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RESEARCH ARTICLE

Comparative studies on some yield contributing traits of wheat sown in binary mixtures

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Abstract **Cultivar mixtures have been suggested as ways to increase crop productivity. This field study was conducted to investigate the competition among five cultivated varieties of wheat (*Triticum aestivum* L.) for the traits like plant height, flag leaf area, fertile tillers per plant, spike length, spikelets per spike, spike density, grain weight per spike, and seed index in relation to competition with yield per plant. It was observed that cultivar mixtures ought to be more productive than corresponding pure stands. Four binary combinations of Seher2006-Kohistan97, Farid2006-SH2002, SH2002-Shahkar95, and SH2002-Kohistan97 were superior in performance, showing land equivalent ratio (LER) values greater than one for plant height, fertile tillers per plant, spike density, grain weight per spike, and grain yield per plant. It was observed that the performance of binary mixtures was mainly due to the increased average performance in spike density, grain weight per spike, and grain yield per plant. The competitive ability of wheat varieties in mixtures was independent of each other for the respective traits, which lead to cumulative effects for the increased performance within the associates in mixtures.**

Keywords wheat, binary mixtures, land equivalent ratio (LER), grain yield

Introduction

Being a staple diet, wheat is the most important crop in Pakistan and contributes 13.1% to the value added in agriculture and 2.8% to GDP. It is cultivated with an area of 9.0 Mha, showing an increase of 5.9% over the area of 8.3 Mha in 2009. The production of wheat crop is provisionally estimated at 23.4 million tons, with 11.7% more than that in 2009 (Economic Survey of Pakistan, 2009). As the demand of wheat in the country is higher than the achieved production, the Pakistan government imported 2.5 million tons of wheat in 2008. To fill the gap between demand and production is a big challenge for agriculturists. This challenge could be achieved by exploring the level of genetic diversity in crop germplasm and its exploitation for breeding.

High crop yield is a principal objective of modern agriculture. It has been suggested that cultivar mixtures are the pathway to achieve high crop productivity. Cultivar blending is a good strategy to stabilize yield, agronomic performance, and end-use quality (Lee et al., 2006). Mixtures can work in commercial and modern agriculture (Bowden et al., 2001). Variety mixtures have been studied primarily for increasing yields and disease control (Mundt, 2002). Breeding should aim at improving yield stability and product quality, and better yield stability can be realized by increasing within-crop diversity using the mixtures of conventionally bred varieties or crop populations. Finckh et al. (2000) studied cereal cultivar and species mixtures and reported that genetic diversity is a way to stabilize yield using the crop self-regulation potential. Variety mixtures offer a fast method to exploit all the benefits of modern research and agronomic advances and the biodiversity provides assurance against unforeseen environmental effects. A variety mixture is an approach to building this protection into agricultural practices rather than keeping it in store for use in the event of disaster. They also offer the opportunity to reduce inputs, which can increase profitability and lower risk in a well-designed program (Newton et al., 1998) as a quicker and cheaper way to formulate and modify than multilines. When assessing

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the productivity of mixture of oats (*Avena sativa*) and wheat (*Triticum aestivum*), Sobkowicz and Tendziagolska (2005) showed partial complementarity in the use of limited resources by the species mixtures. Cultivar mixtures enable to contribute not only to the diversification of resistance genes but also to the combination of other mutually complementary characteristics not present in single host genotypes, which is particularly effective in cereal production. Tratwal et al. (2007) studied the impact of four different barley varieties by selecting two and three component mixtures. He observed 1%–15% yield increase in mixtures compared to pure stands and suggested that winter barley variety mixtures could construct an alternative way of growing winter barley, especially in low-input and ecological agriculture. Gallandt et al. (2001) observed 1.5% higher yield of mixtures than the mean yield of their pure line cultivar components, suggesting that mixtures could be formulated to meet the specific production requirements. Cowger and Weisz (2008) and Swanston et al. (2005) also found mixtures that significantly out-yielded their pure line components.

The main objective of our study was to test the performance of some existing wheat varieties in both pure stands and mixtures in order to develop some general recommendations for blending wheat varieties to boost up wheat production in Pakistan under uncertain environmental situations.

Materials and methods

The field experiment was conducted by growing five different cultivated varieties of wheat (*Triticum aestivum* L.) namely, Seher2006, Farid2006, SH2002, Kohistan97, and Shahkar95 in the wheat research area of the Department of Plant Breeding and Genetics, University of Agriculture, Faisalabad, in a binary mixture fashion to evaluate the genotypes on the basis of their performance as solo crops and biblends. The experiment was laid out in a randomized complete block design with three replications. Each replication consisted of 15 plots, and in each plot, there were ten biblends and five uniblends. Interrow and interplant distances were kept uniform with the help of a template, which was a square board of 1 m^2 area with 49 holes at 6 inches length. Each path between replications was kept at 1 m apart; seeds of component varieties of each binary mixture were sown in inter and intra row holes in an alternating fashion, i.e., three rows for one variety (21 holes) and four rows for other varieties (28 holes) at 2–3 inches depth. Two seeds per hole were sown to ensure full crop stand. After germination, seedlings were thinned to one plant per hole. From each replication, ten guarded plants of each plot were selected randomly, and data were recorded on the morphological traits, such as plant height, flag leaf area, fertile tillers per plant, spike length, spikelets per spike, spike density, grain weight per spike, seed index, and grain yield per plant.

Statistical analysis was carried using common analysis of variance (Steel et al., 1997). The least significant differences were calculated by using Duncan's Multiple Range test. Land Equivalent Ratios were calculated by using the concept of relative yield totals (RYT) of DeWit and Den Bergh (1965) to compare the characteristics of varieties in pure stands as well as in different 1:1 mixtures.

Results and discussion

The results revealed that some varieties in binary mixtures were more stable than the pure ones by yield, and its components and the varieties differed significantly from each other for all the morphological traits (Table 1), indicating that, among the pure lines or unitary varieties, Seher2006 was the tallest cultivar with the highest mean plant height value (95.21 cm), and the shortest cultivar was Farid2006, which was the most suitable cultivar with the smallest mean plant height value (82.36 cm) as a desirable short stature plant. Among the binary mixtures, Seher2006-SH2002, Seher2006-Shahkar95, Farid2006-Kohistan97, and SH2002-Shahkar95 showed decreased height as compared to the average performance when observed in pure stands. It was revealed that in pure stands, flag leaf area ranged from 23.82 cm^2 to 30.64 cm^2. Eight out of ten binary mixtures exhibited a negative response showing a reduction in flag leaf area from 2.12% to 19.03% over their midparents. Only two combinations named as Seher2006 with Kohistan97 (3.08%) and Farid2006 with Shahkar95 (1.53%) produced more flag leaf area than their midparents (Table 2). Differential behavior was observed by the genotypes in mixed stand for flag leaf area. The present findings were in accordance with those of Cousens et al. (1991) who indicated different responses of the genotypes in mixtures for plant height and flag leaf area.

With regard to the number of fertile tillers per plant, significant differences were found among the treatment means, which ranged from 6.56 to 8.03 in pure culture. The maximum tillers were found in Shahkar95 (8.03), while the

Table 1 Analysis of variance for some important yield contributing traits of wheat

Source of variation	*DF*	Plant height (cm)	Flag leaf area (cm^2)	Tillers per plant	Spike length (cm)	Spikelets per spike	Spike density	Grain weight per spike (g)	Seed index (g)	Grain yield per plant
Replications	2	21.1*	26.93*	0.003	0.07	3.16*	0.03*	0.12*	0.08*	1.8
Varieties/biblends	24	54.1*	16.57*	2.11*	0.82*	2.53*	0.04*	0.26*	0.59*	54.8*
Error	48	13.1	6.73	1.33	0.62	2.02	0.01	0.03	0.03	2.5

Note: * means significant at 5% level.

Table 2 Percent (%) increase or decrease of genotypes over the midparents and LER values (Parenthesis) of different binary mixtures of wheat

Genotype combinations	Plant height (cm)	Flag leaf area (cm^2)	Tillers per plant	Spike length (cm)	Spikelets per spike	Spike density	Grain weight per spike (g)	Seed index (g)	Grain yield per plant (g)
Seher2006-Farid2006	4.02	−5.29	−1.40	−3.66	−0.86	3.64	1.20	−9.73	1.43
	(1.04)	(0.95)	(0.99)	(0.96)	(0.99)	(1.04)	(1.03)	(0.89)	(1.03)
Seher2006-SH2002	−4.18	−19.03	1.48	−4.55	−5.26	0.64	5.18	−5.45	0.62
	(0.96)	(0.81)	(1.01)	(0.95)	(0.95)	(1.01)	(1.06)	(0.94)	(1.01)
Seher2006-Kohistan97	1.46	3.08	5.53	−0.55	0.49	1.26	−2.11	−8.22	1.91
	(1.01)	(1.03)	(1.05)	(0.99)	(1.01)	(1.01)	(0.98)	(0.92)	(1.02)
Seher2006-Shahkar95	−0.66	−9.43	−0.89	0.28	−3.45	−3.66	−1.42	0.54	4.47
	(0.99)	(0.91)	(1.01)	(1.00)	(0.97)	(0.97)	(0.99)	(0.99)	(1.05)
Farid2006-SH 2002	0.79	−7.35	1.43	−5.70	−4.84	1.26	1.58	1.23	6.25
	(1.01)	(0.93)	(1.02)	(0.94)	(0.95)	(1.01)	(1.02)	(1.02)	(1.06)
Farid2006-Kohistan97	−0.33	−5.39	7.77	−4.53	−2.62	1.85	−2.92	−2.30	4.56
	(0.99)	(0.95)	(1.08)	(0.95)	(0.97)	(1.02)	(0.96)	(0.98)	(1.05)
Farid2006-Shahkar95	2.91	1.53	−6.42	−3.01	−3.95	−0.60	2.94	−1.62	1.33
	(1.03)	(1.02)	(0.94)	(0.97)	(0.96)	(0.99)	(1.03)	(0.99)	(1.01)
SH 2002-Kohistan97	0.78	−4.56	12.64	1.64	−0.99	−2.59	2.48	−5.56	1.52
	(1.01)	(0.96)	(1.13)	(1.02)	(0.99)	(0.98)	(1.03)	(0.95)	(1.01)
SH2002-Shahkar95	−0.44	−7.29	0.00	0.71	2.49	3.79	0.25	−1.64	7.59
	(0.99)	(0.94)	(1.01)	(1.01)	(1.02)	(1.03)	(1.01)	(0.98)	(1.09)
Kohistan97-Shahkar95	1.29	−2.12	−4.29	−1.81	−1.96	0.00	1.10	−4.35	−0.60
	(1.01)	(0.98)	(0.96)	(0.98)	(0.98)	(1.00)	(1.01)	(0.96)	(0.99)

minimum tillers per plant were recorded in Seher2006. Fifty percent of binary mixtures displayed an increase in the tiller number over their midparents (Table 2). The LER values of 4 out of 10 biblends expressed reduced the tiller number per plant, while SH2002 with Shahkar95 showed no differential behavior in mixtures. The research of Treder et al. (2008a, 2008b) also indicated that the loss in the number of tillers per plant in wheat cultivar blends is evident. Spike length differed significantly in wheat biblends, as also proposed by Treder et al. (2008a). It was concluded that in monocultures, the longest spike with maximum length (13.11 cm) was produced by the genotype Kohistan97. On the other hand, Shahkar95 produced the shortest spikes, i.e., 12.29 cm. In varietal blends, only three binary mixtures named as Seher2006-Shahkar95, SH2002-Shahkar95, and SH2002-Kohistan97, achieved LER values greater than one and manifested 0.28%, 0.71%, and 1.64% increase in spike length over their respective mid-parents (Table 2), respectively. The genotype Farid2006 produced the plants with no improvement in spike length when grown in combination with any of the other associates and displayed the reduction in spike length ranging from 3.01% to 5.70%.

The genotypic combination of Shahkar95 with SH2002 showed the highest mean number of spikelets per spike (22.87) (Table 3), but SH2002 itself gave a declining response to its associate, with the poorer performer among the genotypes in pure stands. The response of almost 80% binary mixtures was negative, showing a reduction in the number of spikelets per spike ranging from 0.86% to 5.26% over their midparents. Although in pure stands, all the genotypes on the average gave more than 20 spikelets per spike; in biblends, they could not be composite for the same. The varieties Farid2006 and Shahkar95 achieved the maximum spike density of 1.66, while in 1∶1 biblend mixture, the response was negative with a value of 0.60 (Table 2). However, the varietal blends exhibiting negative response over their mid parent values for spike length and spikelets per spike displayed a positive response to spike density. It was observed from the statistical analysis that the grain weight per spike ranged from 2.43 g Seher2006 to 1.60 g Farid2006 when genotypes were sown in pure stands. Variations in genotypic behaviors for grain weight per spike were evident in binary mixtures with other genotypes. Seven out of 10 biblends indicated an LER value above one, and a positive sign toward increased yield per plant. Similar results were predicted by Cowger and Weisz (2008).

It was evident that from all the genotypes grown in monoculture that the cultivar Seher2006 showed the highest seed index (3.90 g), while the genotype with the lighter grain weight (2.67 g) was found to be Farid2006. The genotypes produced heavier grains in some mixtures and lighter in other combinations in comparison to their pure stands. However, eight out of 10 biblends did not exceed the LER value above one expressing a decreasing trend with respect to seed index ranging from 0.54% to 9.73%. Only two binary mixtures Seher2006-Shahkar95 and Farid2006-SH2002 showed a positive response and LER value equal to and more than one, respectively. Alexander et al. (1986) and Newton et al. (2008) have also revealed significant differences for seed index between pure stands and mixed stands in wheat.

Table 3 Statistical significance of some important yield contributing traits in pure and mixture stands of wheat

Varieties/ combinations	Plant height (cm)	Flag leaf area (cm^2)	Tillers per plant	Spike length (cm)	Spikelets per spike	Spike density	Grain weight per spike (g)	Seed index (g)	Grain yield per plant (g)
Seher2006	95.21 ghi	30.64f	6.56abc	12.47bcde	20.20abcd	1.62cdef	2.43ef	3.90m	41.74efgh
Farid2006	82.36ab	24.49abcd	7.70efg	12.93bcde	21.60de	1.66def	1.60ab	2.67bc	38.69cdef
SH2002	88.93cdef	29.70ef	6.96bcd	13.03bcde	19.70abcd	1.51bcd	2.20cdef	3.80kkm	40.67defgh
Kohistan97	89.83def	25.16abcd	7.36cd	13.11cde	20.40bcd	1.55bcde	1.83abcd	3.40efghi	32.54abc
Shahkar95	86.94abcde	23.82abc	8.03def	12.29bcd	20.40bcd	1.66def	1.80abc	3.50fghij	31.39ab
Seher2006-Farid2006	96.35 ghi	28.12def	6.60abc	12.35bcd	20.03abcd	1.62cdef	2.29cdef	363ijkl	43.11hi
Seher2006-SH2002	89.83def	24.15abc	6.36a	11.21a	18.77ab	1.68ef	2.20cdef	3.87lm	42.53 ghi
Seher2006-Kohistan97	96.97hi	30.95f	6.53ab	12.49bcde	20.30abcd	1.62cdef	2.37def	3.37efgh	41.43efgh
Seher2006-Shahkar95	96.66hi	26.78cde	7.93cdef	12.46bcde	19.90abcd	1.59bcde	2.40def	4.20n	43.00hi
Farid2006-Seher2006	87.33bcdef	24.10abc	7.46cde	12.12abc	21.40cde	1.78fg	1.79abc	2.30a	38.47bcde
Farid2006-SH2002	83.18ab	24.47abc	7.31cd	12.01abc	20.20abcd	1.68def	1.73abc	2.83c	40.15defg
Farid2006-Kohistan97	82.13a	21.73a	8.10efg	12.37bcd	20.37abcd	1.64def	1.40a	2.57b	39.87cdef
Farid2006-Shahkar95	76.01abcd	22.59ab	7.36cd	12.14abc	20.30abcd	1.67def	1.69ab	2.77bc	39.17cdef
SH2002-Seher2006	86.60abcde	24.71abcd	7.36cd	13.13cde	19.10abc	1.46ab	2.67f	3.40efghi	40.39defg
SH2002-Farid2006	89.46def	25.73bcd	7.56cde	12.47bcde	19.13abc	1.53bcde	2.13cde	3.73jklm	44.17i
SH2002-Kohistan97	89.01cdef	26.08bcd	8.10efg	13.31de	19.53abc	1.46abc	2.14cde	3.33efg	41.77fghi
SH2002-Shahkar95	88.96cdef	25.32abcd	8.13fg	13.52e	18.37a	1.35a	2.11cde	3.57 ghijk	40.53defg
Kohistan97-Seher 2006	91.39efg	26.57cde	8.16 g	12.95bcde	20.53bcd	1.58bcde	1.80abc	3.33efg	34.27bcd
Kohistan97-Farid2006	89.49def	25.26abcd	8.13fg	12.49bcde	20.66bcd	1.65def	1.93bcd	3.37efgh	34.61bcd
Kohistan97-SH2002	92.14fgh	26.28cde	8.03def	13.26de	20.23abcd	1.52bcde	1.99bcd	3.47efghi	32.55abc
Kohistan97-Shahkar95	92.32fgh	23.65abc	8.20 g	12.90bcde	20.10abcd	1.56bcde	1.97bcd	3.53 ghij	31.51ab
Shahkar95-Seher2006	84.28abc	22.54ab	6.53ab	12.37bc	19.33abc	1.57bcde	1.77abc	3.23de	33.40abc
Shahkar95-Farid2006	88.21cdef	26.46cde	7.36cd	12.32bcd	20.03abcd	1.62cdef	1.81abcd	3.30ef	30.74a
Shahkar95-SH2002	86.12abcd	24.29abc	6.86bcd	11.98ab	22.87e	1.90 g	1.90bcd	3.60hijk	35.83bcde
Shahkar95-Kohistan97	86.73abcde	24.28abc	6.53ab	12.04abc	19.90abcd	1.65def	1.70abc	3.07d	30.95a

Note: Letters represent the DMR test rankings of the means of each trait. Letter a represent the lowest and letter i the highest value in the table.

The highest yielding cultivar was Seher2006, obtaining 41.74 g grain yield per plant, while Shahkar95 with 30.30 g grain yield per plant was found to be the lowest yielding variety when the genotypes were grown in a uniblend fashion (Table 2). A perusal of Table 3 displayed that except one mixture, all the other genotype mixtures showed an LER value above one and, thus, exhibited the yield advantage of the genotypes ranging from 7.59% to 0.62% over their respective midparents. A significance performance was seen by the cultivar SH2002, which did not only give the maximum wheat yield in pure stand at the second position but also manifested a remarkable gain of 7.59% and 6.25% in binary mixtures with Shahkar95 and Farid2006, respectively. These observations are in accordance with those of Gallandt et al. (2001), Lee et al. (2006), and Treder et al. (2008a, 2008b).

Conclusion

The binary mixture of Farid2006 with SH 2002 proved to be the best associates for traits like plant height, tillers per plant, spike density, grain weight per spike, seed index, and grain yield. While, Seher2006 with Kohistan97 and SH2002 with Shahkar95 showed increased grain yield due to compensation effects among traits like tillers per plant, spikelets per spike, spike density, and grain weight per spike. The following experiment indicated a positive response that varietal blends have a potential as a means of increasing crop yield in comparison to the yield of their individual pure line components. It was further concluded that varietal blends can ensure genetic diversification with an advantage that they can be grown to increase yield per unit area. They can reduce and compensate the yield losses caused due to various biotic and abiotic factors of environment, i.e., diseases, late sowing, drought, etc. In the present study, it was observed that the competitive ability of wheat genotypes was independent of the action produced by the other member in mixtures for the respective traits, which leads to a cumulative effect to increase the performance within the associates in mixtures.

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