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Acceptance and competitiveness of new improved wheat varieties by smallholder farmers

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ABSTRACT

We conducted this research because earlier research revealed that Pakistani farmers were growing 8–10-year-old wheat (Triticum aestivum L.) varieties and hence not benefitting from the recent advances in wheat breeding. Participatory varietal selection (PVS) trials were conducted to have farmers validate and include newly released wheat varieties into seed-production stream to speed up replacement of old and obsolete wheat varieties by farmer-preferred new high-yielding varieties. Fourteen new varieties recommended for irrigated and eight for rainfed environments were evaluated in this research involving smallholder farmers in food-deficit districts of Pakistan. Collaborating farmers preferred 10 varieties from the PVS trials, eight of which were germplasm from the International Maize and Wheat Improvement Center (CIMMYT) that yielded on average 5–17% more grain than local checks. Local checks used in the PVS trials in Sindh and Khyber Pakhtunkhwa were old improved varieties. Greater yield advantage from new varieties over local checks was reported from rainfed environments and areas where old local checks were used. The PVS research showed the possibility of ensuring food security of smallholder farmers as new high-yielding varieties gave an additional 0.3 – 0.5 tons of grain per ha, sufficient to feed two to three persons per year. Research also revealed that innovative farmers in rainfed regions grew wheat varieties recommended for irrigated regions to identify high-yielding wheat varieties with stable performance. Feedback by farmers to wheat breeding research system was to develop even higher yielding new wheat varieties with diseases resistance to replace old and obsolete varieties to boost food security.

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Age of varieties; farmers' innovation; food security; PVS; replacing old varieties; variety popularization; yield advantage

Introduction

Wheat (*Triticum aestivum* L.) is a major staple crop, providing 60% of calorie requirements in the Pakistani diet. Pakistan had a global hunger index (GHI)

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score of 45 in 1992, which dropped to 35.1 in 2008 and 33.4 in 2016 (Grebmer et al. 2016). Even the level of most recent hunger index score has been classified as serious (Grebmer et al. 2016). Zulfiqar and Hussain (2014) studied gaps between wheat production and consumption in the country using two scenarios: 125 kg/capita/annum and 150 kg/capita/annum. The gap between wheat grain availability and national demand as per their first scenario was 0.17 million tons in 2013, which was predicted to increase to 0.50 million tons in 2025. However, this gap at the level of 150 kg/capita/annum could range from 5 million tons in 2013 to 7 million tons in 2025. Braun et al. (2016) reported that from 2005 to 2014, average wheat imports in Pakistan were slightly above 700,000 tons per year. According to PARC (2014), wheat productivity growth averaged around 1.97% across 10 years in Pakistan; nevertheless, wheat production in the country during 2015–2016 was record high at 25.47 million tons, making the country self-sufficient in wheat (PARC 2016). However, it is currently unknown whether wheat productivity during 2016–2017 can be maintained at the level of last year because rainfall has been insufficient this year (2016–2017) during wheat planting and early growth. Ensuring future food security will largely depend on sustained improvement in wheat yield levels beyond the current population growth rate of 1.92% in the country (MoF, 2016).

Farmers can benefit from improved yield potential and/or better disease resistance in the newer varieties because of recent advances in plant breeding methodologies, but these gains can only be realized by delivering improved varieties to farmers rapidly (Lantican et al. 2016; Witcombe et al. 2016). A continuous flow of improved and competitive crop varieties produced by breeding programs is a prerequisite for the replacement of old and obsolete varieties to ultimately improve crop productivity and address the overall challenge of food security. However, delivering new varieties to farmers does not guarantee that they will necessarily be adopted. Studies have shown that smallholder farmers regard high yield of new varieties as the most important trait (Hossain and Jaim 2012; Walker et al. 2015). According to Walker et al. (2015), increased productivity gains, reduction in poverty and contribution to food security lead to the adoption of improved varieties. Similarly, it has been shown that particular varietal attributes can lead to strong farmer preferences for adopting specific cultivars. For example, resistance to biotic and abiotic stresses, high yield and superior quality are the major attributes that determine the level of adoption of new wheat varieties (Lantican et al. 2016). In the case of rice, however, improved grain quality, shorter maturity, improved lodging resistance, high milling recovery, improved resistance/tolerance to insect pests, and diseases were found to be important secondary traits (Hossain 2012).

Progress on annual average genetic gain of wheat has slowed down globally and the average breeding progress in wheat yield during

2009–2011 was around 0.5% per annum (Fischer 2009, Sadras and Lawson 2011). Crespo-Herrera et al. (2017) reported that recent genetic gains per annum in CIMMYT wheat germplasm over widely grown Attila variety of wheat ranged from 0.31 to 2.7%, whereas the genetic gains over local checks were between 0.41 and 1%. Historically, it has generally been thought that every new batch of recommended crop varieties would be more competitive, appropriate, and profitable for farmers than the currently most widely grown varieties. Any failure to adopt was assumed to be attributable to factors unrelated to varietal traits or shortcomings. Until now, there have been few studies conducted in partnership with farmers that have actually compared the competitiveness (breeding progress) of new improved varieties with old improved varieties on farmers' fields to be able to replace old and obsolete varieties by new ones.

The PVS is a broadly accepted method, which involves on-farm testing by farmers a diverse range of new varieties (Witcombe and Yadavendra 2014). It is a simple, rapid, and cost-effective way of evaluating the suitability of a large number of new varieties in trials conducted by farmers on their own fields entirely under their own management across many countries and crops (Joshi and Witcombe 2002). It is an effective means of rapidly identifying high-yielding and farmer-preferred varieties, while also identifying unsuitable varieties with one or more weaknesses. The PVS provides an initial test to determine if a crop variety is worth investing resources in before popularizing it and engaging in large-scale seed production thereof. Farmers' participation in varietal selection research is vital both before and after release of improved crop varieties for their verification, rapid uptake, and adoption (Douthwaite, Keatinge, and Park 2001; Joshi et al. 2012, 2014; Joshi and Witcombe 1996; Kerr et al. 2007; Thapa et al. 2009; Witcombe et al. 1996).

Several studies have indicated that, for one reason or another, not all the crop varieties released get into seed production stream (Walker et al. 2015; Witcome et al. 1996, Hossain and Jaim 2012). Javed et al. (2015), while assessing the impact of new wheat varieties reported that only eight out of 28 varieties released between 1981 and 2011 covered nearly 84% of total wheat area in Punjab (Pakistan); conversely, Watan, a variety not formally released, occupied nearly 6% area. CIMMYT wheat varieties (germplasm) have excellent adaptation to a wide range of environments, including high temperatures in South Asia (Mondal et al. 2016). However, when it comes to uptake and adoption of new crop varieties, noticeable yield advantage plays a decisive role. For example, Bangladeshi farmers selected only those wheat varieties that had at least 10% yield advantage over the checks (Pandit et al. 2010). Walker et al. (2015) stressed that the absence of detectable yield differences between improved and traditional crop varieties was thought to be the main determinant in the non-adoption of improved varieties.

Additionally, assessing the comparative advantage of new improved varieties over old, improved varieties, on-farm, is important to deliver new, improved varieties to farmers rapidly. It also helps provide valuable feedback on the strengths and weaknesses of new varieties to international wheat breeding programs. Average age of wheat cultivars in Pakistan during 2014 was 8–10 years. Thus, farmers did not benefit from the latest advances in wheat breeding. This knowledge gap existed because farmers lack information about newly released wheat varieties and also have limited access to seeds of new varieties and because of a lag phase after the release of new varieties as well as inadequate availability of seeds before release. In this context, participatory on-farm research was done to validate wheat varieties released after 2010 by farmers and enter farmer-preferred, best wheat varieties into seed-production stream to rapidly replace old and obsolete wheat varieties by new ones.

Materials and methods

Wheat varieties

The PVS trials were conducted in Khyber Pakhtunkhwa (KP), Punjab, and Sindh provinces during 2014–2015 and 2015–2016 wheat seasons (Tables 1–3, Figure 1). Eight wheat varieties in rainfed areas and 14 in irrigated areas were evaluated in the trials. Of these, 18 were released (mostly after 2010), whereas four were in the pipeline at the time of evaluation (Table 1). Galaxy-13 wheat variety was excluded from this research because earlier reports indicated that it had lost resistance to rust. A couple of varieties recommended for irrigated areas were also included in the PVS trial set of rainfed areas. Each set of four PVS trials (number and composition of wheat varieties in PVS trials varied between the provinces and for rainfed and irrigated areas) was replicated three times at each location. The size of the trial plot varied across provinces; it was half an acre (2,000 m^2) per variety in Sindh and the plains areas of KP. In Punjab, plot area was 800 m^2 during 2014 and 2015, whereas in the hilly areas of KP, plot area was 1 *Kanal* (one eighth of an acre, i.e., 506 m^2). Grain yield in these trials was measured from the whole plot harvest. In addition, farmers' preference ranking was determined for all the trials in Punjab and Sindh. Close to crop maturity, farmers participating in the PVS trials and other farmers from the neighboring areas were invited to examine the performance of all the new improved wheat varieties and to rank them relative to the local check in the trial, considering all the important criteria from farmers' point of view. A consensus rank by the farmers for each variety was noted by the researchers at each location.

Most of the wheat varieties evaluated in the first year were also included in the second year of testing after excluding those that farmers did not like, as

Table 1. Summary of wheat varieties in participatory varietal selection (PVS) trials in Pakistan during 2014–2015 and 2015–2016.

Variety	Pedigree/parentage	Year of release	Province of release	Moisture regime
Pirsabak-13	CMSS97M04005T-040Y-020Y-030M-020Y-040M-28Y-3M-0Y CS/TH.SC//3*PVN/3/MIRLO/BUC/4/MILAN/5/TILHI	2013	KP	Irrigated
Shahkar-13	CMSS93Y006285-7Y-010Y-010M-010Y-010M-OY-3KBY-0KBY CMH84.3379/CMH78.578//MILAN	2013	KP	Rainfed
NIFA-Lalma	CM 103733-42M-030Y-010M-4Y-010Y-0MPASTOR/3/ ALTAR 84/AEGILOPS SQUARROSA (TAUS)//OPATA	2013	KP	rainfed
AAS-11	PRL/PASTOR//2236(V6550/SUTLEH-86);BR.4489-3B-6B-1B-0B	2011	Punjab	Irrigated
Chakwal-50	CMBW90M4860-0T0PY-16M-10M-010Y-1M-015Y-0Y; ATTILA/3/HUI/CARC//CHEN/CHTO/4/ATTILA	2008	Punjab	Rainfed
Dharabi-11	CMSS97Y03676S-040Y-050M-040SY–030M-21SY-010M-0Y-0SY; HXL7573/2*BAU//PASTOR	2011	Punjab	Rainfed
DH-31	GA-2002/Chakwal-50	Pipeline	Punjab	Rainfed
6C002	CMSS97M00316S-040M-040SY-030M-040SY-27M-0Y-0SY; Pastor/3/Altar-84/Ae.Sq//Opata	Pipeline	Punjab	Irrigated
Lasani-08	PBP29645-14A-18A-8A-4A-2A-0A; LUAN/KOH-97	2008	Punjab	Irrigated
Millat-11	Pb.30321-5A-0A-6A-0A; CHENAB2000/INQ-91	2011	Punjab	Irrigated
NARC-09	CGSS99B00015F-099Y-099M-099Y-099M-29Y-0B-0ID; INQALAB 91*2/TUKURU	2009	Punjab	Rainfed
NARC-11	CMSS00Y01881T-050M-030Y-030M-030WGY-33M-0Y-01D; OASIS/SKAUZ//4*BCN/3/2*PASTOR	2011	Punjab	Rainfed
Pakistan-13	PTSS02B00132T-0TOPY-0B-0Y-0B-38Y-0M-0SY MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN	2013	Punjab	Rainfed
Punjab-11	Pb.30196-1a-0a-2a-0a; AMSEL/ATTILA//INQ.91/PEW 'S'	2011	Punjab	Irrigated
Ujala	CGSS02B00125T-099B-099Y-099M-099Y-4WGY-0B ;KIRITATI/4/2*WEAVER/TSC//WEAVER/3/WEAVER	Pipeline	Punjab	Irrigated
NR-421 (Zincole)	CMSS07Y01302T-099Y-19M-0Y-2B-0Y-01D ;OASIS/SKAUZ//4*BCN/3/2*PASTOR/4/T.SPELTA PI348449/5/BAV92/3/OASIS/SKAUZ//4*BCN/4/PASTOR/6/ WBLL1*2/CHAPIO	Pipeline	Punjab	Irrigated
NIA-Amber	VEE#5 'S'/SARA//Soghat90	2010	Sindh	Irrigated
Benazir-13	CMSS93B01854T-040Y-08Y-010M-010Y-010M-8Y-0M.... CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/VEE#7/ BOW/4/PASTOR	2012	Sindh	Irrigated
Hamal-12	CMBW 89Y1044-0t0PM-8Y-010M-020M-0NPL-010Y-3M....	2013	Sindh	Irrigated
NIA-Sarang	SHA4/WEAVER//SKAUZ*2/SRMA	2013	Sindh	Irrigated
NIA-Sundar	Sarsabz /Sunco*2	2011	Sindh	Irrigated
NIA-Sunahari	Cham4//Ures/Bow 'S'	2010	Sindh	Irrigated
Total				

indicated by their preference ranking and subsequent feedback. A couple of new varieties were also added in the second year, particularly in irrigated areas. New improved varieties were compared with a range of old, improved varieties as local checks grown widely by the collaborating farmers (Table 2). The names of the wheat varieties used as local checks were confirmed by the researchers after discussing with farmers.

Table 2. Local check varieties grown by farmers in PVS trials in 2014–2015 and 2015–2016 in Khyber Pakhtunkhwa, Punjab, and Sindh.

Name of local check	Year of release	Recommendation domain	Khyber Pakhtunkhwa	Punjab	Sindh
Fakhr-e-Sarhad	1997	Irrigated	√		
Pirsabak-04	2004	Irrigated	√		
Prisabak-05	2005	Rainfed	√		
Pirsabak-08	2008	Irrigated	√		
Hashim-08	2008	Irrigated	√		
Seher-06	2006	Irrigated	√	√	
Tatara	1996	Irrigated	√		
Siran	2010	Rainfed	√		
Zam	2004	Rainfed	√		
Inqalab-91	1991	Irrigated	√	√	√
Uqaab-2000	2000	Irrigated	√		
Galaxy-13	2013	Irrigated	√	√	
AAS-11	2011	Irrigated		√	
Bhakkar-02	2002	Irrigated		√	
Faisalabad-08	2008	Irrigated	√	√	
Punjab-11	2011	Irrigated		√	
Lasani-08	2008	Irrigated		√	
NARC-09	2009	Rainfed		√	
Chakwal-50	2008	Rainfed		√	
TD-1	2004	Irrigated			√
TJ-83	1983	Irrigated			√
Red Mexi (Mexi-Pak)	1965	Irrigated			√
Pavan	1978	Irrigated			√
Kiran-95	1995	Irrigated			√
Mehran	1989	Irrigated			√
Sarsabiz	1985	Irrigated			√

Table 3. Number of wheat varieties, testing sites, planting, and harvesting time for PVS trials in Pakistan.

			Number of variety		Number of site		Number of farmers	
Year	Planting date	Harvesting date	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
2014–15	29 October to 15 December 2014	18 March to 12 May 2014	12	8	16	8	240	285
2015–16	21 October to 19 December 2015	15 March to 13 May 2015	11	4	18	6	195	60

Testing sites and collaborating smallholder farmers

Sites for the PVS trials were selected to represent the major wheat-growing domains in Pakistan. In addition to physical environments, important consideration was given to food security issues. The Integrated Food Security Phase Classification (IPC) map for Pakistan (www.ipcinfo.org) was used to select test locations (the map was prepared by the Food and Agriculture Organization of the United Nations [FAO] and the World Food Program [WFP] in collaboration with a number of national stakeholders of Pakistan). The work was undertaken by the Agricultural Innovation Program (AIP) for

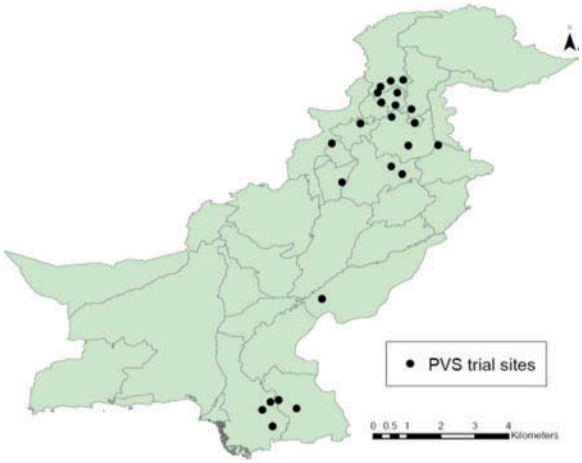

Figure 1. Testing locations of wheat participatory varietal selection trials.

Pakistan. Wheat varietal interventions were targeted toward moderate to severe food-insecure districts that also had a higher than average area under wheat production.

Districts with acute food deficiency were not included mostly because of a lack of agricultural lands suitable for growing wheat or security concerns or both. Two Union Councils (UCs)—the lowest unit of administration in Pakistan—were selected from each of the identified districts using a combination of criteria, for example, limited access of farmers to seed of new varieties and improved agronomic practices, distance from the urban areas and market centers and weak presence of private or public sector service providers. The two-year research collaboration involved 780 smallholder farmers, of which 21.5% were from KP, 60.7% Punjab and 17.8% from Sindh (Table 3). From the selected UCs, 73% of collaborating farmers cultivated up to six acres (2.42 ha) of land, whereas nearly 21% of them cultivated between 2.42 to 5 ha of lands; all of them were smallholders as per the Pakistan standards (PBS, 2012).

Partners

In KP, the Department of Agricultural Extension implemented this research; for Punjab and Sindh, the National Rural Support Program (NRSP) was the implementing agency. In Sindh, in addition to NRSP, the Arid Zone Research Institute of Pakistan Agricultural Research Council (PARC) collaborated in conducting PVS trials in Umerkot district. A summary of PVS trials is given in Table 3.

Rainfall data

Rainfall data from a few key locations in Pakistan were collected. These data were used to interpret results of PVS trials from rainfed locations.

Statistical analysis

Data on farmers' preference ranking were subjected to analysis of variance. Grain yield (GY) data were analyzed by using a mixed model for computing the least square means (LSMEANS) for each genotype at individual locations and across locations in each year using the program 'Multi Environment Trial Analysis with R' for Windows (METAR, Alvarado et al., 2015). The Dunnett's (one-tail) test was conducted, and Fisher's protected LSD was computed to compare the mean grain yield of the varieties. The estimated LSMEANS of GY for each genotype were expressed as a percentage of the local check (LC) using the following formula:

$$\%GY = \left(\frac{GY_g}{GY_c}\right) \times 100$$

where GY_g is the mean GY of a genotype, and GY_c is the mean GY of the local check.

Repeatability (H) was estimated for grain yield for all the locations where trials were planted using the following formula:

$$H = \frac{{\sigma_g}^2}{{\sigma_g}^2 + \frac{{\sigma_{ge}}^2}{e} + {\sigma_e}^2/er}$$

where ${\sigma_g}^2$ is the genotypic variance, ${\sigma_{ge}}^2$ is genotype x environment (or location) interaction variance, ${\sigma_e}^2$ is residual variance, e is the number of environments (or locations), and r is the number of replicates.

Results

Local checks used in the trial and their age

Analysis of age of check varieties and frequency of their use by the farmers in PVS trial revealed that farmers in KP grew the largest number of check varieties, followed by Sindh and Punjab. Conversely, farmers in Sindh used the oldest varieties, for example, TD-1 released in 2004 was the most recent variety used as a check, whereas rest of the check varieties were released before 1990. Farmers in Punjab grew varieties released after 2006, with one exception (Figure 2).

Grain yield performance of new improved varieties in Khyber Pakhtunkhwa

There were no statistically significant differences relative to mean grain yield between new wheat varieties and the checks in the PVS trials conducted in the 2014–2015 season, but in the 2015–2016 season, all three wheat varieties were superior to the local checks and their mean grain yield ranged from 3.4 to 3.6 t/ha. Although combined analysis was statistically non-significant,

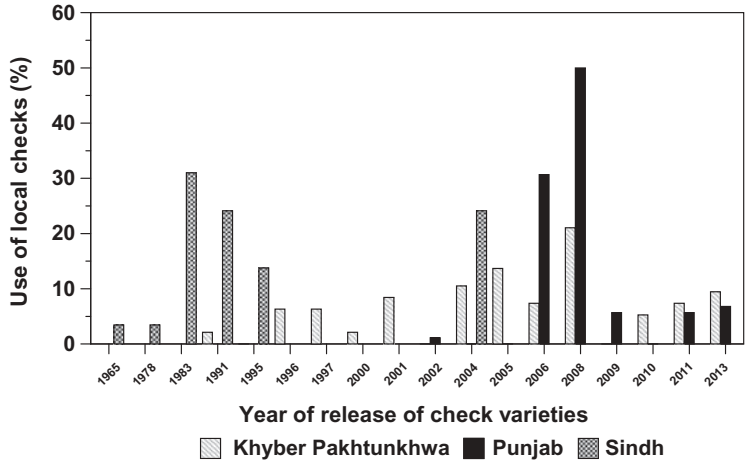

Figure 2. Year of release of wheat varieties in Pakistan and frequency of their use in PVS Mother Trials as local checks during 2014–2015 and 2015–2016.

based on two-year results, Pirsabak-13 was the best-performing variety across locations in KP and its yield advantage over local checks was 12%. Yield advantage of the highest-yielding Pirsabak-13 variety was 0.5 t/ha, whereas overall yield advantage of all three new varieties over check was 0.43 t/ha. The repeatability of combined grain yield was 0.63 (Table 4).

Grain yield performance of new improved varieties and their preferences by farmers in rainfed areas of Punjab

In the rainfed areas of Punjab, yield level of the same wheat varieties varied between the two seasons. Overall, yield levels were much higher in 2015–2016 compared with the previous year, whereas yield differences among varieties were significant in 2014–2015. Mean square for grain yield was also highly significant, with Pakistan-13 being the only variety significantly superior to all new varieties and the checks in the trial. Yield advantage attributable to the highest-yielding variety Pakistan-13 was 0.39 t/ha, whereas the other two new varieties, in fact, yielded less than the local check. The repeatability of grain yield ranged from 0.23 to 0.77 (Table 5).

Farmers' preference ranking for wheat varieties in rainfed areas of Punjab varied greatly. Pakistan-13 and Dharabi-11 were preferred over farmers' widely grown varieties both in 2014–2015 and in 2015–2016. Pakistan-13 maintained its distinct preference by growers over rest of the varieties in both years, whereas preference for Dharabi-11 was less consistent (Table 5). Farmers' rankings were statistically significant. Local checks were also ranked among the top five varieties in three to four locations across both years.

Table 4. Performance of four new wheat varieties in comparison to local checks (LC) evaluated in PVS trials in irrigated and rainfed locations of Khyber Pakhtunkhwa.

	2014–15		2015–16		Combined	
Variety	Grain yield (t/ha)	% Grain yield (LC)	Grain yield (t/ha)	% Grain yield (LC)	Grain yield (t/ha)	% Grain yield (LC)
NIFA-Lalma	3.0	101.0	3.4	116.4	3.2	108.2
Pakistan-13	3.0	101.7	-	-	-	-
Pirsabak-13	3.0	100.7	3.6	121.9	3.3	112.0
Shahkar-13	3.1	102.0	3.6	123.6	3.2	111.0
Local check	2.99		2.9		2.8	
Trial mean	3.0		3.4		3.1	
Fisher's LSD (at 0.05)	0.156		0.40		0.379	
Repeatability	0.26		0.89		0.63	

Grain yield performance of new improved varieties and their preferences by farmers in irrigated areas of Punjab

In the irrigated areas of Punjab, new varieties did not show much advantage in grain yield performance over the old, improved varieties grown by collaborating farmers. Punjab-11 had slightly more than 5% grain yield advantage during both years. Ujala and Zincole had slightly more than 6% yield advantage over the check varieties (Table 6). Grain yield differences among wheat varieties were statistically significant during 2014–2015 but not during 2015–2016. The repeatability of grain yield ranged from 0.34 to 0.95 (Table 6).

Table 5. Performance of four new wheat varieties evaluated in comparison to local checks (LC) in PVS trials and their preference ranking by farmers in rainfed locations of Punjab during wheat growing season of 2014–2015 and 2015–2016.

	2014–2015				2015–2016				Combined	
Variety	Grain yield (t/ha)	% Grain yield (LC)	Mean rank[†]	Overall rank order	Grain yield (t/ha)	% Grain yield (LC)	Mean rank[‡]	Overall rank order	Grain yield (t/ha)	% Grain yield (LC)
6C002	1.74	93.6			2.84	103.6			2.29	99.5
Dharabi-11	1.82	97.9	4.0	2	2.51	91.6	3.8	4	2.17	94.3
Pakistan-13	2.28	122.6	1.7	1	3.1	113.1	1.7	1	2.69	116.9
NR-421 (Zincole)	–	–			2.46	89.8			–	
NARC-11	–	–	4.7	5			–	–		
Local check[§]	1.86		4.4	4	2.74		3.5	5	2.3	
Trial mean	1.86		4.0		2.73		3.0		2.34	
Fisher's LSD (at 0.05)	0.309		0.928		0.657		0.819		0.269	
Repeatability	0.77		<0.000		0.23		<0.000		0.36	

[†]Farmers' preference ranking was done in a 9-entry trial in rainfed areas during wheat growing season of 2014–15, where 1 = best and 9 = worst considering all the traits of importance by farmers.

[‡]Farmers' preference ranking was done in a 5-entry trial in rainfed areas during wheat growing season of 2015–16, where 1 = best and 5 = worst considering all the traits of importance by farmers.

[§]See Table 2 for the name of local checks. Local checks may vary by site even within a province.

Considering overall traits, farmers found only AAS-11 to be better than the rest of the varieties evaluated in the PVS trials in 2014–2015 in the irrigated areas of Punjab, whereas in 2015–2016, farmers were unable to detect any differences between new improved and old improved varieties in their overall preferences (Tables 6 and 7). Overall, rank of local check variety was better than that of some of the new improved varieties.

Grain yield performance of new improved varieties and their preferences by farmers in Sindh

Only one to two new wheat varieties evaluated in PVS trials had a distinct yield advantage over the check varieties during both the years. Grain yield differences were statistically significant only during 2015–2016. New improved varieties gave 3–11% yield advantage over checks; yield advantage attributable to three highest-yielding varieties, viz., Benazir-13, NIA-Amber and NIA-Sarang was 0.3 t/ha, whereas overall yield advantage attributable to all five new varieties over local check was 0.18 t/ha. Overall repeatability for grain yield was 0.29 (Table 8).

In Sindh, throughout the 2014–2015 seasons, farmers did not see much difference among the varieties they evaluated. In 2015–2016, Benazir, NIA-Sunder, and NIA-Amber were ranked higher than check varieties and this difference in rankings was statistically significant (Table 9). Benazir and NIA-Sunder were considered similar, although, overall, Benazir ranked first. NIA-Amber was ranked third in order of preference. This variety was particularly

Table 6. Performance of four new wheat varieties evaluated in comparison to local checks (LC) in PVS trials and their preference ranking by farmers in irrigated locations of Punjab during wheat growing season of 2014–2015 and 2015–2016.

	2014–2015				2015–2016				Combined	
Variety	Grain yield (t/ha)	% Grain yield (LC)	Mean rank[†]	Overall rank order	Grain yield (t/ha)	% Grain yield (LC)	Mean rank[‡]	Overall rank order	Grain yield (t/ha)	% Grain yield (LC)
AAS-11	2.56	95.2	2.8	3	3.63	97.6	3.0	4	2.59	96.3
Punjab-11	2.83	105.2	5.9	6	3.92	105.9	2.80	1	2.83	105.2
Ujala	–	–	–	–	3.96	106.7	2.93	3		
NR-421 (Zincole)	–	–	–	–	3.95	106.2	2.91	2		
Local check[§]	2.69		4.5	4	3.71		3.27	5	2.69	
Trial mean	2.63		3.67		3.83		3.0		2.63	
Fisher's LSD (at 0.05)	0.105		0.438		0.446		–		0.357	
Repeatability	0.95		<0.000		0.47		ns		0.34	

[†]Farmers' preference ranking was done in a 6-entry trial in Irrigated areas of Punjab during 2014–15, where 1 = best and 6 = worst considering all the traits of importance by farmers.

[‡]Farmers' preference ranking was done in a 5-entry trial in irrigated areas during 2015–16, where 1 = best and 5 = worst considering all the traits of importance by farmers.

[§]See Table 2 for the name of local check. Local checks may vary by site even within a province.

Table 7. ANOVA for farmers' preference ranking of wheat varieties evaluated in rainfed and irrigated environments of Punjab during 2014–2015 and 2015–2016.

	2014–2015 rainfed		2014–2015 irrigated		2015–2016 rainfed		2015–2016 irrigated	
Source of variation	Degrees of freedom	Mean Square	Degrees of freedom	Mean Square	Degrees of freedom	Mean Square	Degrees of freedom	Mean Square
Replication	9	0.124	9	0.407	13	0.001	14	0.001
Variety	8	4.766***	5	26.267***	4	13.107***	4	0.0467
Error	72	0.096	45	0.852	52	1.68	56	2.65

***Significant at $P < 0.001$.

preferred in Umerkot because of its adaptation and overall phenotypic performance, including uniformity. Interestingly, local checks were also ranked among the top five varieties in two to three locations in 2014–2015 and 2015–2016.

Discussion

New improved wheat varieties identified

This research offered an increased choice of new wheat varieties to farmers across the three provinces. Eight out of 10 wheat varieties identified in this research as competitive and acceptable represented CIMMYT germplasm. While Pakistan-13 was preferred in the rainfed areas of Punjab, Shahkar-13 and NIFA-Lalma were preferred in KP. Pakistan-13 was also preferred in areas with limited irrigation, as it saves on cost of irrigation because of its drought tolerance. Benazir-13,

Table 8. Performance of six new wheat varieties evaluated in comparison to local checks (LC) in PVS trials and their preference ranking by farmers in irrigated (including few sites with limited irrigations) locations of Sindh during 2014–2015 and 2015–2016.

	2014–2015				2015–2016				Combined	
Variety	Grain yield (t/ha)	% Grain yield (LC)	Mean rank[†]	Overall rank order	Grain yield (t/ha)	% Grain yield (LC)	Mean rank[‡]	Overall rank order	Grain yield (t/ha)	% Grain yield (LC)
Benazir-13	3.3	110.0	3.0	2	4.3	110.3	1.73	1	3.9	111.4
NIA-Amber	3.4	113.3	3.44	3	4.1	105.4	2.80	3	3.8	108.6
NIA-Sarang	3.1	103.3			4.3	110.3			3.7	105.7
NIA-Sunder	3.1	103.3	2.77	1	3.9	100.0	1.73	2	3.5	100.0
NIA-Sunahri	3.0	100.0			-				3.5	100.0
Local check[§]	3.0		3.44	6	3.9		3.73	4	3.5	
Trial mean	3.2		3.07		4.1		2.54		3.6	
Fisher's LSD (at 0.05)	0.375		-		0.25		0.387		0.441	
Repeatability	0.28		ns		0.79		<0.000		0.29	

[†]Farmers' preference ranking was done in a 6-entry trial in Irrigated areas of Sindh during 2014–15, where 1 = best and 6 = worst considering all the traits of importance by farmers.

[‡]Farmers' preference ranking was done in a 5-entry trial in irrigated areas of Sindh during 2015–16, where 1 = best and 5 = worst considering all the traits of importance by farmers.

[§]See Table 2 for the name of local check. Local checks may vary by site even within a province.

Table 9. ANOVA for farmers' preference ranking of wheat varieties evaluated in irrigated environment of Sindh during 2014–2015 and 2015–2016.

	2014–2015		2015–2016	
Source of variation	Degrees of freedom	Mean Square	Degrees of freedom	Mean square
Replication	8	0.379	14	0.0006
Variety	5	0.829	4	10.45***
Error	40	2.563	56	0.592

***Significant at $P < 0.001$.

NIA-Amber, and NIA-Sarang were preferred in Sindh. Pirsabak-13 was considered the best wheat variety in irrigated areas of KP. This germplasm was also released in India in 2013 as PBW 658. It is interesting that this was not picked up in provinces other than KP. Field observations revealed that seeds of this variety were continuing to spread across Punjab, which borders KP. One of the farmers from Punjab purchased seeds of this variety from Miankhail Seed Corporation (a private seed company and one of the partners in the AIP project in KP) for 240 ha during 2015–2016 (Hussain A. *pers comm. March 2016*). Although trading seeds of crop varieties not released in the same province is considered illegal in Pakistan, it is not uncommon in informal trade. Grain yield of Zincole, a zinc-enriched variety, was at par with the check varieties, and more importantly, it is adapted to both rainfed and irrigated conditions. It is highly preferred for its cooking quality and taste. Its uptake by farmers can be accelerated by creating awareness and knowledge about the additional advantage of growing this variety for the benefit provided by its zinc-enriched grains. Ujala, a new wheat variety for irrigated areas, had grain yield at par with local checks. Farmers ranked Pakistan-13, Zincole, and Dharabi-11 as the top three varieties, considering taste, texture, and softness of *roti/chapatti* several hours after cooking. It is also noteworthy that wheat varieties developed through the Nuclear Institute for Food and Agriculture (NIFA), KP and Nuclear Institute of Agriculture (NIA), Sindh, were evaluated on-farm at this scale for the first time.

Yield advantage of new improved varieties

Contrary to the widely held belief of the farmers that all newly released wheat varieties will out-yield the existing old, improved varieties in farmers' fields, the findings from PVS trials indicated that this was not necessarily the case (Figure 3). Similar findings were also reported by Joshi et al. (2016). Grain yield advantage in farmers' fields from new best varieties from KP ranged between 8 and 12%, and it was 6–11% in Sindh. In the Punjab, grain yield advantage in irrigated areas was between 6 and 7%, whereas in rainfed areas, Pakistan-13 performed very well, with nearly 17% yield advantage. A couple of new varieties were lower yielding than the local checks at all the trial sites. Grain yield advantage was lowest in irrigated areas of Punjab possibly because farmers in this area grew most recently released wheat varieties. Except for Pakistan-13, other new wheat varieties evaluated in rainfed

areas of Punjab did not have significant yield advantage over checks. Possible reasons could be as follows: (i) In nearly 50% of cases in the rainfed areas, the local checks used were varieties recommended for irrigated areas. For example, new lines bred for rainfed environments could not out-yield Sehar-06, Faisalabad-08, Galaxy-13, AAS-11, Punjab-11, Lasani-11, and Bhakkar-02. Farmers have been growing these varieties in rainfed areas because of their higher yield even under rainfed or partially irrigated conditions. (ii) Yield differences between new varieties for rainfed areas and checks may have evened out because of well distributed and timely rainfall during 2015–2016 (Figure 4) compared with the previous year. In this research, wheat varieties for rainfed domains were more competitive than those for irrigated areas, which is because seven out of eight rainfed varieties in the trial were from the International Maize and Wheat Improvement Centre (CIMMYT). Conversely, only seven out of 14 varieties for irrigated areas represented CIMMYT germplasm.

Current research revealed that the best varieties across locations yielded 0.3–0.5 ton extra grain yield/ha just by replacing old varieties by new ones without any extra investment in inputs and management. Considering the highest wheat grain requirement of 150 kg/person/annum, this extra yield can easily feed 2–3.3 persons per year, which is not insignificant for smallholder farmers in ensuring household food security. Farmers continuing to grow old and obsolete varieties would obviously lose these benefits.

Age of local checks in pvs trials and farmers' innovations

Age of check varieties was variable across the provinces, with Sindh using the oldest check varieties, followed by KP and Punjab. Use of old check varieties can

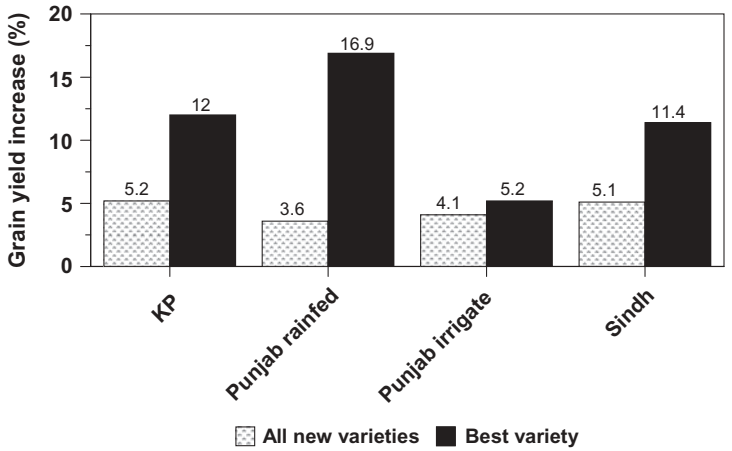

Figure 3. Overall mean grain yield increase due to newly released wheat varieties (over local check varieties) evaluated in participatory varietal selection trials (see Tables 4–7 for the average grain yield of the best wheat varieties and corresponding local checks in all the three provinces).

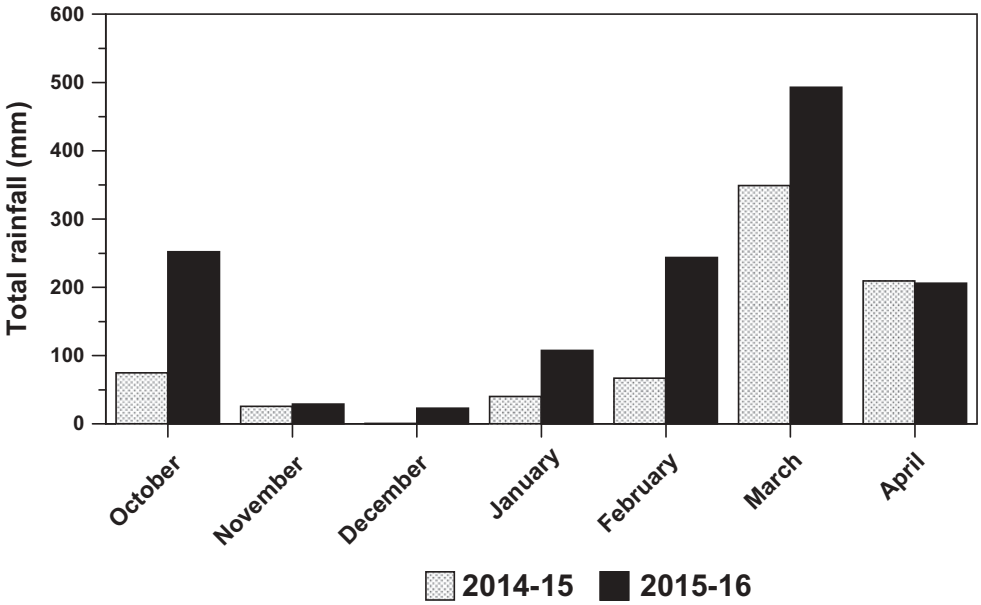

Figure 4. Rainfall pattern of the locations where PVS trials were conducted during 2014–2015 and 2015–2016 wheat growing seasons.

be explained by the slow breeding progress in Sindh, for example, after the release of TD-1 in 2004, there was a gap of nearly six years before a new variety was released in 2010 (data not shown). An explanation could be that new varieties released after 2010 lacked a clear grain yield advantage over old, improved varieties (with some exceptions). This is confirmed by grain yield data and also verified by farmers' preference ranking (Table 7, Figure 2). Another interesting finding from this research was that not only the age of check varieties differed across locations, but also there was frequent movement of wheat varieties recommended for irrigated areas to rainfed domains. This happened as farmers innovated on their own in searching for and evaluating new germplasm from various sources and adopted the ones they liked the most. For example, several of the wheat varieties recommended for irrigated domains in Punjab were adopted by farmers in rainfed areas of Punjab Pothwar region, for example, AAS-11, Punjab-11, Faisalbad-08, and Seher-06. This is also true for other parts of Pakistan, as has been confirmed by local check varieties used in the PVS trials conducted as part of the AIP project in Pakistan. The PVS trial in this context has been very supportive in systematizing and accelerating farmers' innovations regarding varietal selection and replacement.

Varietal turnover

The ultimate objective of any breeding programs is to provide new varieties regularly with a best combination of increased yield, disease resistance,

acceptable grain quality and other traits of economic importance to farmers for adoption. Varietal turnover and cultivar age can be important reflections of performance and efficiency of breeding programs. In 1997, Pakistani farmers grew 6- to 8-year-old wheat varieties, and by 2014, the average age of wheat cultivars was 8–10 years. Conversely, during the same period, Bangladesh and Nepal markedly improved weighted average age down to 8–10 years from >14 years in 1997 (Lantican et al. 2016). This implied that old improved varieties were hard to replace in Pakistan. A recent impact assessment of wheat in Punjab (Pakistan) indicated that nearly 28% of wheat area was planted to varieties released mostly before 1990; four varieties, viz., Seher-06, Safaq-06, Faisalabad-08 and Lasani-11, covered 70% of land area in 2013–2014 (Javed et al. 2015). It was interesting that Inqalab-91 covered 50% of the wheat area up to 2007–2008, and then, its area declined once it became increasingly susceptible to rust.

Effectiveness of PVS approach

Evaluating pipeline wheat varieties using PVS before their release could be more logical than evaluating the released ones, as the approach is effective in culling out totally unacceptable varieties and also for identifying the most competitive and acceptable ones to advance to national coordinated yield trials. In this research, out of 22 released wheat varieties, 10 having yield advantage or at least yield at par with local checks were acceptable to farmers. Lacoste et al. (2012) found the PVS trials to be effective tools for new variety selection by farmers; this approach was vital in facilitating early uptake and adoption of farmer-preferred varieties as much as 80%. Lacoste et al. (2012) also reported that planting material from a third of the trial was shared with an average of five non-participating households. Pandit et al. (2010) also agreed with the finding that seed dissemination through this approach was rapid. Tiwari et al. (2010) and Thapa et al. (2009) highlighted the power of evaluating new varieties under farmers' management to greatly enhance cultivar identification based on farmers' choice, a process that leads to the selection of varieties with yield stability and ultimately provides additional benefits to farmers.

The PVS also provides opportunities for farmers to take into account varietal performance during the entire crop growth period and also for assessing important post-harvest traits. Through these opportunities, farmers learn how to strike a balance between various traits, which ultimately leads to adoption or non-adoption. Farmers' preference ranking in this research was useful and complementary in most cases in detecting yield potential as well as other traits of economic importance that contribute to farmer acceptance/adoption. The ranking of wheat varieties by farmers close to maturity closely matched with grain yield data. It is interesting that farmers' best ranked varieties were also the highest yielding. Farmers' preference ranking becomes

more effective when several varieties in the trial produce competitive yield performance. In that context, farmers resort to discriminating among varieties, considering traits other than yield and phenotypic appeal in choosing varieties.

Since the initiation of PVS trials, the most preferred and distinctly high yielding wheat varieties routinely get included in the seed production stream by private seed companies in KP, Sindh, and Punjab as well as by village-based seed-producer groups in Punjab and other provinces. It is noteworthy that these varieties have started replacing some of the old and obsolete varieties in the project area.

Conclusions

This research is novel in that it holistically examined the choice of acceptable and competitive wheat varieties available to collaborating farmers in irrigated and rainfed environments. Grain yield advantage offered by new batch of wheat varieties in comparison to most popular commercial wheat varieties in Pakistan was examined from the perspective of replacing old varieties by new ones. Findings from the PVS trials indicated that nearly 50% of the newly released wheat varieties (all CIMMYT germplasm) offered on average 5–17% yield advantage on-farm over the popularly grown, old improved check varieties in Pakistan. Noticeable yield advantage plays a decisive role in the uptake and adoption of new crop varieties by farmers. It is still challenging to replace most popular old improved wheat varieties in irrigated areas in spite of their susceptibility to rust and other diseases because of their good yield in normal years and established seed and marketing systems. This is an important finding from on-farm participatory research that can benefit the entire wheat breeding research community and needs proper attention to address future food security at large.

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