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Rice production in India-varietal dynamics and diversity: Insights from empirical analysis of breeder seed indents

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Abstract

In the present study an attempt has been made to analyse rice varietal dynamics and diversity in India, using breeder seed indents data of selected years. An attempt has also been made to identify underlying factors of varietal dynamics and measures to improve varietal turnover by reviewing literature. It is observed that in recent years there is increase in rice varietal diversity at All India level. However higher weighted average age of top 10 varieties is indicating that varietal replacement is taking place with substitution by older varieties. In case of Basmati rice varieties also varietal diversity increased over the years in terms of number of varieties and decreasing share of top 3 varieties. In indent for *Kharif* 2015 and *Kharif* 2020, Seed Association of India share was 20 and 31 per cent, respectively. Multiple factors are influencing rice varietal dynamics. Hence for promoting adoption of improved rice varieties with reduced adoption lag there is a need for multi-pronged strategy. Targeted extension interventions based on share of farmers of different types of learning patterns, nudging varietal adoption behaviour by leveraging policies of subsidy and competition in seed sector, encouraging private sector participation in research and varietal commercialization, facilitating marketing of output of rice varieties of different durations by synchronizing marketing periods with crop harvesting period and participatory plant breeding are some of the suggested components in the multi-pronged strategy. In future different mechanisms for indenting for varieties and price fixation for breeder seed based on whether a variety is protected or not under PPV&FR Act, may also influence varietal dynamics.

Keywords: Varietal dynamics, Varietal diversity, Varietal concentration, Paddy, Rice, Weighted average age

Introduction

Rice is the main staple crop in India. In 2017-18 rice was cultivated in 43.79 million hectares in India, resulting in rice production of 112.91 million tonnes (DES, 2019). In 2016-17, Gross Value of Output (GVO) of rice crop (1.76 lakh crore rupees at 2011-12 prices) constituted 13.8 per cent of total GVO of crops and 50.8 per cent of GVO of cereals in India in monetary terms (GOI, 2019). In spite of its importance, rice yield in India is much below global average level. In 2017-18, rice yield across important rice cultivating states in India ranged from 1256 Kg per hectare (Chhattisgarh) to 4366 Kg/ha (Punjab), resulting in average yield of 2578 Kg per hectare at all India level. In 2016, average paddy yields in India stood at 3790 Kg/ha against world average of 4577 Kg/ha (DES, 2019).

Using simulation models, some studies reported heterogeneous impact of changes in various climatic factors on autumn, winter and summer rice in various ecosystems in India (Dabi and Khannan, 2018) and Asia (Matthews *et al*., 1997). One third of rice area in India is affected by drought (Birthal *et al*., 2015). Hence, efforts are being made to develop rice varieties/hybrids with higher productivity, climate resilience and biotic stress tolerance, and suitable for different ecosystems in India, through All India Coordinated Rice Improvement Project (AICRIP). So far 1329 high yielding rice varieties, which include 107 rice hybrids were released under AICRIP (Rao *et al*., 2019). These varieties are developed not only by public sector but also by private sector. More specifically, in hybrid rice development, private sector is playing important role (Senguttuvel *et al*., 2019) and its share in total rice hybrids released stands at 66 per cent. The aggregate effect of these crop improvement efforts in rice economy will depend on spread and adoption extent of these varieties across various ecosystems in the country. Further rice varietal diversity in a given region/ecosystem can contribute to risk reduction in production besides influencing yield directly. Duncan *et al*. (2017) reported that at All India level rice crop yield sensitivity to year to year fluctuations in climate shocks (drought and extreme heat exposure) has not decreased over time (during 1980 to 2009).

Studies on varietal adoption dynamics and varietal diversity in different crops including rice, used diverse data sources *viz.*, field level data (Byerlee and Heisey.,1990; Joshi *et al.*, 2018a), data collected through expert elicitation (Pandey *et al.*, 2012 & 2015; Pavithra *et al.*, 2017; Witcombe *et al.*, 2017; Pavithra *et al.*, 2018), certified seed distribution (Praveen *et al.*, 2017) and breeders seed indent/production data (Virk *et al.*, 1995, Witcombe *et al.*, 1998). Tsusaka et al. (2015) and Pandey et al. (2015) employed household surveys to validate the estimates obtained from expert elicitation in the context of South Asian countries. Singh and Kalra (2002) used crop cutting experiments data for analysing rice varietal adoption pattern in Punjab state of India.

Virk *et al.* (1995) and Witcombe *et al.* (1998) reported that at All India level weighted average age of rice varieties was 11.5 years during 1993. But the age of oldest cultivar was 25 years and its share in total breeder seed indent was 3 per cent. Further they reported that during 1993, there was breeder seed indent for 20 varieties of rice and most popular 3 varieties share in indent was 38 per cent during 1986-88 to 1990-93. Witcombe *et al.* (1998) observed that during 1986-88 to 1990-93, share of top 10 rice varieties in breeder seed indent was 60.4 per cent. Virk *et al.* (1995) argued that one of the major reasons for low adoption and replacement was lack of quick and wider dissemination of information about new rice varieties released and poor popularization.

Singh and Kalra (2002) reported that in Indian Punjab, there had been about 10 to 12 varieties in the field in any year during 1984-85 to 1998-99 and share of basmati variety ranged between 3 to 7 per cent in different years (despite of its lower yield compared to other high yielding varieties and not being covered under price support program) due to price advantage associated with it. They reported that rice variety PR-106 remained dominant for a decade and covered 63 per cent area in 1991-92 and was relegated to third position in 1998-99 by Pusa 44 and PR 111 varieties. They observed that aggregate level varietal diversity index in rice was not able to explain yield levels but average age of variety positively affected the yield of rice. They inferred that varieties with more stable yield stayed longer in field. Singh (2010) viewed that though Pusa 44 variety was not recommended for Punjab (in view of its high water requirement and susceptibility to bacterial leaf blight) it became popular with farmers due to higher yield and better quality. Manan *et al.* (2018) in the context of Kapurtala district of Indian Punjab (where farmers grow three crops per year), observed that farmers experience of problem in marketing of Paddy variety PR-126 (because of its early harvesting time than that notified by the Government) led to their preference for PR-121 variety.

Joshi *et al.*, (2018a) reported that in Punjab, "varietal stickiness" *i.e.* inertia to change from long duration Pusa-44 variety rice- (which was released in 1994) was due to combination of three factors *viz.*; higher yields of the variety, assured procurement and tariff free electricity. On the contrary Joshi *et al.*, (2018b) observed that the average age of basmati rice varieties cultivated in Punjab and Haryana was six years. This indicates that varietal replacement was faster in basmati rice. *Joshi et al.*, (2018b) also observed higher varietal diversity in Haryana compared to Punjab. They inferred that public private partnership, farmers' beliefs regarding attributes (pest resistance, more yield of fodder, premium price for grain) and influence of early adopters (peer effect) have played role in faster diffusion of Pusa Basmati-1121 rice variety in Punjab and Haryana. Singh *et al.* (2018) reported that compared to traditional basmati rice, Pusa Basmati-1121 was of shorter duration and with double yield. These attributes also led to wider adoption of variety with a share of 63% of area under basmati rice in India in the year 2015. However, Pusa Basmati-1121 became susceptible to pests and diseases and hence being used as a parent in developing biotic stress resistant basmati varieties.

Gauchan and Pandey (2012) reported that a handful of older vintage improved rice varieties dominated in South Asia and the average varietal age was found to be in excess of 19 years in all locations studied. They reported that in India, rice variety Lalat was dominant in drought prone areas in Odisha, Mahsuri in submergence prone environment in Assam, Ranjit in submergence, prone environment in Assam and West Bengal, Swarna in all environments. Walker *et al.* (2015) observed average age of modern varieties of rice as 15.8 years and adoption rate of 38 per cent in Sub Saharan Africa. Malabayabas *et al.* (2012) reported weighted average age of paddy varieties in eastern India as 31 years indicating lower adoption of modern varieties. Singh (2015) reported that 50% varieties released during 2001-2013 were in active seed chain in India. However, during 2012-2014, only 24 varieties in breeder seed indent (out of indent for 226-275 varieties) constituted approximately 60 per cent share. Out of these 24 varieties, 13 were new varieties (released after 2001). Pandey *et al.*, (2015) reported the average rice varietal age in Nepal as 20 years based on expert elicitation method and 24 years based on a household survey. Tsusaka *et al.* (2015) observed that average varietal age (as of year 2010) in rice ranged between 15 (Bhutan) to 23 years (West Bengal, India) in the case of different south Asian countries. They further observed that average lag in adoption ranged from 11-15 years, with the exception of Bhutan (7 years). Further, they observed that area under rice varieties of more than 10 years, constituted more than 60 per cent of area planted. Witcombe *et al.*, (2017) in the context of Nepal, analysing household data pertaining to 18 districts at two points of time (*i.e.*, 2008 and 2011) reported increase in rice varietal diversity. They observed that 13 varieties made up 75 per cent of the area in 2011 instead of nine in 2008. They also observed spatial variation in varietal distribution. Further, the average varietal age of varieties covering 75 per cent of area was 21.8 years in both the years and only two varieties were of less than 15 years age. Weighted average age of predominant varieties was 23 and 22.5 years in 2008 and 2011, respectively. Pandey *et al.*, (2017) in the context of Odisha state in India, observed that in 2014, top 10 rice varieties seeds in public system accounted for 95 per cent of total quantity produced, top three varieties constituted 70 per cent of total seed production. Further all the three top varieties were released prior to year 2000. Atlin *et al.* (2017) reported that in India, the weighted average age of rainfed rice in the year 2014 was 28 years.

Veettil *et al.* (2018) in a study focusing on Bihar, West Bengal and Odisha states (based on farm level data) observed that average age of varieties was highest in the case of Bihar (38.37 years) followed by 32.28 years in case of West Bengal and 23.66 years in case of Odisha. On an average, the varieties were replaced in every 7.30 years and the seeds were replaced in every 2.75 years. Bihar was the state with fastest varietal replacement (5.31 years) followed by Odisha and West Bengal (8.35 years). Bihar was the state with fastest seed replacement (1.57 years) followed by West Bengal and Odisha (3.09 years). They also observed that varietal replacement is done with older varieties instead of new varieties leading to a very high average age of rice varieties.

From the literature it is clear that, so far the metrics used for assessing crop dynamics in case of paddy were (i) total number of varieties at two points of time (ii) weighted average age/average age of all varieties at two points of time (iii) age of oldest variety and its share (iv) number of varieties contributing 75% area and their average age at two points of time (v) number of varieties of below 10/15 years age and their share (vi) number of years for replacing a variety with another variety (at farm level) (vii) number of states/regions in which a particular variety is grown and (viii) average rice area per one improved variety of rice (Janaiah and Hossain, 2004). In some other crops, additional metrics were used *viz.*, (i) proportion of area sown to varieties not sown in earlier period (Johnson and Gustafson,1963) (ii) proportion of the area that is sown to varieties released in the previous 5-10 years (Auer, 1963) or proportion of the area that is sown under varieties of less than 10 years old (Latha *et al.*, 2018) **(**iii)) number of varieties which were sown on more than 5 per cent of total area individually (Brennan, 1984) and (iv) spatial indices like Herfindahl index calculated by squaring share of each variety in crop area or seed distributed and then summing these values across varieties, Margalef indices (ratio of number of varieties of a particular crop to logarithm of total area under the crop in a given locality in a given year) (Praveen *et al.*, 2017).

In this backdrop, in the present study, an attempt has been made to analyse rice varietal dynamics and diversity in India using breeder seed indents data of selected years. An effort was also made to identify measures to improve varietal turnover by reviewing literature. Some additional metrics of varietal dynamics in paddy are used *viz.*, (i) Number of varieties common in two selected years and their share and (ii) Number of varieties common in both years, with increased quantity indented in the second year.

Methodology

Data: This study is based on breeder seed indent data for selected years *viz.*, 1997, 2007, 2015 and 2020. More specifically the current study was focused on rice varieties only (excluding rice hybrids, as hybrid rice adoption is limited to only 6 per cent of rice area in India confining to specific geographic areas). For the years 1997 (oldest year for which data was available in public domain) and 2007 data were collected from Directorate of Rice Research (DRR) Annual report and AICRIP report respectively, which gave variety wise indent only but not indenter-wise varietal demand. For the years 2015 and 2020 indenter-wise data for different rice varieties was collected from seednet website (https://seednet.gov.in).

Methodology: Simple tabular approach was used for analysing the data collected. Indenter-wise number of varieties indented was used as a simple measure of varietal diversity. Share of top 1 variety, top 3/5/10 varieties and number of varieties constituting 75 per cent of total indent were used as other measures of varietal diversity/ concentration at all India level.

Weighted average age of top 10 varieties was used as a measure of temporal diversity *i.e*., cultivar replacement frequency. Varietal age was calculated as duration from the year of notification to a reference year. Weighted average age of top 10 varieties was calculated by dividing the sum of quantity weighted age of top 10 varieties with sum of quantity of top 10 varieties. That is, if age of top 10 varieties is represented as A1,A2,A3,A4,A5,A6,A7,A8,A9, A10 and quantity of seed indented of top 10 varieties is represented as Q1,Q2,Q3. Q4,Q5,Q6,Q7,Q8,Q9,Q10, then weighted average of top 10 varieties is calculated as

(A1 x Q1) + (A2 x Q2) + (A3xQ3) +..........+ (A10 x Q10) / (Q1 + Q2 + Q3+.........+ Q10).

Hence Weighted Average Age (WAA) of top 10 varieties = $\sum_{i=1}^{10} AQ \div \sum_{i=}^{10} Q$ where i ranges from 1 to 10 (*i.e* top 10 varieties).

In this study, varietal newness was measured as age below 10 years. Some metrics of varietal diversity were calculated at indenter level. In this paper words ‘paddy’ and ‘rice are used interchangeably in all portions except in introduction section where reference is made to paddy yields and rice yields with distinction.

Results and Discussion

Rice varietal dynamics and diversity

Some details regarding rice varietal dynamics at all India level are presented in Table1. In 1997 there were breeder seed indents for 56 varieties. It increased to 304 varieties in year 2020. There were only 34 varieties that were common in the indents for the years 1997 and 2007 contributing 77 and 53 per cent of total quantity of seed indented in the respective years. Out of the 34 varieties common in both the years, only in case of 15 rice varieties, quantity of seed indented in 2007 was more than that indented in 1997, indicating that in the case of other 19 common varieties indented quantity of seed decreased. Thus, in varieties common in both the selected years, some were in rising phase and some were in declining phase in accordance with established literature on varietal adoption pattern (initiation, increase and declining phase). Similar dynamics were observed between different years.

It is evident from Table 1 that when higher is the time period between selected years, lower is the number of varieties common in selected years. Further though total share of common varieties was always lower in second year (among selected years), there were some common varieties with increased seed quantity indent in second year. The results clearly indicate varietal dynamics with some deletions, some additions, and in common varieties some in increasing demand phase and some in decreasing demand phase in selected years.

Table1: Rice varietal dynamics in India

Period	Total number of varieties		Number of varieties common in both the years	Share of common varieties in total quantity of seed indented (%)		Number of common varieties in which quantity of seed indent increased in period 2 compared to period 1
	Year 1	Year 2		Year 1	Year 2	
1997-2007	56	113	34	77	53	15
2007-2015	113	218	70	86	52	30
2015-2020	218	304	133	89	65	55
1997-2020	56	304	24	61	14	8
2007-2020	113	304	55	77	27	17

Source: Computed from breeder seed indent data from (i) DRR Annual Report 1996-97, (ii) DRR Progress Report Varietal Improvement Vol 1, 2006 and (iii) https://seednet.gov.in

Rice varietal dynamics at state level was analysed using data on breeder seed indents for the years 2015 and 2020 and the results are presented in Table 2. In the year 2015, the number varieties for which indents were received ranged from 2 (Rajasthan) to 50 (Odisha). In the year 2020, the number of varieties for which indents were received ranged from 1 (Rajasthan) to 66 (West Bengal).

As it is evident from Table 2, the number of varieties common in indent for both the years (2015 and 2020) ranged from zero (Rajasthan) to 25 (West Bengal). The number of common varieties with respect to which indented quantity of seed increased in 2020 compared to 2015 ranged from zero (Assam, Haryana, Maharashtra, and Rajasthan) to 15 (West Bengal). In the case of indents from two organizations *i.e.*, Seed Association of India (SAI) and National Seed Corporation (NSC), the number of varieties for which indents were received in 2020 were more (134 and 60, respectively) compared to number of varieties in 2015 (106 and 33, respectively). But only in case of some states, the number of varieties for which indents were received in 2020 was more compared to number of varieties in 2015.

Table 2: Rice varietal dynamics across different indenters in selected years

Indenter	Number of varieties		Number of varieties common in both years	Share of common varieties in total indented breeder seed quantity (%)		Number of common varieties in which quantity of breeder seed indent increased in 2020 compared to 2015	Top three common varieties in which breeder seed indent increased in 2020 compared to 2015
	2015	2020		2015	2020		
Undivided Andhra Pradesh	22	37	17	90	61	8	MTU-1075, Jyothi, MTU-1061/RGL-2537
Assam	11	10	1	16	7	0	
Bihar	13	14	4	48	42	2	Sahabhagidhan, Sampada
Chhattisgarh	21	27	14	79	83	9	Swarna, Swarna Sub-1,IGKVR-1
Haryana	7	10	3	75	30	0	
Himachal Pradesh	5	4	3	58	70	3	HPR-2143, HPR-1156, Basmati Kasturi
Jammu & Kashmir	6	4	3	36	88	1	Basmati-370
Jharkhand	9	15	7	72	45	4	Rajendra Mahsuri-1, Sahabhagidhan, Naveen
Karnataka	18	22	16	99	84	9	Jyothi, Tunga, MTU-1010
Madhya Pradesh	8	35	7	99	36	4	Pusa Sugandh-5, Mtu-1010, MTU-1001
Maharashtra	26	26	14	81	77	0	
Odisha	50	46	18	87	63	1	Mrunalini
Punjab	9	13	4	81	42	2	Pusa Basmati-1121, PR-114
Rajasthan	2	1	0	0	0	0	
Tamil Nadu	5	5	2	54	76	2	Nellore Mahsuri, Swarna Sub-1
Tripura	10	12	8	90	83	4	Narendra Dhan-97, Naveen, Sahabhagidhan
Uttar Pradesh	28	20	4	11	40	4	Pusa Basmati-1509, NDR-2065, Pusa Basmati-1
Uttarakhand	33	13	8	40	23	1	HKR-127
West Bengal	34	66	25	90	63	15	Shatabdi, Swarna, Rajendra Bhagavathi
SAI	106	134	55	92	63	21	Pusa Basmati-1509, Puas-44, Swarna
NSC	33	60	18	77	59	3	Jyothi, Jaya, Gontra Bidhan-1

Source: Computed from breeder seed indent data from https://seednet.gov.in

Table 3: Rice varietal diversity concentration at all India level in selected years

Particulars	Unit	Year			
		1997	2007	2015	2020
Total quantity seed indented	Quintals	816.70	2100.41	4279.64	4805.32
Top 1 variety seed quantity indented and name of the variety	Quintals Name	73.70 IR-64	217.03 IR-64	498.63 MTU-1010	351.73 MTU-1010
Top 1 variety share (%) in total indent	Per cent	9	10	12	7
Age of top most variety	Years	6	16	15	20
Top 5 varieties seed quantity indented	Quintals	291.65	841.32	1509.04	1196.13
Top 5 varieties seed share (%) in total indent	Per cent	36.0	40	35	25
Top 10 varieties seed quantity indented	Quintals	462.65	1223.6	2221.25	1779.14
Top 10 varieties share (%) in total indent	Per cent	57	58	52	37
Weighted average age of top 10 varieties	Years	13	17	15	19
Average age of top 10 varieties	Years	13	17	16	16
Maximum age (top 10 varieties)	Years	28	27	35	40
Minimum age (top 10 varieties)	Years	6	7	4	4
Age range of top 10 varieties	Years	22	20	31	36
Number of varieties of below 10 years age in top 10 varieties	Number	5	2	3	4
Quantity of varieties of below 10 years age in top 10 varieties in total quantity seed	Quintals	209.30	237.17	704.7	530.6
Share of varieties of below 10 years age in top 10 varieties, in total quantity seed	Per cent	26	11	16	11

Source: Computed from breeder seed indent data from (i) DRR Annual Report 1996-97, (ii) DRR Progress Report Varietal Improvement Vol 1, 2006 and (iii) https://seednet.gov.in

Details of rice varietal diversity/concentration at all India level in selected years are presented in Table 3. At all India level indents for breeder seed quantity increased by around 6 times for *Kharif* 2020 compared to 1997. During the same years, share of top 5 varieties and top 10 varieties in total quantity of seed indented was decreased for 2020 compared to 1997, indicating increasing varietal diversity. But average age as well as weighted average age of top 10 varieties increased in indent for *Kharif* 2020 compared to *Kharif* 1997 indent. In indent for the year 1997 age range of top ten varieties was between 6 to 28 years while, the same in indent for 2020 ranged from 4 to 40 years. This indicates decrease in lower age limit of varieties indented but increase in upper age limit. This can be due to targeted policy intervention of introducing new varieties coupled with stable performance of older varieties. Among top 10 varieties, only 5 varieties were of age lower than 10 years in 1997. Corresponding figure in the case of indent for 2020 stood at 4. Share of these varieties of below 10 years age (in top 10 varieties) in total quantity of seed indent for 1997 and 2020 stood at 26 and 11 per cent, respectively. This lower share of new varieties (of below 10 years age) has led to higher weighted average age of top 10 varieties in indent for *Kharif* 2020.

Results of another way of looking at varietal dynamics/ diversity at all India level are presented in Table 4. The number of varieties constituting 75 per cent to total breeder seed was 18 in 1997 increased to 21 in 2007, 27 in 2015 and 52 in 2020, once again indicating decreasing varietal concentration. But both average age as well as weighted average age of these varieties has not followed any consistent pattern. Share of varieties of below 10 years age (in varieties constituting 75 per cent of total seed indent) in total seed indent also did not follow any consistent pattern, stood at 35 per cent in 1997 and at 30 per cent in indent for *Kharif* 2020.

Table 4: Another approach to look at Rice varietal dynamics and concentration in India

Particulars	Unit	1997	2007	2015	2020
Total indented quantity of seed	Quintals	816.7	2100.41	4279.64	4805.32
Number of varieties indented	Number	56	113	218	304
Number of varieties constituting 75% of total quantity of breeder seed indent	Number	18	21	27	52
Average age of varieties	Years	13	17	14	13
Weighted average age	Years	13	17	15	16
Maximum age	Years	28	38	35	51
Minimum age	Years	3	3	3	2
Age range	Years	25	35	32	49
Number of varieties of below 10 years age in varieties constituting 75% of total quantity of breeder seed indent	Number	9	5	11	27
Seed quantity of below 10 years age varieties in varieties constituting 75% of total quantity of breeder seed indent	Quintals	282.3	331.92	1091.28	1417.6
	Share (%)	35	16	25	30

Source: Computed from breeder seed indent data from (i) DRR Annual Report 1996-97, (ii) DRR Progress Report Varietal Improvement Vol 1,2006 and (iii) https://seednet.gov.in

A weighted average age of less than 10 years and adoption rates of improved varieties to the extent of 35 per cent are generally considered as indicators of good progress in plant breeding (Walker *et al*. 2015). From this perspective weighted average age of more than 10 years of varieties constituting 75 per cent of breeder seed indent (Table 4) and lower share of varieties of below 10 years age are some indicators of Indian rice seed system that needs attention. However, literature indicates that optimum period for varietal replacement in a crop will vary over time and is dependent on (i) the yearly genetic gain in yield or improvement in other desirable characteristics (ii) the rate of varietal decay caused by breakdown in disease/pest resistance (iii) genetic diversity for disease resistance in varieties that are currently grown (iv) cost of breeding and multiplying seeds of new varieties (v) cost of providing extension to substitute new varieties (vi) farmers' seed purchase and learning costs (Heisy, 1990) and (vii) cost of seed and capital, margin required to encourage farmers to replace seed (Heisy and Brennan,1991). Hence, there can be regional variation in rice varietal dynamics. This aspect is examined and results are presented in Table 5.

In indent for *Kharif* 2015 and *Kharif* 2020, Seed Association of India (SAI) share was 20 and 31 per cent, respectively. Among states, Odisha was the topmost indenter (25%) with topmost variety age of 16 years in 2015 and 11 years for 2020 indent; Chhattisgarh was the topper with 21 per cent of total all India breeder seed indent with topmost variety age of 20 years. Consequently at all India level age of topmost rice variety indented was 15 and 20 years in 2015 and 2020 indents, respectively. States together with SAI indents constituted 98 and 99 per cent of total quantity of seed indented at all India level in 2015 and 2020, respectively.

In indent for *Kharif* 2015, across states, top most variety share ranged between 11 per cent (Odisha, Uttarakhand) to 94 per cent (Rajasthan). In indent for *Kharif* 2020 top most variety share ranged between 11 per cent (Odisha) to 100 per cent (Rajasthan). Age of top most rice variety ranged between 2 years (Haryana, Punjab) to 35 years (Tripura and Uttarakhand) in indent for *Kharif* 2015. Age of top one rice variety ranged between 2 years (Assam) to 47 years (Jammu and Kashmir) in indent for *Kharif* 2020. In 2015, in case of 7 states (Bihar, Haryana, Himachal Pradesh, Punjab, Tamil Nadu, Uttar Pradesh and West Bengal) top most variety age was below 10 years. In 2020 indent, in case of 7 states (Undivided Andhra Pradesh, Assam, Bihar, Punjab, Rajasthan, Uttar Pradesh and Uttarakhand) top most variety age was below 10 years. Thus, only in case of Bihar, Punjab and Uttar Pradesh, age of topmost variety was below 10 years in both 2015 and 2020 indents.

Table 5: Selected Indenter wise varietal concentration and varietal age

Indenter	Total quantity seed (Quintals)		Top most variety share (%)		Age of top most variety (years)		Top 10 varieties share (%)		Weighted average age of top 10 varieties (years)		Top 10 varieties age range in indent for 2015 (years)			Top 10 varieties age range in indent for 2020 (years)		
	2015	2020	2015	2020	2015	2020	2015	2020	2015	2020	Max	Min	Range	Max.	Min.	Range
Undivided Andhra Pradesh	317.5	237.06	31	13	15	4	87	70	19	15	35	5	30	31	2	29
Assam	204	270	34	15	21	2	98	100	21	6	41	6	35	14	2	12
Bihar	312	330.1	22	22	6	9	91	98	13	7	37	4	33	12	3	9
Chhattisgarh	739.44	988.4	19	18	15	20	74	82	12	19	19	3	16	40	5	35
Haryana	1.28	0.8	63	10	2	13	100	100	6	13	21	2	19	31	3	28
Himachal Pradesh	24	40	33	35	9	14	100	100	11	14	26	9	17	31	7	24
Jammu &Kashmir	9.6	4.3	52	58	10	47	100	100	19	38	42	2	40	47	19	28
Jharkhand	87	116.81	23	20	24	40	100	89	16	20	26	4	22	40	4	36
Karnataka	57.75	71.9	20	18	24	29	88	83	20	26	46	7	39	51	4	47
Madhya Pradesh	106	447.3	42	15	15	20	100	66	20	13	33	5	28	23	2	21
Maharashtra	129.05	51.2	20	29	22	27	76	82	17	26	46	5	41	51	4	47
Odisha	1067.6	274.7	11	11	16	11	80	63	14	19	35	4	31	40	5	35
Punjab	2.02	2.28	50	18	2	9	100	95	8	9	20	2	18	19	2	17
Rajasthan	0.8	0.1	94	100	10	7	100	100	10	7	10	8	2	7	7	0
Tamil Nadu	13	15.5	38	58	5	10	100	100	12	9	26	4	22	11	2	9
Tripura	2.05	2.6	29	19	35	27	100	96	20	20	35	4	31	40	5	35
Uttar Pradesh	122.6	153.3	15	20	6	7	69	81	13	6	41	4	37	9	1	8
Uttarakhand	17.86	15.2	11	53	35	6	61	94	18	8	35	2	33	40	5	35
West Bengal	89	211	17	13	9	20	79	57	16	19	35	4	31	40	5	35
SAI	872.89	1503.72	16	9	10	26	62	54	16	21	35	6	29	51	3	48
All India	4279.64	4805.32	12	7	15	20	52	37	15	19	35	4	31	40	4	36

Source: Computed from breeder seed indent data from https://seednet.gov.in

In indent for *Kharif* 2015, across states top 10 varieties share ranged between 61 per cent (Uttarakhand) to 100 per cent (Tripura) and their weighted average age ranged between 6 years (Haryana) to 21 years (Assam). In indent for *Kharif* 2020, across states top 10 varieties share ranged between 57 per cent (West Bengal) to 100 per cent (Chhattisgarh) and their weighted average age ranged between 6 years (Assam and Uttar Pradesh) to 38 years (Jammu and Kashmir). In 2015 indent, only with respect to two states (Haryana and Punjab) weighted average age of top 10 varieties was below 10 years. In 2020 indent, weighted average age of top 10 varieties was below 10 years in case of 7 states. Punjab was the only state indenter with weighted average age of top 10 varieties of below 10 years in both 2015 and 2020. In 2015, top 10 rice varieties with maximum diversified age range of 41 years (maximum 46 years and minimum 5 years) was observed in case of Maharashtra. In 2020 indent, top 10 rice varieties with maximum diversified age range of 47 years (maximum 51 years and minimum 4 years) was observed in case of Karnataka.

Details of top 10 varieties at all India level in terms of breeder seed indent (quantity) in selected years are presented in Table 6. Both in year 1997 and 2007, top 3 varieties were IR-64, MTU-7029 and IR-36 in that order. MTU-1010 (Cottondora Sannalu) variety which was in fourth place in 2007, became top most variety in 2015 and maintained its position in 2020 indent also. Jaya rice variety, was in fifth place in 1997, moved to 15th place in 2020 indent (with an age of 51 years) contributing 1.4 per cent of total breeder seed indent. In 2020 indent, major indenters for Jaya variety were Seed Association of India, Karnataka and Maharashtra. In 2020 indent, age of top two varieties *i.e* MTU-1010 and MTU-7029 varieties were 20 years and 40 years, respectively and their individual shares in breeder seed indent were 7.32 and 7.26 per cent, respectively. In 1997, 2015 indents, among top 10 rice varieties, one variety was Basmati variety. In 2020 breeder seed indent, among top 10 varieties, 2 were Basmati rice varieties.

Table 6: Top 10 varieties at all India level based on quantity of breeder seed indented

Rank	Year			
	1997	2007	2015	2020
1	IR-64	IR-64	MTU-1010	MTU-1010
2	MTU-7029 (Swarna)	MTU-7029 (Swarna)	Swarna-Sub 1	MTU-7029 (Swarna)
3	IR-36	IR-36	MTU-1001	Swarna-Sub 1
4	Kalinga-III	MTU-1010	MTU-7029 (Swarna)	Sahabhagi Dhan
5	Jaya	Samba Mahsuri	Sahabhagi Dhan	Pusa Basmati-1509
6	Heera	MTU-1001	Samba Mahsuri	Pusa-44
7	Samba Mahsuri	Kranti	Pusa Basmati-1121	DRR Dhan-42
8	Rasi	Shatabdi	IR-64	Sri Dhruthi
9	Pusa Basmati-1	NLR-145	Pratikshya	MTU-1001
10	Annada	Lalat	Pooja	Pusa Basmati-1121

Source: Computed from breeder seed indent data from (i) DRR Annual Report 1996-97, (ii) DRR Progress Report Varietal Improvement Vol 1,2006 and (iii) https://seednet.gov.in

Details of top 10 varieties at all India level in terms of number of indenters are presented in Table 7. MTU-1010 was the variety with highest number of indenters followed by Swarna-Sub1 in 2015 indent as well as in indent for 2020.

Basmati rice is a special rice type with IPR protection under Geographical Indications (GI) in India. Basmati rice is significant contributor in earnings from exports of rice from India. In 2018-19, earnings from basmati rice exports was 4.72 billion US$ against export earnings of 3.05 billion US$ from non-basmati rice exports (APEDA, 2020). Hence Basmati rice varietal dynamics was analysed separately and the results are presented in Table 8. So far 32 Basmati rice varieties were notified (AIREA, 2019). Number of Basmati varieties with respect to which breeder seed indent received in 1997 was three, it gradually increased to 14 in 2020. In 2020, share of Basmati indents in total quantity of rice breeder seed indent stood at 8.27 per cent. Age of top most Basmati rice variety indented was higher than age of topmost (all) rice variety seed indented in 1997 and 2007, but was lower in 2015 and 2020. Top 3 Basmati rice varieties share in total Basmati varieties breeder seed was 100 per cent in 1997, gradually declined over years and was 70.87 per cent in 2020 indent, indicating decrease in varietal concentration. Pusa Basmati-1 was the topmost variety in 1997 and was relegated to second position in 2015. Pusa Basmati-1121 which was in third position in 2007 became topmost variety in 2015, but was relegated to second position in 2020. Pusa Basmati -1509 variety which was in third position in 2015, became topmost variety in 2020 indent.

Table 7: Top 10 varieties at all India level based on number of indenters

	Year				
2015			2020		
Rank	**Variety**	**Number of indenters**	**Rank**	**Variety**	**Number of indenters**
1	MTU-1010	16	1	MTU-1010	12
2	Swarna Sub-1	14	2	Swarna Sub-1	11
3	MTU-7029 (Swarna)	13	3	DRR Dhan-42	10
4	Sahabaghi Dhan	12	4	MTU-7029(Swarna)	10
5	Samba Mahsuri	12	5	Sahabaghi Dhan	9
6	MTU-1001	12	6	MTU-1001	9
7	Pusa Basmati-1121	11	7	DRR Dhan-44	8
8	IR-64	10	8	CO-51	7
9	Pusa Basmati-1509	8	9	DRR Dhan-45	6
10	Shatabdi	7	10	Sambha Sub-1	6

Source: Computed from breeder seed indent data from https://seednet.gov.in

Table 8: Varietal dynamics in Basmati rice varieties

	Unit	**1997**	**2007**	**2015**	**2020**
Total number of varieties	Number	56	113	218	304
Number of Basmati varieties	Number	3	7	12	14
Total indented quantity of all varieties	Quintals	816.7	2100.41	4279.64	4805.32
Basmati varieties quantity indented	Quintals	41.70	43.93	274.50	397.41
Share of Basmati varieties in total indented quantity	Per centage	5.11	2.09	6.41	8.27
Maximum Age of Basmati variety	Years	24	34	42	47
Minimum Age of Basmati variety	Years	8	2	2	2
Age of topmost Basmati variety	Years	8	18	10	7
		Top 3 Basmati Varieties and their share in total Basmati seed indent			
		Pusa Basmati-1 (71.94)	Pusa Basmati-1 (58.11)	Pusa Basmati - 1121 (58.94)	Pusa Basmati-1509 (33.95)
		Kasturi (16.79)	Vasumathi (18.10)	Pusa Basmati-1 (18.21)	Pusa Basmati - 1121 (24.47)
		Basmati-370 (11.27)	Pusa Basmati - 1121 (9.86)	Pusa Basmati-1509 (8.16)	Pusa Basmathi-1637 (12.45)
Share of top 3 Basmati varieties in total Basmati varieties	Per centage	100	86.07	85.31	70.87
Weighted average age of top 3 Basmati varieties	Years	10	13	13	9

*Figures in parentheses indicate per centages

Source: Computed from breeder seed indent data from (i) DRR Annual Report 1996-97,(ii) DRR Progress Report Varietal Improvement Vol 1, 2006 and (iii) https://seednet.gov.in

Details of state-wise top 5 rice varieties based on quantity of breeder seed indent are presented in Table 9. MTU-1010 was the topmost variety in the case of undivided Andhra Pradesh, Chhattisgarh and Madhya Pradesh in 2015 indent. However, in indents for the year 2020, MTU-1010 rice variety was the topmost variety only in case of Chhattisgarh and Madhya Pradesh. In case of undivided Andhra Pradesh, KNM-118 became the topmost variety indented for year 2020. MTU-7029 was the topmost variety in case of Tripura, Uttarakhand in 2015 indent, but was topmost variety in case of only Jharkhand in 2020.

Table 9: State wise top 5 varieties in 2015 and 2020 breeder seed indents

		Rank				
Indenter	**Year**	**1**	**2**	**3**	**4**	**5**
Undivided Andhra Pradesh	2015	MTU-1010	Samba Mahsuri	MTU-1001	MTU-7029	Swarna-Sub 1
	2020	KNM-118	Samba Mahsuri	MTU-1010	RNR-15048	MTU 1075
Assam	2015	Ranjeet	Swarna-Sub-1	IR-64	Masuri	Bahadur
	2020	Bahadur Sub-1	Ranjit Sub-1	CR Dhan-310	Gitesh	CR Dhan 505
Bihar	2015	Swarna-Sub 1	Sahabhagi Dhan	MTU-1010	Samba Mahsuri	MTU-1001
	2020	Sahabaghi Dhan	Rajendra Baghavathi	Sabour Ardhjal	Sabour Surbhit	Sabour Shree
Chhattisgarh	2015	MTU-1010	Mahamaya	Narendra-8002	MTU-1001	PKV HMT
	2020	MTU-1010	MTU-7029	Swarna-SUB 1	IGKVR-1	Mahamaya
Haryana	2015	Pusa Basmati-1509	HKR-127	HKR-47	PR-113	PR-114
	2020	Pusa Basmati-1718	Pusa Basmati 1637	Pusa Basmati 1728	Pusa 1592	Pusa Basmati-1509
Himachal Pradesh	2015	HPR 2143	HPR-1068	HPR-1156	RP-2421	Basmati Kasturi
	2020	HPR 2143	HPR-2612	HPR-1156	Basmati Kasturi	
Jammu and Kashmir	2015	Pusa Basmati-1121	Basmati-370	Chenab	Pusa Basmati-1509	Giza-14
	2020	Basmati-370	Chenab	PR-113	Giza-14	
Jharkhand	2015	IR-64	Lalat	Abhishek	Rajendra Mahsuri-1	Sahabaghi Dhan
	2020	MTU-7029	IR64 DRT 1	Sahabhagi Dhan	Rajendra Mahsuri-1	MTU-1010
Karnataka	2015	IR-64	Samba Mahsuri	MTU-1001	Uma	JGL-1798
	2020	IR-64	MTU-1001	RNR-15048	MTU-1010	Jaya
Madhya Pradesh	2015	MTU-1010	IR-64	MTU-1001	Kranti	IR-36
	2020	MTU-1010	Pusa Sugandh-5	IR64 DRT 1	MTU-1001	Sahabhagi Dhan
Maharashtra	2015	Indrayani	MTU-1010	PKV HMT	Jaya	Karjat-3
	2020	Indrayani	MTU-1010	Jaya	CO 51	RTN-5
Odisha	2015	Pooja	Sahabhagi Dhan	Swarna-Sub 1	MTU-1010	Pratikshya
	2020	Swarna-Sub 1	Pooja	MTU-1010	MTU-1001	MTU-7029
Punjab	2015	Pusa Basmati-1509	PR-114	PR-111	PR-113	Pusa Basmati - 1121
	2020	PR 121	PR-114	PR-126	Pusa Basmati -1121	PR-127
Rajasthan	2015	Pusa Basmati - 1121	Improved Pusa Basmati-1			
	2020	Pratap -1				
Tamil Nadu	2015	NLR-34449	Samba Mahsuri	Swarna - Sub 1	Sahabahagi Dhan	JGL-1798
	2020	NLR-34449	Swarna-Sub 1	DRR Dhan-45	Sambha Sub - 1	DRR Dhan 50
Tripura	2015	MTU-7029	Naveen	Sahabhagi Dhan	Narendra Dhan-97	Shatabdi
	2020	Naveen	MTU-7029	Sahabhagidhan	Narendra Dhan-97	CO 51

Uttar Pradesh	2015	Swarna-Sub 1	Improved Samba Mahsuri	Narendra Dhan -359	Samba Mahsuri	NDR 2065
	2020	Pusa Basmati-1509	Pant Dhan-24	NDR 2065	PR 121	Sambha Sub - 1
Uttarakhand	2015	MTU-7029	VL.Dhan 85	Sarjoo-52	Vivek Dhan-62	Swarna-Sub 1
	2020	VL Dhan 68	VL Dhan 157	PR 121	HKR-127	VL Dhan 85
West Bengal	2015	Pratikshya	Swarna-Sub 1	MTU-7029	MTU-1010	Gontra Bidhan-1
	2020	Shatabdi	MTU-7029	Pratikshya	Swarna-Sub 1	MTU-1010

Source: Computed from breeder seed indent data from https://seednet.gov.in

Table 10: Top 10 varieties in breeders seed indent of SAI

2015			2020		
Variety	**Share in total SAI indent (%)**	**SAI share in total All India indent (%)**	**Variety Name**	**Share in total SAI indent (%)**	**SAI share in total All India indent (%)**
Pusa Basmati - 1121	16	84	Pusa-44	9	100
Swarna-Sub 1	9	21	MTU-7029 (Swarna)	8	35
MTU-7029 (Swarna)	8	33	Pusa Basmati-1509	7	76
Pusa-44	6	99	Sri Dhruthi	7	89
Pusa Basmati-1	6	98	Pusa Basmati -1121	6	94
Gontra Bidhan-1	5	88	PR-113	4	99
IR-64	4	26	Jaya	4	85
MTU-1010	4	7	Indrayani	3	77
PR-118	3	98	Pusa Basmati -1718	3	99
Shatabdi	3	67	Pusa Basmati 1637	3	89
Top10 varieties total	62	34		54	73

Source: Computed from breeder seed indent data from https://seednet.gov.in

In 2015 indent, Swarna-Sub 1 was the topmost variety in case of Bihar and Uttar Pradesh. In 2020 indent, Swarna-Sub 1 was the topmost variety in case of Odisha. Only in case of 6 states, there was no change in topmost variety in 2015 and 2020 indents. They are Chhattisgarh (MTU-1010), Himachal Pradesh (HPR-2143), Karnataka (IR-64), Madhya Pradesh (MTU-1010), Maharashtra (Indrayani), and Tamil Nadu (NLR-34449). Only in case of three states, there was no change in second top variety. They are undivided Andhra Pradesh (Samba Mahsuri), Maharashtra (MTU-1010) and Punjab (PR-114).

Varietal dynamics in seed indent of SAI in 2015 and 2020 was analysed separately and results are presented in Table 10 and 11. Share of topmost rice variety in SAI indent was 16 and 9 per cent in indents for 2015 and 2020, respectively with topmost variety of age of 10 and 26 years. Share of top 10 varieties indents in SAI indent was 62 and 54 per cent in 2015 and 2020 respectively. Among top 10 varieties of SAI indents in 2015 and 2020 only 3 varieties were common indicating high varietal dynamics. A comparison of top ten varieties at all India level (Table 6) and top ten varieties in SAI indents (Table 10) yields some interesting insights. In 2015, there were 4 varieties common in both the tables and in 2020 the number of common varieties increased to 5. In 2015 common varieties, SAI share in total all India level indent ranged from 21 to 84 per cent and in 2020 the range varied 35 to 100 per cent. From the Table 10 it is evident that, indents for certain varieties like Pusa-44, PR-118, PR-113 which is cultivated in Punjab and Haryana, were reflected in SAI indent (constituting more than 90 per cent of indented quantity for these varieties), rather than direct indents from the states. Same is the situation with Basmati rice varieties also as more quantity is indented by SAI than states like Punjab and Haryana. In 2015 at all India level there were indents for 12 Basmati varieties, SAI indent was there for seven Basmati varieties accounting for 80 per cent of Basmati varieties, seed indent at all India level. In 2020 at all India level, there were indents for 14 Basmati varieties, SAI indent was there for 11 Basmati varieties accounting for 84 per cent of Basmati varieties seed indent at all India level.

Table 11: Frequency distribution of number of varieties in SAI indent based on their share in total all India breeder seed indent

Share of SAI indent in total indent (%)	Number of varieties	
	2015 indents	2020 indents
100	29	44
90-99	9	12
80-89	4	13
70-79	4	5
60-69	5	2
50-59	2	1
40-49	3	9
30-39	9	4
20-29	7	12
10-19	13	9
<9	21	23
Total number of varieties	106	134

Source: Computed from breeder seed indent data https://seednet.gov.in

In 2015, SAI indent was for 106 varieties, out of this only in case of 53 varieties, share of SAI in total quantity of breeder seed indent was below 50 per cent (Table 11). Similarly in 2020, SAI indent was for 134 varieties, out of this only in case of 57 varieties, share of SAI in total quantity of breeder seed indent was below 50 per cent. Thus SAI indent was above 50% of total breeder seed indent in case of 53 varieties in 2015 and in case of 77 varieties in 2020. This might have some extent masked the indent for these varieties from states. Totally in 2015 indent, 100 per cent indent was from SAI for 29 varieties and in 2020 for 44 varieties. In other words if SAI indent was not there for these varieties, total number of varieties for which breeder seed indents received would have decreased to 189 and 260 in place of 218 and 304 in 2015 and 2020, respectively.

In January 2019, the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA) through its notice on plant breeder's rights stated that the procedure of compiling indents by Central and State Government organizations for seed production and fixing of breeder seed price under Seeds Act (1966) henceforth will be restricted only to varieties which are not registered under (Protection of Plant Varieties and Farmers' Rights Act) PPV&FR Act 2001 or those whose period of protection under the registration has expired on the date (PPV&FRA, 2019). Thus, in future there will be different mechanisms for indenting for varieties based on whether a variety is protected or not under PPV&FR Act. Accordingly mechanism of price fixation for breeder seed also will differ and in turn may influence varietal dynamics.

Measures for improving rice varietal turnover

In the case of wheat cultivation in Punjab of India, Smale *et al.*, (2008) observed that slow varietal change had offset the positive productivity effects of diversifying the genetic base in wheat breeding during post green revolution period. Hence nudging varietal turnover in a particular direction by discouraging breeder seed indent for older varieties or withdrawal of old varieties can be a option for promoting varietal turnover (Krishna *et al.* 2014, Atlin *et al.* 2017). They also suggested the measures of withdrawal of seed subsidy for obsolete varieties, setting targets for the average varietal age in foundation seed production and farmers' fields (below 10 years). Spielman and Smale (2017) suggested leveraging seed subsidy program by targeting subsidy on a variety-specific basis with the goal of removing older varieties. Some efforts in this direction were observed in the case of Telangana and Andhra Pradesh states in recent years, wherein subsidy rates for paddy seeds are different, more for varieties less than 10 years old and less for varieties of more than ten years old. In recent draft seed bill (2019) of India, proposal of a validity period of ten years for registered variety of annual crops like rice also can be considered as a targeted policy approach for improving varietal turnover. However, it is being viewed that it is difficult to decide regarding the resistance threshold at which a variety should be withdrawn from circulation.

Supply side constraint with respect to new varieties can act as hindrance in promoting varietal turnover (Krishna *et al.* 2014). Atlin *et al.* (2017) observed that competitive commercial seed industry in temperate regions was able to address this supply side constraint. Further, Atlin *et al.* (2017) argued that rapid release of varieties by utilizing breeding tools based on sound quantitative genetics principles thereby reducing breeding cycle length is a key to cropping system adaptation to climate change. Witcombe *et al.* (2013) opined that efficiency of breeding programs would be increased by making fewer crosses among more carefully chosen parents. Muralidharan *et al.* (2019) in the context of India, suggested focussed rice breeding in four mega environments namely rainfed unfavourable uplands, rainfed favourable uplands, irrigated areas and rainfed lowlands.

Spielman and Smale (2017) suggested some policy measures for accelerating varietal turnover. They are (i) accelerating varietal registration and release (like recent agreement between India, Nepal, Bangladesh, Srilanka and Cambodia (IRRI, 2017) and harmonizing rice varietal registration procedure and mutual recognition of registration among countries) (ii) improving quality assurance systems (iii) increasing access to early generation seed (through licensing) (iv) leveraging seed enterprises marketing capabilities and (v) leveraging competition policy and antitrust regulation. But they also indicate that there can be trade-off between spatial and temporal diversification, making it complex to decide about appropriate policy choices. Some researchers also suggested leveraging competition and fast tracking release of varieties resistant or tolerant to biotic and abiotic stress for accelerating varietal turnover (Das *et al.*, 2019, Berhanu *et al.*, 2019).

Joshi *et al.*, (2001) reported that in Nepal spread of rice varieties from a participatory plant breeding commenced five to six years earlier than would have been the case in a conventional system. Witcombe and Yadavendra (2014) reported that in India, Ashoka rice varieties developed through Client Oriented Breeding (COB) replaced landraces or varieties adopted from conventional breeding. Ashoka 200F rice variety was notified in 2005 (for Jharkhand, though it was identified for release in 2002) and 2006 (for Gujarat, Rajasthan and Madhya Pradesh) and in 2013, breeders seed indent for it was 16^{th} highest of 225 notified rice varieties. Pray *et al.*, (2011) reported that Gramin Vikas Trust (GVT) the developer of Asoka varieties was unsuccessful in getting approval for the varieties as there was no provision for release of new varieties by NGO under Indian seed regulation. Later GVT collaborated with Birsa Agricultural University (BAU) and Asoka rice varieties were released as BAU varieties.

Singh *et al.* (2014) reported that a salt tolerant rice variety CSR-43 developed through participatory variety selection (during 2001-2007) was widely adopted in sodic areas of Indo-Gangetic plains and was officially released in 2011. Conny *et al.* (2019) argued that many of currently used research methods are weak on capturing real-life context and provided fragmented snapshot nature understanding of farmer's preferences and demand for seeds. Carlo *et al.* (2019) suggested triadic comparison of varieties (involving repeated participatory evaluation under farm condition) can help in delivering the best seeds based on the actual climatic conditions of a particular village.

Narappa *et al.*, (2018) reported that in Karnataka, seed village program helped in introduction of new rice variety "Gangavathisona" in 2011-12. They inferred that increase in salinity affected area in Tungabadra Project (TBP) Command area, susceptibility of rice variety samba mahsuri (BPT 5204) to pests and diseases, higher yields of Gangavathisona rice variety (compared to BPT-5204) under direct seeded rice practice and soil salinity led to spread of Gangavathisona rice variety to the extent of 15.1 per cent rice area in TBP area in 2014-15.

Nayak and Mosharaf (2019) observed in Odisha, in Evidence Hubs (EH), a new generation platform where in multiple varieties of rice were exhibited for performance evaluation by different stakeholders under different management or ecological condition, led to (a) selection of varieties such as CR 1009 Sub1, Swarna-Sub 1, Bina Dhan 11 and other climate resilient varieties in coastal areas and (b) selection of varieties like Sahabhagi Dhan, DRR Dhan-44 and Bina Dhan11 in upland areas. They further observed that though Bina Dhan 11 was the best variety in terms of yield, Sahabhagi Dhan was rated highest based on multi-attributes. Some unreleased varieties which were performing high in terms of stakeholders rating, triggered policy dialogue for release of those varieties.

Gars and Ward (2019) indicated that differences in learning behaviour of farmers can also lead to different pattern of technology adoption. They distinguished four types of learning processes. They are (i) Bayesian learning (belief updating as additional information becomes available) (ii) impressionable learning (first impression based) (iii) reactionary learning (give importance to recent information only) and (iv) myopic learning (not only give more weight to recent information but also do not consider the probabilities over which they are making their choices). They suggested pilot surveys for assessing share of farmers of different learning types in a location, for planning future interventions based on nature of technology.

Conclusions and Way forward

From the results of current study it can be concluded that rice varietal diversity in India in recent years is increasing in terms of metrics (i) number of varieties for which breeder seed indents received (ii) number of varieties contributing 75 per cent of total indented quantity and (iii) lower share of top 10 varieties in total breeder seed indent. However, a higher weighted average age of top 10 varieties is indicating that varietal replacement is taking place with substitution by older varieties.

Literature indicates that multiple factors *viz.*, characteristics of new varieties, market potential for different varieties of rice, divergent perceptions and learning behaviour of farmers and divergent contextual factors (like hydrology, soil suitability etc) are influencing rice varietal dynamics. Hence, for promoting adoption of improved rice varieties with reduced adoption lag, a multi-pronged strategy need to be adopted. Reducing breeding cycle length, targeted extension interventions based on share of farmers of different types of learning patterns, nudging varietal adoption behaviour by leveraging policies of subsidy and competition in seed sector, encouraging private sector participation in research and varietal commercialization, facilitating marketing of output of rice varieties of different durations by synchronizing marketing periods with crop harvesting period are some of the suggested components in the multi-pronged strategy.

The current study is based on macro level breeder seed indents only with some limitations. Hence, in future more disaggregated studies can yield more insights on varietal dynamics in different rice ecosystems and associated factors.

References

AIREA 2019 https://www.airea.net/basmati-varieties/. APEDA2020https://agriexchange.apeda.gov.in/indexp/reportlist.aspx accessed on 06-02-2020

Atlin Gary N, Jill E Cairns and Biswanath Das. 2017. Rapid breeding and varietal replacement are critical to adaptation of cropping systems in the developing world to climate change. *Global Food Security*, 12: 31-37

Auer L. 1963. Impact of crop yield technology on U.S. Crop production. Unpublished Ph.D thesis. Iowa State University of Science and Technology, Iowa,409 p.

Berhanu T Ertiro, Girum Azmach, Tolera Keno, Temesgen Chibsa, Beyene Abebe, Girma Demissie, Dagne Wegary, Legesse Wolde, Adefris Teklewol and Mosisa Worku. 2019. Fast-tracking the development and dissemination of a drought-tolerant maize variety in Ethiopia in response to the risks of climate change. P.79-86. In Todd S. Rosenstock, Andreea Nowak, Evan Girvetz (ed.) The Climate-Smart Agriculture papers -Investigating the business of a productive, Resilient and Low Emission Future. Springer Open.

Birthal Pratap S, Digvijay S. Negi, Md. Tajuddin Khan and Shaily Agarwal. 2015. Is Indian Agriculture becoming resilient to droughts? Evidence from rice production systems. *Food Policy*, 56:1-12

Brennan John P. 1984. Measuring the contribution of new varieties to increasing wheat yields. *Review of Marketing and Agricultural Economics*, 52(3): 175-195.

Byerlee Derek and Heisey Paul. 1990. Wheat varietal diversification over time and space as factors in yield gains and rust resistance in the Punjab. p. 5-24. In Heisy. P.W (ed.) Accelerating the transfer of wheat breeding gains to farmers : a study of the dynamics of varietal replacement in Pakistan. CIMMYT Research Report No.1.CIMMYT. Mexico.

Carlo Fadda and Jacob Van Etten. 2019. Generating farm validated variety recommendation for climate adaptation. p. 127-138. In Todd S. Rosenstock, Andreea Nowak, Evan Girvetz (ed.). The Climate-Smart Agriculture papers -Investigating the business of a productive, Resilient and Low Emission Future. Springer Open.

Conny JM Almekinders, Koen Beumer, Michael Hauser, Michael Misiko, Marcel Gatto, Agnes O Nkurumwa and Olaf Erenstein. 2019. Understanding the relations between farmers' seed demand and research methods: The challenge to do better. *Outlook on Agriculture*, 48(1): 16-21.

Dabi T and Khannan VK. 2018. Effect of climate change on rice. *Agrotechnology*, 7(2) DOI: 10.4172/2168-9881.1000181.

Das Biswanath, Francois Van Deventer, Andries Wessels, Given Mudenda, John Key and Dusan Ristanovic. 2019. Role and challenges of the Private seed sector in developing and disseminating Climate-Smart Crop varieties in Eastern and Southern Africa. P. 67-78. In Todd S. Rosenstock, Andreea Nowak, Evan Girvetz (ed.) The Climate-Smart Agriculture papers -Investigating the business of a productive, Resilient and Low Emission Future. Springer Open.

DES. 2019. Agricultural Statistics at a Glance -2018. Ministry of Agriculture and Farmer's Welfare, Department of Agriculture, Cooperation and Farmers Welfare, Directorate of Economics and Statistics. Government of India.

Draft Seed Bill. 2019. http://seednet.gov.in/Draft%20 Seed%20Bill/DraftSeedBill.pdf.

DRR Annual Report 1996-97. Directorate of Rice Research, Rajendranagar, Hyderabad-500030, India.

DRR (Directorate of Rice Research). 2007. Progress Report, 2006. Vol. 1 Varietal Improvement. All India Coordinated Rice Improvement Program. Directorate of Rice Research, Rajendranagar. Hyderabad-500030. India.

Duncan JMA, J Dash and EL Tompkins. 2017. Observing adaptive capacity in Indian rice production systems. *AIMS Agriculture and Food,* 2(2): 165-182.

Gars Jared and Ward Patrick S. 2019. Can differences in individual learning explain patterns of technology adoption? Evidence on heterogeneous learning patterns and hybrid rice adoption in Bihar, India. *World Development,* 115:178-189.

Gauchan. D and Pandey S. 2012. Synthesis of key results and implications. P.1-18. In Pandey S, Gauchan D, Malabayabas M, Bool Emerick M, Hardy B. (ed.) Pattern of adoption of improved rice varieties and farm level impacts in stress prone rainfed areas in South Asia. International Rice Research Institute.

GOI. 2019. State-wise and Item-wise value of output from agriculture, forestry and fishing,2011-12 to 2016-17. National Statistical Office, Ministry of Statistics and Programme Implementation, Government of India.

Heisey Paul W. and Brennan John P. 1991. An analytical model of farmers demand for replacement seed. *American Journal of Agricultural Economics,* 73(4): 1044-1052.

Heisy PW 1990. Accelerating the transfer of wheat breeding gains to farmers: a study of the dynamics of varietal replacement in Pakistan. CIMMYT, 1990.

IRRI. 2017. https://www.irri.org/news-and-events/news/agreement-multi-country-seed-sharing-reached.

Janaiah Aldas and Hossain Mahabub. 2004. Partnership in public sector agricultural R&D-evidence from India. *Economic and Political Weekly,* 39(50) :5327-5334.

Johnson DG. and Gustafson RL. 1963. Grain yield and the American food supply-an analysis of yield changes and possibilities. Second Impression, University of Chicago Press, Chicago.

Joshi KD, Sthapit BR and JR. Witcombe. 2001. How narrowly adapted are the products of centralized breeding? The spread of rice varieties from a participatory plant breeding programme in Nepal. *Euphytica,* 122: 589-597.

Joshi Kuhu, PK Joshi, Md. Tajuddin Khan, Avinash Kishore. 2018a. ‘Sticky rice’ Variety inertia and groundwater crisis in a technologically progressive State of India. IFPRI discussion paper-01766. International Food Policy Research Institute, South Asia Regional Office, New Delhi.

Joshi Kuhu, PK Joshi, Md. Tajuddin Khan, Avinash Kishore. 2018b. Insights on the rapid adoption of Pusa-1121 basmati variety in North India, IFPRI discussion paper-01756 International Food Policy Research Institute, South Asia Regional Office, New Delhi.

Krishna Vijesh V, David J Spielman, Prakashan C Veettil and Subash Ghimire. 2014. An empirical examination of the dynamics of varietal turnover in Indian Wheat. IFPRI Discussion paper 01336, International Food Policy Research Institute, U.S.A.

Latha Nagarajan, Anwar Naseem, Carl Pray. 2018. Contribution of policy change on maize varietal development and yields in Kenya. Selected Poster prepared for presentation at the 2018 Agricultural &applied economics association annual meeting during 5-7 August 2018 at Washington D.C.

Malabayabas M, Gauchan D and Pandey S. 2012. Comparative analysis of rice variety adoption patterns in Eastern India and Central Luzon (Philippines) IRRI.http://www.aares.org.au/aares/documents/2012ACPapers/Malabayabas.pdf.

Manan Jatinder, Manoj Sharma and Manpreet Jaidka. 2018. Factors affecting the adoption of paddy varieties in Kapurthala district of Punjab, India. *International Journal of Current Microbiology and Applied Sciences,* 7(9):3014-3020.

Matthews RB, MJ, Kropff, T Horie and D. Bachelet 1997. Simulating the impact of climate change on rice production in Asia and evaluating options for adaptation. *Agricultural Systems,* 54(3): 399-425.

Muralidharan K, GSV. Prasad, CS. Rao and EA. Siddiq. 2019. Genetic gain for yield in rice breeding and rice production in India to meet with the demand from increased human population. *Current Science,* 116(4): 544-560.

Narappa G, Negalur RB, Roopashree DH and Guruprasad GS. 2018. Seed Village Programme - a boon to the rice growing farmers for variety replacement with economic stability. *International Journal of Current Microbiology and Applied Sciences*, 7(4):3862-3868.

Nayak Swati and Hossain Mosharaf. 2019. Not just crop cafeterias! A evidence-based varietal evaluation and selection process to create seed demand and market. P.254-261 In Rasheed Sulaiman V, Onima V.T, Nimisha Mittal and Athira E.(ed). Taking stock and shaping the future: conversations on extension. Published by Agricultural Extension in South Asia (AESA).

Pandey S, Gauchan D, Malabayabas M, Bool-Emerick M, Hardy B. 2012. Pattern of adoption of improved rice varieties and farm-level impacts in stress-prone rainfed areas in South Asia. International Rice Research Institute. 318 pp.

Pandey Sushil, Debdutt Behura, Maria Lourdes Velasco. 2017. Transitions in Rice seed provisioning in Odisha-constraints and reform agenda. *Economic and Political Weekly*, 52(1): 83-91.

Pandey. S, Ma L Velasco and T, Yamano 2015. Scientific strength in rice improvement programmes, varietal outputs and adoption of improved varieties in South Asia. In Walker T.S, and Alwang. J (ed.) Crop improvement, adoption and impact of improved varieties in food crops in Sub-Saharan Africa, Published by CGIAR and CAB International.

Pavithra S, Christian Boeber, Showkat Ahmad Shah, SP Subash, PS Birthal and Surabhi Mittal. 2018. Adoption of modern maize varieties in India: Insights based on expert elicitation methodology. *Agricultural Research*, 7(4):391-401.

Pavithra S, Surabhi Mittal, SA. Bhat, PS. Birthal, SA.Shah and Vinod K Hariharan 2017. Spatial and Temporal Diversity in adoption of modern Wheat varieties in India. *Agricultural Economics Research Review*, 30(1): 57-72.

PPV&FRA 2019 http://www.plantauthority.gov.in/pdf/noticeonPlant-BR-29-01-2019.pdf.

Praveen K.V, KS. Aditya, P. Anbukkani, Pramod Kumar and Amit Kar. 2017. Spatial diversity in Indian Wheat and its determinants. *Agricultural Economics Research Review*, 30(2): 213-222.

Pray Carl, Latha Nagarajan, Luping Li, Jikun Huang, Ruifa Hu, KN Selvaraj, Ora Napsintuwong and R Chandra Babu.2011. Potential impact of biotechnology on adoption of agriculture to climate change: the case of drought tolerant rice breeding in Asia. *Sustainability*, 3:1723-1741.

Rao Subba LV, Fiyaz RA, Jukanti AK, Padmavathi G, Badri J, Anantha MS, Nagrjuna. E and Voleti.SR.2019. Coordinated Rice Improvement project in India: Its significant achievements and future prospects. *Oryza*, 56 (Special Issue):82-91.

Senguttuvel P, Revathi P, Kemparaju KB, Sruthi K, Sadat Ali M, Koteswara Rao P, and AS Hari Prasad. 2019. Rice hybrids released in India, Compendium No.103/2019.ICAR-Indian Institute of Rice Research, Rajendranagar, Hyderabad. P.127.

Singh Joginder. 2010. Genetic diversity for sustainability of rice crop in Indian Punjab and its implications. *Journal of Plant Breeding and Crop Science*, 2(9): 293-298.

Singh Karam and Sajl Kalra. 2002. Rice production in Punjab: system, varietal diversity, growth and sustainability. *Economic and Political Weekly*, 37(30) : 3139-3148.

Singh RP. 2015. Varietal replacement rates among field crops: current status, constraints, impact, challenges and opportunities for the Indian seed Industry. *Seed Times*, July-Dec 2015, P:71-89.

Singh Vijaipal, Ashok Kumar Singh, Trilochan Mohapatra, Gopala Krishnan S and Ranjit Kumar Ellur. 2018. Pusa Basmati-1121- a rice variety with exceptional kernel elongation and volume expansion after cooking. *Rice*, 11:19 doi: 10.1186/s12284-018-0213-6. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5890003/.

Singh YP, Nayak AK, Sharma DK, Gautam RK, Singh RK, Ranbir Singh, Mishra VK, Paris T and Ismail AM. 2014. Farmer's participatory varietal selection: A sustainable crop improvement approach for the 21st Century. *Agroecology and Sustainable Food System*, 38(4): 427-444.

Smale Melinda, Joginder Singh, Salvatore Di Falco and Patricia Zambrano. 2008. Wheat breeding, productivity and slow variety change : evidence from the Punjab of India after the green revolution. *The Australian Journal of Agricultural and Resource Economics*, 52: 419-432.

Spielman David J and Smale Melinda. 2017. Policy options to accelerate variety change among smallholder farmers in South Asia and Africa South of the Sahara. IFPRI discussion paper 01666, International Food Policy Research Institute.

Tsusaka Takuji, Lourdes Ma. Veasco, Takashi Yamano and Sushil Pandey. 2015. Expert elicitation for assessing agricultural technology adoption: The case of improved rice varieties in South Asian Countries. *Asian Journal of Agriculture and Development,* 12(1) :19-33.

Veettil PC, A Devi and I Gupta. 2018. Caste, informal social networks and varietal turnover. Paper presented in 30th International Conference of Agricultural Economists at Vancouver during July 28 to August 2, 2018.

Virk DS, Packwood AJ and Witcombe JR. 1995. Varietal testing and popularization and research linkages. Paper presented at the ICAR/ODA Workshop on Research for rainfed farming, September 11-14, 1995 at Hyderabad, India.

Walker TS, Alwang J, Alene A, Ndjuenga J, Labarta R., Yigezu Y, Diangne, A, Andrade R, Muthoni Andriatsitohaina R, De Groote R, Mauch K, Yirga C, Simotowe F, Katungi E, Jogo W, Jaleta M, Pandey S and Kumara Charyulu D. 2015. Varietal Adoption, Outcomes and Impact. P. 388-405 In T.S. Walker and J. Alwang (ed.) Crop improvement, Adoption and Impacts of Improved varieties in food crops in Sub-Saharan Africa. CGIAR and CAB International.

Witcombe JR and Yadavendra JP. 2014. How much evidence is needed before Client-Oriented Breeding (COB) is institutionalized? Evidence from rice and maize in India. *Field Crops Research*, 167: 143-152.

Witcombe JR, Packwood AJ, Raj AGB and Virk DS. 1998. The extent and rate of adoption of modern cultivars in India. P.53-68. In Witcombe JR, Virk DS and Farington J (ed.) Seeds of choice. Intermediate Technology Publications Ltd.

Witcombe JR Khadka K Puri RR, Khanal NP, Sapkota A Joshi KD. 2017. Adoption of rice varieties-1.Age of varieties and patterns of variability. *Experimental Agriculture,* 53(4): 512-527

Witcombe John R, Sanjaya Gyawali, Madhu Subedi, Daljit S.Virk and Krishna D Joshi. 2013. Plant breeding can be made more efficient by having fewer better crosses. *BMC Plant Biology,* 13:22.