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Spatial and Temporal Diversity in Adoption of Modern Wheat Varieties in India

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Abstract

In this study, adoption rates of modern wheat varieties in India have been estimated using expert elicitation methodology. The study has found that the wheat varietal output has increased during the period 2010-2015. The most widely cultivated wheat varieties in the study states are HD 2967, PBW 343, PBW 550, Lok 1 and PBW 502. The temporal and spatial diversity indices have been calculated based on the perceived adoption rates. Wheat varietal turnover has been highest in Punjab (7.50 years) and lowest in Rajasthan (19.25 years). The Berger Parker index has shown that relative abundance of varieties was lowest in Punjab (1.76) and highest in Madhya Pradesh (7.10). The concentration of wheat area under dominant varieties was highest in Punjab and lowest in Rajasthan as indicated by the Marglef index. The cultivation of older varieties and dominance of a few varieties deprive the farmers of the advantages of productivity gains, genetic improvement, in addition to increasing crop vulnerability to pests and diseases. The study has concluded that besides varietal development, it is also important to focus on reducing the socio-economic and institutional barriers to adoption of improved crop varieties. In this direction, it is important to create an enabling institutional environment for increasing the rate of varietal replacement, promote spatial heterogeneity in crop varieties cultivated, identify and effectively bring the potential varieties under the seed chain system and enhance the outreach of improved wheat varieties with an inclusive approach to reach even the resource-poor farmers.

Key words: Expert elicitation, wheat varietal adoption, age of wheat variety, temporal diversity, spatial diversity, varietal diversity indices, variety replacement rate

JEL Classification: Q16, Q18

Introduction

Wheat is a prominent crop of India from the point of view of food security. It occupies an area of 30.47 million ha and has a total production of 95.84 million tonnes (DES, 2013). The 'Wheat Revolution' in India got a momentum with the identification/ development of amber or white seeded genotypes like Kalyan Sona, Sonalika, Safed Lerma and Chhoti Lerma in 1967. In the subsequent years, several high-yielding varieties of wheat crop were developed which boosted the yield levels and increased the overall wheat production in the country. The role of genetic improvement in enhancing wheat productivity is well established (Byerlee and Traxler, 1995; Pingali and Rajaram, 1999; Evenson and Gollin, 2003). Pinagli (2012) has discussed the diffusion of crop genetic improvements and its effect on productivity and food prices in the

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context of green revolution. The elasticity of poverty reduction with increase in agriculture value added is expected to be 0.4 per cent for India in the short-run and 1.9 per cent in the long-run owning to its indirect effects of low food prices and higher wages (Ravallion and Datt, 1996). Studies have shown that the adoption of improved crop varieties does have an impact on the economic benefits received by the producers, poverty reduction, food security and household welfare (Zeng *et al.*, 2015; Macharia *et al.*, 2012; Birthal *et al.*, 2012; Shiferaw *et al.*, 2008; 2014; Asfaw *et al.*, 2012). The success of the crop improvement programs hinges on the decisions of millions of farmers to adopt, or replace older wheat varieties with superior material (Dixon *et al.*, 2006). Therefore, it is pertinent to understand the diffusion and adoption of the improved varieties in order to assess the outreach of benefits of the crop breeding programs. This study is another step towards understanding the diffusion and adoption rates of modern wheat varieties in India using the expert elicitation methodology along with the broad objectives of documenting the varietal research output of wheat crop in India, tracking the adoption of modern wheat varieties and exploring the feasibility of using expert elicitation methodology for large scale adoption studies. The underlying hypothesis of the study was that the diffusion of new varieties is in general slower in India and that the adoption of new modern varieties is faster in the states covered under the green revolution belt such as Punjab and Haryana in comparison to the other wheat-producing states like Uttar Pradesh, Madhya Pradesh, Bihar and Rajasthan.

To understand crop varietal adoption patterns, few recent studies have used expert elicitation approach (Pandey *et al.*, 2012; Tsusaka *et al.*, 2015; Charyulu *et al.*, 2013). We have used the same approach in our study. Further, the national level farm surveys are considered to be more relevant in terms of their wider area coverage, for providing a representative picture at the farm level. However, the accuracy of such information is conditional on the fact that such surveys are representative and that farmers have a precise record/knowledge on the exact name of the crop variety on field (Doss, 2013; Pandey *et al.*, 2015; Walker, 2015).

The farm level surveys may not always take into account the information on seed material exchanged by the farmers through fellow farmers, NGOs and other research organizations. On the other hand, seed sale based statistics do not account for the informal exchange of seeds across the famers in various states. Thus, seeds of a variety not officially released in a particular state, may actually be under cultivation because of informal seed exchanges. In such cases, by not accounting for spillover effects of crop improvement, seed statistics may prove to be less effective in capturing the area under the varieties that are not in the official seed chain of the crop in different states. Thus, resulting in the under-estimation of area sown to such varieties. Finally, the choice of a methodology depends heavily on the availability of financial and scientific resources, time frame and access to additional statistics on seed sale and production.

In this study we have used expert elicitation methodology for obtaining the perceived adoption rates of modern wheat varieties in six major wheat-producing states of the country, viz. Punjab, Haryana, Bihar, Uttar Pradesh, Madhya Pradesh and Rajasthan. This methodology has some inherent limitations, the major limitation being its heavy reliance on the perceptions of experts. However, given that there are no structured national level surveys to document the crop varietal adoption pattern in the country, we believe our efforts would contribute to filling the void in such knowledge.

Data and Methodology

Data — The information on wheat varietal output was obtained from the ICAR-Indian Institute of Wheat and Barley Research (IIW&BR), Seeds Division, Department of Agriculture & Cooperation, portals of various State Agricultural Universities and the published literature for estimating period-wise varietal output of the crop[1]. In the present study, a modern variety was defined as the variety developed by breeders in the formal system. Expert elicitation workshops were conducted across six major wheat-producing states of the country which together accounted for about 85 per cent of the total gross cropped area under wheat. The study was conducted in the year 2014-15 and the reference period for the

[1] Varietal output was estimated based on the release year of the variety; if information on the exact release year was not available, year of notification of the variety was used.

Table 1. Area, production and productivity of wheat in selected states of India: TE 2014-15

State	Area ('000 ha)	Production ('000 tonnes)	Productivity (kg/ha)
Bihar	2137 (7.01)	4717 (5.08)	2207
Haryana	2530 (8.30)	11593 (12.50)	4582
Madhya Pradesh	5413 (17.76)	13417 (14.46)	2478
Punjab	3510 (11.52)	16663 (17.96)	4747
Rajasthan	3063 (10.05)	9270 (9.99)	3026
Uttar Pradesh	9807 (32.17)	28470 (30.69)	2903
All India	30480 (86.81)	92768 (90.69)	3044

Source: Directorate of Economics and Statistics
Note: Figures given within the parentheses refer to per cent of the total area and production at all-India level

study was 2013-14 (*rabi* season) for which the varietal adoption rates were obtained from the experts on recall basis. Details about study states, along with wheat area, production and productivity, are presented in Table 1.

Selection of Experts — The total number of experts participating in the expert elicitation workshops in different states ranged from 9 to18, depending on the geographical area of the state and the availability of experts. Best possible efforts were made to include experts from the National Agricultural Research System (NARS), which included the IIW&BR, State Agricultural Universities, Krishi Vigyann Kendras (KVKs), Agricultural Technology Management Agency (ATMA), Agricultural Technology Information Centre (ATIC) as well as the non-NARS institutions such as the International Maize and Wheat Improvement Center (CIMMYT), Department of Agriculture of various states, representatives from farmers' associations and progressive farmers.

Estimation of Perceived Adoption Rates — Adoption of crop varieties vary depending on the agro-climatic regions, crop production conditions (mainly rain-fed or irrigated), crop growing seasons and agronomic practices such as late sowing, early sowing. Keeping in view, such complexities, the lowest unit of disaggregation at which adoption of wheat varieties could vary was identified as a crop production domain. Thus, a domain could be an agro-climatic zone, season, production condition or a combination of these. Since, wheat is a *rabi*-season crop in India, the domains were identified mainly based on the agro-climatic zone and production conditions of the crop. Thus, the final estimates of wheat varietal adoption were obtained by aggregating the domain level estimates using district level crop area weights as follows.

In a domain, the total per cent area under all wheat varieties (D_m) included area under modern varieties (M_m) and area under local or traditional varieties (L_m) such that

$$D_m = M_m + L_m \quad \ldots(1)$$

The perceived adoption rate of the variety (V_p) was weighed using domain level crop area as weight (A_i) to obtain the area share of an individual variety (V_k) in any domain:

$$V_p = V_k A_i \quad \ldots(2)$$

Thus, $A = \Sigma A_i$ was the total gross cropped area under wheat in a state. Therefore, area under *'n'* number of modern varieties of a domain may be obtained as,

$$M_m = \sum_{k=1}^{n} V_p A_i \quad \ldots(3)$$

The adoption estimate for the k^{th} variety is rescaled (V_{rk}) at the state level, using the total area under modern wheat varieties in the state (M) as weight, such that

$$V_{rk} = V_k M \quad \ldots(4)$$

Hence, the total area under modern wheat varieties in a state (M) may be aggregated as

$$M = \sum_{k=1}^{n} V_p A_i M \text{ or } M = \sum_{k=1}^{n} V_{rk} \quad \ldots(5)$$

Therefore, the total area under all cultivated varieties in the state is given by,

$$A = \sum_{k=1}^{n} V_{rk} + L = M + L \quad \ldots(6)$$

Table 2. Description of temporal and spatial diversity indices used in the study

Index	Category	Mathematical expression	Description
Shannon	Evenness	$D = -\sum p_i \ln hp_i$	p_i = Area share occupied by the i^{th} variety
Simpson	Evenness	$D = 1 - \Sigma P_i^2$	P_i = Area share occupied by the i^{th} variety
Margalef	Richness	$D = (S - 1)/\ln hN$	S = Number of wheat varieties grown in a season, N = Total hectares under wheat in that season
Berger-Parker	Inverse dominance	$D = 1/(N_{max}/N)$	Inverse of maximum area share occupied by any single wheat variety

Source: Meng *et al.* (2009)

Thus, the total area under the modern varieties in a state (M) was obtained by summing up the area under the individual varieties across the domains.

The total area under the k^{th} variety (V_k) at the state level for state (S_{Vk}) is the aggregation of the area under the variety over the domains (D_m).

Thus, $S_{vk} = \sum_{m=1}^{n} V_{rk}$, the total proportional area under all varieties being 100.

Rigour of Methodology — In view of the potential sources of bias and errors in using the expert elicitation methodology for adoption studies, due care was taken during expert selection as well as implementation stages to avoid the dominance of experts from a particular discipline, region or institute. The presence of such a diverse panel of experts including representations from progressive farmers and NGO members, ensured minimization of potential bias in expert opinions. Further, each expert elicitation was carried out at three different levels, viz. individual, group and group consensus levels. The ultimate goal of this approach was to progressively eliminate the bias resulting from individual and group level perceptions. All the final adoption estimates are based on 'consensuses' of the expert panel which approves the credibility of methodological approach in minimizing the potential bias.

Estimation of Varietal Diversity — The age of a variety was calculated in terms of number of years since its release/notification till the year under cultivation, i.e. 2013-14. The temporal diversity in wheat variety or the rate of varietal turn over at a period 't' was calculated as the average age of the cultivated varieties weighted by the area under cultivation , as estimated from the perceived adoption rates and was given by: $WA_t = \Sigma_i P_{it} R_{it}$ (Brennan and Byerlee,1991). The spatial diversity of cultivated wheat varieties was analysed using diversity indices, the description of which is provided in Table 2.

Results and Discussion

Varietal Output of Wheat in India

The NARS has developed a large number of wheat varieties suitable for cultivation across various agro-climatic zones of the country for increasing the yield levels as well as for improving the qualitative attributes of the crop. The database on varietal release was compiled for all the released varieties in India since 1960. A total of 483 wheat varieties were released from pre-1965 to 2015-16. Period-wise release of wheat varieties in India is depicted in Figure 1. The starting years of varietal improvement, viz. pre-1960s, witnessed development of 60 wheat crop varieties. A similar trend was noticed during the period 1981-1985. During the period 1986-1990, the number of varietal releases was less with a release of 23 wheat varieties. Since the green revolution helped in achieving food security, wheat breeding for yield was not the sole priority during the post-green revolution period. It was during these later stages that apart from yield enhancement, other varietal traits such as suitability to cope with climate risks, various production conditions (e.g., zero tillage) and varieties for production of specialized products, e.g. pasta, noodles, biscuits, etc., became the focus of varietal improvement programmes. However, the largest number of new improved wheat varieties were released during the period 2010-2015. On an average, about 40 new wheat varieties are released every 5 years from the NARS.

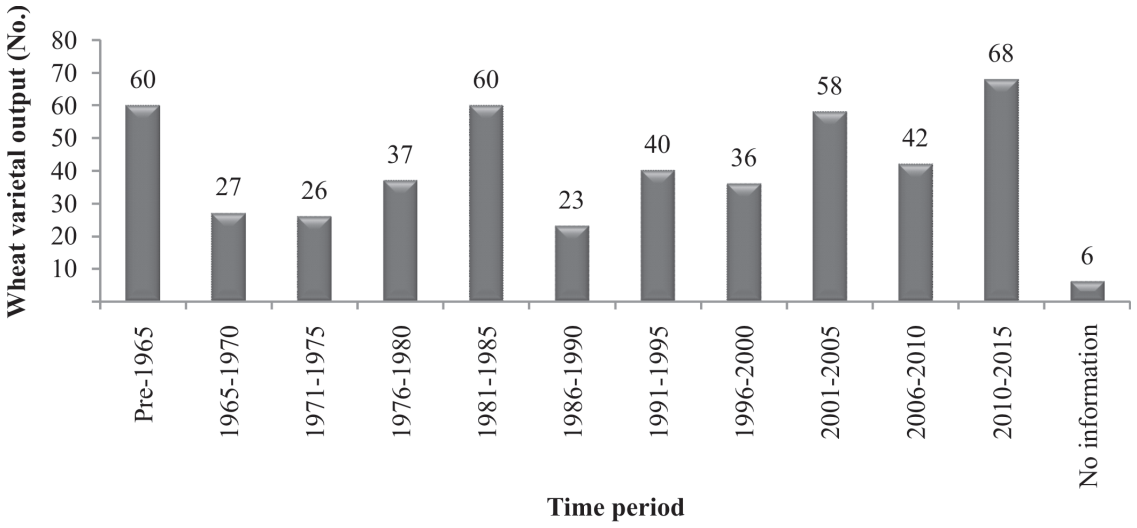

Figure 1. Period-wise release of wheat varieties in India: Pre-1965 to 2010-2015
Source: Compiled from the Indian Institute of Wheat and Barley Research (IIWB&R)
Note: Information on release year was not available in the case of 6 varieties

Adoption of Modern Wheat Varieties in India

Wheat crop is under a continuous process of varietal improvement given its importance in ensuring food security. Also, improved wheat variety was one of the technologies that quickly diffused across the farmers during the green revolution period. As a result, very little area of this crop is under the traditional varieties or land races. It is evident from the experts' estimates on the extent of area under traditional and modern varieties, as provided in Table 3. Hence, in wheat crop, it is more pertinent to examine the rate at which the newly released modern varieties are replacing the older improved varieties that are already under cultivation than focussing on the extent of area under traditional varieties. In three states, viz., Haryana, Punjab and Madhya Pradesh, the entire area under wheat crop is covered by the modern varieties. Such a trend is expected in the case of Haryana and Punjab states which form the cradle region of green revolution.

Table 3. Area under local and modern wheat varieties in major producing states: 2013-14

State	Per cent area under different varieties	
	Local variety	Modern variety
Haryana	Nil	100
Uttar Pradesh	1	99
Punjab	Nil	100
Bihar	1	99
Madhya Pradesh	Nil	100
Rajasthan	2.8	97.2

Source: Perceived adoption rates estimated from the state level expert elicitation workshops

In Uttar Pradesh and Bihar, 99 per cent of total wheat cropped area is under modern varieties while, in Rajasthan about 3 per cent of wheat area is under the traditional varieties.

Furthermore, we estimated the wheat area covered under each modern variety. Accordingly, top five widely cultivated wheat varieties in each of the study states has been listed along with their area coverage and year of variety release, in Table 4. Three important observations emerge from these results. First, the extent of concentration of wheat area under the top most varieties varied widely across the states. The gross wheat area covered under the major 5 varieties of a state ranged from 88.66 per cent in Punjab to 42.93 per cent in Uttar Pradesh. Thus, more than 80 per cent of wheat area is distributed over only five varieties in Haryana (79.05%), Bihar (80.75 %) and Punjab (88.66 %) states. The concentration of wheat area under top 5 varieties was least in Uttar Pradesh (42.93 %), followed up by Madhya Pradesh (48.14 %) and Rajasthan (60.88 %). Also, it is worthwhile to note that wheat varieties WH 711 and PBW 343 occupied about 20 per cent of

the wheat area in Haryana, while HD 2967 which is the most widely cultivated variety in Punjab, covered about 57 per cent of the wheat area, indicating greater outreach and popularity of this variety among the farmers. Such a trend of a single variety occupying a large area share has been reported earlier in the case of variety C591[2] which had occupied nearly 80 per cent of wheat area in Punjab by the year 1955 (Pal, 1966).

Table 4. Adoption of modern wheat varieties in the Indian States: 2013-14

State	Top five varieties	Year of release	Age of variety (years)	Area under adoption (%)	Area coverage (ha)	Area under top varieties (ha)	Total area under top 5 varieties (%)
Haryana	WH 711	2001	15	21.20	4,56,542	17,02,342	79.05
	PBW 343[3]	1995	21	20.25	4,36,084		
	HD 2967	2011	5	14.50	3,12,258		
	HD 2851	2003	13	13.10	2,82,109		
	DBW 17	2006	10	10.00	2,15,350		
Punjab	HD2967	2011	5	56.95	20,00,084	31,13,739	88.66
	PBW550	2007	9	10.63	3,73,326		
	PBW343	1995	21	9.82	3,44,878		
	PBW621	2011	5	9.30	3,26,616		
	HD2932	2007	9	1.96	68,835		
Uttar Pradesh	PBW343	1995	21	14.67	14,43,410	42,23,967	42.93
	PBW502	2003	13	8.41	8,27,476		
	PBW550	2007	9	7.10	6,98,583		
	HUW234	1985	31	6.91	6,79,889		
	HD2687	1999	17	5.84	5,74,609		
Bihar	PBW343	1995	21	30.03	66,276	1,78,215	80.75
	HD2733	2001	15	21.75	48,002		
	PBW502	2003	13	14.28	31,516		
	PBW373	1996	20	12.05	26,594		
	HD2967	2011	5	2.64	5,826		
Madhya Pradesh	Lok 1	1981	35	14.10	8,57,242	29,26,783	48.14
	GW 322	2002	14	13.20	8,02,525		
	JW 3211	2008	8	8.57	5,21,033		
	HI 1544	2007	9	6.37	3,87,279		
	Sujata	1983	33	5.90	3,58,704		
Rajasthan	RAJ 4037	2003	13	19.10	6,04,363	19,26,367	60.88
	RAJ 3077	1989	27	17.60	5,56,900		
	RAJ3765	1995	21	15.02	4,75,263		
	PBW 550	2007	9	4.94	1,56,312		
	RAJ 1482	1982	34	4.22	1,33,529		

Source: Perceived adoption rates estimated based on the state level expert elicitation workshops

[2] Released in the year 1934, C 591 was suitable for medium fertile district of United Punjab; this variety remained popular over a long time across a wide range of agro-climatic conditions in north and central parts of India. The variety is reported to have had excellent chapatti making quality and rich in micro nutrient content even as compared to HD 2329 and PBW 343. However, this tall variety was susceptible to yellow rust, but moderately resistant to brown and black rusts (Gill, 1979; Nagarajan, 2009). This variety was estimated to cover more than 50 per cent of the irrigated area and 31 per cent of the unirrigated area in Punjab during the early- 1940s (Sukhatme, 1945)

[3] PBW 343 represents a classic case wherein the new varieties replace the exceptional and widely cultivating existing varieties. This variety is reported to have replaced the outstanding wheat varieties like WL711 and HD 232.Within a span of 5 years of its release, it covered about 80 per cent of the wheat area in Punjab (Chahal and Gosal, 2002).

Table 5. Area under five most widely cultivated wheat varieties in India: 2013-14

Variety	States of adoption	Area (ha)	Area share (%)
HD 2967	Haryana, Rajasthan, Bihar, Uttar Pradesh , Punjab, Madhya Pradesh	27,54,310	11.03
PBW 343	Haryana, Rajasthan ,Punjab ,Bihar ,Uttar Pradesh, Madhya Pradesh	23,63,034	9.46
PBW 550	Haryana, Rajasthan ,Bihar ,Uttar Pradesh, Punjab	12,52,850	5.02
Lok 1	Madhya Pradesh, Bihar ,Rajasthan	9,85,700	3.95
PBW 502	Rajasthan, Bihar ,Uttar Pradesh	9,03,607	3.62
	Total	82,59,501	33.08

Source: Perceived adoption rates estimated based on the state level expert elicitation workshops

Secondly, the age of major varieties cultivated also varied across the states, reflecting the difference in extent of diffusion of new varieties. The youngest variety under cultivation was HD 2967 released in the year 2011, while the oldest variety under cultivation as identified by the experts was Lok-1, released in the year 1981. The popularity of HD 2967, that was released about five years ago and the extent of its area coverage in Punjab and Haryana states points towards quick diffusion and wide outreach of this variety. The wheat varieties such as PBW 343, HD 2687, Raj 3765, released during the 1990s and Lok 1, HUW 234, Raj 1482, Sujata and Raj 3077, released during the 1980s were also identified as the most important varieties in various states. Thus, wheat varieties released even about 20-35 years ago, are still under cultivation in the major wheat-producing states, accounting for a significant proportion of wheat area. A detailed discussion on the age of wheat varieties cultivated in various states is covered in the subsequent sections.

The third observation is related to the spread of varieties. The wheat varieties are released through the Central Varietal Release Committee (CVRC) as well as the State Varietal Release Committee (SVRC). A variety may be released to suit the production conditions of a specific state or for cultivation at the agro-ecological zone level, covering various states. Wheat varieties, HD 2967, PBW 343, PBW 550, Lok 1 and PBW 502, had a wide geographical coverage as they were grown across the major wheat-producing states and also accounted for a significant share in the total wheat area. These five varieties alone cover one-third of the total area under wheat. Heisey *et al* . (1997) highlighted that such concentration of wheat area under a few popular varieties depresses the yield potential and aggravates the crop's vulnerability to plant diseases.

The area under the most popular wheat varieties that are widely cultivated across the states was aggregated to identify the top most popular wheat varieties in the country (Table 5). The variety HD 2967 emerged as the most popular wheat variety on farmers' fields accounting for 11 per cent of the total gross cultivated area under wheat in these six states.

The wheat variety PBW 343 was also spread in all the six major wheat-producing states covering about 9.5 per cent of total gross cropped area. The other three important wheat varieties were PBW 550, Lok 1 and PBW 502. It was observed that all the topmost popular wheat varieties had occupied some area in Bihar and Rajasthan states[4].

It was interesting to note that the wheat varieties HD 2967, PBW 343,PBW 550 and PBW 502 released for cultivation in the North West Plain Zone, were also being cultivated in Bihar and Madhya Pradesh which fall under the North Eastern Plain Zone and Central Zone of wheat production, respectively. This depicts the spillover effects of crop varietal improvement efforts across the different cultivation zones.

Robustness of Adoption Estimates Obtained from Expert Elicitation Methodology

Each of the methods used for varietal adoption estimates has its own advantages and limitations in capturing the adoption pattern. Due to lack of organised

[4] The wheat variety PBW 550 did not appear in the list of top five varieties cultivated in Bihar; however, its area share in the state was 1.89 per cent. Similarly, the area under wheat variety HD 2967 was very marginal at 0.03 per cent in Madhya Pradesh.

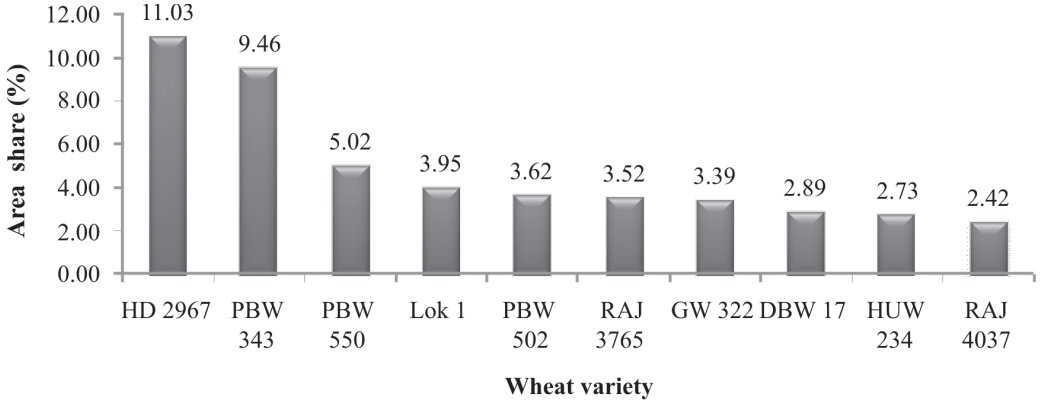

Figure 2. Distribution of wheat area under the major wheat varieties in India: 2013-14
Source: Perceived adoption rates estimated based on the state level expert elicitation workshops

farm-level surveys, the empirical evidence on the adopted varieties of wheat is scarce with respect to India. Also, owning to the extensive use of farmers' own saved seeds, prevalence of farmer-to-farmer exchange of seeds, seed movement across the states and farmers' access to seeds that are not officially released, seed sales data may not be the true representative of the varietal adoption pattern in a state.

In this section, we have compared the varietal adoption estimates obtained from expert elicitation methodology, with the existing information based on literature review as well as household level data. Though estimates from different sources may not be exactly comparable given the differences in methodological approaches, it might provide some insights on the robustness of estimates obtained through expert elicitation. Household level data were obtained from the Village Dynamics in South Asia (VDSA) database of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) for Bihar and Madhya Pradesh states for the year 2013-14; this information was not available for wheat crop for the remaining states under this study. The proportion of wheat area under different varieties was estimated with respect to the total area under wheat among the sample households. Since, the focus of the VDSA survey was not exclusively on studying the varietal adoption pattern and that the geographical coverage of the survey was limited, such a comparison only provided limited field level evidences on major wheat varieties cultivated in Bihar and Madhya Pradesh.

Keeping in view the approach used under expert elicitation, wherein the domain level varietal adoption estimates representing all the wheat cultivating districts were rescaled to obtain the state level estimates, we compared only the major varieties cultivated and not their area share. The results of the adoption estimates were fairly comparable with some of the varieties reported from the existing literature (Table 6). Though the VDSA survey was a small scale study, the major varieties identified from Bihar (HD 2733, PBW 343, PBW502 and PBW 373) and Madhya Pradesh (Lok-1 and GW 322) were in line with the wheat varieties identified through expert elicitation for these states. Further, the breeder seed indent data for various states for the year 2013-14 approved with the major wheat varieties identified across the study states from the expert elicitation methodology (Table 7). The detailed examination of breeder seed data clearly indicated that varieties with highest indent for breeder seed were more than 10 years old, except in the case of HD 3043, HD 2987 and DPW 621-50 varieties.

Temporal Diversity in Wheat Varieties Cultivated in India

The rate at which the newly released modern wheat varieties replace the older varieties is an important indicator of varietal replacement and turn over. As discussed earlier, wheat varieties as old as 20-35 years continue to be under cultivation and rule a significant proportion of area in the major producing states. Some of the varieties identified by the experts in the exhaustive list of wheat varieties under cultivation, were older than 30-40 years. A study conducted by Ghimire *et al.* (2012), in Haryana also highlighted that farmers continue to grow wheat varieties that are

Table 6. Top five widely cultivated wheat varieties in selected states of India as identified under various methodological approaches

State	Expert elicitation	Evidences from literature	Remarks	Household survey	Remarks
Punjab	HD2967 PBW550 PBW343 PBW621 HD2932	PBW 343, PBW 502, UP 262, WH 711, PBW550,HD2851 (Ghimire *et al.,*2012)	Based on farmers' survey (N=1200) in the Indo Gangetic Plains covering Punjab, Haryana, Bihar and Uttar Pradesh	NA	-
Haryana	WH 711 PBW343 HD 2967 HD 2851 DBW 17	PBW 343, PBW 502, UP 262, WH 711, PBW 550,HD 2851 (Ghimire *et al.,*2012)	Based on farmers' survey (N=1200) in the Indo Gangetic Plains covering Punjab, Haryana, Bihar and Uttar Pradesh	NA	-
		HD 2733, PBW 502, PBW 550, DBW 17, Lok1 (Krishna *et al.,* 2014)	National level breeder seed production data and farm level survey (year 2010) of 323 farm households across the three districts	NA	-
Bihar	PBW343 HD2733 PBW502 PBW373 HD2967	PBW 343, PBW 502, UP 262, WH 711, PBW 550,HD, 2851 (Ghimire *et al.,*2012)	Based on farmers' survey (N=1200) in the Indo Gangetic Plains covering Punjab, Haryana, Bihar and Uttar Pradesh	*HD 2733, PBW 343, PBW502,UP 262, PBW 373, Swarna (HI 1479), HD 1553	VDSA household survey of 348 households for the year 2013, covering an area of 206 ha in Bihar[5]
Uttar Pradesh	PBW343 PBW502 PBW550 HUW234 HD2687	PBW 343, PBW 502, UP 262, WH 711, PBW 550,HD2851 (Ghimire *et al.,*2012)	Based on farmers' survey (N=1200) in the Indo Gangetic Plains covering Punjab, Haryana, Bihar and Uttar Pradesh	NA	-
		PBW 343, UP 262, PBW 154, PBW 226, HD2285, Raj 3765, PBW 502 (Singh *et al.,*2014)	Not a structured farm level survey, focus was on assessment of wheat outreach in 13 districts	NA	-
Madhya Pradesh	Lok 1 GW 322 JW 3211 HI 1544 Sujata	NA	NA	*C 306, Lok-1, GW 322	VDSA household survey of 68 households for the year 2013, covering an area of 270 ha in Madhya Pradesh[6]
Rajasthan	RAJ 4037 RAJ 3077 RAJ 3765 PBW 550 RAJ 1482	RAJ 4037 (Meena *et al.,*2016)	Survey of 105 farmers from Baran district of Rajasthan, adoption data for five years period from 2008-09 to 2014-15 showed significant increase in area under the wheat variety RAJ 4037	NA	-

*Note:**Authors' estimates based on VDSA household level data

[5] The survey covered four villages from two districts (Darbhanga and Patna) under the irrigated ecosystem of Bihar under the irrigated ecosystem.

[6] Data refer to three villages from the Raisen district, under the rain-fed ecosystem of Madhya Pradesh state.

Table 7. Wheat varieties with highest breeder seed indent during 2013-14

Wheat Variety	Zone	States covered	Breeder seed indent (quintals)
HD 2967	North West Plain Zone	Punjab, Haryana, Western Uttar Pradesh, parts of Rajasthan and parts of Himachal Pradesh	1313.88
GW 322	Central Zone	Gujarat, Madhya Pradesh and parts of Rajasthan	1162.20
DBW17	North Western Plain Zone	Punjab, Haryana, Western Uttar Pradesh, parts of Rajasthan and parts of Himachal Pradesh	1010.98
GW 366	Central Zone	Gujarat, Madhya Pradesh and parts of Rajasthan	833.95
PBW 550	North West Plain Zone	Punjab, Haryana, Western Uttar Pradesh, parts of Rajasthan and parts of Himachal Pradesh	757.30
GW 273	Central Zone	Gujarat, Madhya Pradesh and parts of Rajasthan	750.00
Lok-1	Central Zone	Gujarat, Madhya Pradesh and parts of Rajasthan	729.30
Raj 4037	Central Zone	Gujarat, Madhya Pradesh and parts of Rajasthan	717.60
HD 3043	North West Plain Zone	Punjab, Haryana, Western Uttar Pradesh, parts of Rajasthan and parts of Himachal Pradesh	689.60
DPW 621-50	North West Plain Zone	Punjab, Haryana, Western Uttar Pradesh, parts of Rajasthan and parts of Himachal Pradesh	621.37
HD 2987	North Western Plain Zone	Punjab, Haryana, Western Uttar Pradesh, parts of Rajasthan and parts of Himachal Pradesh	224.80

Source: Directorate of Wheat Development, Ministry of Agriculture

15-20 years old. The oldest wheat varieties under cultivation were, K-65 released in the year 1964 cultivated in the Arid Western: IA, IC and IIB zones in Rajasthan state and C306 a variety released in the year 1965, cultivated in Madhya Pradesh and Rajasthan states. The varieties released during the 1970s and 1980s that were listed by the experts as being under cultivation in various states though not in the category of top 5 cultivars, are presented in Table 8. Thus, considering all the varieties that are cultivated in a state

Table 8. Wheat varieties of more than 25 years of age cultivated in India: 2013-14

Sl. No.	Variety	Release year	Age (years)	States where cultivated
1	K-65	1964	52	Rajasthan
2	C-306	1965	51	Madhya Pradesh, Rajasthan
3	UP-262	1977	39	Bihar
4	WL-711	1977	39	Rajasthan
5	WH-147	1978	38	Haryana, Madhya Pradesh, Uttar Pradesh
6	Lok-1	1981	35	Bihar, Rajasthan
7	Kundan	1981	35	Uttar Pradesh
8	Raj-1555	1982	34	Madhya Pradesh, Uttar Pradesh
9	HD-2285	1985	33	Uttar Pradesh
10	K-8027	1984	32	Uttar Pradesh
11	HUW-234	1985	31	Bihar, Uttar Pradesh
12	WH- 283	1985	31	Haryana
13	PBW-154	1988	28	Bihar, Uttar Pradesh
14	PBW-175	1989	27	Punjab

Source: Authors' estimates based on varietal release/notification data

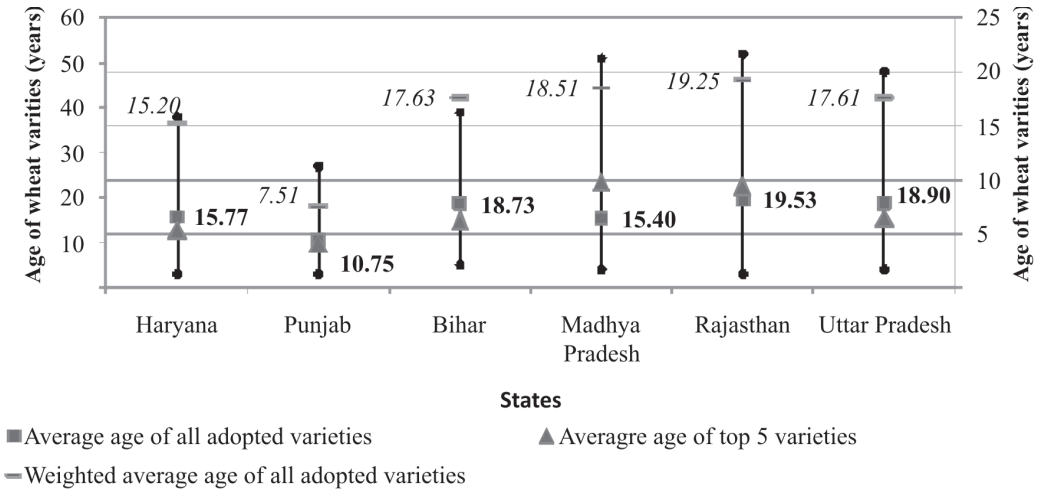

Figure 3. Average age of modern wheat varieties cultivated in India: 2013-14
Source: Authors' estimates based on the varietal adoption and release/notification data

the average age[7] of wheat varieties cultivated ranged from 10.75 years in Punjab to 19.50 years in Rajasthan (Figure 3).

In Uttar Pradesh, the average age of a wheat variety under cultivation was about 19 years, while, in Bihar, Haryana and Madhya Pradesh, it was 18.73 years, 15.77 years and 15.40 years, respectively. This pattern in the age of wheat varieties under cultivation depicts that the diffusion of new varieties is taking place at a faster pace in Punjab than in other five states. Rajasthan seemed to be having the slowest pace of varietal diffusion, as is evident from the average age (19.5 years) of wheat varieties cultivated in this state. However, the average age of top 5 wheat varieties varied from about 10 years in Punjab to 23 years and 22 years in Madhya Pradesh and Rajasthan, respectively.

Witcombe *et al.* (2016) have highlighted that the weighted average age measure underestimates the true age of the varieties that is defined by the year of release. In our study, the average age and weighted average age of the varieties varied significantly only in the case of Punjab and Madhya Pradesh states. Smale *et al.* (2008) have made similar observations in the case of Punjab and concluded that in high potential environments the weighted and unweighted average age of varieties move closely, indicating a fairly uniform spatial distribution of varieties over time. Further, the weighted average age of wheat varieties cultivated in Punjab was estimated at 7.5 years which matches with the results of Smale *et al.* (2008). An important inference from these results is that the average age of the top 5 wheat varieties is higher than the average age of all the varieties under cultivation in Madhya Pradesh and Rajasthan, implying that the proportion of area covered under the older wheat varieties is higher in these states. Hence, in these states, the new improved varieties have not reached the farmers' fields as expected. Dixon *et al.* (2006) have made a similar observation stating that though many smallholders throughout the developing world have benefited from the introduction of first-generation green revolution cultivars that replaced lower-yielding landraces, adoption of second- and third-generation cultivars offering improvements in yield, output quality, and stress resistance seems to be occurring at a much slower pace. Witcombe *et al.* (2016) in their recent study have found that the average age of rice varieties adopted in Nepal was 20 years. The authors remarked that the cultivation of older varieties is a widespread phenomenon in the developing world.

It is worth noting that the seeds of many of the oldest wheat varieties are not produced under the formal seed production systems as they have been removed from the formal seed chain. Therefore, the seed demand for these varieties is met through farmers' own seeds and farmer- to-farmer exchange of the same. Thus, the

[7] The average age of a variety was calculated as the average of number of years completed by all the identified varieties of the states from its release/notification year till the study period, i.e., 2013-14.

Table 9. Spatial diversity in adoption of modern wheat varieties in India

State	Shannon index	Simpson index	Marglef index	Berger Parker index
Haryana	2.11	0.86	0.82	4.72
Punjab	1.46	0.70	0.80	1.76
Bihar	1.77	0.85	1.14	3.33
Madhya Pradesh	2.90	0.93	1.86	7.10
Rajasthan	2.67	0.90	1.94	5.24
Uttar Pradesh	3.05	0.94	1.86	6.81

Source: Authors' estimates based on state level expert elicitation workshops

concern is that the genetic gains of new varieties developed from crop improvement research are not being harnessed by the wheat farmers, especially in Madhya Pradesh and Rajasthan. The varietal change and genetic diversity are important means of combating crop losses. A slower pace of varietal change offsets the positive productivity effects of diversified genetic base (Smale *et al.*, 2008).

The varietal turnover is a measure of varietal diversification over time. The varietal replacement rate, as measured by the weighted average age of the wheat varieties, is also portrayed in Figure 3. The varietal turnover rate was in the range of about 7 years in Punjab to 18.5 years in Rajasthan. Brennan and Byerlee (1991) had suggested that the weighted average age of 7 years was consistent keeping in view the economics of varietal replacement and the epidemiology of disease pathogens. However, a varietal turnover of about 15 years or more for the adoption of new wheat varieties clearly implies the lag in the diffusion of crop improvement efforts. Also, it reflects on the loss of genetic gains which could have accrued due to the crop improvement (Witcombe *et al.,*1998). In a recent study on varietal turnover of wheat in India, based on the breeder seed production statistics, Krishna *et al.* (2014) have found that within the span of a decade the varietal turnover rate in India has slowed down to average of 13-14 years from 9-10 years.

Spatial Diversity of Wheat Varieties Cultivated in India

To assess the spatial diversity of wheat varieties in terms of richness, evenness and dominance in the study states, we estimated four distinct indices of crop diversity (Table 9). Species richness refers to the number of species encountered in the given geographical area. Relative abundance gives the number of individuals associated with each species or variety while, species evenness represents the proportional abundance or uniformity of wheat varieties.

The spatial diversity and evenness of varietal spread was lower in the case of wheat varieties grown in Punjab, as indicated by the lower value of Shannon index and Simpson index, whereas, the species evenness or the equitability was highest in Uttar Pradesh, Madhya Pradesh and Rajasthan. The Marglef index of richness was highest at 1.94 in Rajasthan, followed by Madhya Pradesh, Uttar Pradesh and Bihar. The varietal richness was lowest in Punjab (0.80) and Haryana (0.82). The Berger Parker index for dominance of few varieties was highest in Punjab with the lowest index value of 1.76, followed by Bihar (3.33) and Haryana (4.72). It was interesting to note that the dominance of varieties in terms of larger area-share was higher in Bihar than in Haryana. Thus, the dominance of wheat varieties was highest in Punjab followed by Bihar and Haryana.

All the diversity measures point towards the fact that the varietal evenness and richness was lower and the dominance of the leading varieties was higher in Punjab, Bihar and Haryana, as compared to the other three major wheat-producing states. We conclude that there is a slow varietal turnover in wheat crop, besides concentration of wheat area under a few dominant varieties in major wheat producing states of India.

Drivers and Constraints for Wheat Varietal Adoption Insights from Expert Elicitation Workshops

Considering the rich field-level expertise of the specialists who participated in the expert elicitation,

we encouraged in-depth interactions on the varietal preferences of the farmers in the study states. This section briefly explains the driving factors behind the farmer's choice of varieties as discussed with the experts. Though these discussions were not based on the organized primary surveys on determinants of varietal adoption as in several existing studies (Bellon, 1996; Hintze, 2003; Iqbal *et al.,*2002; Sarap *et al.,*1994; Matuschke *et al.,*2007), they might be useful as first-hand information from the perspective of experts involved in varietal promotion and related activities.

Wheat experts affirmed that rust disease is a major challenge to wheat cultivation in the study states. Many of the existing varieties such as WH 711 and PBW 550, have shown susceptibility to wheat rust and are replaced with other tolerant varieties. Apart from disease resistance, good chapati making quality is one of the preferred attributes of wheat varieties. The variety HUW 234 released in the year 1985, is still popular among the farmers because of its excellent chapati making qualities. The varieties are also chosen because of their drought resistance nature (e.g., K 0307 and Sujata), bold seeds (e.g., HD 2824), wide adaptability (e.g., Lokpal or Lok-1 and HD 2967), suitability for short duration of cultivation (e.g., HUW 510) and late sown conditions (e.g., HD 2733). The varieties are also preferred based on their ability to survive under abiotic stress conditions such as terminal heat (e.g., PBW 373, HD 2733) and lodging tolerance (e.g., HD 2733). The choice of varieties is also guided by the agronomic practices, for example variety HD2733 is cultivated in Ghazipur, Mau, Balia districts of Uttar Pradesh under direct sown conditions and the variety Berbet is cultivated in Punjab under zero tillage conditions. The adoption of K0307 variety was due to its good straw production quality.

Some varieties have location-specific adoption as they suit the local production conditions. For instance, the variety PBW 660 is preferred in the rain-fed Kandvi areas of Punjab. Similarly, variety K0307 is cultivated in Allahabad and Pratapgarh districts under restricted conditions with no secondary top dressing of fertilizers, while WH 147 is cultivated in the terminal heat-affected areas such as Gwalior and Bhind districts of Madhya Pradesh. Experts also shared that varieties covered under the subsidy scheme of the states are also widely adopted due to better seed availability. The variety PBW 502 which is well spread across the Champaranya and Begusarai districts of Bihar, is a good example for such a case.

Some old wheat varieties such as Lok-1, HUW 234, and Sujata are still being cultivated on a larger area because of their wide adaptability, excellent chapati making quality and suitability for rain-fed cultivation respectively. The Lok-1 variety is prevalent more in the central zone, especially in Madhya Pradesh. The variety has completed its full age and has been enlisted under the non-recommended varieties/varieties slated for replacement, however it accounts for a larger share in national seed indent. Seeds of this variety are found to have good test weight and the variety is known to have stable yield level over the years. Usually, farmers use own-saved seeds of this variety, preferably under the late sown conditions. Sujata is another old wheat variety which is popular among the farmers in Madhya Pradesh. This variety is found highly suitable for rain-fed conditions and thrives well under drought conditions, thus reducing yield lose to farmers. As per the experts, 60 per cent of the area under this variety is under partial irrigation conditions. The variety HUW 234 is preferred for its market acceptability and high adaptability besides its suitability for cultivation under low input conditions and brackish water regions.

The seeds of old wheat varieties are mostly sourced through farmer-to-farmer exchange or own- saved seed material. Thus, easy availability of seeds along with their wide adaptability and certain other preferred attributes have enabled these wheat varieties to sustain on fields over the years. Joshi *et al.* (2007) and Yadav *et al.* (2010) have emphasized the extensive role of farmers' saved seed in South Asia, particularly in the case of wheat in India and have highlighted the weak seed delivery and weak linkages in the case of new varieties.

On the other hand, some of the modern varieties have not been adapted by the farmers due to reasons such as low yield on farmers' fields, shrivelled grains, low threshing efficiency, grain shattering and susceptibility to diseases, especially wheat rust. Certain institutional constraints were also reported to have hindered the adoption of modern wheat varieties at field level. Non-availability of promising, high-yielding wheat varieties and sluggish promotional efforts have limited the adoption of potential wheat varieties. Some of the potential varieties were reported to be not in the

seed chain (e.g., HD 2733, HD 2824 and NW 2036[8]). The existing studies indicate that the drivers of adoption of improved varieties include socio economic factors such as farmers' education levels, availability of credit, farm size and access to information along with institutional factors such as improved wheat variety demonstrations and extension activity (Dixon, 2006; Smale *et al.,* 2008; Matuschke *et al.,* 2007; Ghimire *et al.,* 2012; Krishna *et al.,* 2014). Yadav *et al.* (2010) have opined that successful technologies may not be adopted at the farm level, in case of non-involvement of farmers in planning and lack of farmers' confidence in the new technologies. Therefore, it emerges, that removing barriers to information on new varieties, participatory varietal development to suit the adaptive needs of farmers, creating an enabling institutional environment through extensive demonstration and promotion of new varieties are important. To enhance the outreach of modern and new varieties, it is necessary to encourage public-private partnership in the seed sector along with sustained investments in varietal development and seed supply. Strengthening seed distribution system, improved access to quality seeds of improved varieties and strengthening plant breeders' rights could foster innovations and increase outreach of improved varieties even among the resource-poor farmers.

Conclusions and Policy Implications

The study has estimated adoption of modern wheat varieties in the major wheat-producing states of India using expert elicitation methodology. Wheat varietal output has improved during the period 2010-2015; however, a larger share of area under wheat is concentrated among a few varieties in the leading wheat-producing states such as Punjab, Bihar and Haryana. The average age of wheat varieties cultivated across these states ranges from 10.75 years in Punjab to 19.53 years in Rajasthan, implying the vast difference in diffusion of improved varieties and the prominence of old varieties in certain states. The varietal turn-out of wheat crop is low in Madhya Pradesh, Rajasthan and Uttar Pradesh. The spatial diversity of wheat varieties is skewed towards adoption of a few leading varieties in Punjab, Bihar and Haryana. A considerable proportion of area is still covered under old varieties such as Lok-1, HUW 234 and Sujata in Madhya Pradesh, Rajasthan and Uttar Pradesh indicating the slow pace of wheat varietal replacement in these states. Some of the old wheat varieties are preferred for their favourable attributes such as wide adaptability, suitability to low input, rain-fed conditions, consistent yield, etc. However, it is at the cost of genetic gains and the economic profits thereon which the farmers could have obtained had they used the high-yielding improved varieties. The cultivation of old varieties increases the crops' vulnerability to diseases and pests and dampens productivity (Smale *et al.,*2008; Witcombe *et al.,*2016). This is also evident by the lower wheat-yield levels in the states where the average age of varieties cultivated is higher and varietal replacement rate is lower. Apart from yield gain, the benefits of improved crop breeding for specific traits such as grain quality, nutritional improvement or quality protein, tolerance to abiotic stress factors such as drought, salinity, herbicide resistance, suitability for conservation tillage, biotic stress tolerance, etc. would not reach the farmers.

The attributes of widely adopted wheat varieties were general resistance to diseases, especially wheat rust, bold seeds, good chapati making ability, suitability to fit various cropping systems through preferred crop duration and sowing time, market preference, tolerance to abiotic stress such as drought, lodging, low input conditions and general wide adaptability promote the adoption of modern varieties. However, extensive use of farmers' own-saved seeds, seeds exchanged through fellow farmers and non-availability of seed might be the factors for farmers' for heavy reliance on old varieties. On the other hand, the socio-economic and institutional factors such as lack of access to information, input resource constraint, lack of vigorous promotional programmes, non-availability of seeds, incidence of spurious seeds, input and resource constraints of the farmers hinder the diffusion and adoption of new varieties. Several studies have emphasized on the poor adoption of wheat technologies and the role socio-economic and institutional factors in slow varietal turnover in wheat crop (Krishnan, *et al.,*2014; Singh *et al.,*2014; Matuschke *et al.,*2007). It is high time to create an enabling institutional environment for increasing the rate of varietal

[8] Experts shared that HD 2733 is a potential variety suitable for terminal heat affected areas in Bihar, similarly, HD 2824 is a bold seeded high-yielding variety of wheat.

replacement, promoting spatial heterogeneity in crop varieties cultivated, identifying and effectively bringing the potential varieties under the seed chain system and enhancing the outreach of improved wheat varieties with an inclusive approach so as to reach even the resource-poor farmers.

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