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Spatial Diversity in Indian Wheat and its Determinants

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Abstract

Spatial diversity of crop varieties is an indicator of richness of genetic base, and has a bearing on productivity and sustainability of crop production. This paper has analysed the spatial distribution of wheat varieties in five Indian states using three spatial diversity concepts, to measure the richness, inverse dominance and evenness. All the three indices have revealed a higher spatial diversity in the states of Uttar Pradesh and Madhya Pradesh and a lower diversity in the states of Punjab and Haryana. The effect of varietal demand and supply factors, and agro-ecologies on the spatial distribution has been established through Zellner's seemingly unrelated regression (SUR) estimation.

Key words: Spatial diversity, wheat varieties, Zellner's seemingly unrelated regression model, Margalef richness index, Berger-Parker inverse dominance index, Shannon evenness index

JEL Classification: Q16, Q18, Q57

Introduction

The contribution of wheat towards food security of India is unquestionable. The share of wheat in the total foodgrain production of the country is about 36 per cent (GoI, 2014). In the early 1960s, when India was facing acute shortage of foodgrains, agricultural researchers identified that dwarf wheat varieties could help managing food shortage. Subsequently, with the help of imported wheat lines from the International Maize and Wheat Improvement Centre (CIMMYT), India introduced semi-dwarf high-yielding wheat varieties which led the path to green revolution and helped India to attain self-sufficiency in foodgrain production (Nagarajan, 2004). Wheat production in India has increased at the annual growth rate of 3.9 per cent since introduction of high-yielding varieties elevating the importance of wheat in achieving food security (Singh *et al.* 2013). Since then many wheat varieties, suiting to different agro-climatic conditions, have been developed and released for cultivation by both public and private sectors. The pattern of spatial

distribution of crop varieties influences production as well as production pattern of a region. Different wheat varieties carry inherent genes in them, and act as banks of genetic base. Thus, spatial distribution is an indicator of crop genetic diversity. The crop genetic base that an agricultural system carries contributes heavily towards its sustainability.

The diversity in varieties grown by a farmer not only influences the yield, but also determines the magnitude of the associated production risk (Smale *et al.*, 2003). If most of the cropped area is under one variety, the production system is prone to more risks. Agricultural systems that lack in genetic diversity have been proved to be vulnerable to biotic and abiotic stresses of various kinds and magnitude (Frankel and Bennett, 1970; Smale, 1997). It is therefore important to influence and modify the genetic diversity for enhanced efficiency and sustainability gains. This calls for scientific investigations on the genetic diversity of crops in different regions of the country. Since genetic diversity is a complicated subject, the concept of spatial diversity of crop varieties can be considered as a proxy and has been dealt with in the present paper.

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Data and Methodology

Spatial diversity indices can be used to study the varietal distribution effectively. These indices are commonly used in the ecological studies to measure species diversity. In this study, three such indices have been used to measure diversity in wheat varieties. The distribution of varieties depends on a number of factors. The farmers' varietal choice is the primary among them, and it depends directly on the morphological characteristics or the phenotype of varieties. The farmers' demand for improved varieties, availability of varieties and agro-ecological factors of production in a region are the three broad factors that influence the spatial diversity.

In this study, the spatial diversity indices of wheat have been computed, in terms of richness, dominance and evenness, for five major wheat-growing Indian states, viz. Bihar, Haryana, Madhya Pradesh, Punjab and Uttar Pradesh using the panel data on varietal shares in seed distribution. Indices have been calculated for six years, from 2010-11 to 2015-16. The factors that explain the variability in these indices have also been tested using Zellner's seemingly unrelated regression (SUR). The data on the shares of different varieties in total certified seed distribution of wheat were compiled from the farmers' portal of the Government of India (<http://farmer.gov.in/>). The characters of individual varieties were compiled from Kundu *et al.* (2006).

Diversity and Diversity Indices

The diversity essentially exemplifies the heterogeneity and variability of any parameter under consideration. Numerous indices are available for use in diversity analysis and the selection of any such

indices depends upon the requirement of the study (Meng *et al.*, 1998). Our aim is to analyse the varietal diversity in wheat, with respect to its spatial distribution. No single index is sufficient to describe the concept of diversity as it is multi-dimensional in nature (Hurlbert, 1971; Purvis and Hector, 2000). We have used three different diversity indices which are predominantly used in ecosystem studies. The modification of these indices to suit our study and the explanation of variables are presented in Table 1.

In analysis of diversity, richness is a widely accepted concept. In biodiversity studies, it indicates the number of species or attributes present in a population (Whittaker, 1972). The popularity of richness measures in assessing the diversity is primarily due to its simplicity. We have used Margalef richness index, which is represented by the ratio of number of wheat varieties grown in an area to the logarithm of the total wheat area in that year. A higher diversity is indicated by the higher value of richness index. The dominance or abundance of a variety is studied using Berger-Parker index (May, 1975; Caruso *et al.*, 2007). This index calculates the relative abundance of a variety with the highest area share by taking the inverse of its area share in total wheat area. The certified seed distribution values of wheat varieties (compiled from the farmers' portal, GoI) were taken as proxy to their area coverage. The higher dominance is indicated by lower value of the index. Efforts to construct a single index that takes both, richness and dominance into consideration, resulted in Shannon index (Magurran, 2004). Shannon index is calculated by taking the negative of the summation of product of proportion of area share and its logarithm. The higher values of this index suggest greater equality in distribution of individual variety.

Table 1. Spatial diversity indices

Index	Concept	Mathematical depiction	Variable explanation
Margalef	Richness	$D = (S-1)/\ln N$	S is the number of wheat varieties grown in a season, and N is the total area of wheat in that year
Berger-Parker	Inverse dominance or relative abundance	$D = 1/(N_{\max}/N)$	N_{\max} is the maximum area occupied by a single variety
Shannon	Both richness and relative abundance	$D = -\sum p_i \ln p_i$	p_i is the area share occupied by the i^{th} variety

Source: Adapted from Smale *et al.* (2003)

Table 2. Variables used in regression and their definitions

Variables	Definition	Data source
D ^c	Maraglef richness index for wheat varieties grown	Authors' calculations based on certified seed distribution
D ^d	Berger-Parker dominance index for wheat varieties grown	Authors' calculations based on certified seed distribution
D ^e	Shannon evenness index for wheat varieties grown	Authors' calculations based on certified seed distribution
X (Farmers' demand for trait)	Average yield potential of wheat varieties (tonnes/ha)	Kundu <i>et al.</i> (2006)
	Average hardness index of wheat varieties	Kundu <i>et al.</i> (2006)
	Yield potential of variety with highest seed distribution (tonnes/ha)	Kundu <i>et al.</i> (2006)
	Days to mature of variety with highest seed distribution (No.)	Kundu <i>et al.</i> (2006)
	Plant height of variety with highest seed distribution (cm)	Kundu <i>et al.</i> (2006)
	Hardness of variety with highest seed distribution	Kundu <i>et al.</i> (2006)
S (Supply of varieties)	Number of varieties released in past 5 years for cultivation in respective states	Kundu <i>et al.</i> (2006)
	Recommended varieties as proportion of varieties grown	Kundu <i>et al.</i> (2006)
Z (Production environment)	Average rainfall (cm)	Agricultural Statistics at a Glance
	Variables for states	

Determinants of Spatial Diversity

The area that a farmer allocates to a particular variety depends on its traits vis-à-vis others. Trait preference of farmers is the first factor that determines the spatial diversity. Availability or the supply of the variety in the form of seeds and the agro-ecological factors also significantly influence the spatial diversity. Regression analysis was done using variables that fall under one of the above three groups. The definitions of these variables have been specified in Table 2. The farmers' demand for traits (X) of varieties could affect the spatial diversity. The factors that determine the demand for traits could be yield potential, hardness, days to maturity and plant height¹. The wheat varietal supply (S) has been explained in terms of the number of varieties released in the past five years for cultivation in the states, and the ratio of varieties recommended to varieties grown. Finally, the agro-ecological factors (Z) were taken into consideration through rainfall. Three

different regressions were estimated for the three concepts of spatial diversity, resulting in three equations which were specified as a function of a set of variables (related to trait demand, varietal supply, and agro-ecological factors). The general forms of the three equations are:

$$\text{Richness index} = a_1 + \beta_1 X + \beta_2 S + \beta_3 Z + u_1 \quad \dots(1)$$

$$\text{Inverse dominance index} = a_2 + \gamma_1 X + \gamma_2 S + \gamma_3 Z + u_2 \quad \dots(2)$$

$$\text{Evenness index} = a_3 + \alpha_1 X + \alpha_2 S + \alpha_3 Z + u_3 \quad \dots(3)$$

where, X is the farmers' demand for varieties which is proxied by traits like yield, grain hardness, days to maturity, and height. S is the varietal supply which incorporates the varieties released in the past 5 years and the proportion of recommended varieties to the cultivated varieties, and Z is the agro-ecological factors encompassing rainfall and states where the crop is grown.

¹ Resistance to biotic and abiotic stresses, particularly to yellow rust, and adaptability to sowing time could also determine the demand for a wheat variety. Since different varieties have varying degrees of resistance (low to high) to yellow rust, and since it varies across regions and crop season, we could not include it as an explicit factor in our analysis. The adaptability to sowing time is intrinsic in the days to maturity factor considered.

Zellner's seemingly unrelated regression (SUR) model was used for the analysis since the errors that affect the richness may also affect relative abundance and evenness. The SUR estimates these equations jointly, thus exploiting the above mentioned assumption. The benefits of using the SUR will be larger if the correlation among the error-terms is higher and the matrices of independent variables are distinct (Greene, 1997).

Results and Discussion

Wheat Varieties in India

The government of India has implemented several successful programmes to ensure improvement of wheat yield. The "wheat programme" of 1965 is believed to be the back bone of varietal development attempts in the country. Since this programme was rolled out, about 400 wheat varieties have been released. The varieties like Kalyansona, Sonalika, Lerma Rojo, etc., which were released in the 1960s became popular within a very short span of time. These varieties along with several others released by the government and adopted by farmers were later replaced by the improved ones. The PBW, GW, HD and HI varieties (and several other improved varieties) were the newer ones that occupied the wheat producing area of the country in the post-2000 era. Some of the

varieties which were released in the 1980s continued to occupy the farmers' fields even though their share in area has decreased. The age and average yield of major varieties of the major wheat-growing states of the country are presented in Table 3. The age of most of the top five wheat varieties in these states is less than 10 years. In some states, the farmers have shown the tendency to continue with the old varieties which are with them for the past 20 to 30 years. The average yield of the popular wheat varieties given in Table 3 is 4.6 to 5.0 tonnes per ha. Thus, yield is not the only factor that determines the popularity of a wheat variety. The suitability of a variety to a particular region and other preferences of farmers like seed texture, plant height, crop duration, etc. are also important. The certified seed distribution values and the likely area coverage of the popular ten wheat varieties in selected states (Table 4) also support this. The evolution of wheat varieties is a continuous process and it is important while we study the diversity in wheat varieties.

Spatial Diversity Indices

Figures 1, 2 and 3 depict the Margalef richness, Berger-Parker relative abundance and Shannon evenness indices, respectively for the wheat varieties grown in the five selected states of India from 2010-11 to 2015-16. The spatial diversity of wheat varieties

Table 3. Age and average yield of popular wheat varieties in selected states of India, 2015

Wheat variety	Age (years)	Average yield (t/ha)	Wheat variety	Age (years)	Average yield (t/ha)	Wheat variety	Age (years)	Average yield (t/ha)
Bihar			Haryana			Uttar Pradesh		
HD 2967	4	5.04	HD 2967	4	5.04	PBW 590	8	4.7
DBW 17	9	4.84	HD 2851	12	4.5	PBW 502	12	4.62
PBW 550	8	4.77	DBW 17	9	4.84	PBW 550	8	4.77
PBW 502	12	4.62	PBW 343	20	4.92	PBW 343	20	4.92
PBW 343	20	4.92	WH 711	14	4.8	HD 2967	4	5.04
Madhya Pradesh			Punjab					
GW 322	13	4.47	HD 2967	4	5.04			
GW 366	9	5.17	PBW 550	8	4.77			
Lok 1	34	3.8	PBW 621	4	5.1			
GW 273	18	4.47	HD 3086	1	5.4			
HI 1544	8	5.14	HD 2932	8	4.2			

Source: Kundu *et al.* (2006)

Table 4. Distribution of certified seeds of major wheat varieties in selected states, 2015

Wheat variety	Seed distributed (‘000 quintals)	Likely area coverage based on seed distribution (‘000 ha)	Wheat variety	Seed distributed (‘000 quintals)	Likely area coverage based on seed distribution (‘000 ha)
Bihar			Haryana		
HD 2967	155.53	366.13	HD-2967	775.30	1291.29
DBW-17	142.50	335.46	HD-2851	184.15	306.71
PBW-550	134.50	316.63	DBW-17	100.28	167.02
PBW-343	101.00	237.76	WH 1105	88.87	148.02
PBW-502	100.04	235.49	WH 711	87.08	145.04
DPW 621-50	70.00	164.79	PBW-343	83.61	139.26
HD 2824	51.75	121.82	Sapthara	32.99	54.95
PBW-373	50.00	117.70	PBW-550	31.35	52.21
PBW-154	30.40	71.57	RAJ-3765	27.96	46.57
CBW-38	20.58	48.44	C-306	19.65	32.72
Madhya Pradesh			Punjab		
LOK-1	537.46	2102.53	HD-2967	1042.37	2955.52
GW-322	311.28	1217.72	Ganga	115.64	327.89
HI-1544	179.52	702.28	PBW-550	19.10	54.16
GW-366	82.89	287.91	DBW-17	12.75	36.16
HI8663	71.49	248.31	HD-2851	11.51	32.62
GW-273	46.93	162.98	PBW-343	9.07	25.71
HI-8498	35.51	123.33	WH 711	7.22	20.47
WH-147	20.57	71.44	HD-2733	6.16	17.45
HI - 1531	17.45	60.62	HD 2932	4.13	11.72
MP-1203	14.52	56.80	PBW-621	2.98	8.45
Uttar Pradesh					
HD-2967	730.11	1788.93			
PBW-550	692.34	1696.38			
DBW-17	522.17	1279.44			
PBW-502	297.66	729.33			
PBW-343	275.74	675.62			
DPW 621-50	216.30	529.99			
PBW-590	160.06	392.18			
DBW 39	150.70	369.26			
CBW-38	136.81	335.20			
RAJ-4120	84.133	206.14			

Source: Farmers’ portal, Government of India

Note: Likely area coverage is calculated using the total and variety wise seed distribution and total wheat area of each state

in terms of richness is highest in the states of Uttar Pradesh and Madhya Pradesh vis-a-vis other states. Bihar has the least diversity, followed by Punjab and Haryana. The higher richness values for Uttar Pradesh and Madhya Pradesh are due to cultivation of more number of wheat varieties in these states. The dominance of a single variety, as revealed by the Berger-Parker dominance index, is more in the states of Punjab, Haryana and Madhya Pradesh in the year 2015-16. The popularity of the variety HD 2967² in

Haryana and Punjab has led to its dominance in these states. In Madhya Pradesh, Lok-1³ is the most popular wheat variety with highest share in seed distribution. The spatial diversity has been found to be less in the states of Punjab, Haryana and Madhya Pradesh than in other states. The Shannon evenness index values suggested that the equality in distribution of varieties is highest in the state of Uttar Pradesh, followed by Bihar and Madhya Pradesh, and is least in Punjab followed by Haryana.

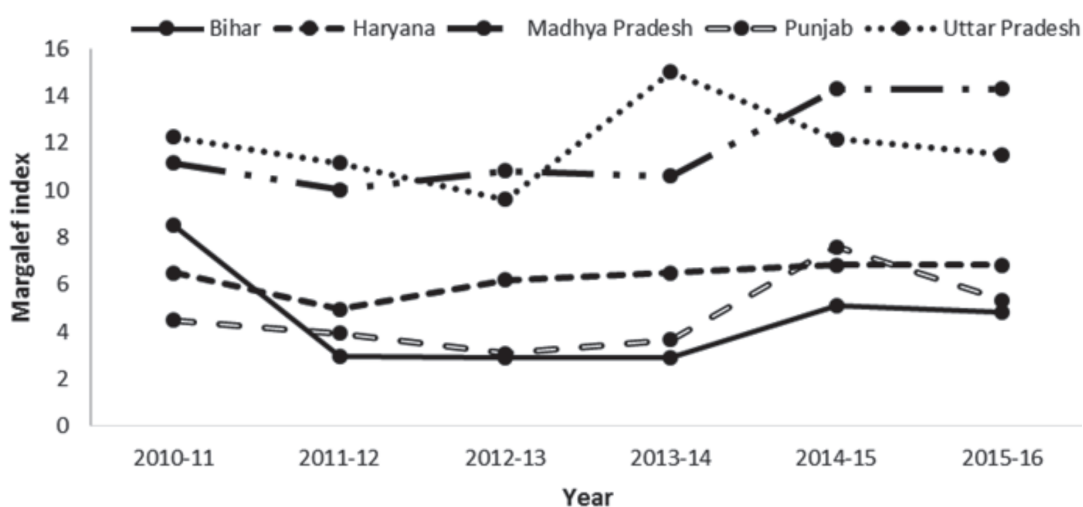


Figure 1. Margalef richness index for selected wheat-growing states of India, 2010-11 to 2015-16

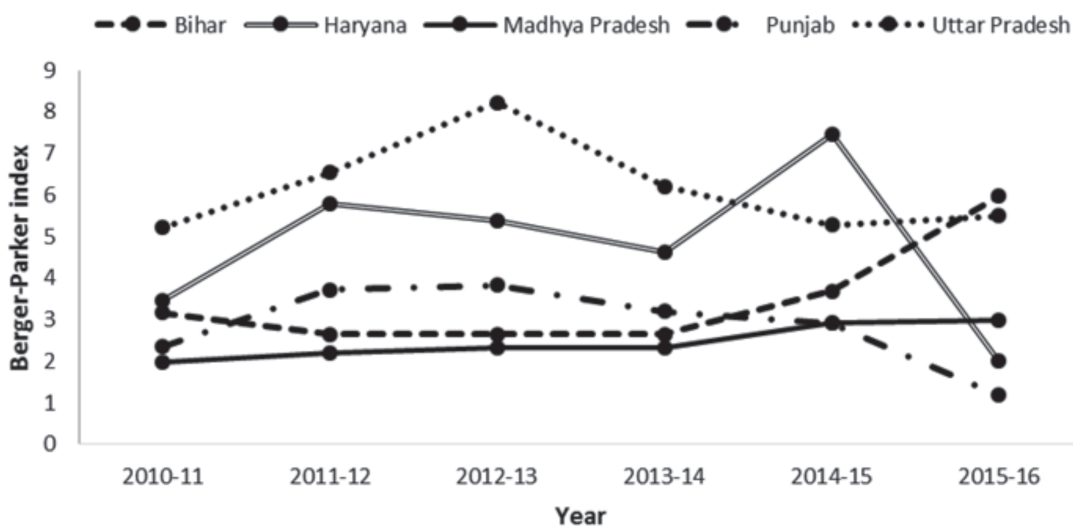


Figure 2. Berger-Parker relative abundance index for selected wheat-growing states of India, 2010-11 to 2015-16

² The variety HD 2967, also known as PusaSindhu Ganga, is a popular wheat variety released in the year 2011 for cultivation in the states (initially released for North Western Plains Zone and then spread to the North Eastern Plains Zone) of Punjab, Haryana, Delhi, Rajasthan, Plains of Jammu & Kashmir, Himachal Pradesh, Uttarakhand, Eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, West Bengal, Assam and Plains of NE states.

³ The variety Lok-1 is a highly popular variety of wheat released in the year 1981 for cultivation in the central zone of the country.

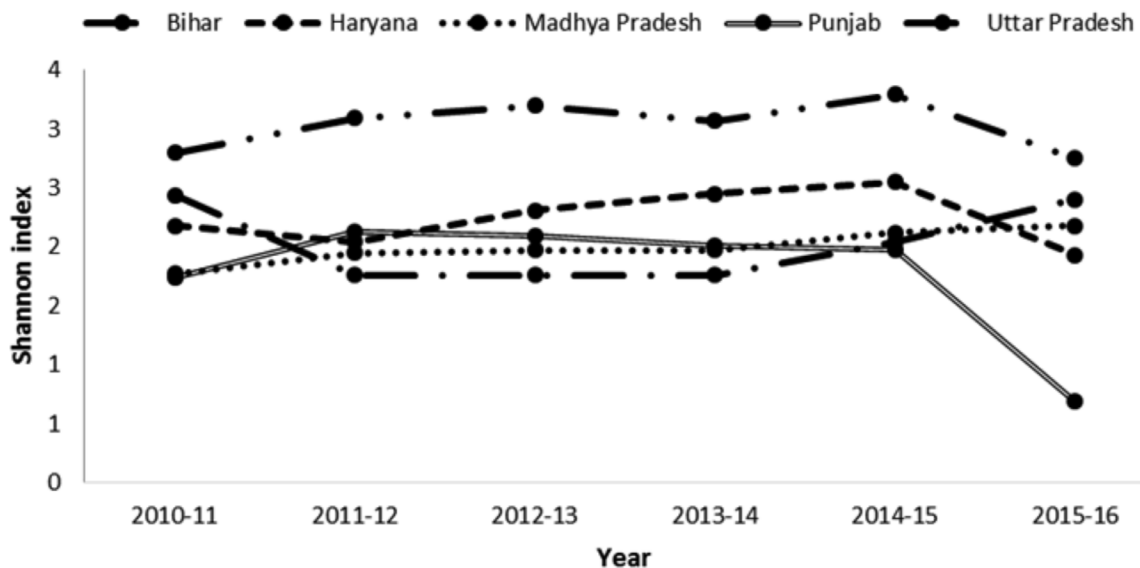


Figure 3. Shannon evenness index for selected wheat-growing states of India, 2010-11 to 2015-16

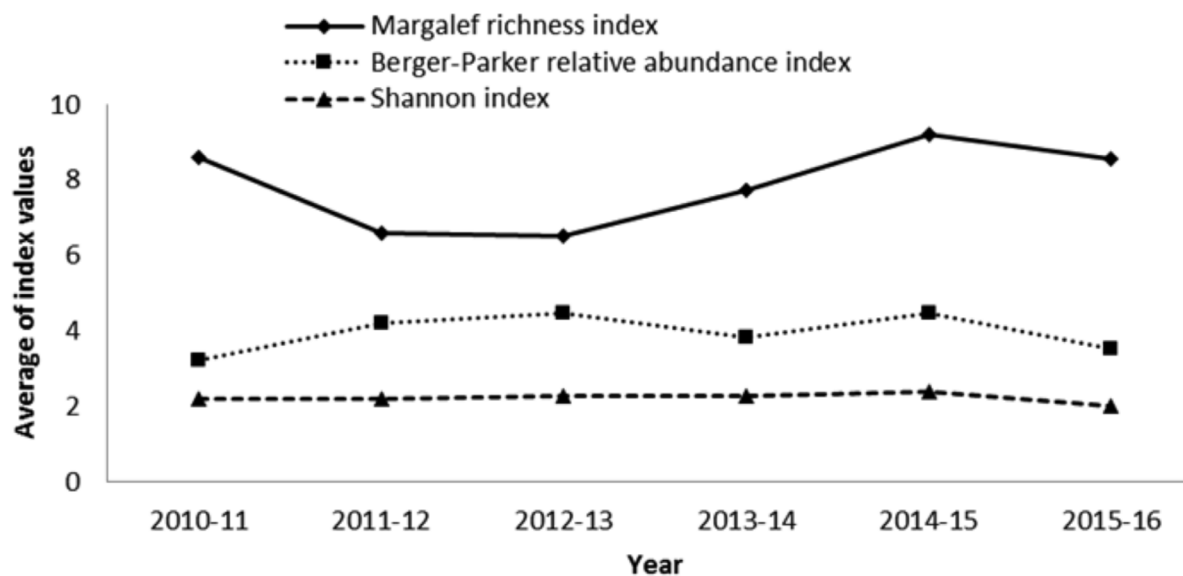


Figure 4. Spatial diversity indices for wheat varieties grown in India, 2010-11 to 2015-16 (average of five states, 2010-11 = 1)

Figure 4 shows the relationship in scale and variation of the three spatial diversity index measures for the wheat varieties grown in the five selected states (average of five selected states). The relative abundance and the evenness indices moved almost in the same direction, both hitting their highest values in the year 2012-13, and then moving slightly downwards, before moving up again in the year 2014-15. Finally in the year 2015-16, both the indices settled down at the relatively lower values. This suggests that the domination of a single variety can co-exist with a fair

level of equity in the abundance of all the varieties. In other words, the emergence of new and improved varieties may lead to their domination in a particular region or state, or it may also lead to improvement in the evenness values in some other region or state. The variation over the years was higher for richness index in comparison to that for the other two indices. At some instances, the movement of richness was exactly against that of the relative abundance and evenness. The richness index depicted the highest value in the year 2014-15, and least in the year 2012-13. In general,

Table 5. Descriptive statistics for spatial diversity indices of wheat varieties grown in five selected states of India

Particulars	Margalef index	Berger-Parker index	Shannon index
Mean	7.87	3.95	2.21
SD	1.11	0.51	0.13
Minimum	6.53	3.23	1.99
Maximum	9.2	4.48	2.4

the richness index moved upwards which is most important since it shows the efforts of the wheat improvement programmes of the country.

The descriptive statistics of the indices are shown in Table 5. The mean and standard deviation (SD) values are higher for the Margalef index than for the other two measures. The higher SD values suggest a higher coefficient of variation (CV), which implies that the variability in the number of varieties of wheat grown in a state or region is higher than the domination of a single variety and the evenness in distribution of

the varieties in terms of their share in area occupied. The lower CV for Shannon index suggests the higher stability in the area share occupied by the varieties. The index value is however not very high, which suggests that there exist many varieties that occupy minor shares in the total wheat area, but are not completely replaced by the modern varieties. The non-availability of the desired high-yielding varieties (HYVs) on time and at affordable price levels, could be the reasons for this.

Determinants of Spatial Diversity

The results of the SUR model used to find the determinants of spatial diversity are presented in Table 6. The statistical significance of the equations is satisfactory as suggested by R^2 and p-values. However, all the exogenous variables selected for the analysis do not impact the diversity. The marginal effect of these variables and its direction are not restricted by any means while doing the analysis.

The varietal traits could affect the spatial diversity in several ways. For example, yield, hardness of grain,

Table 6. Estimates of seemingly unrelated regression (SUR) of wheat diversity indices on its determinants

Variable	Richness coefficient	Standard error	Dominance ⁻¹ coefficient	Standard error	Evenness coefficient	Standard error
Average yield	2.35*	1.29	3.53	3.14	0.06	0.83
Average hardness of grains	0.04	0.06	0.44***	0.15	0.07*	0.04
Yield of variety with highest share	0.15	0.19	0.22	0.47	-0.16	0.12
Days to maturity of variety with the highest share	0.02	0.02	-0.07	0.06	0.01	0.02
Height of crop variety with highest share	-0.03	0.02	0	0.05	-0.02	0.01
Hardness of variety with highest share	0	0.02	-0.07	0.06	0	0.02
Varieties released in past 5 years	0	0.02	-0.01	0.04	0.02*	0.01
Proportion of recommended varieties to that cultivated	19.33***	1.02	-2.59	2.51	1.11*	0.66
Average rainfall	0.01	0.001	0.02	0.001	0.04	0.001
Bihar	-1.32*	0.61	2.14	1.49	0.41	0.39
Haryana	-0.83*	0.49	-0.98	1.19	0	0.31
Madhya Pradesh	3.02**	1.27	1.34	3.09	-0.3	0.82
Uttar Pradesh	-4.07***	1.04	5.59**	2.53	0.31	0.67
Constant	-15	8.87	-35.23	21.68	-3.19	5.72
R^2	0.99		0.74		0.80	
Number of observations	30	30	30	30	30	30

Note: *, **, and *** indicate 10 per cent, 5 per cent and 1 per cent level of significance respectively

days to maturity, and height of crop varieties are some of the variables that could have an impact on the diversity. The analysis shows that the richness in the varieties grown is positively related to the average yield value. This result is rather against the common belief that higher yield will lead to specialization towards high-yielding varieties. Another meaning emerging out of this result could be that many of the varieties that are currently being cultivated have higher average yield values. Thus, the emergence of a new and improved variety with a slightly higher yield than the existing ruling variety, can gain a share in area, but cannot replace the existing varietal cafeteria completely. Thus, even though a new cultivar with higher yield is released, probability that the number of varieties being cultivated would drop down, is very less. It also signifies that farmers' choice of varieties does not depend on yield alone. Other varietal traits also affect the variation in spatial diversity, like higher the average hardness of grain of popular variety, greater will be its ability to dominate the scene. This is because hardness is the most important trait of a variety that determines its milling quality. The hard grain wheat usually produces flour with higher level of damaged starch after milling. This higher starch damage leads to higher water absorption of dough and better bread yield (Stenvert, 1974). The spatial distribution is also made more equitable by the higher grain hardness value.

The supply of variety is another important factor that could determine the spatial diversity. The number of varieties released in the past five years for cultivation in selected states, and the proportion of number of varieties to that cultivated ones are the variables considered for analysis. The results reveal that varieties released in the past five years are positively influencing the spatial diversity. It is because of occupation of greater area by these improved varieties at a fast pace vis-a-vis the existing ones. These new varieties however could not completely replace the older ones. This entire process is continuously leading to improved spatial diversity.

The results also reveal that with increase in the proportion of recommended varieties in the total varieties, the richness and evenness too increases. Amongst the agro-ecological factors, the average rainfall does not affect the spatial diversity. The variety of wheat grown in Madhya Pradesh could lead to higher spatial diversity in terms of richness, than that grown

in Bihar, Haryana and Uttar Pradesh. The variety of wheat in Uttar Pradesh could lead to better dominance of the most popular variety.

Conclusions

The study has computed spatial diversity indices for wheat varieties cultivated in the five selected states of India. Three concepts of spatial diversity, richness, inverse dominance and evenness, which are commonly used in ecological studies have been modified and used for analysis. Three indices, viz. Margalef richness index, Berger-Parker relative abundance index and Shannon evenness index have been constructed to measure these concepts. Even though variation did exist in these indices across the selected states, in general the spatial diversity has been found higher in the states of Uttar Pradesh and Madhya Pradesh and lower in Punjab and Haryana. For instance, the richness index is higher for Uttar Pradesh and Madhya Pradesh and lower for Bihar, Punjab and Haryana, meaning the existence of higher spatial diversity in cultivation of wheat varieties in Uttar Pradesh and Madhya Pradesh. Interestingly, the values of inverse dominance index have been found higher for Bihar and Uttar Pradesh which suggest lower varietal dominance and higher spatial diversity. The evenness index has been observed higher for Uttar Pradesh, Bihar and Madhya Pradesh, suggesting higher diversity in comparison to the other states considered.

The variables deciding the demand for varieties, supply of varieties and ecological factors have been hypothesised to determine the spatial diversity. The SUR estimation has suggested that the average yield affect the richness, whereas hardness affect the relative abundance and evenness. This is important since we could infer that for a new wheat variety to dominate the scene, yield advantage alone would not be sufficient for its adoption. The dominance is also related to other characteristics like grain hardness. Evenness is also determined by the number of varieties released in the past five years and the proportion of recommended varieties in the total number of varieties grown. The agro-ecological factors also have shown significant effects, especially on the richness and inverse dominance. This regression result has lent meaningful insights of the importance of policies on agricultural research. If the researchers and policymakers decide

that achieving maximum area share of a particular wheat variety would be beneficial, then the identification of determinants and their values for achieving this will be easy through the model used in this paper. If a disease resistant variety is to be popularised in a particular state, then the required policy changes can be guided by insights generated by the model. It also warns the states with lower spatial diversities in wheat varieties against the epidemic of biotic and abiotic stresses of various kinds including pest attack and drought situations. The importance of maintaining an even distribution of the genetic base to achieve resilience in agri-production system is also stressed upon.

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