Journal of Cereal Research
Volume 15 (1): 144-156
Homepage: http://epubs.icar.org.in/ejournal/index.php/JWR

Commentary

Development and Deployment of High Yielding Rust Resistant Wheat Varieties in India – Insights from Technology Transfer and Policy Response from the National Seed Production Program

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Article history:
Received: 27 Jan., 2023
Revised: 19 Mar., 2023
Accepted: 10 Apr., 2023

Citation:
Sendhil R, AK Sharma, R Kumar, CN Mishra, A Kumar, S Singh and GP Singh. 2023. Development and Deployment of High Yielding Rust Resistant Wheat Varieties in India – Insights from Technology Transfer and Policy Response from the National Seed Production Program. *Journal of Cereal Research* ***15 (1):*** *144-156. http://doi.org/10.25174/2582-2675/2023/131519*

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Abstract

Wheat, a major Indian staple food crop, is largely prone to rust infection. *Inter alia*, wheat producers have been advocated to adopt the recently released high yielding rust resistant wheat varieties to counter the significant yield losses. In the *milieu*, we investigated the technological trend in seed indent followed by policy options for the transfer of technology at farmers' fields. Research findings indicated that the wheat producers adopted old varieties. In the recent past five years, the trend hasn't witnessed any drastic change despite several rust-resistant varieties having been tested and released for various agro-climatic conditions. Recent varieties take about 5 years to reach their peak adoption since release which is attributed to the innovative transfer of technologies. At the producers' level, technologies (varieties) have been upscaled through frontline demonstrations, especially in cluster mode. Demonstrations resulted in an average yield gain of 699 kg/ha for innovative rust-resistant technology (HD 2967) compared to its check. Despite the increasing demand and promotion of the latest technologies, the need and availability of 'producer choice variety' is persisting and has to be addressed. Innovations like 'community seed banks', strengthening public-private partnerships, contract farming (quadpartite model), participatory demonstrations, and blockchain-enabled 'seed tracker' will strengthen the transfer of technology system in Indian wheat production.

Keywords: Breeder seed production; rust-resistant varieties; seed replacement rate (SRR); seed bank; HD 2967; HD 3086.

1. Introduction

Seed is the most crucial input and prime channel for technology delivery in crop production, but there is a minimum trickle-down effect of seed replacement and varietal replacement in India with the exception of progressive states like Punjab and Haryana implying the need for policy response in technology transfer. Wheat, being one of the major staple cereals in India, is largely prone to rust infection. The incidence of stem and stripe rusts can result in yield loss upto 100 per cent, and leaf rust may lead to around 50 per cent loss (under severe epidemics) causing a devastating decline in profit levels (Bhardwaj and Singh, 2019). In light of the likelihood of rust incidence, researchers advocate the farmers to cultivate the improved and/or recently released wheat varieties that are resistant/tolerant to multiple biotic and abiotic stresses including rusts to counter the significant yield as well as profit loss. Despite promotion by various stakeholders, India faces a demand-supply gap in the seed sector. As per the recent fourth advance estimates, wheat has been cultivated in a 31.62mha area during the past *Rabi* season, 2020-21 (MoA&FW, 2021). On average, the recommended seed rate for wheat is 100 kg per ha (Kumar *et al.*, 2014). With this recommendation, the total area under wheat requires 3.15 million tonnes of seed for a complete replacement with new varieties. However, the seed replacement rate (SRR) is only 40.30 per cent as per the estimates from the All India Coordinated Research Project (AICRP) on National Seed Project (NSP)[1], which means only 12.67 mha area is currently replaced with the new seeds. As per the SRR, 1.27 million tonnes of seeds have been used, which puts the demand-supply gap at 1.88 million tonnes, i.e., a 59.70% gap still exists in the seed sector, implying the scope for seed production and technology transfer.

The persisting demand-supply gap can be discussed as a vicious circle. The demand-supply gap is due to the lack of access to quality seed. Even if quality seeds are available and farmers have access to it, desired variety is a big concern. Looking into the existing seed replacement rate (SRR), farmers try to sow with the available seeds from the market or from the harvested wheat crop from the previous season. This again results in a demand-supply gap leading to a situation of farmers getting trapped in a vicious circle. One of the primary objectives of the AICRP is to provide improved genetic material in the form of modern varieties to farmers [4]. To increase the SRR, rusts resistant wheat varieties developed under the All India Coordinated Research Project (AICRP) on Wheat have been promoted extensively. Till date, 504 wheat varieties (rust resistant) have been released and 3000-3500 tonnes of breeder seed comprising about 150 varieties are produced annually to cater to the needs of farmers across diverse agro-climatic conditions. Yet, the SRR and variety replacement rate are lower which hinders the introduction of high-yielding varieties(Tiwari *et al.*, 2018; Dirisala*et al.*, 2017; Singh, 2015).

In this context, an attempt has been made to capture the demand for rust-resistant wheat varieties in terms of seed indent, analyse the extent of adoption lag,and identify the constraints in the adoption of improved varieties at farmers' fields followed by policy options for effective transfer of technology. The paper sourced primary and secondary data from multiple sources to draw some insights and policy implications for strengthening the transfer of technology system in Indian wheat production. Data were marshaled from the AICRP on Wheat, AICRP on NSP, frontline demonstrations (FLDs) on Wheat(ICAR-IIWBR, 2019; Singh *et al.*, 2019b), focused group discussion, field days of FLD and Delphi technique[2]. The data captured through these methods were subjected to conventional analysis like tabular, graphical, and trend to arrive meaningful conclusions.

2. Development of Rust Resistant Varieties – An Overview

AICRP on wheat is one of the oldest coordinated research projects in the world, which has its inception during 1964-65 that set the dawn for the 'Green Revolution' in India (Singh *et al.*,2019a). The success of AICRP on wheat is monumental in terms of increasing crop productivity since its establishment(Ramadas *et al.*, 2019) and is attributed to the development of high-yielding rust-resistant genotypes. The importance of evaluation of entries in different trials and nurseries in AICRP is reflected in the effective management of wheat rusts in India through the deployment of diverse rust-resistant wheat varieties based on the pathotype distribution in different areas. The breeding lines are screened and evaluated before national yield evaluation and hence only resistant genotypes are promoted to evaluation in the coordinated trials. During the process of evaluation, rust responses at each location are recorded following the modified Cobbs scale (Peterson *et al.*, 1948), and the 'Coefficient of Infection' is calculated following (Saari and Wilcoxson, 1974) and (Pathan and Park, 2006) by multiplying of disease severity (DS) and constant values of infection type (IT). To effectively monitor coordinated trials, multidisciplinary teams are constituted to monitor trial-conducting centres across wheat growing zones. Monitoring and evaluation are carried out for examining the scientific conduction of trials and performance of test genotypes in each of the five wheat growing zones (Kumar *et al.*, 2014). The collective decisions of the monitoring team members on the acceptance/rejection of a trial are considered for monitoring reports (Singh, 2019; Tandon *et al.*, 2015). Based on three-year performance at multiple locations, the best performing test entry will be identified in the annual wheat researchers' workshop by the "Varietal

Identification Committee (VIC)" constituted in advance. Subsequently, the identified variety is released by the Central Sub-Committee on Crop Standards, Notification, and Release of Varieties appointed by the Central Seed Committee under Section 3 of the Seed Act, 1966 in 1994 (Chand *et al.*, 2020). A released variety comes under the seed chain with notification in the Gazette of India which also helps in the genesis of the original variety based on its pedigree along with regulation of any kind of infringement in the later stages of varietal promotion. Post notification, the seeds of the varieties are disseminated to the farmers' field using multiple transfer of technology options viz., demonstrations, mini-kit trials, and farmers meet, to cite a few.

2.1. Procedure for Testing of New Wheat Materials in the Coordinated Trials

Materials are evaluated for one year in station trials for yield potential and for disease reactions in Initial Plant Pathological Screening Nursery (IPPSN) before entering the national testing system under AICRP

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One-Year Inter-Zonal Test

Trial Series	*Criteria of promotion/retention*
Respective NIVT (NIVT-1A, NIVT-1B, NIVT-2, NIVT-3A, NIVT-3B, NIVT-4, NIVT-5A, NIVT-5B	Yield potential, disease reactions, and quality parameters are taken into account for promoting materials into various zonal-level AVTs.

↓

AVT-I (First year)

One-Year Zonal Test

Trial Series	*Criteria of promotion/retention*
AVT-IR-TS-TAS/TAD/TDM AVT-IR-LS-TAS/TAD AVT-RIR-TS-TAD	Yield potential, disease reactions, and quality parameters are taken into account for retaining materials in AVT-II.

↓

AVT-II (Final year)

One-Year Zonal Test

Trial Series	*Criteria of promotion/retention*
AVT-IR-TS-TAS/TAD/TDM AVT-IR-LS-TAS/TAD AVT-RIR-TS-TAD	Yield potential, disease reactions, quality parameters, and agronomical evaluations are performed on final-year entries.

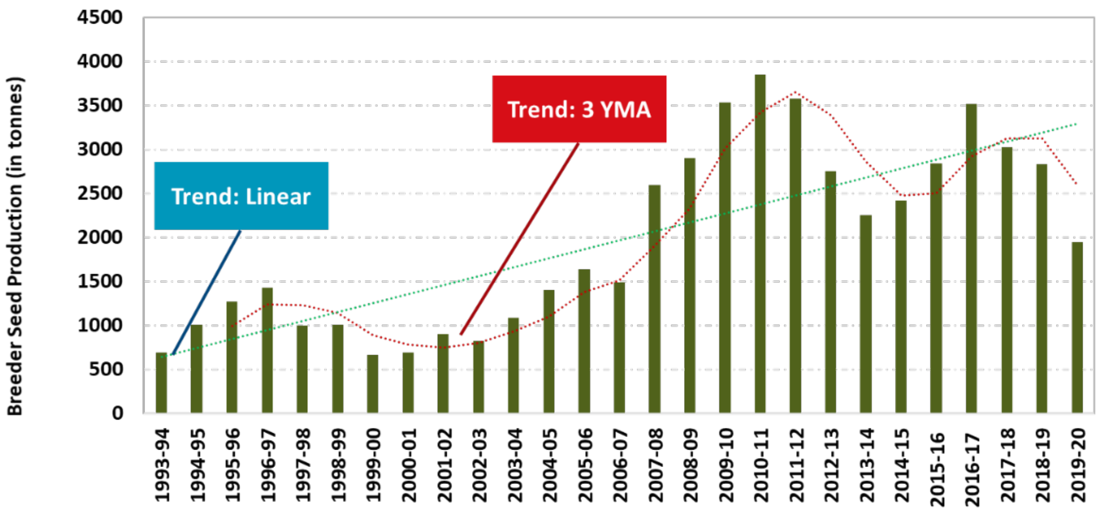
NIVT: National Initial Varietal Trial and AVT: Advance Varietal Trial

3. Insights from Seed Production and Promotion Program for Wheat in India

3.1. Wheat Seed Sector

Seeds serve as a principal vehicle for technology delivery to farmers (Ramaswami, 2002). The seed system in India is strongly governed by the public sector, especially for rice and wheat (Chauhan *et al.*, 2017 and 2016a). Systematic seed production for the wheat crop is carried out at multiple levels by different public and private organisations(Chauhan *et al.*, 2016a) (Figure A1). To start with, the breeder seed indent collected by the Department of Agriculture Cooperation & Farmers Welfare (DAC&FW) under the aegis of the Ministry of Agriculture and Farmers Welfare (Government of India) from various organisations like State Agriculture Departments, Public Subsidiaries or Public Sector Undertakings and private seed companies through National Seed Association of India, which in turn compiles the whole information pertaining to wheat and send it to the crop-specific Project Coordinator or Director in Indian Council of Agricultural Research (ICAR) for final allocation for its production in different State Agricultural Universities (SAUs) and ICAR institutions. The allocation responsibility of breeder seed production is discussed and entrusted to various breeder seed production centres in the crop workshop held annually. The decision is based on the facilities and capabilities available at the centres of seed production coupled with the availability of nucleus seed of a particular variety. The actual breeder seed produced by different centres is compiled and intimated to DAC&FW by ICAR for its supply to all the indenters as per their indent submission. In the case of varieties that are relevant only to a particular State, the indents for breeder seed are placed by the concerned Director of Agriculture with the SAUs located in the State directly. The breeder seed lifted is utilized for the foundation and certified seed production by the indenting agencies under the supervision of state seed certification agencies (Chauhan *et al*., 2017 and 2016b).

India's National Agricultural Policy is strongly oriented towards high-yielding varietal adoption and hence latest wheat varieties are taken to farmers' fields through the National Agricultural Research System (NARS). Seed multiplication and the spread of rust-resistant high-yielding genotypes played a major role in the quantum jump in wheat production. A comparison of pre- and post-AICRP on Wheat shows that before the implementation of the coordinated research, farmers used to grow traditional landraces resulting in low yield levels (Singh *et al*., 2019b) wherein, seed replacement is almost negligible. Unlike in the past, things have changed drastically in recent years with the evolvement of the seed sector and the deployment of high-yielding varieties (HYVs) which are resistant to biotic and abiotic stresses including rusts, helped to attain the nation a record level production i.e., 109.52mt (MoA&FW, 2021). To increase wheat production and productivity on a sustainable basis, deploying recent varieties is a pre-requisite as contribution through genetic improvement in yield has been realized to the tune of 50 per cent (Fugita, 2013). Post coordinated research – over five decades – seed requirement has increased by 2.15 times which is a good sign and reveals the scope for strengthening the seed system as well as developing strategies and policies for the effective transfer of technology. Looking into the trend, both linear and 3-year moving average (YMA) in breeder seed production for the past 25 years, it's clear that the overall production has increased over time but with a mixed year-to-year fluctuations (Figure 1). Table 1 liststhe top 10 cumulative breeder seed indent wheat varieties for the past 25 years. Lok 1 tops the list with 2149 tonnes of breeder seed indent with a surplus production estimated at 3195 tonnes for the whole period. The variety was released in 1982 and reached its peak indent as well as production in 2007-08 with a gap of 26 years. Similarly, the rest of the top varieties have a different level of the gap between release and peak indent or production.



3 YMA indicates the 3 Year Moving Average

Figure 1. Breeder seed production trend in wheat.

Table 1. Top 10 wheat varieties indented for breeder seed production (1993-94 to 2017-18).

Wheat Variety	Release Year	Total BSI[1] (in tonne)	Share in overall indent (%)	Total BSP[2] (in tonne)	Share in overall Production (%)	Peak Year		Gap (years)
						BSI[1] (in tonne)	BSP[2] (in tonne)	
Lok 1	1982	2149.00	5.68	3195.03	6.54	2007-08 (277.14)	2007-08 (349.30)	26
PBW 343	1996	1805.63	4.77	2743.09	5.61	2009-10 (193.68)	2008-09 (256.38)	23
HD 2967	2011	1298.43	3.43	1787.82	3.66	2016-17 (307.99)	2016-17 (431.98)	6
PBW 502	2004	1150.02	3.04	1445.18	2.96	2009-10 (217.05)	2010-11 (274.84)	7
GW 322	2002	967.63	2.56	1736.48	3.55	2012-13 (129.12)	2011-12 (282.73)	10
PBW 550	2008	918.89	2.43	981.23	2.01	2011-12 (193.11)	2011-12 (166.20)	4
Raj 3765	1996	903.79	2.39	1504.29	3.08	2010-11 (116.06)	2010-11 (145.37)	15
PBW 373	1997	843.36	2.23	1032.21	2.11	2007-08 (99.56)	2008-09 (121.60)	12
GW 273	1998	840.68	2.22	1610.62	3.30	2009-10 (126.03)	2010-11 (309.36)	13
DBW 17	2007	660.85	1.75	776.04	1.59	2011-12 (158.60)	2009-10 (123.00)	3

[1]BSI: Breeder Seed Indent and [2]BSP: Breeder Seed Production

The presence of old varieties in the top indenting list was a matter of concern because of their low productivity due to their susceptibility to rusts and the system of indenting had been revamped to infuse the latest high yielding and rusts resistant varieties, shedding the poor old varieties indent at Government and ICAR level. Also, the seeds of new varieties are promoted by holding Seed day and Farmer-Scientist Interaction Workshops, varietal promotion activities through frontline demonstrations, and village-level demonstrations through the *'Mera Gaon Mera Gaurav'* (My Village My Pride) Scheme (Singh *et al.,* 2016) etc. where small samples of newly identified and notified varieties were supplied to the farmers for enabling them to experience the performance of these varieties in their fields itself. As the seed system underwent structural changes, the gap got reduced for a majority of the varieties. Table 2 shows the list of the top 10 cumulative breeder seed indent wheat varieties for the past five years (2013-14 to 2017-18). A radical shift in the varietal spectrum has been noticed as the period changes. Prominent and mega varieties like Lok 1, HD 2967, and HD 3086 have taken their own slots based on the seed indent, a proxy for seed demand. The implication is that the gap between release and peak indent or production has narrowed as the period changes to a recent time. Several reasons shall be attributed to this like a spectrum of improved HYVs with a better seed delivery system that lets the variety adoption cycle narrow down, unlike the past periods. Yet, there are some exceptions like Lok 1 which is still having demand, attributed to farmers' and traders' preferences. The prominent mega and promising wheat varieties at farmers' fields have shown a conspicuous trend in breeder seed indent as well as production. For instance, analysing the trend for Lok 1 wheat variety which was released in 1982 indicated a long-run preference due to its bold and lustrous grain which fetch a premium price in the market and was popular among its stakeholders (Figure 2 (a)). Surprisingly the seeds for Lok 1, a variety that was released almost 38 years back is still having demand among farmers as evident by the breeder seed indent as well as production. However, the peak indent was placed during 2007-08 which led to peak production as well. Now, the variety has been replaced by other newly released varieties.

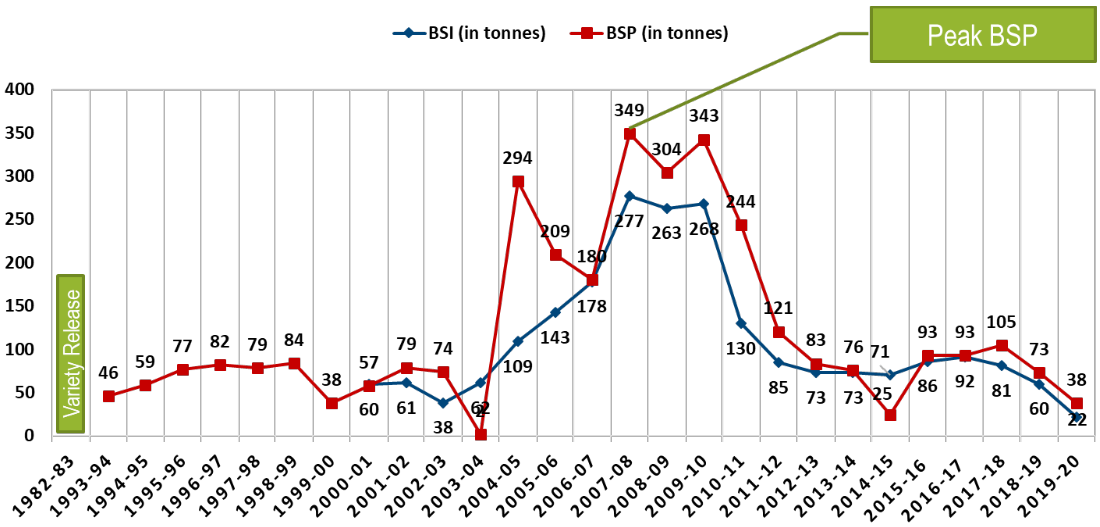
Table 2. Top 10 wheat varieties indented for breeder seed production (2013-14 to 2017-18)

Wheat Variety	Release Year	Total BSI[1] (in tonne)	Total BSP[2] (in tonne)	Peak Year		Gap (years)
				BSI[1] (in tonne)	BSP[2] (in tonne)	
HD 2967	2011	1275.35	1755.12	2016-17 (307.99)	2016-17 (431.98)	6
GW 322	2002	414.12	839.24	2012-13 (129.12)	2011-12 (282.73)	10
Lok 1	1982	402.57	391.58	2007-08 (277.14)	2007-08 (349.30)	26
GW 366	2007	343.37	687.79	2012-13 (98.81)	2012-13 (208.48)	6
Raj 4079	2011	343.19	342.68	2015-16 (98.50)	2016-17 (114.43)	6
WH 1105	2013	336.53	418.50	2016-17 (136.70)	2016-17 (165.44)	4
PBW 550	2008	306.80	380.58	2011-12 (193.11)	2011-12 (166.20)	4
HD 3086	2014	305.22	391.65	2016-17 (134.72)	2017-18 (168.50)	4
Raj 4120	2009	279.28	321.74	2014-15 (95.56)	2014-15 (97.98)	6
DPW 621-50	2011	270.52	353.82	2014-15 (66.06)	2013-14 (104.72)	3

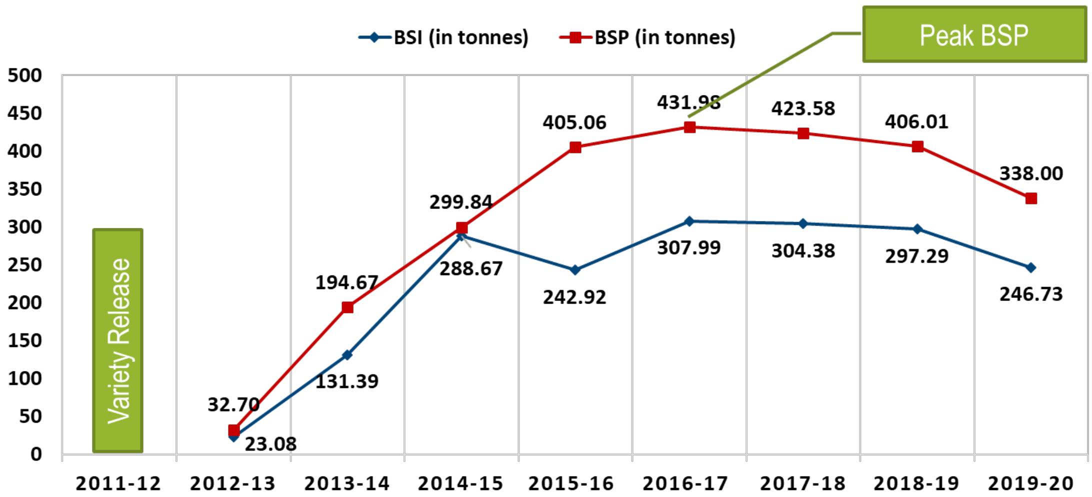
[1]BSI: Breeder Seed Indent and [2] BSP: Breeder Seed Production.

Analysing the trend for the recent mega variety of the decade – HD 2967 – indicates that the seed indent and production witnessed a consistent increase with an estimated acreage of about 40 per cent (~ 12 million hectares) in total wheat area. Interestingly, the variety which was released in 2011 initially for adoption in the north western plains zone (NWPZ) of India, later outscaled to north eastern plains zone (NEPZ) in 2013-14 due to its yield potential along with other traits including rust resistance (ICAR-IIWBR, 2018). A similar case of upscaling and outscaling is witnessed for recent varieties like HD 3086 and DBW 187. In recent years, the top slots for breeder seed indent and seed production of wheat varieties haven't witnessed much change. HD 2967 still holds the prime position having its peak indent of 308 tonnes and production of 432 tonnes during 2016-17 (Figure 2 (b)). A similar pattern was noticed for HD 3086 (Figure 2 (c)).

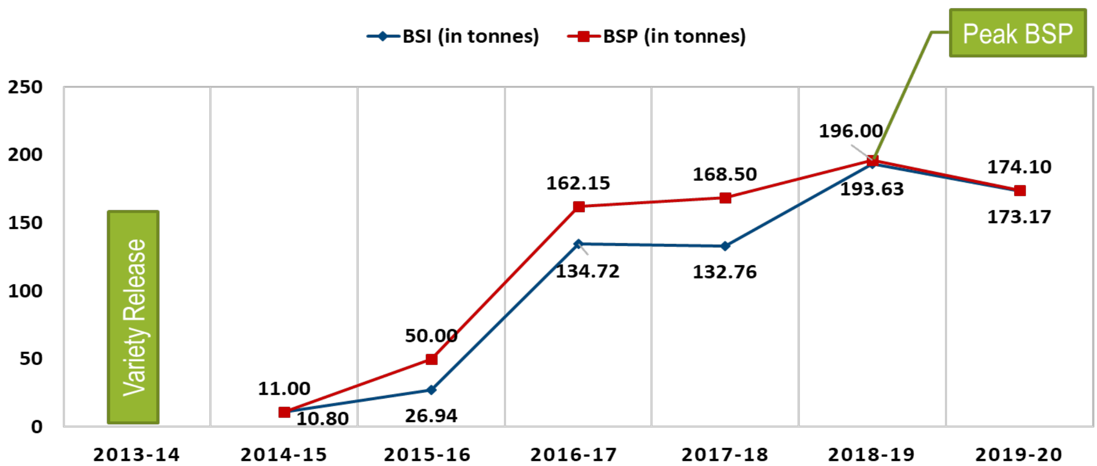
Over the years, the life of wheat varieties has been declining unlike in the past owing to the consistent release of promising HYVs once in every 2-3 years, more so in the wheat bowl of India - NWPZ. In the recent period, a variety to reach its peak adoption takes about five years since its release as the improved varietal replacement rate effectively brings potential varieties under the seed chain system (Pavithra *et al.,* 2017). The rapid varietal replacement should also be accompanied by the active withdrawal of obsolete varieties (Atlin *et al.,* 2017). The varietal replacement rate (VRR) is the accelerated replacement of older varieties with newer ones, however, the adoption of these varieties largely depends on farmers' acceptance apart from the breeding attributes. Improving the locally adapted genotypes or transferring the adaptation traits would help in increasing the VRR. The role of pre-breeding in improving the VRR as a strategy has also been proposed by Singh *et al.* (2019c). So, to accelerate the VRR, several strategies like pre-breeding, participatory plant breeding, maintenance breeding, quality seed systems, and policy support are needed (Singh *et al.,* 2019c). The success of the breeding programme mainly depends on the farmers' decision to adopt newer varieties by replacing the older ones with superior materials (Dixon *et al.,* 2006).



(a) Lok 1



(b) HD 2967



(c) HD 3086

Figure 2. Trends in breeder seed indent (BSI) and breeder seed production (BSP) for prominent varieties

3.2. Reflection from Farmers' Field

At the farmers' field, recently released varieties have been upscaled through frontline demonstrations funded by the MoA&FW. In the past 10 years (2008-09 to 2017-18) around 117 improved wheat varieties that are resistant to biotic and abiotic stresses including rusts have been demonstrated at various locations benefitting around 13318 farmers (Singh et al., 2019b). For instance, 1511 demonstrations were conducted for HD 2967 in NWPZ and NEPZ which led to an average yield gain of 699 kg/ha in comparison to its check varieties (Table 3). Similarly, the demonstrated wheat varieties have shown a different level of incremental yield in their region of adoption ranging from +365 kg/ha to 748 kg/ha (Singh et al., 2019b).

Table 3. Varietal spectrum and impact of rust-resistant wheat FLDs

S. No.	Variety (Zone)	No. of FLDs	Average Yield (kg/ha)	Yield Range (kg/ha)	Yield Gain (kg/ha)	Average Incremental Returns [1] (₹/ha)
1	HD 2967 (NWPZ, NEPZ)	1511	4029	3010-7200	699	12862
2	K 307 (NEPZ)	714	3863	1220-6500	748	13763
3	DBW 17 (NWPZ)	658	4728	2600-7000	367	6753
4	HD 3086 (NWPZ)	421	4943	3200-7000	534	9826
5	CBW 38 (NEPZ)	417	3677	1280-6200	529	9734
6	VL 892 (NHZ)	348	2018	1000-4500	436	8022
7	WH 1105 (NWPZ)	301	4767	3020-6200	490	9016
8	DBW 110 (CZ)	292	4332	2000-7260	606	11150
9	Raj 4238 (CZ)	267	4389	3690-4800	554	10194
10	PBW 550 (NWPZ)	253	4838	3500-6500	365	6716
11	HD 2932 (CZ)	225	3680	2180-6000	676	12438
12	VL 953 (NHZ)	195	2879	1200-3750	717	13193
13	VL 907 (NHZ)	190	2938	1300-5000	641	11794
14	DBW 39 (NEPZ)	184	3466	1610-5500	521	9586
15	K 1006 (NEPZ)	175	3294	1400-5200	555	10212

[1] indicates the monetary value at the 2018-19 support price (₹ 1840 per quintal) and adapted from [9].

Adoption of a variety is a complex phenomenon that is influenced by several factors. A variety to reach its popularity (peak adoption) among farmers should perform better than the standard varieties which obviously takes some time interval. This varies from variety to variety (Tables 1 and 2), technically known as "adoption lag". At the farmers' field, seed replacement, as well as variety replacement, is low with the exception of the NWPZ. As indicated earlier, variety adoption is multifaceted. Hence it depends on several factors like farmers' choice of variety, access to their preferred variety, and the existing demand-supply gap. The main reason for the adoption lag in farmers' fields is due to the existing knowledge gap (Sendhil et al., 2014), the non-availability of seeds (Singh et al., 2019b) and indeed varietal adoption depends on the associated cost. A variety can be successful unless and until it fulfills the farmers' needs, and preferences as well its accessibility at affordable cost. Any technology having a relative advantage over the existing one will be easily adopted by the farmers. The five main factors influencing the adoption of an innovation or technology among farmers are: relative advantage, compatibility, complexity, trialability, and observability(Rogers, 1962).

3.3. Seed Production, Distribution, and Promotion

Sustainable growth is driven by the development and diffusion of improved technologies (Ramaswami, 2002). Taking a clue from past experience, ICAR-Indian Institute of Wheat and Barley Research has developed a Public-Private Partnership (PPP) model for seed production, distribution, and promotion (Figure 3). Clearly, the involvement of the private sector will increase the efficiency of the system. The idea here is that once the promising varieties are notified post the rigorous process; a seed production agreement is made with the seed producers by signing the memorandum of agreement (MoA). The process is followed by quality seed production to cater to the demand of the farmers. Simultaneously, demonstrations of improved varieties are also carried out at multiple farmer locations to promote the variety as well as educate the farmer to adopt the latest varieties in the subsequent season aiming for an increased rate of seed as well as variety replacement ensuring quantum jump in wheat production at the national level.

Figure 3. Seed production, distribution and promotion model

4. Policy Response for Effective Technology Transfer

Seed diffusion in India, precisely for cereals, is primarily carried out by the public sector (Ramaswami, 2002). Growing demand for high-quality seeds and timely dispersion requires synergy between multiple stakeholders across the value chain. In this context, we suggest some policies for strengthening the existing seed system.

4.1. Fostering Farmer Choice and Preference

One of the major demand-supply gap reasons prevailing in the wheat seed sector is the access of farmers to their preferred choice of variety. Clearly, farmers choose a variety based on the yield level, followed by other quality traits despite quality-driven procurement or marketing is not in practice barring a few millers or processing companies in contract with middlemen or aggregators. A majority of the time, wheat varieties picked by the farmers go by their own experience or are suggested by fellow farmers in the case of varieties already in practice or extension personnel that fits prominent as well new varieties. Unfortunately, every farmer may not have access to the variety which they wish to cultivate due to a mismatch between production (as indicated by the seed indent) and supply. Further, some farmers prefer an old variety (like Lok 1 which was released 38 years back) which currently has a better replacement among the existing varietal spectrum. So, it is suggested to foster the farmers' choice and preference varieties which are only upto 5 years' old that should get reflected in seed indent. The varieties should be promoted at farmers' fields based on their higher yield evidence at experimental plots coupled with quality traits.

4.2. Participatory Cluster Demonstrations

Inter alia, demonstrations help to transfer the technologies at farmers' field and motivate them and neighbours to adopt the validated technologies (variety in our case) in the subsequent season. Involving farmers in each and every demonstration carried out cluster level will facilitate to enhance of the variety as well as SRR. 'Seeing is believing' and 'learning by doing' are worth pursuing and such type of participatory demonstrations is highly advocated in regions like north-eastern India wherein the SRR is low.

4.3. Establishment of 'Community Seed Banks'

Access to the preferred varieties at an appropriate time window before sowing due to the source distance leading to a lengthy seed marketing channel as well as limited authentic sources is a major concern in the seed sector. Though private sector involvement exists in seed production and distribution, the seed cost between private and public is quite significant. To counter that, progressive farmers can start "Community Seed Banks" at the regional level (atleast one per block) and promote the latest varieties. Interested stakeholders can receive training on quality seed production and practice at their farms for incremental revenue. Additionally, the SRR and VRR get increased over time. It is important to build seed reserves for crop security just like grain reserves for food security (Swaminathan and Bhavani, 2013).

4.4. Utilising Rural Networks for Seed Distribution

Reaching each and every farmer's doorstep for seed distribution is not a feasible solution. Hence, seed distribution through well-connected rural networks like post offices can be thought of especially in times of a pandemic like COVID-19 wherein restriction of movement is exercised.

4.5. Signing Memorandum of Agreements

It has been already proven that the public-private partnership leads to increased efficiency and such collaboration helps to fill the existing demand-supply gap, especially in seed production. To capitalise on the increasing demand for the newly released wheat varieties, a large number of memorandum of agreements have to be signed with the seed-producing companies following the guidelines of intellectual property rights.

4.6. Contract Farming

Contract farming is one of the options wherein the seed production system can be strengthened. Research institutes can get into contract with the local producers apart from the firm and sponsor bank (quadpartite model), especially smallholders protecting their rights and interest, under a buy-back agreement to cater to the growing demand for improved varieties. Clearly, capacity building of such stakeholders becomes mandatory for quality seed production.

4.7. Own Farm Own Seed Concept

Seed quality alone contributes to 30 per cent of crop yield (Sahu et al., 2018). To produce quality seeds and to transform every wheat farmer a seed producer skill upgradation has to be done through specialised training and result demonstrations.

4.8. Propagation of Seed Village Concept

The whole village can be developed as a seed hub under the guidance of scientists associated with seed production at each and every step. Training for all the farmers on all technical issues can be done before the crop season.

4.9. Exploring Alternate Avenues

With the advent of the internet of things, the possibilities of seed trade through electronic modes like futures markets under national level commodity exchanges[3], the e-national agriculture market (e-NAM)[4] can be explored since around 1000 wholesale markets are already being integrated electronically[5].

4.10. Seed Tracker

The Indian seed industry is projected to grow rapidly in the future (Shiva et al., 1998). So, to increase the transparency as well as strengthen the complete seed value chain in wheat, a seed tracker has to be established using the blockchain concept – digitizing the seed system. It's a real-time solution for tracking wheat seed production through the registration of seed producers, quality assessment, and assertion. Such innovations with great success in crops like cassava[6] can be replicated in wheat where the role of the informal sector is still substantial.

Conclusions

To sum up, till now 504 varieties that are rust resistant have been released since the establishment of the coordinated research project on wheat, out of which about 150 varieties are showing their presence in the 'Seed Chain'. Variety development and seed system in wheat have witnessed structural changes and so the breeder seed indent (a proxy for demand) showed a radical shift in the varietal spectrum, especially in recent past years. HD 2967, a mega variety occupied around 40 % (~ 12 mha) of the total wheat area. Initially, it was released for NWPZ and later outscaled to NEPZ. A similar pattern was noticed for HD 3086 and DBW 187. Several factors played their role in the Indian wheat program for crossing 107 million tonnes and of them,the deployment of rust-resistant HYV takes the top slot. In farmers' fields in the recent past decade, approximately 5 years gap exists between a variety release and its peak adoption. Landmark varieties like HD 2967 have been promoted through mass demonstrations which resulted in an average yield gain of 699 kg per ha. We also documented that the speed of adoption (with respect to the latest HYVs) is increasing across zones, especially in the NWPZ. However, the lack of knowledge among farmers and the demand-supply gap in the seed system still persist indicating the scope for strengthening the transfer of technology system in Indian wheat production. In regions wherein a low seed replacement rate exists like in NEPZ, participatory cluster demonstrations have to be carried out. Further, fostering 'farmer preferred' varieties (which are upto 5 years old) with good yield and quality traits needs emphasis. To minimise the demand-supply gap, the establishment of 'Community Seed Banks' (minimum one per block) is suggested. Also, the feasibility of transforming rural 'Post Offices' as 'Seed Distribution Counters' has to be worked out. In order to strengthen the seed production sector and its efficiency more MoAs have to be taken up as a priority availing the benefits of PPP. Alternatively, for seed production and distribution; avenues like contract farming protecting the smallholders right and interest, futures trading under national-level exchanges, and involving electronic national markets for distribution has to be explored. With the advent of technology, blockchain-enabled 'Seed Tracker' will certainly increase transparency as well as strengthen the complete seed system in wheat.

Appendix A

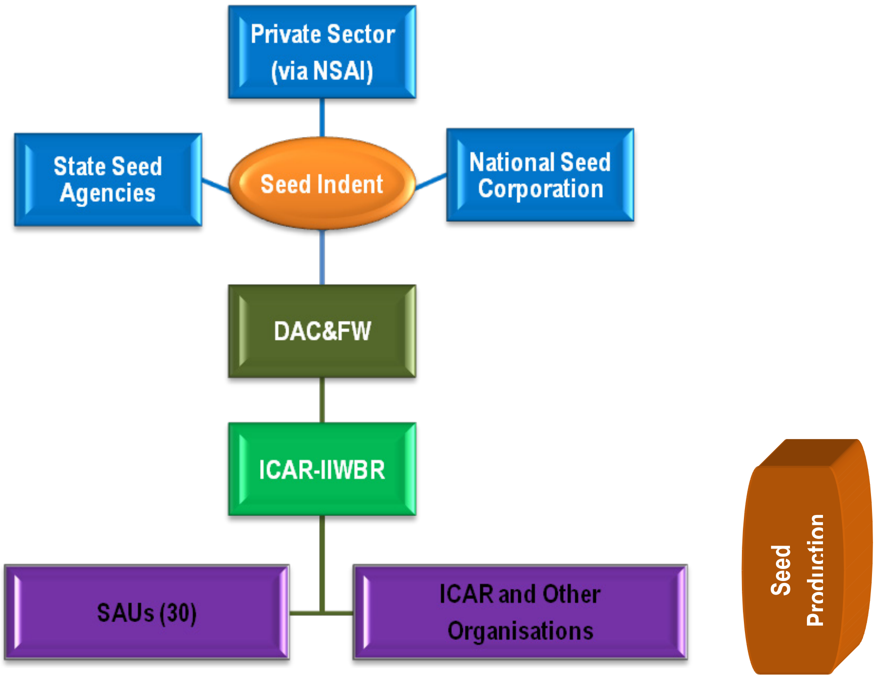


Figure A1. Indian wheat seed system

NSAI: National Seed Association of India (https://nsai.co.in/)

DAC&FW: Department of Agriculture Cooperation and Farmers Welfare (http://agricoop.nic.in/)

ICAR-IIWBR: ICAR-Indian Institute of Wheat and Barley Research (https://iiwbr.icar.gov.in/)

SAU: State Agricultural Universities (www.icar.org.in/content/state-agricultural-universities-0)

ICAR: Indian Council of Agricultural Research (https://icar.org.in/)

Author contributions

Conceptualization of experimentation (RS, AK, SS & GPS); Designing of the experiments (RS, AKS, RK & CNM); Experimental materials (RS, AK & SS); Execution of field experiments and data collection (RS, AKS, RK & CNM); Analysis of data and interpretation (RS); Preparation of the manuscript (all authors).

Conflict of interest

The authors declare no conflict of interest.

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(Endnotes)

1 https://aicrp.icar.gov.in/nsp/enhancement-in-seed-replacement-rate-srr/

2 It is a process wherein an estimate is arrived by a consensus among a group of experts (wheat in our case) while maintaining their anonymity. A coordinator sends baseline data (if required) and questions to the experts, their comments are shared, discussed, and a consensus is reached finally. The technique is considered an alternative when there is no real-time estimate though it is time consuming.

3 https://www.ncdex.com/GlobalSearch/Search.aspx?SearchText=WHEATFAQ&SearchTitle=WHEAT

4 https://enam.gov.in/web/apmc-contact-details

5 https://economictimes.indiatimes.com/news/economy/agriculture/e-nam-platform-onboards-1000-mandis-in-21-states/uts-centre/articleshow/75764965.cms

6 https://www.rtb.cgiar.org/news/seed-tracker-how-one-app-can-enhance-seed-systems-for-many-crops/