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Yield and Profit from New and Old Wheat Varieties Using Certified and Farmer-Saved Seeds

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Abstract: Wheat is a strategic crop for food security in Pakistan with predominance of smallholder farmers. Farmer-saved seed (FSS) is used nearly by 75% of farmers for wheat production. Frequent variety or seed replacement is uncommon even among large-scale farmers, and certified seed (CS) is mostly bought to verify the value of new varieties. Replacing old and obsolete varieties by new high yielding disease resistant varieties is key to transferring new genetic gains to farmers. For the first time in Pakistan, on-farm factorial experiments involving seven new and five old wheat varieties and their corresponding CS and FSS were conducted. A total of 49 farmers representing major wheat cropping patterns throughout the country participated in these trials in the 2014 and 2015 wheat growing seasons. Analysis of variance revealed that there was highly significant difference between wheat varieties and between seed classes. New variety + CS gave 33.8% more grain yield as well as higher marginal return over farmers' variety + FSS. Grain yield and returns from new variety + FSS and farmers' variety + CS were at par. Scientific knowledge generated in this research demonstrated that use of CS of new wheat varieties is best option, while growing new varieties with FSS is a second choice for the advantages accruing from their built-in genetic traits of economic importance over growing CS of old and obsolete varieties. Having more flexible seed system will help accelerate the delivery of new genetic gains to farmers' fields.

Key words: Certified seed, farmer-saved seed, variety and seed replacement, smallholder farmers, yield, return, varietal popularization.

1. Introduction

Certified seed (CS) of new varieties offers benefits of yield increasing traits, disease resistance and tolerance to biotic and abiotic stresses due to their improved genetics [1]. Guarantee for genetic purity is the primary goal and main mission of CS programs [2].

It is estimated that more than one billion ha each year are planted to farmer-saved seed (FSS) with an estimated total value of around $7 billion at 2005 prices [3]. In South Asia and Sub-Saharan Africa (SSA), due to the predominance of smallholder farmers, 80% to 90% of planting materials are FSS [4]. Analysis of three-year data for 40 crops across six countries in Africa concluded that farmers access 90.2% of their seeds through informal systems [5].

In addition to developing economies, the use of FSS in developed countries for various crops was reported between 7% to 95% in Europe, Canada, Australia, the

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United States and Argentina [1, 3, 6, 7]. Canadian farmers are allowed to save and clean their own production of FSS for the purpose of planting it on their own land [1]. For example, only 10% of the wheat area of surveyed farmers was seeded with CS in Western Canada in 2004, while approximately 70% of total wheat area was planted with FSS [7]. The percentage of FSS wheat used in Kansas in 1984 ranged between 51% and 67%. The main reasons that farmers preferred FSS include the reduced upfront cost. The quality is considered just as good as CS, and surveyed farmers said “I know what I am getting” [8].

CS covered nearly 35% of the 8.9 million ha wheat-growing area in Pakistan in 2015 and 2016 [9]. Pakistani farmers were growing 8-10 years old wheat varieties in 2014 compared to 6-8 years old in 1997 [10]. This is because the formal seed sector tends to promote the established and popular varieties, which are generally old to save on operating costs, despite having indications that some might be becoming susceptible to rust. Farmers buying CS from the market may end up buying seed of one of the older varieties. Secondly, “variety replacement” and “seed replacement” are often used interchangeably, although using CS of newly-released, high yielding, disease resistant varieties versus CS of old and obsolete varieties is quite different.

Smallholder farmers make up 73% of all farms in Pakistan [11] with an average land holding of 1.1 ha [12]. About 66% of the population lives in rural areas, most of who are smallholder farmers, tenants, landless and vulnerable people [13] that depend on wheat. It is vital to strengthen the seed system that smallholder farmers in far-flung areas of Pakistan use. For smallholder farmers, access to new wheat varieties with built-in genetic traits for high yield and tolerance to biotic and abiotic stresses is of high importance. Validation and popularization of new high yielding, rust resistant wheat varieties and sustainable provision of their quality seeds (not necessarily the CS) will directly contribute to improving overall wheat productivity in the country, as well enhancing food and livelihood security of smallholder farmers [14, 15].

In this context, a simple but powerful participatory on-farm factorial trial was conducted to compare new and old wheat varieties and their corresponding CS and FSS to understand the effect of varieties and the effect of seed classes in wheat grain yield advantages and gross profits.

2. Materials and Methods

2.1 Experimental Details

For the first time in Pakistan, on-farm factorial experiments involving two factors—wheat variety and class of seed with four treatments were conducted: T1—new wheat variety + CS; T2—new variety + FSS; T3—farmer’s variety (old variety) + CS; T4—farmer’s variety (old variety) + FSS.

Seven highest yielding new (varieties released after 2010 were considered new) and five most popular farmers’ old wheat varieties were compared in these trials (Table 1). They were laid out in a randomized complete block design (RCBD) with a plot size of 250 m^2 per treatment. One set of the trial was conducted on station, while the rest of the trials were conducted in the farmers’ fields. An individual farmer was considered as one replication. Overall, 49 farmers collaborated in the research, and the research was conducted under farmers’ level of inputs and management during the 2014 and 2015 wheat growing seasons. Seven national partners implemented the trials jointly with the International Maize and Wheat Improvement Center (CIMMYT), among which five were from the public sector and two from the private sector, for implementation across Khyber Pakhtunkhwa (KP), Punjab and Sindh (Table 2). Partner organizations selected the collaborative farmers in representative areas with interest in the study.

The CS and FSS (in few cases) used in the trials was supplied by the implementing partners. Collaborating farmers in majority of cases used FSS from their own sources. Seed used in the trial was

Table 1 Wheat varieties included in on-farm factorial trials in Pakistan during 2014-2015 and 2015-2016 growing seasons.

Varieties	Pedigree and parentage	Year of release	Yield potential* (ton/ha)	Rust reaction**		
				Yellow rust	Leaf rust	Stem rust
New varieties						
Benazir-13	CHEN/AEGILOPS SQUARROSA (TAUS)//BCN/3/VEE#7/BOW/4/PASTOR; CMSS93B01854T-040Y-08Y-010M-010Y-010M-8Y-0M…..	2013	8.0	10 MRMS	10 MSS	R
Dharabi-11	HXL7573/2*BAU//PASTOR; CMSS97Y03676S-040Y-050M-040SY--030M-21SY010M…..	2011	5.3	20 MR	30 MSS	R
Galaxy-13	Punjab 96/V-87094//MH-97; Pb.30398-0a-0a-0a-45a-0a	2013	6.7	17 MSS	23 MRS	70 MSS
Pirsabak-13	CS/TH.SC//3*PVN/3/MIRLO/BUC/4/MILAN/5/TILHI; CMSS97M04005T-040Y-020Y-030M-020Y-040M-28Y…..	2013	7.0	10 MRMS	TMS	60 MRMS
Shahkar-13	CMH84.3379/CMH78.578//MILAN; CMSS93Y006285-7Y-010Y-010M-010Y-010M-0Y….	2013	6.0	5 MRMS	5 MSS	70 MS
Pakistan-13	MEX94.27.1.20/3/SOKOLL//ATTILA/3*BCN; PTSS02B00132T-0TOPY-0B-0Y-0B-38Y-0M-0SY	2013	5.3	5 R	R	10 MS
Punjab-11	AMSEL/ATTILA//INQ.91/PEW ‘S’; Pb.30196-1a-0a-2a-0a	2011	6.2	7 MSS	1 S	40 MR
Old varieties						
TJ-83	TZPP/PL//7C; CM5287-J-1Y-2M-2Y-3M-0Y-0PAK	1983	5.5	80 S	50 MSS	40 MS
Chakwal-50	ATTILA/3/HUI/CARC//CHEN/CHTO/4/ATTILA; CMBW90M4860-0T0PY-16M-10M-010Y-1M-015Y-0Y	2008	5.5	20 MSS	10 MSS	40 MR
Sehar-06	CHILL/2*STAR/4/BOW//BUC/PVN/3/2*VEE#10; CMSS95Y00645-100Y-200M-17Y-10M-0Y-0PAK	2006	7.0	29 MS	67 S	70 MSS
Pirsabak-08	KAUZ/PASTOR; CMSS93B00025S-48Y-010M-010Y-4Y-0M	2008	6.0	10 MRMS	TMSS	20 MR
Faisalabad-08	PBW65/2*Pastor; CGSS974000367-099 TOP-067Y-099M--099Y-099B-16Y--0B	2008	6.7	20 MRMS	10 MSS	60 MSS

*: resource from Ref. [16]; ** resource from Ref. [17].

R = resistant; S = susceptible; MR = moderately resistant; MRMS = moderately resistant-moderately susceptible; MSS = moderately susceptible-susceptible; MS = moderately susceptible; TMS = traces of moderately susceptible; TMSS = traces of moderately susceptible-susceptible.

Table 2 Treatment combinations in the trial.

Partner organization	District with their coordinates			Treatments				Wheat varieties recommended for rainfed or irrigated condition	
	Name	Latitude	Longitude	T1	T2	T3	T4		
				New variety + CS	New variety + FSS	Old variety + CS	Old variety + FSS	New	Old
NARC	Jhelum	32°56′27″	73°43′28″	Pakistan-13	Pakistan-13	Faisalabad-08	Faisalabad-08	Rainfed	Irrigated
BARI	Chakwal	32°55′54″	72°51′17″	Dharabi-11	Dharabi-11	Chakwal-50	Chakwal-50	Rainfed	Rainfed
BARI	Attock	33°46′24″	72°21′20″	Dharabi-11	Dharabi-11	Chakwal-50	Chakwal-50	Rainfed	Rainfed
WRI, Faisalabad	Faisalabad	31°25′2″	73° 4′53″	Galaxy-13	Galaxy-13	Sehar-06	Sehar-06	Irrigated	Irrigated
WRI, Faisalabad	T.T. Singh	30°58′28″	72°29′2″	Galaxy-13	Galaxy-13	Sehar-06	Sehar-06	Irrigated	Irrigated
Engro	Shiekhupura	31°42′55″	73°59′27″	Punjab-11	Punjab-11	Sehar-06	Sehar-06	Irrigated	Irrigated
CCRI	Nowshera	34°0′56″	71°58′41″	Pirsabak-13	Pirsabak-13	Pirsabak-08	Pirsabak-08	Irrigated	Irrigated
Pride seed company	Mardan	34°12′4″	72°3′7″	Shahkar-13	Shahkar-13	Faisalabad-08	Faisalabad-08	Rainfed	Irrigated
WRI, Sakrand	Benezairabad	26°16′12″	68°23′38″	Benezair-13	Benezair-13	TJ-83	TJ-83	Irrigated	Irrigated

CS = certified seed; FSS = farmer-saved seed; NARC = National Agriculture Research Centre; BARI = Barani Agricultural Research Institute; WRI = Wheat Research Institute; CCRI = Cereal Crops Research Institute.

inspected during preparation, properly labeled and checked again during sowing. FSS used in the trial was checked by the researchers for any possible varietal mixture before planting the trial. In a few instances, varietal mixture or weed seeds, wheat straw or other trash were also detected in FSS, which was cleaned before sowing.

The trials covered all major wheat-based cropping patterns in Pakistan. For example, in Khyber Pakhtunkhwa, the trials were conducted in maize-wheat cropping systems, in irrigated Punjab, trials were conducted in rice-wheat and cotton-wheat cropping systems, in rainfed Punjab, trials were conducted in wheat mono crops and in Sindh, they were conducted in cotton-wheat cropping systems. Time of trial planting in 2014-2015 and 2015-2016 was spread between November 15 and December 10, while trial harvesting was undertaken from April 4 to May 25.

2.2 Statistical Analysis

At maturity, plots were individually harvested, threshed and grain yield was recorded. Combined analysis of variance (ANOVA) for all seven varietal combinations (Table 2) was undertaken for grain yield. In the case of comparison between Punjab-11 and Sehar-06, ANOVA was also done for the number of plants/m^2 at emergence and the number of productive tillers/m^2 at physiological maturity. The difference between the treatments was tested based on the least significant difference (LSD) at a 5% probability level. The significance between treatments refers to the effect of wheat variety, seed class and interaction between variety and seed class. Marginal return from each treatment was estimated. Unit price of CS and FSS was recorded to get the difference in cost between the seed classes. The price of FSS was aligned with the unit price of wheat grains during October-November 2014 and 2015 and were obtained from the Pakistan market price bulletin published by the United Nations World Food Programme [18, 19], while the cost of CS were taken from official sources [9]. Secondary data on the quantity of CS used in Pakistan and national average wheat productivity from 1994-1995 to 2015-2016 [12, 20] were also collected, and a regression analysis was performed between these two variables to understand what extent of variation in wheat productivity (dependent variable) can be explained by the variation in the use of wheat CS (a predictor) over a 22 year period. Initially, national wheat productivity was regressed with the actual values of CS that were bigger by hundred thousand fold compared to the productivity data, while it resulted in a very small significant error of slope of the regression b = 4.29E – 07. To normalize this, all the CS data were divided by 1,000 that improved the b by thousand times.

3. Results and Discussion

3.1 Effect of Variety on Grain Yield

Irrespective of seed class, seven newly released wheat varieties produced significantly higher grain yield (LSD = 0.285; P = 0.0000) than the five old wheat varieties used by farmers in the trials. On average yield advantage due to new wheat variety was nearly 18% over widely grown farmers' varieties. Increase in grain yield between treatments ranged from 2.85% to 33.8%. New variety with CS gave the highest actual grain yield and the highest rate of increase in grain yield.

New varieties + FSS and old varieties + CS were at par for grain yield, while farmers' wheat varieties with farmer-saved seed performed poorly (Fig. 1). These yield benefits were purely due to the effect of genetic contribution disregarding the effect of seed classes. Sehar-06 is one of the most widely grown wheat varieties in Pakistan because of its high grain yield, good grain quality and the established seed and grain markets. In the absence of rust disease, its yield potential is at par with Galaxy-13, which is highest yielding wheat variety in Pakistan currently. It is worth noting that leaf rust incidence on Sehar-06 was

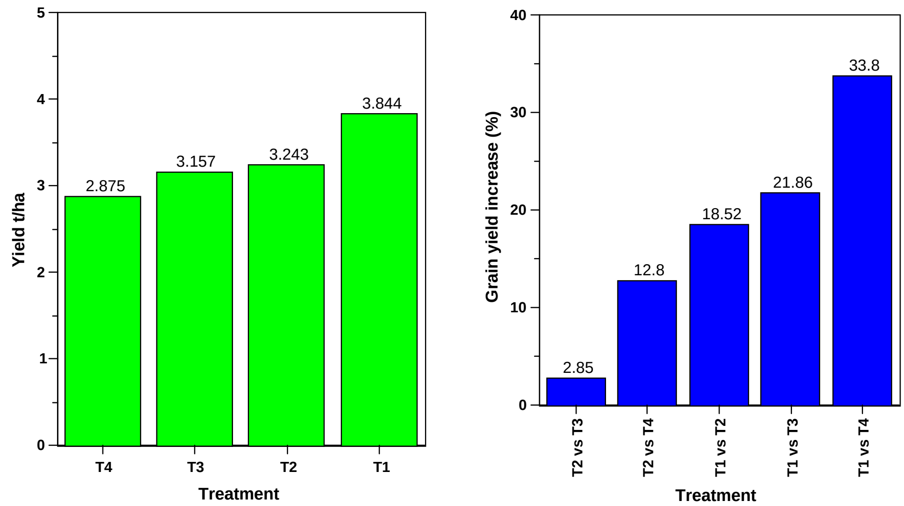

Fig. 1 Comparison of new and old wheat varieties with their CS and FSS for actual grain yield and increase in grain yield among various treatments during 2014-2015 and 2015-2016 wheat growing seasons.
T1 = new variety + CS; T2 = new variety + FSS; T3 = old variety + CS; T4 = old variety + FSS.

high, while Galaxy-13 also showed susceptible reaction to leaf rust during the research (Table 1).

In spite of susceptibility to rust, the formal seed sector tends to promote old wheat varieties [10, 21], such as Sehar-06, to reduce their operating costs, ignoring the potential threat of rust epidemics from such older varieties. Smallholders continue using popular varieties, because knowledge about newly released varieties is not readily available to them due to a lack of systematic popularization efforts. As a result, demand for wheat seed in the existing marketing system is determined by popularity rather than genetic attributes or agronomic performance of newly released varieties. This needs to be understood in the context of the current dilemma, wherein the terms "seed replacement" and "variety replacement" are often used interchangeably, when in fact CS of newly-released, high yielding and disease resistant varieties versus CS of old and obsolete varieties is not the same thing. Moreover, in developing countries, crop breeding and variety testing and release procedures take long time, with a lag phase of 6-8 years after the release of a variety and before any substantial adoption [22-25]. Varieties released by this method no longer remain a "new variety" in the true sense. Considering the background described above, it is not surprising that any farmer buying CS may end up actually using seeds of "old and obsolete" varieties.

3.2 Effect of Class of Seed on Grain Yield

The grain yield of wheat also varied significantly due to the effect of seed class (LSD = 0.285; $P < 0.001$). It is obvious from the result that grain yield from CS of old varieties produced 86 kg/ha less yield compared to the grain yield from the new variety + FSS, while the grain yield from the old variety + FSS was the lowest of all (Fig. 1). The main element responsible for the significant effect of seed class can also be attributed to the high grain yield performance of new varieties with CS rather than the low grain yield from CS of old varieties. Among others reasons, incidence of leaf rust on Sehar-06 and other varieties grown by farmers in the trial resulted in lower grain yield (Tables 1, 3 and 4 and Fig. 1). Rust had dual effects: firstly it reduced the yield of wheat in the trial with FSS treatments and secondly grains of Sehar-06 were shriveled as a result of rust on previous crop. Once such FSS was used for planting, it had an impact on the number of plants at emergence and the number of productive tillers at physiological

Table 3 Number of plants at emergence and number of productive tillers at physiological maturity.

Variety combinations	No. of plants/m^2 at emergence	No. of productive tillers/m^2 at physiological maturity
Punjab-11 + CS	164	255
Punjab-11 + FSS	126	230
Sehar-06 + CS	144	236
Sehar-06 + FSS	119	222
LSD test variety (V)	13.82*	NS
LSD test class of seed (S)	13.82***	14.91**
LSD (V × S)	NS	NS

LSD = least significant difference; NS = not significant; * = significant at $P < 0.05$; ** = significant at $P < 0.01$; *** = significant at $P < 0.001$.

Table 4 Marginal returns from new wheat varieties compared with old ones with the use of CS and FSS in Pakistan during 2014-2015 and 2015-2016 wheat growing seasons.

Parameters	New variety + CS (T1)	New variety + FSS (T2)	Old variety + CS (T3)	Old variety + FSS (T4)
Cost of seed ($/ha)	57.60	41.62	57.60	41.62
Grain yield (ton/ha)	3.844	3.240	3.160	2.880
Price of grain/ton ($)	337.0	337.0	337.0	337.0
Gross revenue from the sale of grain ($/ha)	1,295.4	1,092.9	1,063.9	968.9
Marginal return ($/ha)	1,237.8	1,051.3	1,006.3	927.3
Marginal rate of return	21.5	25.3	17.5	22.3

maturity (Table 3), ultimately resulting in reduced grain yield. All of these differences were statistically highly significant, as shown in Table 3. Earlier studies indicated that seed produced from the crop damaged by rust have poor emergence and low vigour after germination [26].

In the developed world, when farmers buy CS, they are certain that it will be of a newly released crop varieties. Hence motivation to buy CS in those countries is to have access to newly released wheat varieties with proven high yield and other genetic attributes of economic importance. Comparatively, CS carries an upfront cost to producers, although it provides a quality and performance guarantee in the genetics of new varieties [1]. Grain yield advantages for CS over FSS vary year to year, and using CS does not always guarantee higher yield because weather may cause partial or total crop failure [2]. Moreover, farmers see the risk with CS that a totally new and unknown variety may perform poorly, it may have less than desirable value/quality and variety is not readily available. Conversely, in emerging and low-income countries, CS may be of any variety from very old to new ones. However, CS is not always available for new varieties when they are released, and getting it of high quality and with genetic purity is also hard, because fraudulent seed dealers and middlemen often sell poor quality seeds, or the label of the seeds will say one thing, but the seed inside will be of an entirely different variety. Some seed dealers even may mix seed or sell mere grain in bags labeled CS at low prices to lure smallholders, according to a number of several private seed companies [14].

The FSS is readily available without any out-of-pocket cost, and farmers perceived their own seeds of equal or higher yield over CS [1]. The overwhelming use of FSS for all the major cereals, cotton and legumes by farmers in Pakistan is due to unavailability of CS in the rural areas when needed [27, 28], but it is also because farmers do not see much value in getting it from distant markets by paying higher prices [29]. The more common practice even in the developed world is to plant CS of new variety in a certain area of their field to take advantage of newly released wheat varieties with potential to increase yield and wheat quality [8] for using the FSS for planting in subsequent years.

3.3 Effect of Interaction between Wheat Varieties and Classes of Seed on Grain Yield

Findings revealed that the interaction between wheat variety and seed class was statistically not significant (LSD = 0.48; P = 0.273). This indicates that the interaction effect of a wheat variety on CS as well as FSS is same and equals its main effect. Same explanation applies to the effect of seed classes as well.

3.4 Marginal Return Due to Variety and Seed Class

Difference between treatment combinations for marginal return was high. The highest return was obtained from T1 (new variety + CS) ($1,237.8/ha), which was also the highest yielding treatment in the trial. The return from T2 (new variety + FSS) was $45/ha more than the marginal return obtained from farmers' variety + CS, while the lowest marginal return was obtained from T4. A highly significant difference in the yield of the new varieties versus old varieties was the main factor contributing to higher marginal return in case of T1 in comparison to rest of the treatments (Fig. 1). The technical message with regards to the promotion of CS in the past was misleading in majority of cases. This was because the age of cultivars in offer for CS are hardly mentioned in formal seed trade and as a result CS overshadowed the importance of new germplasm. This finding provides very convincing and useful insights with regard to the use of CS in developing countries that have a predominance of smallholder farmers. More restrictive seed systems in developing countries are often dominated by older crop varieties. Without relating the age of crop varieties with CS, farmers buying CS from the market in developing countries may very well end up buying seed of an older variety, and as a result, lose out in total returns. Over emphasis on certified seeds and not recognizing alternative seed production and provisioning systems, which may be popularizing new varieties may be counterproductive.

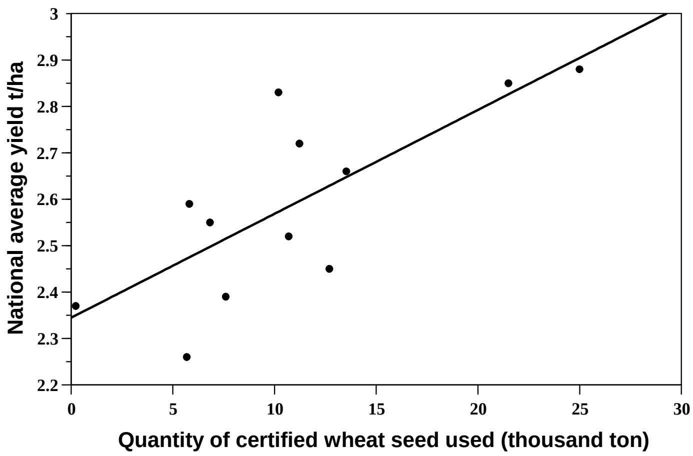

Fig. 2 Regression analysis between wheat CS used and national average wheat productivity in Pakistan from 1994-1995 to 2015-2016.

Table 5 Regression results for the quantity of CS seed used over 22 years and national average wheat yield.

Parameters	No. of observations	Coefficient	SE of constant	T statistics	*P* value	Regression error (mean square)
Intercept	22	2.12470	0.0817	26.01	0.0000	0.03325
Quantity of CS	22	0.22214	0.0005	4.98	0.0001	0.8235

SE = significant error.

3.5 Use of Wheat CS and National Average Wheat Productivity in Pakistan

Findings revealed that quantity of wheat CS used over 22 years could only explain about 53% of variation (adjusted r^2 = 0.53) on average national wheat productivity ($P < 0.0001$) in a situation, when the use of CS increased more than five folds from around 78,000 tons in 1994 to over 408,000 tons in 2015 (Fig. 2, Table 5). The amount of CS used did contribute to increasing the average national wheat productivity, although the proportion of this increase was small, which was also shown by the slope of regression of 0.0005 (Fig. 2). This is because several other factors influence the average wheat yield, not just the amount of CS used. More importantly, it is likely that old wheat varieties may have dominated CS supply that did not increase productivity as also demonstrated in this research. The trend line based on the predicted values from the regression equation is $Y = 2.1247 + 0.0021 \times CS$, with $n = 22$.

4. Conclusions and Recommendations

It can be conclude that growing new high yielding, disease resistant wheat varieties using CS is the best choice for the farmers to get the highest grain yield and highest marginal returns. This should form the main scientific and technical message for the popularization of new varieties that will ultimately contribute to fast tracking replacement of low yielding old obsolete varieties by new ones. Scientific knowledge generated in this research supports the use of FSS of new high yielding varieties (for two to three years) as the next best option considering its built-in genetic traits of economic importance and recent genetic gain. Use of CS of old and obsolete varieties is not advisable as neither it gave higher grain yield nor higher marginal return over FSS of new varieties in this research. Creating knowledge and demand for new high yielding varieties quickly after their release is vital for varietal popularization. Alternate flexible system of having access of farmers to quality seeds of new wheat varieties will be a practical means to improve wheat productivity and enhance food security at the household level.

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