with continued reliance on staples.

4. Southern Region (Andhra Pradesh, Karnataka, Tamil Nadu, Kerala)

The Southern region remained nearly stable overall, with a small dip in food crop area (64.20% to 63.70%). However, internal variation is clear: Karnataka and Tamil Nadu increased food crop shares, while Andhra Pradesh slightly reduced it. Kerala showed the largest shift, with a major decline in food crops and an increase in non-food crops, consistent with its strong plantation and horticulture sector. The region displays diverse state-level dynamics rather than a single uniform trend.

5. Eastern Region (Odisha, Bihar, West Bengal, Assam)

The Eastern region saw an increase in food crop share (87.51% to 89.31%), strengthening its role as a food-grain-focused region. Odisha and Bihar particularly showed strong increases, while Assam and West Bengal had only minor adjustments. Non-food crops declined slightly overall. This indicates a growing consolidation of land under food crops, likely linked to rice dominance and limited diversification opportunities.

Measures of Crop Diversification

1) Simpson Diversity Index (SDI)

The Simpson Diversity Index measures the extent of diversity or degree of crop diversification.

$$D_1 = 1 - \Sigma Pi^2$$

Where, Pi = Proportionate area of the i^{th} crop in the gross cropped area.

The index ranges between 0 and 1. Higher values indicate high degree of crop diversification. Simpson's index, which was created by Edward H. Simpson in 1949, is a weighted arithmetic mean of proportional abundance that quantifies the likelihood that two randomly chosen individuals from a sample will be members of the same species. Because the mean of the proportional abundance of the species rises as the number of species decreases and the abundance of the most abundant species increases, the value of this index receives small values in data sets with high diversity and large values in data sets with low diversity (Simpson, E. H. 1949 and Magurran, A. E. 1988).

Degree of Crop Diversification (TE 2016-17)

Rajesh *et al.,* 2021 categorizes states based on the range of diversity. The categories are low, medium and high. For each category, states are grouped based on whether they primarily grow food crops or non-food crops.

1. Low diversity index (0.00 – 0.30)

These states show low variation or low diversification in the measured Sd value. Punjab and Haryana states have stable, intensive food crop agriculture, especially wheat and rice. Odisha, Madhya Pradesh, and Chhattisgarh states fall into the low Sd category for non-food crops, indicating low variability or limited cultivation of non-food crops.

2. Medium diversity index (0.31 – 0.60)

Medium diversity index category contains the largest number of states, indicating moderate Sd levels of diversity. States like Uttar Pradesh, Bihar, West Bengal, Assam shows moderate level of diversity or variability in food crop production. States such as Punjab, Rajasthan, Gujarat, Andhra Pradesh and Karnataka have medium Sd values for non-food crops. This indicates these states have moderate non-food crop cultivation.

3. High diversity index (0.61 – 1.00)

This category shows high variability or high intensity in Sd values of diversity index. Kerala and Karnataka states show high Sd values for food crops, possibly due to diverse crops and climatic variations. Uttar Pradesh, Haryana, Bihar, West Bengal, Assam and Maharashtra states have high Sd values for non-food crops, suggesting strong or diverse non-food crop production.

States with intensive food grain agriculture (Punjab, Haryana, UP, Bihar) fall mostly in low or medium Sd categories except Kerala and Karnataka. Many industrial crop producing states (Maharashtra, Gujarat, Karnataka, Tamil Nadu) fall in medium or high Sd categories. The Sd value likely represents a diversity index and statistical dispersion related to cropping pattern.

2) Index of Maximum Proportion:

Index of maximum proportion represents the highest percentage of the total cropped area occupied by the ith crop. It is an indicator of concentration of crops. As crop diversity increases, index of maximum proportion decreases (Bhatia, S. S. 1965a).

$$\mathbf{D_1 = Max\ Pi;\ i = 1, 2, \ldots, r}$$

Where, r is the total number or types of crop

$$Proportion\ of\ area\ under\ ith\ crop = \frac{Pi\ Actual\ area\ under\ crop}{Total\ cropped\ area}$$

3) Entropy Index:

It is having logarithmic character and is inverse measure of concentration. The range of Entropy index is 0 to 1 (Theil, 1967).

$$D2 = \sum_{i=1}^{r} Pi \log\left(\frac{1}{Pi}\right)$$

Where, Pi = Proportionate area under the i^{th} crop and r = Number of crops

4) Herfindahl – Hirschman (HHI) Index:

Competitiveness of crops in terms of concentration is estimated by Herfindahl – Hirschman index. It is used to determine the level of crop diversity and the area-occupied by a certain crop in an area. HHI has a range of 0 to 1 Complete specialization is symbolized by an index value of 0, while complete diversification is denoted by a value of 1 (Herfindahl, O. C. 1950) and (Hirschman, A. O. 1964).

$$D3 = \sum_{i=1}^{r} Pi^2$$

Where, Pi = Proportionate area under the i^{th} crop in gross cropped area and r = Number of crops

Table 3 : Herfindahl Index of Crop Diversity in Various States in India (Mallick and Pattanayak, 2019)

States	2007-08	2013-14	% Change
Andhra Pradesh	0.0765	0.0442	-42.22
Bihar	0.0259	0.0278	7.33
Gujarat	0.5525	0.2122	-61.59
Haryana	0.024	0.018	-25
Karnataka	0.1542	0.199	29.05
Maharashtra	0.1463	0.1202	-17.84
Odisha	0.0166	0.0151	-9.03
India	**0.0575**	**0.0616**	**7.13**

The data from Mallick and Pattanayak (2019) shows that diversity of crops, as measured by the Herfindahl index, changed unevenly across Indian states between 2007-08 and 2013-14. States like Gujarat, Andhra Pradesh, Haryana, and Maharashtra experienced a significant reduction in diversity, indicating less diverse crop cultivation. Odisha also showed marginal improvement. In contrast, Karnataka and Bihar recorded an increase in Herfindahl index values, reflecting rising crop diversification, likely due to climatic or structural factors. At the national level, India's Herfindahl index increased slightly by 7.13%, suggesting a modest rise in overall crop diversification despite improvements in several major states.

5) Simpson's Diversification Index and Gini-Simpson Index:

The value of Simpson's index ranges from 0 to 1, with 0 representing infinite diversity and 1 representing no diversity. So, the larger the value of D_4, the lower the diversity. For this reason, Simpson's index is also expressed as its inverse, which is known as Inverse Simpson's index (Simpson, E. H. 1949).

Simpson's Diversification Index (D_4) = ΣPi^2

Inverse Simpson's index (D_5) = ($1/ D_4$)

Where, D_3 - Herfindahl – Hirschman index

6) Alternative Gini-Simpson Index (AGSI)

Gini-Simpson Index is defined above as the reverse of Simpson index. Actually, it mainly represents the reverse of concentration of crops in terms of weighted average of number of crops occupying an area in a region. This can also be alternatively defined as the reverse of the weighted average of the proportion of area occupied by a crop in a given region. Thus, the Alternative Gini-Simpson Index (AGSI) is given as

$$\mathbf{D_7 = (1 - D_3)}$$

Where, D_3 - Herfindahl – Hirschman index

The value of Alternative Gini-Simpson index ranges from 0 to 1, with 0 representing complete specialization and 1 representing complete diversification (Shiyani, R. L. and Pandya, H. R. 1998).

7) Shannon Diversity Index (H′)

Shannon diversity index is widely used to measure crop diversity, accounting for both the number of crops and the evenness of their area distribution (Jost, L. 2006). It is calculated as,

$$H' = \sum_{i=1}^{r} Pi^2 \; ln\,(Pi)$$

Where, Pi = Proportionate area under the i^{th} crop in gross cropped area and r = Number of crops

8) Effective Number of Crop Species (ENCS)

Aguilar *et. al.,* (2015) reported a crop diversification index called the 'Effective Number of Crop Species' (ENCS) which is calculated as follows:

$$\mathbf{ENCS = e^{H'}}$$

Where, H - Shannon diversity index

Table 4 : State wise number of effective crop species

State	Effective Number of Crop Species		
	2005-06	2010-11	2015-16
All India	18.7	18.6	18.1
Maharashtra	15.8	14.7	14.7
Andhra Pradesh	14.2	12.8	14.6
Arunachal Pradesh	5.9	5.0	6.5
Assam	5.8	5.8	5.7
Bihar	5.7	6.1	5.7
Chhattisgarh	4.0	3.8	3.8
Delhi	5.1	5.0	4.8
Goa	6.1	5.8	6.1
Gujarat	15.5	14.9	16.0
Haryana	7.4	7.1	6.1
Himachal Pradesh	6.3	6.0	6.3
Jammu and Kashmir	6.7	6.9	6.8
Jharkhand	3.7	4.4	4.8
Karnataka	20.1	21.0	21.0
Kerala	11.2	11.0	10.6
Madhya Pradesh	11.5	10.9	9.7
Maharashtra	15.8	14.7	14.7
Manipur	3.2	4.8	5.7
Meghalaya	11.6	10.8	13.3
Mizoram	5.4	10.8	10.6
Nagaland	10.0	10.2	10.5
Odisha	6.8	2.5	2.1
Punjab	4.5	4.2	4.0
Rajasthan	10.9	12.3	11.7
Sikkim	8.2	11.7	10.9
Tamil Nadu	13.6	14.1	13.3
Telangana	1.0	1.0	8.5

Tripura	1.6	6.7	7.7
Uttar Pradesh	8.3	8.1	7.9
Uttarakhand	8.5	8.2	8.4
West Bengal	5.1	5.9	6.0
Andaman and Nicobar	5.1	7.2	6.8
Chandigarh	3.1	2.5	1.5
Dadra and Nagar Haveli	6.4	6.1	5.7
Daman and Diu	1.5	3.8	3.6
Lakshadweep	2.2	2.3	1.0
			(GOI, 2021)

The number of crops that are considered to dominate production in a given area is indicated by the ENCS value. Therefore, high crop diversification is indicated by a higher ENCS value, while low crop diversity is indicated by a low value.

From the table 4., signifies that the effective number of crop species (ENCS) across India shows a slight decline from 18.7 in 2005–06 to 18.1 in 2015-16, indicating marginal reduction in overall crop diversity. State-level trends, however, vary widely. States like Karnataka, Gujarat, Meghalaya, Mizoram, Nagaland, Manipur, Telangana and Tripura experienced noticeable increases in ENCS over time.

In contrast, states such as Madhya Pradesh, Kerala, Haryana, Punjab, Odisha, and Delhi show declining ENCS, with Odisha experiencing a sharp fall from 6.8 to 2.1. Many states exhibit fluctuations rather than consistent trends, reflecting influences of regional cropping patterns, climatic conditions, market demands and policy shifts. Overall, the data suggests that while India's crop diversity is relatively stable nationally, several individual states exhibit either strong diversification or significant narrowing of crop species over the decade.

Benefits of Crop Diversification

1. Biodiversity

Crop diversification increases agricultural biodiversity (genetic, species and ecosystem) Beillouin *et al.,* 2019; Jarvis *et al.,* 2011; Joshi *et al.,* 2020), improves crop yields (Nankya *et al.,* 2017, Vernooy and Vongkhamsao, 2015) and produces quality to address both food Aggarwal *et al.* 2018, Bezner Kerr *et al.*, 2019, Mango *et al.,* 2018) and nutritional security (Mabhaudhi *et al.,* 2019, Nelimor *et al.,* 2019.

This practice also reduced pest and disease pressure (Jarvis *et al.*, 2011, Kozicka *et al.,* 2020), because it can provide several agronomic advantages for managing pests by disrupting the cycles of insects and diseases, decreasing weeds and soil erosion, and preserving soil moisture. The population of beneficial pest-fighting microorganisms in the soil is more multifaceted in farming systems with a greater diversity of plants, animals, and soil-borne organisms.

2. Cultural

Crop diversification is an integral part of traditional cultural heritage practices, which link the development of natural elements, governance systems, cultural values and sociocultural patterns. In order to adapt agriculture to climate change, local communities' traditional knowledge of ecosystem management and sustainable use of natural resources is crucial. This knowledge can be strengthened through local seed systems, farmers' rights to traditional crops, and market access for local varieties. Traditional crop varieties are more affordable, more accessible, more diverse and more climate-resistant than contemporary hybrids. (Swiderska *et al.,* 2011).

3. Climate change

Crop diversification offers resistance to hostile, erratic conditions inevitably brought on by climate change (Kozicka *et al.,* 2020, Makate *et al.,* 2016, Vernooy and Vongkhamsao 2015). It reduces greenhouse gas emissions while increasing soil carbon sequestration (Mabhaudhi *et al.*, 2019; Meldrum *et al.,* 2018).

Crop diversification is most promising sustainable agricultural management practices to maintain existing soil organic carbon stocks and restore them in carbon-depleted soils which simultaneously address food security, soil degradation, and also increase adaptive capacity to climate change (Abu-Zaitoun *et al.,* 2018; Aggarwal *et al.*, 2018, Kozicka *et al.,* 2020, Nelimor *et al.,* 2019, Md and Jensen 2017).

4. Socio-economical

Farming families can lower the financial risks associated with unfavourable weather or market shocks by spreading production and economic risk over a wider variety of crops through crop diversification. A rural community's economic potential can be enhanced by the incorporation of a variety of crops, which in certain places can result in the creation of new agriculture-based companies. This strategy can boost revenue for small agricultural holdings while lowering production expenses. (Beillouin, Ben-Ari, and Makowski 2019, Meldrum, Sidibe and Padulosi 2020, Vernooy and Vongkhamsao 2015, Tesfaye and Tirivayi 2020) and reduce poverty (Michler and Josephson 2017). Crop diversification may strengthen the innovation capacity of farmers about crops and cropping system (McCord *et al.,* 2015). It creates more marketing opportunities for farmer (McCord *et al.,* 2015).

Challenges in Crop Diversification

Crop diversification in India faces numerous structural and resource-related challenges. A major constraint is that nearly 117 million hectares about 63 percent of the total cropped area depend entirely on rainfall, making agricultural production highly vulnerable to climatic variability. Resource use is often sub-optimal, with both over-exploitation and inefficient utilization of soil, water and nutrient inputs. Diversification efforts are further limited by an inadequate supply of quality seeds and planting materials of improved cultivars. The fragmentation of landholdings restricts the adoption of modern technologies and mechanization, while poor rural infrastructure, including roads, power, transport and communication, hinders market access and timely agricultural operations.

Additionally, post-harvest technologies remain insufficient, leading to high losses and reduced profitability. The country's agro-based industries are relatively weak, limiting value-addition opportunities. Institutional issues such as weak research extension farmer linkages reduce the effective transfer of technologies to the field. Moreover, declining public and private investment in agriculture over the years has further constrained the development of diversified and resilient farming systems.

Researchers have identified several critical challenges in the crop diversification as follows:

1. Maladaptation from Unbalanced Crop Portfolios

A key challenge in crop diversification research is the risk of maladaptation arising from unbalanced crop portfolios. Meldrum *et al.,* (2018) emphasize that when farmers depend excessively on a narrow set of crops, diversification strategies may fail to enhance resilience and can even increase vulnerability to climatic or market shocks.

2. Insufficient insight into multiple dimensions of poverty

Another major limitation is the inadequate understanding of how crop diversification interacts with different dimensions of poverty. Feliciano (2019) and Hansen *et al.*, (2019) highlight that most studies overlook the complex socioeconomic factors such as access to land, capital and technology that shape diversification outcomes, thus limiting the effectiveness of poverty focused interventions.

3. Limited understanding of crop quality, income and profitability

Crop diversification research often focuses on area-level measures while neglecting quality attributes, marketability, and profitability. Beillouin, Ben-Ari and Makowski (2019) point out that without incorporating economic dimensions, diversification assessments fail to capture real benefits for farmers.

4. Limited insights into the dimensions of resilience

Although diversification is widely promoted as a resilience strategy, Onyeneke *et al.,* (2019) argue that empirical studies rarely address the multiple dimensions of resilience *viz.,* ecological, economic and social leading to incomplete understanding of how diversification truly contributes to system stability.

5. Lack of gender-disaggregated analyses

Several studies observe a critical gap in examining the gendered nature of diversification outcomes. Reports by FAO (2016) and studies by De Pinto *et al.* (2020) and Reynolds *et al.,* (2020) reveal that women's roles, constraints, and benefits are often overlooked, resulting in gender-blind policies.

6. Inadequate analysis of social resilience

The role of social resilience including farmer networks, knowledge exchange and community institutions remains insufficiently studied. Altieri *et al.,* (2015), along with Beillouin, Ben-Ari and Makowski (2019) and Hufnagel, Reckling and Ewert (2020), highlight that ignoring social dynamics limits the understanding of diversification's broader impacts.

7. Underexplored political dimensions of resilience

Political factors such as governance, institutional support and power relations are seldom incorporated into diversification. Cordoba V., Hortua, R. and Leon, S. (2019) emphasize that political conditions strongly shape farmers' diversification decisions but remain understudied.

8. Insufficient policy analysis

Multiple authors including Bedmar, V., Di Falco, Bezabih and Yesuf (2010), Duong *et al.,* (2019) and Rampa and Knaepen (2019) observed that policy influences on crop diversification are rarely analysed in depth. This gap limits understanding of how subsidies, trade policies, or extension programs impact diversification outcomes.

9. Conceptual ambiguity in crop diversification

Finally, Hufnagel, Reckling and Ewert (2020) noted that crop diversification lacks a coherent conceptual framework. There is inconsistency in definitions, indicators, and methodological approaches.

Conclusion

Crop diversification is a key strategy for improving sustainability, farm income, and climate resilience in Indian agriculture. Evidence from long-term trends and diversification indices indicates that although India has gradually moved toward high-value crops such as horticulture, oilseeds, and plantation crops, cereal dominance particularly rice and wheat continues in many regions. Diversification patterns vary widely across states, with rainfed regions generally showing higher diversity than irrigated, input-intensive areas.

The use of multiple indices reveals that national-level crop diversity has remained relatively stable, but significant state-level disparities persist, including declining diversity in several major agricultural states. While crop diversification offers substantial benefits in terms of biodiversity, resource conservation, climate adaptation, and livelihood security, its potential is constrained by structural, institutional, and policy related challenges. Moreover, poorly balanced diversification strategies may fail to enhance resilience and can even increase vulnerability. Therefore, crop diversification in India requires context-specific, economically viable and institutionally supported approaches to achieve sustainable outcomes.

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