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GENETIC EXPRESSION OF YELLOW RUST RESISTANCE, YIELD AND YIELD RELATED TRAITS IN WHEAT USING GRIFFING'S COMBINING ABILITY ANALYSIS

KHILWAT AFRIDI[1,2], NAQIB ULLAH KHAN[1*], FIDA MOHAMMAD[1], SHAHID ULLAH KHAN[3], SAFDAR HUSSAIN SHAH[3] AND SYED JAWAD AHMAD SHAH[4]

[1]*Department of Plant Breeding and Genetics, The University of Agriculture, Peshawar, Pakistan*
[2]*Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera - Pakistan*
[3]*Institute of Biotechnology and Genetic Engineering (IBGE), The University of Agriculture, Peshawar, Pakistan*
[4]*Nuclear Institute for Food and Agriculture (NIFA), Peshawar, Pakistan*
[*]*Corresponding author's email: nukmarwat@yahoo.com*

Abstract

Knowledge of traits inheritance is a prerequisite for any plant breeding program. Wheat cultivars like Pirsabak-85, Khyber-87, Saleem-2000, Pirsabak-04, Pirsabak-05 and Shahkar-13 were crossed in 6 × 6 half diallel fashion during 2010-11 at the Cereal Crops Research Institute (CCRI), Pirsabak - Nowshera, Pakistan. The F_1 and F_2 half diallel hybrids in comparison with parental genotypes were studied during 2011-12 and 2012-13, respectively. The aim of the present work was to explore the genetic basis of yellow rust (*Puccinia striiformis* West. f. sp. *tritici*) resistance, flag leaf area, 1000-grain weight and grain yield in F_1 and F_2 wheat hybrids through Griffing's combining ability approach. Significant ($p\leq0.01$) differences were observed among the genotypes for all the traits. Mean squares due to general combining ability (GCA) and specific combining ability (SCA) were significant ($p\leq0.01$) for majority of the traits in both the generations. Genetic components of variances due to GCA and SCA revealed that SCA variances excelled the GCA for majority of the traits, thus non-additive type of gene action controlled the inheritance of such traits. However, flag leaf area and 1000-grain weight in F_1 generation showed preponderance of GCA variances and revealed additive type of gene action advocating those traits. Based on GCA effects, Pirsabak-05 was considered as the best general combiner for rust resistance and yield traits in F_1 generation. However, in F_2 generation, cultivar Shahkar-13 appeared to be the best general combiner for rust resistance and grain yield. The F_1 hybrid Pirsabak-85 × Pirsabak-04 and F_2 population Pirsabak-05 × Shahkar-13 performed better for majority of the traits. Therefore, these promising populations need to be further exploited for yellow rust resistance and grain yield in future breeding programmes.

Key words: Combining ability, GCA and SCA effects, Additive and non-additive gene action, Yellow rust resistance, Grain yield, *Triticum aestivum* L.

Introduction

Wheat is the leading food grain of Pakistan and being the staple diet of the people and occupies a central position in agricultural policies. Wheat contributes 10.3% to the value addition in agriculture and 2.2% to GDP (Anon., 2015). Pakistan is the 4th largest producer of wheat in Asia and stands 11th in world production.

Climate change increased the risk of food security for some vulnerable group of crops like wheat, rice and maize. In current situation of climatic change, major limitations in wheat production are drought, heat, and irregular rainfall. Since last few years, frequency of rainfall increased during peak growing stage of wheat development which made micro as well as macro climate conducive for development of different diseases such as yellow rust, fussarium head blight, powdery mildew, black point and karnal bunt. Yellow rust (*Puccinia striformis* f. sp. *tritici* Westtend) mainly develops in cool and moist conditions (Gocmen *et al*., 2003). The distinguishing symptoms of this disease are yellow pustules (urediniospores) appear mostly on the leaves but in severe conditions, it can also be seen on the leaf sheaths, spikes, glumes and awns of the susceptible plants. The urediniospores are elongated and arranged in linear rows between veins of the leaf. The fungus produces linear rows of black teleospores late in the season (Chen *et al*., 2014). Several new wheat cultivars were released after the green revolution. However, development of new pathotypes of rust breakup the resistance and caused severe yield losses (Mateen & Khan, 2014). Chemical control is neither supported by the researcher nor suitable for food grains due to its health hazards. Therefore, the preferable and most economical approach is the deployment of genetic resistance to cope with the wheat rusts.

Grain yield is a complex character made up from interaction between yield components and environmental effects. To develop high yielding wheat cultivars, it is important to study the genetic make-up of diverse wheat lines, inheritance pattern of yield contributing traits and association of various traits with yield under existing environmental conditions. Flag leaf plays an important role in the emergence of the spikes and reproductive growth of the wheat (Ahmad *et al*., 2013). Positive correlation between flag leaf area and yield indicating that flag leaf area might be a useful parameter for selection of high yielding genotypes (Zeuli & Qualset, 1990). Grains with higher 1000-grain weight have better milling quality and ensure better emergence (Protic *et al*., 2007).

Combining ability is an effective technique for isolating the best combiners that may be used in crosses either to exploit heterosis or to accumulate fixable genes and obtain desirable segregates that helps to understand the genetic architecture of various characters. In previous studies, the GCA variances were higher than SCA variances for plant height, spike length, and grain yield in both the generations which revealed that inheritance of these traits was managed by additive type of gene action in different wheat populations (Verma *et al*., 2016). The SCA variances were higher than GCA variances for all the traits which indicated the predominance of non-additive (dominant, overdominance and epistasis) type of gene action in the inheritance of the yield traits in wheat (Mandal

& Madhuri, 2016; Saeed & Khalil, 2017) and barley (Patial *et al*., 2016). However, in some studies mean squares indicated that both additive and dominance genetic components were significant and important for inheritance of the majority of the traits in wheat (Jat *et al*., 2016; Kandil *et al*., 2016). These type of contradictions might be due to nature of the genotypes and the environment where studied. Such knowledge can enable the breeder to design effective strategy for development of the existing materials in future breeding program.

Therefore, the present research was planned with the objectives to study and evaluate the relative importance of general and specific combiners and the genetic components for resistance to yellow rust, flag leaf area, 1000-grain weight and grain yield in 6 × 6 F_1 and F_2 half diallel hybrids of wheat through combining ability analysis.

Materials and Methods

Breeding material and procedure: This study was conducted at Cereal Crops Research Institute (CCRI), Pirsabak-Nowshera, Pakistan during three consecutive growing seasons viz., 2010-11, 2011-12 and 2012-13. The genetic material consisted of six bread wheat cultivars including Pirsabak-85, Pirsabak-04, Pirsabak-05, Shahkar-13, Saleem-2000 and Khyber-87, representing a wide range of diversity for rust resistance, earliness and yield traits. All the six genotypes were crossed in a half diallel fashion to produce 15 F_1 hybrids during 2010-11. Parental genotypes and their F_1 hybrids were sown during 2011-2012 while parents and their F_2 populations were grown during 2012-2013 in a randomized complete block design (RCBD) with two and three replications, respectively. Similarly, recommended and same cultural practices and inputs including land preparation, sowing, weed control, fertilizer application, and irrigation were applied to all the wheat genotypes and experiments to avoid the field variations.

Measurement of traits

Yellow rust scoring: Wheat cultivar Morocco (highly susceptible for all rusts) was sown around the experimental materials in two rows to create inoculum pressure. The yellow rust inoculum was collected from cultivar Morocco and then the urediospores suspension was prepared in sterile distilled water with 2-3 drops of tween-20 (Shah *et al*., 2010). Parental cultivars, F_1, F_2 populations and spreader lines were inoculated uniformly at booting stage in the evening by spraying a suspension of 0.1 g spore in 1-1 water by using hand sprayer. The yellow rust data was recorded following Cobb Scale (Peterson *et al.*, 1948; Stavely, 1985; Ali *et al.*, 2014). The host reaction (HR) types in order of Immune (I), traces (T), resistance (R), resistance to moderately resistance (RMR), moderately resistant (MR), moderately resistant to moderately susceptible (M), moderately susceptible (MS), moderately susceptible to susceptible (MSS) and susceptible (S) were then converted into HR values through assigning values of 0.0, 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 0.9 and 1.0 for each host reaction, respectively (Roelfs *et al.*, 1992; Cheruiyot *et al.*, 2014).

Coefficient of infection (C.I.) = Severity × Value of host reaction

whereas; Severity (%): 0-100

In addition, data were also recorded for flag leaf area, 1000-grain weight and grain yield per plant on 10 randomly tagged plants in F_1 and 20 plants in F_2 populations and parental genotypes. Flag leaf area was measured at post anthesis according to following formula, developed by Francis *et al*. (1969).

Flag leaf area = Maximum width × length × 0.75

After manual threshing, a representative sample of 1000 grains was taken from each entry in each replication and weighed with the help of an electronic balance to record the data on 1000-grain weight. Grain yield per plant was recorded by weighing the grains of each genotype in each replication after threshing with single plant thresher.

Statistical analyses: Data were subjected to analysis of variance according to Steel *et al.* (1997). The genotypes means for each variable were further separated and compared by using the least significant difference (LSD) test at 5% level of probability (Hayter, 1986). Data were further analyzed through combining ability analysis as outlined by Griffing (1956) following Method-II, Model-I to assess the genetic variances due to GCA and SCA effects (Singh & Chaudhary, 1985). For various traits, the variances due to σ^2GCA and σ^2SCA and their ratios (σ^2GCA/σ^2SCA) were also calculated according to Singh & Chaudhary (1985).

Results

Highly significant ($p \leq 0.01$) differences were observed among F_1 and F_2 populations and their parental cultivars for most of the traits (Table 1). However, for flag leaf area the genotypic differences were merely significant ($p \leq 0.05$). Results revealed that these populations have greater genetic variability and suitable for further biometrical study through combining ability analysis. Results about resistance to yellow rust and yield traits for various populations are presented as follows.

Yellow rust resistance: The yellow rust resistance was estimated through average co-efficient of infection (ACI). The ACI varied from 0.00 to 20.00 among parental cultivars, and 0.00 to 3.84 among F_1 hybrids (Table 2). Minimum ACI (0.00) was observed for nine genotypes (including three parental cultivars i.e., Pirsabak-04, Pirsabak-05 and Saleem-2000, and their six F_1 hybrids (Pirsabak-85 × Pirsabak-04, Pirsabak-85 × Pirsabak-05, Pirsabak-04× Pirsabak-05, Pirsabak-05 × Shahkar-13, Shahkar-13 × Saleem-2000 and Shahkar-13 × Khyber-87). However, these genotypes were at par in resistance to yellow rust with six other genotypes (one parental cultivar and five F_1 hybrids) ranging from 0.03 to 0.43. Maximum ACI was recorded for cultivar Pirsabak-85 (20.00). In F_2 generation, the ACI varied from 0.00 to 25.97 among parental cultivars, and 0.58 to 15.66 among F_2 populations (Table 2). Minimum and at par ACI was recorded for two cultivars Pirsabak-05 (0.00), Shahkar-13 (0.02) and three F_2 populations i.e. Pirsabak-05 × Shahkar-13 (0.58), Shahkar-13 × Saleem-2000 (2.58) and Shahkar-13 × Khyber-87 (2.74). However, maximum severity and ACI was noted for cultivar Pirsabak-85 (25.97) and the said genotype was found highly susceptible as compared to all other cultivars and their F_1 and F_2 populations.

Table 1. Mean squares for various traits in 6 × 6 F_1 and F_2 half diallel crosses of wheat.

Variables	F_1 / F_2	Mean squares					CV %
		Genotypes	Parents	F_1 / F_2	Parents vs. F_1 / F_2	Error	
D.F.	F_1	20	5	14	1	20	
	F_2	20	5	14	1	40	
Yellow rust resistance	F_1	45.09**	140.33**	2.26**	168.52**	0.0804	15.13
	F_2	155.77**	379.11**	58.01**	405.10**	2.92	16.96
Flag leaf area	F_1	21.74*	22.67*	19.97*	41.77*	7.86	7.9
	F_2	27.97**	33.59**	14.47**	188.97**	1.46	3.61
1000-grain weight	F_1	5.01**	7.88**	4.32**	0.4^{NS}	1.07	2.61
	F_2	98.34**	193.95**	61.24**	139.83**	8.03	7.69
Grain yield plant^{-1}	F_1	40.29**	51.95**	27.53**	160.7**	8.32	9.2
	F_2	76.98**	140.50**	46.78**	182.11**	13.62	15.31

*, ** = Significant at $p \leq 0.05$ and $p \leq 0.01$, NS = Non-significant

Table 2. Mean performance of 6 × 6 F_1 and F_2 half diallel crosses for yellow rust resistance and flag leaf area.

Parental genotypes, F_1 & F_2 populations	Yellow rust resistance		Flag leaf area (cm^2)	
	F_1	F_2	F_1	F_2
Pirsabak-85	20.00	25.97	33.61	30.03
Pirsabak-04	0.00	18.91	33.17	31.08
Pirsabak-05	0.00	0.00	40.44	35.70
Shahkar-13	0.09	0.02	33.18	28.61
Saleem-2000	0.00	21.46	30.59	26.14
Khyber-87	10.17	18.19	32.55	32.98
Pirsabak-85 × Pirsabak-04	0.00	9.96	36.51	35.33
Pirsabak-85 × Pirsabak-05	0.00	11.70	37.83	34.79
Pirsabak-85 × shahkar-13	0.03	6.65	36.75	33.63
Pirsabak-85 ×Saleem-2000	0.15	15.49	33.63	32.08
Pirsabak-85 × Khyber-87	3.84	10.17	32.91	36.92
Pirsabak-04× Pirsabak-05	0.00	9.75	37.23	36.62
Pirsabak-04× Shahkar-13	0.17	6.35	32.58	33.42
Pirsabak-04×Saleem-2000	0.43	15.66	33.70	30.78
Pirsabak-04× Khyber-87	1.00	10.81	32.65	35.95
Pirsabak-05 × Shahkar-13	0.00	0.58	40.56	37.48
Pirsabak-05 ×Saleem-2000	0.27	10.47	41.60	33.53
Pirsabak-05 × Khyber-87	1.87	8.35	41.75	35.35
Shahkar-13 × Saleem-2000	0.00	2.58	34.51	31.44
Shahkar-13 × Khyber-87	0.00	2.74	35.52	37.97
Saleem-2000 × Khyber-87	1.37	5.93	34.20	33.59
$LSD_{0.05}$	**0.59**	**2.82**	**5.84**	**1.99**

Flag leaf area: Flag leaf area varied from 30.59 to 40.44 cm^2 and 32.59 to 41.75 cm^2 among parental cultivars and F_1 hybrids, respectively (Table 2). In F_1 generation, F_1 hybrids such as Pirsabak-05 × Khyber-87 (41.75 cm^2) and Pirsabak-05 × Saleem-2000 (41.60 cm^2) revealed maximum and similar flag leaf area, and these genotypes were at par with six other genotypes (having one parental genotype and five F_1 hybrids) ranging from 36.51 to 40.57 cm^2. The lowest flag leaf area of 30.59 cm^2 was recorded for cultivar Saleem-2000 which was at par with twelve other genotypes (having four parental cultivars and eight F_1 hybrids) ranging from 32.55 to 35.52 cm^2. In F_2 generation, flag leaf area varied from 26.14 to 35.70 cm^2 and 30.78 to 37.97 cm^2 among parental cultivars and F_2 populations, respectively (Table 2). Maximum flag leaf area of 37.97 cm^2 was noted for F_2 population Shahkar-13 × Khyber-87, which was found at par with three other populations i.e., Pirsabak-04 × Pirsabak-05, Pirsabak-85 × Khyber-87 and Pirsabak-05 × Shahkar-13 ranging from 36.62 to 37.48 cm^2. Minimum flag leaf area was recorded for cultivar Saleem-2000 (26.14 cm^2) in F_2 generation.

1000-grain weight: The 1000-grain weight ranged from 37.00 to 43.00 g and 37.50 to 42.50 g among parental cultivars and F_1 hybrids, respectively (Table 3). In F_1 generation, highest 1000-grain weight was recorded for parental cultivar Pirsabak-05 (43.00 g) and it was found at par with four other F_1 hybrids viz., Pirsabak-04 × Shahkar-13, Pirsabak-04 × Pirsabak-05, Pirsabak-05 × Shahkar-13 and Pirsabak-85 × Pirsabak-05 ranging from 41.00 to 42.50 g. Minimum 1000-grain weight was recorded for Saleem-2000 (37.00 g) and it was at par with eight other genotypes (having two parental cultivars and six F_1 hybrids) ranging from 37.50 to 39.00 g. In F_2 generation, 1000-grain weight varied from 26.12 to 44.55 g and 27.25 to 45.97 g among parental cultivars and F_2 segregants (Table 3). Maximum 1000-grain weight was noted for F_2 population i.e., Pirsabak-05 × Shahkar-13 (45.97 g), and it was found equal in performance with three other genotypes i.e., Pirsabak-05 (44.55 g), Shahkar-13 (42.87 g) and Pirsabak-04 × Pirsabak-05 (41.83 g). Minimum and alike 1000-grain weight was noted for two parental genotypes i.e. Pirsabak-85 (26.12 g) and Saleem-2000 (26.23 g). These genotypes were found at par with two other F_2 populations i.e., Pirsabak-85 × Saleem-2000 (27.25 g) and Pirsabak-04 × Saleem-2000 (30.60 g).

Table 3. Mean performance of 6 × 6 F_1 and F_2 half diallel crosses for 1000-grain weight and grain yield per plant.

Parental genotypes, F_1 & F_2 populations	1000-grain weight (g)		Grain yield plant^{-1} (g)	
	F_1	F_2	F_1	F_2
Pirsabak-85	39.50	26.12	32.50	13.80
Pirsabak-04	39.00	31.15	32.50	16.45
Pirsabak-05	43.00	44.55	33.50	27.52
Shahkar-13	39.50	42.87	25.00	31.02
Saleem-2000	37.00	26.23	23.50	16.92
Khyber-87	38.50	36.05	22.50	22.78
Pirsabak-85 × Pirsabak-04	39.50	36.68	40.50	23.27
Pirsabak-85 × Pirsabak-05	42.50	37.82	38.50	24.88
Pirsabak-85 × Shahkar-13	40.00	39.07	30.00	25.30
Pirsabak-85× Saleem-2000	38.50	27.25	28.50	16.18
Pirsabak-85 × Khyber-87	38.50	40.35	27.50	29.50
Pirsabak-04× Pirsabak-05	41.00	41.83	32.10	27.95
Pirsabak-04× Shahkar-13	41.00	36.72	33.40	22.93
Pirsabak-04× Saleem-2000	37.50	30.60	33.00	19.30
Pirsabak-04× Khyber-87	38.00	34.63	28.20	22.73
Pirsabak-05 × Shahkar-13	41.50	45.97	35.10	31.23
Pirsabak-05× Saleem-2000	40.00	40.08	31.50	26.80
Pirsabak-05 × Khyber-87	40.50	36.62	32.00	25.08
Shahkar-13 × Saleem-2000	38.00	38.93	35.90	26.15
Shahkar-13 × Khyber-87	39.50	40.12	32.50	26.85
Saleem-2000 × Khyber-87	38.50	40.22	30.00	29.50
$LSD_{0.05}$	**2.15**	**4.67**	**6.01**	**6.09**

Grain yield per plant: In F_1 generation, grain yield per plant varied from 22.50 to 33.50 g and 27.50 to 40.50 g among parental cultivars and F_1 hybrids, respectively (Table 3). Maximum grain yield was observed in F_1 hybrid Pirsabak-85 × Pirsabak-04 (40.50 g) and it was found equal in performance with three other F_1 hybrids viz., Pirsabak-85 × Pirsabak-05 (38.50 g), Shahkar-13 × Saleem-2000 (35.90 g) and Pirsabak-05 × Shahkar-13 (35.10 g). Minimum and at par grain yield was noted for two cultivars Khyber-87 (22.50 g) and Saleem-2000 (23.50 g) and these parental cultivars were found at par with four other genotypes ranging from 25.00 g to 28.50 g. In F_2 generation, grain yield varied from 13.80 to 31.00 g among parental cultivars and 16.18 to 31.22 g among F_2 populations (Table 3). Maximum grain yield was observed for F_2 population Pirsabak-05 × Shahkar-13 (31.2 g), and it was found equal to nine other genotypes (with two parental cultivars and seven F_2 populations) ranging from 25.3 to 31.0 g. Minimum grain yield per plant was observed for three genotypes viz., Pirsabak-85 (13.80 g), Pirsabak-85 × Saleem-2000 (16.18 g) and Pirsabak-04 (16.45 g). These genotypes were also found at par with two other genotypes i.e. Saleem-2000 (16.92 g) and Pirsabak-04 × Saleem-2000 (19.30 g).

Combining ability analysis: Combining ability analysis was used to estimate the GCA effects of the parental genotypes, and SCA effects of the specific cross combinations in F_1 and F_2 populations, which could guide the breeder in selecting the desirable parental genotypes and their F_1 and F_2 populations. Variance due to GCA (σ^2GCA) is a measure of additive gene action, while variance due to SCA (σ^2SCA) is measure of non-additive gene action. Combining ability studies showed that mean squares due to GCA and SCA were significant ($p \leq 0.01$) for majority of the traits in F_1 and F_2 populations and their parental genotypes. However, for flag leaf area and 1000-grain weight, the SCA mean squares were nonsignificant in F_1 generation (Table 4).

For yellow rust resistance, the GCA effects ranged from -1.59 to 3.86 and -6.45 to 4.42 in F_1 and F_2 generations, respectively (Table 5). For yellow rust resistance, four parental genotypes were observed with negative GCA effects while two genotypes were recorded with positive GCA effects in F_1 generation. In F_2 generation, two parental cultivars were observed with negative while four other genotypes with positive GCA effects. Among parental cultivars, maximum negative and significant GCA effects for yellow rust resistance were recorded for cultivar Shahkar-13 (-1.59) followed by Pirsabak-04 (-1.44) and Pirsabak-05 (-1.37) in F_1 generation. In F_2 generation, cultivar Shahkar-13 (-6.45) was again the leading genotype by having maximum negative and significant GCA effects followed by Pirsabak-05 (-3.72) for yellow rust resistance. Therefore, cultivar Shakar-13 proved to be the best general combiner by having maximum resistance to yellow rust in both the generations.

The SCA effects for yellow rust resistance ranged from -4.36 to 1.36 and -7.44 to 1.51 in F_1 and F_2 generations, respectively (Table 6). For yellow rust resistance, nine F_1 and eight F_2 populations revealed negative SCA effects while six F_1s and seven F_2s showed positive SCA effects. Among F_1 hybrids, Pirsabak-85 × Pirsabak-05 (-4.36) was the best specific combination whereas in F_2 populations, Saleem-2000 × Khyber-87 (-7.44) was the best specific population for yellow rust resistance by having maximum negative and significant SCA effects. Parental genotypes with positive × negative GCA effects were involved to produce promising F_1 hybrid i.e., Pirsabak-85 × Pirsabak-05 with maximum desirable negative SCA effects. Parental cultivars of cross combination Saleem-2000 (*Yr*-18) × Khyber-87 (*Yr*-9+) were having positive × positive GCA effects to produce F_2 populations with maximum negative and desirable SCA effects for yellow rust resistance. Variances due to σ^2GCA were less than σ^2SCA and ratios due to σ^2GCA/σ^2SCA were also less than unity, presenting predominance of non-additive gene effect for yellow rust resistance in both the generations (Table 4).

Table 4. Mean squares of general and specific combing ability for various traits in 6 × 6 F_1 and F_2 half diallel crosses in wheat.

Variables	F_1/F_2	Mean squares			Variance components		
		GCA	SCA	Error	Σ^2GCA	σ^2SCA	σ^2GCA/σ^2SCA
Yellow rust resistance	F_1	43.08**	15.70**	0.04	5.38	15.66	0.34
	F_2	142.67**	21.67**	0.97	17.72	20.69	0.86
Flag leaf area	F_1	30.65**	4.27^{NS}	3.93	3.34	0.34	9.75
	F_2	19.72**	5.86**	0.49	2.40	5.37	0.45
1000-grain weight	F_1	8.86**	0.39^{NS}	0.53	1.04	-0.14	-7.20
	F_2	90.35**	13.59**	2.68	10.96	10.92	1.00
Grain yield plant^{-1}	F_1	33.31**	15.76**	4.16	3.64	11.60	0.31
	F_2	60.68**	13.99**	4.54	7.02	9.45	0.74

*, ** = Significant at p≤0.05 and p≤0.01, NS = Non-significant

Table 5. General combing ability effects of parental genotypes for various traits in 6 × 6 F_1 and F_2 half diallel crosses in wheat.

Parental genotypes	F_1/F_2 generation	Yellow rust resistance	Flag leaf area	1000-grain weight	Grain yield plant^{-1}
Pirsabak-85	F_1	3.86**	-0.45	0.13	1.32
	F_2	4.42**	-0.21	-3.07**	-2.75**
Pirsabak-04	F_1	-1.44*	-1.19	-0.25	1.60**
	F_2	2.48**	-0.03	-1.90**	-2.45**
Pirsabak-05	F_1	-1.37**	3.92**	-1.81**	2.10**
	F_2	-3.72**	1.84**	4.18**	2.78**
Shakar-13	F_1	-1.59**	-0.28	0.25	-0.31
	F_2	-6.45**	-0.42	3.57**	3.22**
Saleem-2000	F_1	-1.36**	-1.21	-1.31**	-1.69*
	F_2	2.81**	-2.60**	-3.55**	-2.12**
Khyber-87	F_1	1.91**	-0.80	-0.63*	-3.03**
	F_2	0.48	1.41**	0.76*	1.32
S.E. (gj)	F_1	0.06	0.64	0.24	0.66
	F_2	0.32	0.23	0.53	0.69

*, ** = Significant at p≤0.05 and p≤0.01, NS = Non-significant, S.E. (gj) = Standard error

Table 6. Specific combing ability effects in 6 × 6 F_1 and F_2 half diallel crosses for various traits in wheat.

F_1 and F_2 populations	Yellow rust resistance		Flag leaf area		1000-grain Weight		Grain yield plant^{-1}	
	F_1	F_2	F_1	F_2	F_1	F_2	F_1	F_2
Pirsabak-85 × Pirsabak-04	-4.30**	-7.01**	2.65**	2.07**	0.05	4.80**	6.23**	4.37**
Pirsabak-85 × Pirsabak-05	-4.36**	0.92*	-1.13	-0.33	1.00**	-0.15	3.73**	0.74
Pirsabak-85 × Shahkar-13	-4.11**	-1.39**	1.98*	0.75*	0.05	1.71*	-2.36*	0.72
Pirsabak-85 × Saleem-2000	-4.22**	-1.82**	-0.2	1.39**	0.12	-2.98**	-2.48**	-3.05**
Pirsabak-85 × Khyber-87	-3.81**	-4.8**	-1.34	2.22**	-0.57	5.81**	-2.14*	6.83**
Pirsabak-04 × Pirsabak-05	0.94**	0.91*	-1.00	1.31**	-0.13	2.70**	-2.94**	3.52**
Pirsabak-04 × Shahkar-13	1.33**	0.25	-1.46	0.36	1.43**	-1.81**	0.77	-1.94*
Pirsabak-04 × Saleem-2000	1.36**	0.29	0.59	-0.09	-0.51	-0.80	1.74	-0.23
Pirsabak-04 × Khyber-87	-1.34**	-2.22**	-0.86	1.07**	-0.70*	-1.08	-1.72	-0.23
Pirsabak-05 × Shahkar-13	1.09**	0.67	1.42	2.56**	-0.13	1.36	1.97*	1.13
Pirsabak-05 × Saleem-2000	1.13**	1.29**	3.39**	0.79*	-0.07	2.60**	-0.26	2.03*
Pirsabak-05 × Khyber-87	-0.54**	1.51**	3.12**	-1.40**	-0.26	-5.18**	1.58	-3.12**
Shahkar-13 × Saleem-2000	1.08**	-3.86**	0.50	0.95**	-0.51*	2.06**	6.56**	0.94
Shahkar-13 × Khyber-87	-2.19**	-1.37**	1.09	3.48**	0.30	-1.07	4.49**	-1.79
Saleem-2000 × Khyber-87	-1.05**	-7.44**	0.70	1.28**	0.87*	6.16**	3.37**	6.20**
S.E. (ij)	0.08	0.42	0.84	0.29	0.31	0.69	0.86	0.90

*, ** = Significant at p≤0.05 and p≤0.01, NS = Non-significant, S.E. (ij) = Standard error

For flag leaf area, the GCA effects among parental cultivars ranged from -1.21 to 3.92 and -2.60 to 1.84 in F_1 and F_2 generations, respectively (Table 5). For flag leaf area, one parental cultivar in F_1 and two in F_2 generation showed positive GCA effects while five parental cultivars in F_1 and four in F_2 generation were observed with negative GCA effects. Among parental cultivars, for flag leaf area significant and maximum positive GCA effects were recorded for cultivar Pirsabak-05 (3.92, 1.84) in F_1 and F_2 generations, respectively and identified as best general combiner in both generations.

The SCA effects for flag leaf area ranged from -1.46 to 3.39 and -1.40 to 3.48 in F_1 and F_2 generations, respectively (Table 6). For flag leaf area, nine F_1s and twelve F_2s showed positive while six F_1 hybrids and three F_2 populations revealed negative SCA effects. Significant and maximum positive SCA effects were observed for cross combinations i.e. Pirsabak-05 × Saleem-2000 (3.39) and Shahkar-13 × Khyber-87 (3.48) in F_1 and F_2 generations, respectively and ranked as the best specific combinations for flag leaf area. In cross combination Pirsabak-05 × Saleem-2000 (3.39), the parental genotypes with high × low GCA effects were involved to produce F_1 hybrids with maximum SCA effects. However, low × high GCA parents were involved to produce F_2 population i.e., Shahkar-13 × Khyber-87 with highest positive SCA effects (3.48) for flag leaf area. Estimates of σ^2GCA were greater than σ^2SCA and ratio due to σ^2GCA/σ^2SCA was more than unity indicating additive type of gene action for flag leaf area in F_1 generation (Table 4). Variances due to GCA and SCA and ratio of σ^2GCA/σ^2SCA suggested non-additive gene effects for flag leaf area in F_2 generation.

For 1000-grain weight, the GCA effects for parental cultivars varied from -1.31 to 1.81 and -3.55 to 4.18 in F_1 and F_2 generations, respectively (Table 5). Three each parental genotypes showed positive and negative GCA effects for 1000-grain weight in both generations. Maximum positive and significant GCA effects (1.81, 4.18) were recorded for parental cultivar Pirsabak-05 in F_1 and F_2 generations, respectively and ranked as best general combiner for 1000-grain weight in both generations.

Specific combining ability effects for 1000-grain weight ranged from -0.70 to 1.43 among F_1 hybrids and -5.18 to 6.16 among F_2 populations (Table 6). Seven F_1 hybrids were noted with positive and eight with negative SCA effects. Eight F_2 populations were observed with positive and seven with negative SCA effects. The highest positive and significant SCA effects (1.43) were found for F_1 hybrid Pirsabak-04 × Shahkar-13 in F_1 generation. In F_2 generation, F_2 population Saleem-2000 × Khyber-87 revealed significant and maximum positive SCA effects (6.16). Parental cultivars with low × high GCA effects were involved to produce best specific combination i.e., Pirsabak-04 × Shahkar-13 for 1000-grain weight with maximum SCA effects in F_1 generation. Similarly, in F_2 generation, low × high GCA genotypes played an important role in production of best specific combination i.e., Saleem-2000 × Khyber-87 for 1000-grain weight. Variances due to σ^2GCA were greater than σ^2SCA and ratio due to σ^2GCA/σ^2SCA was also greater than one which suggested that 1000-grain weight was under influence of additive type of gene action in both the generations (Table 4).

For grain yield per plant, the GCA effects ranged from -3.03 to 2.10 and -2.75 to 3.22 in F_1 and F_2 generations, respectively (Table 5). Three each parental genotypes were having positive GCA effects in F_1 and F_2 generations, while with same pattern, three each parental varieties showed negative GCA effects in both generations. Among parental cultivars, for grain yield maximum positive and significant GCA effects (1.81, 4.18) were observed for cultivars Pirsabak-05 and Shahkar-13 in F_1 and F_2 generations, respectively which suggested being best general combiners for grain yield in both generations.

For grain yield, the SCA effects ranged from -2.94 to 6.56 and -3.12 to 6.83 in F_1 and F_2 generations, respectively (Table 6). Nine each F_1 and F_2 cross combinations revealed positive while six each F_1 and F_2 populations showed negative SCA effects for grain yield. Significant and highest positive SCA effects (6.56, 6.83) were recorded for Shahkar-13 × Saleem-2000 and Pirsabak-85 × Khyber-87 for grain yield per plant in F_1 and F_2 generations, respectively. The cross combination Shahkar-13 × Saleem-2000 was having parental genotypes with low × low GCA effects to produce F_1 hybrid with maximum SCA effects. However, parental cultivars of the cross combination Pirsabak-85 × Khyber-87 were low × high general combiners to produce F_2 population with maximum positive SCA effects for grain yield per plant. Variances due to σ^2GCA were lesser than σ^2SCA and ratios due to σ^2GCA/σ^2SCA were also less than unity indicating non-additive gene effects for grain yield per plant in both generations (Table 4).

Discussion

Genotypes revealed highly significant differences for yellow rust resistance, flag leaf area and yield traits. This indicated greater genetic variability among the genotypes for the studied traits which can be exploited for the development of high yielding wheat hybrids. Mean squares due to GCA and SCA were also highly significant which validated the diallel analysis in the said breeding material. Mean squares of the genotypes and due to GCA and SCA were found highly significant for all the traits in F_1 and F_2 wheat populations (Verma *et al*., 2016; Mandal & Madhuri, 2016; Saeed & Khalil, 2017; Kandil *et al*., 2016).

In both generations, cultivars Pirsabak-05 and Shahkar-13 showed more resistance to yellow rust with minimum ACI values while Pirsabak-85 with greater ACI values ranked as the most susceptible genotype among parental cultivars. Cultivars Saleem-2000 (*Yr18*) and Khyber-87 (*Yr 9+*) individually showed high susceptibility. However, their F_2 progeny (Saleem-2000 × Khyber-87) showed resistance to prevailing yellow rust races which might be due to accumulation of some resistance genes or combined effect of both parents with *Yr* genes. Majority of Pakistani bread wheat cultivars were protected against stripe rust by incorporating the *Yr* genes like, *YrA*, *Yr2*, *Yr4 Yr6*, *Yr7*, *Yr18*, *Yr9*, *Yr22* and *Yr27;* however, the genes i.e., *Yr6*, *Yr7* and *Yr9* are occurring more frequently either in combination with other *Yr* genes or alone (Qamar *et al*., 2011). The virulence for resistant genes i.e., *YrA*, *Yr2*, *Yr6*, *Yr7*, *Yr8*, *Yr9*, *Yr17*, *Yr27* and gene combinations was reported in Mexican wheat cultivars Opata (*Yr27 +Yr18*) and Super Kauz (*Yr9*, *Yr27* and *Yr18*) under natural conditions over four locations with variable environments (Bux *et al*., 2011, 2012). In F_2 populations, low ACI was mostly observed in genotypes having one of the resistant cultivars i.e., Pirsabak-05 and Shahkar-13 in their parentage.

Flag leaf area play a key role in yield of wheat during spike development, as flag leaf provide photosynthates for grain yield (Ahmad *et al*., 2013). Finding of this study revealed that genotypes with larger flag leaf area produced more grain yield in both generations. Positive correlation was reported between flag leaf area and yield, indicating that flag leaf area might be a useful parameter for selection of high yielding plants (Zeuli & Qualset, 1990). However, crosses among durum wheat genotypes showed that the size of flag leaf was not associated with grain yield (Grignac, 1974). Non-significant mean differences were observed for flag leaf area and grain yield among wheat cultivars (Malik *et al*., 2005; Rahim *et al*., 2006). Results revealed that the genotypes with maximum 1000-grain weight had high grain yield in both generations. Cultivar Pirsabak-05 in F_1 generation and cross combination Pirsabak-05 **×** Shahkar-13 in F_2 generation with maximum 1000-grain weight produced maximum grain yield. Similarly, grains with higher 1000-grain weight have better milling quality and ensure better emergence (Protic *et al*., 2007). Akram *et al*. (2008) also reported that grain yield was positively correlated with 1000-grain weight.

Results revealed that F_1 hybrid (Pirsabak-85 × Pirsabak-04), F_2 population (Pirsabak-05 × Shahkar-13) and cultivars (Pirsabak-2005, Shahkar-13) with highest grain yield were due to their better adaptability and resistance to biotic stress i.e., yellow rust. Past studies revealed that a cultivar grown in diverse environmental conditions had shown better adaptability with low degree of fluctuation in grain yield (Amin *et al*., 2005). Several researchers recorded significant differences among parental cultivars and F_1 hybrids for grain yield in bread wheat (Adel & Ali, 2013; Fellahi *et al*., 2013, 2015).

Parental cultivars of cross combination Saleem-2000 (*Yr*-18) × Khyber-87 (*Yr*-9+) were with positive × positive GCA effects to produce F_2 populations with maximum negative and desirable SCA effects for yellow rust resistance. Parental genotypes with high GCA effects produced hybrid with low SCA effects which might be due to the absence of complementation of the parent's genes (Kumari *et al*., 2015). Variances due to GCA were less than SCA and their ratios were also less than unity, presenting non-additive gene effect for yellow rust resistance in F_1 and F_2 populations. Past studies revealed that parental genotype (MV-17) with low GCA effects for latent period, infection type, pustule size and number of pustules was identified as suitable parent to be used in breeding programs for development of yellow rust resistance lines (Khodarahmi *et al*., 2009). Significant GCA and SCA effects were reported for four yellow rust resistance components (latent period, infection type, pustule density and size) in bread wheat and suggested additive and non-additive effects in genetic control of yellow rust resistance (Khodarahmi *et al*., 2014). Significant GCA and SCA effects suggested the involvement of additive and non-additive gene action for terminal yellow rust severity and area under disease progress curve (Kaur *et al*., 2003).

In cross combination Pirsabak-05 × Saleem-2000, parental genotypes with high × low GCA effects were involved in production of F_1 hybrids with maximum SCA effects for flag leaf area. However, low × high GCA parents were involved to produce F_2 population Shahkar-13 × Khyber-87 (3.48) with highest positive SCA effects for flag leaf area. F_1 hybrid with maximum SCA effects for flag leaf area were noted with high × low GCA parents in bread wheat (Dere, 2006). The crosses involving parents with high × medium, medium × medium and medium × low general combiners, indicated non-additive type of gene actions in specific cross combinations in wheat (Singh *et al*., 2012). Ratio due to GCA and SCA variances was more than unity indicating additive gene effect for flag leaf area in F_1 generation. However, in F_2 generation the said ratio was less than one showing non-additive gene effects for flag leaf area. Greater role of additive genes in genetic regulation of flag leaf area illustrated that genetic efficiency of selection was greater for increasing flag leaf area particularly in early generations in wheat (Golparvar, 2013). Parental cultivars with high GCA effects produced hybrids with low SCA effects which might be due to absence of complementary genes in parental genotypes (Kumari *et al*., 2015).

Parental cultivars with low × high GCA effects were involved to produce best specific combination i.e., Pirsabak-04 × Shahkar-13 with maximum SCA effects for 1000-grain weight in F_1 generation. Similarly, in F_2 generation, low × high general combiners played an important role in production of best specific combination i.e., Saleem-2000 × Khyber-87 for 1000-grain weight. The low × high and high × low GCA crosses, besides exhibiting the favorable additive GCA effects of the parental genotypes, complement the epistatic effects present in the crosses, which would finally result in higher SCA effects. Significant GCA and SCA effects were observed for 1000-grain weight and grain yield in wheat, and were seen to be initiated from genotypes having high × high, high × low, medium × low and low × low GCA effects (Kamaluddin *et al*., 2007). Present results revealed that ratios due to GCA and SCA variances were greater than one, which suggested that 1000-grain weight was controlled by additive type of gene action in both generations. Predominance of non-additive gene effects were observed for 1000-grain weight and other yield traits in wheat (Seboka *et al*., 2009; Majeed *et al*., 2011), however, Chandrashekhar & Kerketta (2004) reported additive type of gene action for yield traits in wheat.

The cross combination Shahkar-13 × Saleem-2000 was having parental genotypes with low × low GCA effects to produce F_1 hybrid with maximum SCA effects for grain yield. However, parental cultivars of the cross combination Pirsabak-85 × Khyber-87 were low × high general combiners to produce F_2 segregants with maximum positive SCA effects for grain yield. The F_1 hybrids demonstrating higher SCA effects for grain yield were observed to be derived from wheat genotypes having high × high, high × low, low × low and medium × low general combiners (Kamaluddin *et al*., 2007). Results further revealed that the ratios due to GCA and SCA variances were less than unity indicating non-additive gene effect for grain yield in both generations. Similarly, non-additive gene effects were exhibited for grain yield, suggesting possibility for improvement of this trait through transgressive segregates and heterosis breeding for developing genotypes with greater yield potential (Sanjeev *et al*., 2005). However, additive type of gene action was observed for grain yield in bread wheat genotypes (Arshad & Chowdry, 2002).

Conclusion

Significant (p≤0.01) differences were observed among the genotypes for all the traits. Mean squares due to general and specific combining ability were significant (p≤0.01) for majority of the traits in both generations. The SCA variances were greater than GCA for majority of the traits, and non-additive type of gene action controlled the inheritance of these traits in both generations. Based on GCA effects, cultivars Pirsabak-05 and Shahkar-13 were considered to be the best general combiners for yellow rust resistance and grain yield in F_1 and F_2 generations, respectively. The F_1 hybrid Pirsabak-85 × Pirsabak-04 and F_2 population Pirsabak-05 × Shahkar-13 performed better for majority of the traits which could be further exploited for improvement in yellow rust resistance and grain yield.

References

Adel, M.M. and E.A. Ali. 2013. Gene action and combing ability in a six parent diallel cross of wheat. *Asian J. Crop Sci*., 5(1): 14-23.

Ahmad, I., F. Muhammad and Aurangzeb. 2013. Breeding bread wheat for low phytic acid using full diallel crosses. *Sarhad J. Agric*., 29(1): 33-42.

Akram, Z., S.U. Ajmal, M. Munir and G. Shabir. 2008. Genetic determination of yield related attributes in bread wheat. *Sarhad J. Agric*., 24(3): 431-438.

Ali, S., M. Leconte, H. Rahman, M.S. Saqib, P. Gladieux, J. Enjalbert and C. De-Vallavieille-Pope. 2014. A high virulence and pathotype diversity of *Puccinia striiformis* f. sp. *tritici* at its centre of diversity, the Himalayan region of Pakistan. *European J. Plant Pathol*., 140: 275-290.

Amin, M., T. Mohammad, A.J. Khan, M. Irfaq, A. Ali and G.R. Tahir. 2005. Yield stability of spring wheat (*T. aestivum* L.) in the Khyber Pakhtunkhwa, Pakistan. *Songklanakarin J. Sci. Technol*., 27(6): 1147-1150.

Anonymous. 2015. Finance Division, Government of Pakistan, Islamabad, Pakistan pp. 03.

Arshad, M. and M.A. Chowdhry. 2002. Impact of environment on the combining ability of bread wheat genotypes. *Pakistan J. Biol. Sci*., 15: 1316-1320.

Bux, H, M. Ashraf, X.M. Chen and A.S. Mumtaz. 2011. Effective genes for resistance to stripe rust and virulence of *Puccinia striiformis* f. Sp. *tritici* in Pakistan. *Afr. J. Biotechnol*., 10(28): 5489-5495.

Bux, H., A. Rasheed, S.M. Mangrio, S.A. Abro, S.J.A. Shah, M. Ashraf and X. Chen. 2012. Comparative virulence and molecular diversity of stripe rust (*Puccinia striiformis* f. sp. *tritici*) collections from Pakistan and United States. *Int. J. Agric. Biol*., 14(6): 851-860.

Chandrashekhar, M. and V. Kerketta. 2004. Estimation of some genetic parameters under normal and late sown conditions in wheat (*T. aestivum* L.). *J. Res. Birsa Agric. Univ. India*, 16(1): 119-121.

Chen, W., C. Wellings, X. Chen, Z. Kang and T. Liu. 2014. Wheat stripe (yellow) rust caused by *Puccinia striiformis* f. sp. *tritici*. *Mol. Plant Pathol*., 15(5): 433-46.

Cheruiyot, D., P.P.O. Ojwang, P.N. Njau, P.F. Arama and G.K. Macharia. 2014. Genetic analysis of adult plant resistance to stem rust (*Puccinia graminis* f. sp. *tritici*) and yield in wheat (*T. aestivum* L.). *Acta Adv. Agric. Sci*., 2: 49-63.

Dere, S. 2006. Predicting of combining ability for length, width and area of flag leaf and grain yield per plant in bread wheat with respect to diallel analysis. *Ege Üniv. Ziraat Fak. Derg*., 43(1): 21-31.

Fellahi, Z.E.A., A. Hannachi and H. Bouzerzour. 2015. Partial diallel analysis of genetic behavior for several polygenic traits in bread wheat (*T. aestivum* L). *Int. J. Plant Biol. Res*., 3(3): 1042.

Fellahi, Z.E.A., A. Hannachi, H. Bouzerzour and A. Boutekrabt. 2013. Line × tester mating design analysis for grain yield and yield related traits in bread wheat (*T. aestivum* L.). *Int. J. Agron*., 2013:1-9.

Francis C.A., J.N. Rutger and A.F.E. Palmer. 1969. A rapid method for plant leaf area estimation in maize. *Crop Sci*., 9: 537-539.

Gocmen, B., S. Albustan, Z. Kaya, S. Keskin and V. Taskin. 2003. Response of 150 F_6 inbred durum wheat lines derived from Kunduru-1149 × Cham-1 cross to yellow rust (*P. striformis*). *Crop Prot*., 22: 787-793.

Golparvar, R.A. 2013. Genetic control and combining ability of flag leaf area and relative water content traits of bread wheat cultivars under drought stress condition. *Genetika*, 45(2): 351-360.

Griffing, B. 1956. Concept of general and specific combining ability in relation to diallel crossing system. *Aust. J. Biol*. 9: 463-493.

Grignac, P. 1974: Relations between yield, components of yield of durum wheat and certain morphological characters. In: (Ed.): Scarascia Mugnozza, G.T. *Proc. Symp. Genet. Breed Durum Wheat*, pp. 275-296.

Hayter, A.J. 1986. The maximum family-wise error rate of Fisher's least significant difference test. *J. Am. Stat. Assoc*., 81: 1001-1004.

Jat, B.S., B. Bharti, B.R. Ranwah and S. Khan. 2016. Combining ability studies for heat tolerance traits in bread wheat (*T. aestivum* L. em. Thell). *Electr. J. Plant Breed*., 7(4): 996-1001.

Kamaluddin, R.M. Singh, L.C. Parsad, M.Z. Abdin and A.K. Joshi. 2007. Combining ability analysis for grain filling duration and yield traits in spring wheat (*T. aestivum* L.). *Genet. Mol. Biol*., 30(2): 411-416.

Kandil, A.A., A.E. Sharief and H.S.M. Gomaa. 2016. Estimation of general and specific combining ability in bread wheat (*T. aestivum* L.). *Int. J. Agron. Agric. Res*., 8(2): 37-44.

Kaur, J., R.G. Saini and L. Kaur. 2003. Gene effects for partial stripe rust resistance in six bread wheat cultivars. *Cereal Res. Commun*., 31(1/2): 41-48.

Khodarahmi, M., F. Afshari and R.J. Kamali. 2009. Diallel analysis of Yellow Rust Resistance components in wheat genotypes. CIMMYT staff publications collection. pp. 154.

Khodarahmi, M., S.A. Mohammadi, M.R. Bihamta, E.M. Hervan and M.R.J. Kamali. 2014. Inheritance and combining ability of yellow rust resistance in some bread wheat commercial cultivars and advanced lines. *Seed Plant Imp. J*., 30(3): 531-544.

Kumari, J., H.K. Dikshit, B. Singh and D. Singh. 2015. Combining ability and character association of agronomic and biochemical traits in pea (*P. sativum* L.). *Scien. Hort*., 181: 26-33.

Majeed, S., M. Sajjad and S.H. Khan. 2011. Exploitation of non-additive gene actions of yield traits for hybrid breeding in spring wheat. *J. Agric. Soc. Sci*., 7: 131-135.

Malik, M.F.A., S.I. Awan and S. Ali. 2005. Genetic behaviour and analysis of quantitative traits in five wheat genotypes. *J. Agric. Soc. Sci*., 1(4): 313-315.

Mandal, A.B. and G. Madhuri. 2016. Combining ability analysis for morphological and yield traits in wheat (*T. aestivum* L.). *J. Plant Sci. Res*., 3(2): 1-4.

Mateen, A. and M.A. Khan. 2014. Identification of yellow rust virulence pattern on wheat germplasm in relation to environmental conditions in Faisalabad. *J. Biol. Agric. and Health Care*, 4(13): 2224-3208.

Patial, M., D. Pal and J. Kumar. 2016. Combining ability and gene action studies for grain yield and its component traits in barley (*H. vulgare* L.). *SABRAO J. Breed. Genet*., 48(1): 90-96.

Peterson, R.F., A.B. Campbell and A.E. Hannah. 1948. A diagrammatic scale for estimating rust intensity of leaves and stem of cereals. *Can. J. Res. Sect. C*., 26: 496-500.

Protic, D., P. Jovin, N. Protic, S. Jankovic and Ž. Jovanovic. 2007. Mass of 1,000 grains in several winter wheat genotypes, at different dates of sowing and rates of nitrogen fertilizer. *Romanian Agric. Res*., 24: 39-43.

Qamar, M., S.D. Ahmad and M. Asif. 2011. Determination of levels of resistance in Pakistani bread wheat cultivars against stripe rust (*Puccinia striiformis*) under field conditions. *Afr. J. Agric. Res*., 7(44): 5887-5897.

Rahim, M.A., A. Salam, A. Saeed, A. Shakeel and G. Abbas. 2006. Combining ability for flag leaf area, grain yield and yield components in bread wheat. *J. Agric. Res*., 44(3): 175-180.

Roelfs, A.P., R.P. Singh and E.E. Saari. 1992. Rust diseases of wheat: Concepts and methods of disease management. VI, pp. 81. CIMMYT, DF, Mexico.

Saeed, M. and I.H. Khalil. 2017. Combining ability and narrow-sense heritability in wheat (*T. aestivum* L.) under rainfed environment. *Sarhad J. Agric*., 33(1): 22-29.

Sanjeev, R., S. Prasad and M.A. Billore. 2005. Combining ability studies for yield and its attributes in *T. durum* L. *Madras Agric*., J. 92(1-3):7-11.

Seboka, H., A. Ayana and H. Zelleke. 2009. Combining ability analysis for bread wheat (*T. aestivum* L.). *East Afr. J. Sci*., 3: 87-89.

Shah, S.J.A., M. Imtiaz and S. Hussain. 2010. Phenotypic and molecular characterization of wheat for slow rusting resistance against *Puccinia striiformis* Westend. f. sp. *tritici*. *J. Phytopathol*., 158: 393-402.

Singh, K., S.N. Sharma, Y. Sharma and B.S. Tyag. 2012. Combining ability for high temperature tolerance and yield contributing traits in bread wheat. *J. Wheat Res*., 4(1): 29-37.

Singh, R.K. and B.D. Chaudhary. 1985. Biometrical methods in quantitative genetic analysis. Kalyani Publishers, New Delhi, Ludhiana, India, pp. 39-78.

Stavely, R.J. 1985. The modified cobb scale for estimating bean rust intensity. *Annu. Rep. Bean Improv*., *Coop*., 28: 31-32.

Steel, R.G.D., J.H. Torrie and D.A. Dickey. 1997. Principles and Procedures of Statistics: A Biometrical Approach, 3rd edition. McGraw Hill Book Co. Inc., New York.

Verma, S., R. Maurya and S. Maurya. 2016. Prediction of gene action and combining ability for yield and quality traits in F_1 and F_2 generations of wheat (*T. aestivum* L.). *Trop. Plant Res*., 3(2): 449-459.

Zeuli, P.L.S. and C.O. Qualset. 1990. Flag leaf variation and the analysis of diversity in durum wheat. *Plant Breed*., 105: 189-202.

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