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Analysis of variance for combining ability and gene action studies for morphological traits on the basis of F_1 and F_2 generation of crosses in winter x spring wheat derivatives

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Abstract
Globally, almost 50% of wheat cultivated in the developing world, including India (50 million ha), is sown under rainfed conditions, which receive less than 600mm of rain per annum. The problem of drought is in the soil with low water holding capacity especially in the rain fed areas of mountainous and sub-mountainous regions. The present investigation was carried out at the research farm of the Division of Plant Breeding & Genetics, SKUAST –Jammu, Chatha, during rabi 2104-15, rabi 2015-16 and rabi 2016-17. Observation were recorded on 50% flowering(no), days to maturity (no), flag leaf area (cm^{2}), plant height (cm).In line x tester analysis, mean squares of treatment combinations (parents, crosses and interactions) significant in both the generations. The mean squares for comparisons of parents' vs crosses were also significant. This revealed that significant magnitude of variability was present in the parental material (line and tester) and on their crossing in F1 and F_2 generation population. Combining ability analysis carried over F_1 and F_2 generation revealed that variance for crosses, testers and partly in lines was significant for almost all the traits. The gca effects was greater than sca effects for most of the traits. The compassion of relative magnitude of gca and sca variances indicated greater magnitude of gca variance than sca variance for morphological traits indicating the presence of additive gene action for the inheritance of these traits.

Keywords: combining ability, gene action, line x tester, winter wheat, spring wheat

1. Introduction
Wheat (*Triticum aestivum* L.), self-pollinated crop of the Poaceae family and of the genus *Triticum*, is the world's largest cereal crop. It is popularly known as 'Stuff of life or King of the cereals' because of the acreage occupied, high productivity and the prominent position it holds in the international food grain trade. Wheat (*Triticum* spp.), is the most important cereal crop and occupies prominent position in Indian agriculture after rice. India is now the second largest producer of wheat in the world with the production hovering around 75 million tonnes during the last decade.). The area and production of wheat in India during year 2016-17 was recorded 30.97 million ha with 97.44 million tonnes production and with an average productivity of 3172 kg ha-1 (Director's Report, IIWBR, Karnal, 2016- 17). The problem of drought is in the soil with low water holding capacity especially in the rain fed areas of mountainous and sub-mountainous regions. Therefore, there is an urgent need for genetic improvement of wheat in such environments. One of the ways by which this can be achieved is by the incorporation of genes from winter wheat. The importance of winter wheat for the improvement of spring wheat under rainfed conditions was highlighted as early as in 1949 by Ackerman and Mackey. The success of winter x spring hybridization depends upon the ability of these two physiologically different ecotypes to combine well with each other. In order to formulate a sound breeding strategy, information on the relative magnitude of genetic variance, heterosis study for grain yield and its related traits is essential. Such information is useful for the selection of parental lines having superior performance and isolation of potential combination for their further use in the breeding programmes. The technique of line x tester analysis tends itself to the detailed genetic analysis and identifies superior parents and cross combinations on the basis of the best heterotic crosses. Thus this strategy of commercial production of hybrid varieties will be helpful to overcome the yield plateau. Further, the winter

wheat when facultative in nature, flower under conducive environmental conditions and can be utilized in hybridization programme.

2. Materials and Methods

The breeding material, represented ten winter wheat and their derivatives that were used as females (lines) and three of spring wheat, used as males (Testers). The above selected ten winter wheat lines used as females were crossed with three spring wheat lines used as males (Testers) in Line x Tester fashion during 2015-2016 at university Research Farm of Sher-e- Kashmir university of Agricultural Sciences and Technology, Jammu (SKUAST,J) Main campus, Chatha, Jammu to generate 30 F_1s. These were advanced in off-season nursery to generate 30 F_2 s. Thirty F_1 crosses then 30 F_2 crosses and 13 Parents (10 lines + 3 testers) were evaluated in Randomized Block Design replicated thrice at the Research Farm of Sher-e- Kashmir university of Agricultural Sciences and Technology, Jammu (SKUAST,J)Main campus, Chatha, Jammu during the rabi season of 2016. Experimental Plot in each replication consisted of a single row of 1.5 m length spaced 25 cm apart for number of such rows. For proper growth the seedling – seedling spacing was maintained at 5 cm. The observation were recorded on five competent for different traits namely: tillers per plant, spike length, grains per plant, 1000 grain weight, Biological yield per plant, grain yield per plant and harvest index.

Analysis of variance (ANOVA) for line × tester mating

Data recorded for various parameters were analyzed following Singh and Chaudhary (1985) to know the significance of differences among genotypes including crosses. Line × tester analysis was performed as outlined in the format of ANOVA given below:

Source of variation	degree of freedom (d.f)	Mean square
Replication *(r)*	*(r–1)*	
Genotypes *(g)*	*(g–1)*	MS_2
Parents *(p)*	*(p–1)*	
Parents vs crosses	*1*	
Crosses *(c)*	*(c-1)*	
Lines *(l)*	*(l–1)*	M_l
Testers *(t)*	*(t–1)*	M_t
Lines × Testers	*(l–1)(t–1)*	*M(l × t)*
Error	*(r–1)(t–1)*	MS_1

Where, MS_2, M_l, M_t, $M_{(l \times t)}$ and MS_1 are estimated mean squares due to genotypes (parent vs crosses), lines, testers, line x tester crosses and error respectively.

Combining ability effects

The estimates of combining ability were computed by using line × tester analysis (Kempthorne, 1957). The estimates of general combining ability (GCA) of lines and testers and specific combining ability (SCA) of the hybrids were calculated as under:

Estimates of GCA effects

(a) *Lines:* $g_i = \frac{x_{i.}}{tr} - \frac{x_{...}}{ltr}$

(b) *Testers:* $g_j = \frac{x_{.j}}{tr} - \frac{x_{...}}{ltr}$

Where, *l* = Number of lines (female parents)
t = Number of testers (male parents)
r = Number of replications

$x_{i.}$ = Total of F_1 resulting from crossing of i^{th} lines with all the testers
$x_{.j.}$ = Total of all the crosses of j^{th} testers with all lines
$x_{...}$ = Grand total of all the crosses

B) Estimates of SCA effects

$$s_{ij} = \frac{x_{ij}}{r} - \frac{x_{i.}}{tr} - \frac{x_{j..}}{lr} + \frac{x_{..}}{ltr}$$

Where x_{ij} = Total of F_1 resulting from crossing i^{th} lines with j^{th} testers

Test of significance for combining ability effects

Significance of combining ability effects were determined by using *t* test at 0.05 and 0.01 levels of probability, respectively.

t (calculated) for lines = $\frac{GCA}{S.E\ ()}$
t (calculated) for testers = $\frac{GCA}{S.E\ ()}$
t (calculated) for line × tester interactions = $\frac{SCA}{S.E\ ()}$

Standard errors for combining ability effects were calculated from the following equations:

i) S.E. (gi) lines = $\left(\frac{Me}{r} \times t\right)^{0.5}$

ii) S.E. (gi) testers = $\left(\frac{Me}{r} \times t\right)^{0.5}$

iii) S.E. (sij) crosses = $\left(\frac{Me}{r} \times t\right)^{0.5}$

iv) S.E. (gi-gj) lines = $\left(\frac{Me}{r} \times t\right)^{0.5}$

v) S.E. (gi-gj) testers = $\left(\frac{2\ Mex\ l}{r}\right)^{0.5}$

vi) S.E. (sij-skl) crosses = $\left(\frac{2Me}{r}\right)^{0.5}$

The distribution of crosses in relation to GCA and SCA effects was worked out by taking significant positive combining ability effects as high, non-significant as average and significant negative as low for all the traits except for days to flowering, days to maturity and plant height wherein significant positive combining ability effects were taken as low, non-significant as average and significant negative as high.

Genetic Components

Genetic components were calculated following Singh and Chaudhary (1985) as mentioned below:

Covariance of half-sib of line = Cov. H.S. (line) = $\frac{(Ml - M\ l \times t)}{rt}$

Covariance of half-sib of tester = Cov. H.S. (tester) = $\frac{(Mt - Ml \times t)}{rl}$

Covariance of full sib:

$$\text{Cov. F.S.} = \left[\frac{-Me) + (Mt - Me) + (Ml \times t - Me}{3r}\right] + \left[\frac{6r\ \text{Cov. H.S.} - r\ (l+t)\ \text{Cov. H.S}}{3r}\right]$$

While Cov. H.S. (average) was calculated by the formula:

Cov. H.S. (average) = $\frac{1}{r\ (2lt - l - t)}[(l-1)\ (Ml) + (t-1)\ (Mt) / \ l+t-2 - Ml \times t]$

Assuming no epistasis, variance due to GCA (σ^2 gca) and variance due to SCA ($\sigma 2$ sca) were calculated as follows:

σ^2 gca = Cov. H.S. = $(1+F/4)\ \sigma^2 A$

$\sigma 2$ sca = $(1+F/2)^2$ D

Additive and dominance genetic variances (σ^2_A and σ^2_D) were calculated by taking inbreeding coefficient *(F)* equal to one i.e. *F*= 1 as cited by Singh and Narayanan (2004) in F_1 generation and *F*= 0.5 in the F_2 generation.

Gene action and degree of dominance

Ratio of $\sigma^2_{gca}/\sigma^2_{sca}$ as less than 1 was taken as preponderance of non-additive type of gene action, greater than 1 as additive and equal to 1 with equal effects of additive and non-additive type of gene action. Similarly dominance ratio of (σ^2_A/σ^2_D) less than 1, was taken as preponderance of non-additive type of gene action, greater than 1, as non -additive and equal to 1 with equal effects of additive and non-additive type of gene action.

3. Results and Discussion

The observational data of the parental spring and winter wheat derivatives and their crosses (winter x spring wheat derivatives) was put to statistical analyses and the results obtained for different traits are presented here under separately for F_1 and F_2 generations.

Analysis of variance

Parents and F_1 Generation crosses

Morphological traits

Analysis of variance Table (1) revealed highly significant variability for all treatments for days to 50% flowering, days to maturity, Flag leaf Area and plant height. The variability among the parents (lines + tester) were also significant for all traits and so was the case for the testers. The crosses arising from spring x winter wheat derivatives releaved highly significant variability for all four morphological traits. Comparing the variability of lines v/s testers significant values were observed for all traits except days to 50% flowering. Similarly, comparing Parents v/s crosses significant variability was observed for flag leaf Area and Plant height only.

Table 1: Analysis of variance for morphological traits on the basis of F_1 generation of crosses in spring x Winter wheat derivatives (Line x Tester)

Sources of Variation	D.F	Days to 50% Flowering(no)	Days to Maturity (no)	Flag Leaf Area (cm^2)	Plant Height (cm)
Replicates	2	22.91	27.66	10.06	2.20
Treatments	42	321.22 **	210.23**	249.32**	168.89**
Parents	12	221.48**	307.14**	224.53**	144.57**
Parents (Line)	9	200.83**	202.67**	221.24**	162.53**
Parents (Testers)	2	417.00**	677.44**	261.39**	85.75**
Parents (L vs T)	1	16.28	506.75**	180.41**	100.55**
Parents vs Crosses	1	0.84	48.13**	866.22**	244.24**
Crosses	29	373.54 **	175.72**	238.30**	176.36**
Error	84	12.06	14.90	11.43	7.65
Total	128	113.67	79.19	89.47	60.48

*, ** significant at 5% and 1% level, respectively.

Analysis of variance for combining ability and estimation of components of variance

Under Morphological traits table results for days to 50% flowering, days to maturity, flag leaf area and Plant height are presented (Table 2).Significant variance for the combining ability was observed for all the four traits in the crosses. The significance in the combining ability variance was contributed by testers for all the four traits while as contribution of line effect was significant only for days to flowering. However, on crossing the lines with testers, the resultant combining ability effect was significant for all the traits.

Estimation of components of variance and genetic variance

Estimation of variance for lines and testers revealed that spring wheat used as a Tester (Male) contributed higher for combining ability than Winter wheat derivatives used as lines (Females).Based on the average of all parents the variance due to general combining ability high. The variance due to Specific Combining ability (line x tester crosses) was lower than the average variance of parents due to general combining ability.

Days to 50% flowering revealed that the additive genetic variance (σ^2_A) was 141.6 as compared to 21.51 for variance due to dominance deviations (σ^2_D (). For days to maturity the additive genetic variance (σ^2_A) was 92.88 as compared to 17.01 arising from dominance deviations (σ^2_D). Flag leaf area revealed additive genetic variance (σ^2_A) of 114.14 as compared to 23.96 due to dominance deviation (σ^2_D). Plant height had the additive genetic variance (σ^2_A) of 118.88 as compared to 6.86 due to dominance deviations (σ^2_D). The genetic dominance ratio σ^2_D/σ^2_A was incomplete for days to flowering, days to Maturity and flag Leaf Area whereas for Plant height the dominance ratio was almost negligible (0.0057). This indicated that all the 4 morphological traits were by and large controlled by additive gene action.

Table 2: Analysis of variance for combining ability for morphological traits on the basis of F_1 generation of cross in winter x spring wheat derivatives (line xtester).

Sources of Variation	D.F	Days to 50% Flowering (no)	Days to Maturity (no)	Flag Leaf Area (cm^2)	Plant Height (cm)
Line Effect	9	178.08 **	122.70	108.02	76.88
Tester Effect	2	2734.05	1737.03***	2157.88**	2272.42 **
Line x Tester Eff.	18	79.98**	75.35***	91.88 **	36.15**
Error	58	12.66	17.14	18.19	74.09
σ^2 GCA Line		6.81	18.07	10.93	9.78
σ^2GCA Tester		75.23	90.62	57.09	71.26
σ^2GCA (Average)		73.88	46.44	57.07	59.44
σ^2L X T (SCA)		21.51	17.01	23.96	6.86

o GCA / σSCA		3.43	2.73	2.38	8.74
σ^2_A		141.76	92.88	114.14	118.88
σ^2_D		21.51	17.01	23.96	6.86
σ^2_D / S^2_A		.145	0.183	0.20	0.057

*, ** significant at 5% and 1% level, respectively.

Parents and F2 generation crosses
Morphological traits

Analysis of variance table (3) for treatments revealed highly significant variability for all traits for Days to 50% flowering, Days to maturity, Flag leaf Area and plant height. The variability among the parents (lines and tester) were also significant for all traits. Among lines significant values were observed for all the traits. Among testers significant values were observed for all the four traits. The crosses arising from spring x winter wheat derivatives releaved highly significant variability for all four morphological traits. Significant difference was observed for traits except Days to 50% flowering and Days to maturity when parents were compared with the crosses (P VS C).

Table 3: Analysis of variance for Morphological traits on the basis of F_2 generation of crosses in spring x Winter wheat derivatives (Line x Tester).

Sources of Variation	D.F	Days to 50% Flowering (no)	Days to Maturity (no)	Flag Leaf Area (cm^2)	Plant Height (cm)
Replicates	2.00	22.91	27.66	10.06	2.20
Treatments	42.00	321.22***	210.23***	249.32***	168.89***
Parents	12.00	221.48***	307.14***	224.53***	144.57***
Parents (Line)	9.00	200.83***	202.67***	221.24***	162.53***
Parents (Testers)	2.00	417.00***	677.44***	261.39***	85.75***
Parents (L vs T)	1.00	16.28	506.75***	180.41***	100.55***
Parents vs Crosses	1.00	0.84	48.13***	866.22***	244.24***
Crosses	29.00	373.54***	175.72***	238.30***	176.36***
Error	84.00	12.06	14.90	11.43	7.65
Total	128.00	113.67	79.19	89.47	60.48

*, ** significant at 5% and 1% level, respectively.

Analysis of variance for combining ability in F2 generation
Morphological traits

Significant variance revealed by the cross Table (4) for all the morphological traits viz: days to flowering, days to maturity, flag leaf area and plant height was the result of highly significant contribution from tester effects for all traits as compared to non-significant contribution from the line effects for all the traits except in case of line x tester effects were highly significant for all traits except days to maturity.

Variance components for general and specific combining ability effects

Components of variance for combining ability revealed that the magnitude of σ^2_{gca} (tester) was several times higher as compared to ($\sigma^2_{gca)}$ (lines) for all traits. The magnitude of σ^2 gca (average) was also high but comparatively slightly lower than the corresponding values of σ^2_{gca} (tester) for all traits Table (13). The values of σ^2 sca (line x tester) was low for all the traits.

Translating the values of combining ability variances due to gca and sca into genetic components it was observed that additive genetic variance(σ^2_A) were 257, 141.44, 139.81, 132.13 with their corresponding (σ^2_D) values of 25.21,7.51, 48.90, 12.50 for days to flowering, days to maturity, Flag leaf Area, Plant height respectively.

Dominance ratio was incomplete for all the traits revealing the importance of additive gene action only for these traits.

Table 4: Analysis of variance for combining ability for Morphological traits on the basis of F_2 generation of cross in spring x Winter wheat derivatives (line x tester)

Sources of Variation	D.F	Days to 50% Flowering (no)	Days to Maturity (no)	Flag Leaf Area (cm^2)	Plant Height (cm)
Crosses	29	373.54 ***	175.72 ***	238.30 ***	176.36
Line Effect	9	287.23 **	46.71	84.13	81.60
Tester Effect	2	3504.55 ***	2051.54***	1983.52***	1866.15 ***
Line X Tester Effect	18	68.80 ***	31.80	121.47 ***	35.99 ***
Error	58	10.86	7.91	8.70	7.04
σ^2 GCA Line		30.57	3.53	8.08	8.22
σ^2GCA Tester		116.42	67.89	65.74	61.95
σ^2GCA (Average)		96.61	53.04	52.43	49.55
σ^2L X T (SCA)		18.91	5.63	36.68	9.44
o GCA / SCA		5.10	9.42	1.42	5.20
σ^2_A		257.6	141.44	139.81	132.13
σ^2_D		25.21	7.50	48.9	12.5
σ^2_D / S^2_A		0.09	0.05	0.34	0.09

*, ** significant at 5% and 1% level, respectively.

The ratio (σ^2 gca / σ^2 sca) being less than unity that revealed greater important of additive gene action in controlling the trait.

Desale and Mehta (2013) studied combining ability in bread wheat which revealed that the mean squares due to both general combining ability (GCA) and specific combining ability (SCA) were significant for all traits indicating both additive and non-additive genetic variances played a vital role in inheritance of all these traits. Lohithaswa *et al.* (2014) found the combining ability for grain yield per plant and its components which revealed that variances due to females, males and female x male were significant for days to fifty per cent flowering, days to maturity, plant height.

Various research workers have observed different estimates of genetic components of variance while working with different sets of materials in wheat crop. For days to 50% flowering reported dominance and partial dominance, while reported only partial dominance. Dominance genetic variance for days to flowering was reported by Sikka *et al.* (1959). Anwar and Chowdhary (1969) [5] and reported importance of additive genetic variance, whereas, both additive and dominance genetic control had been established by Hassan. For days to maturity greater importance of additive genetic variance has been reported by reported greater importance of non-additive gene action. Plant height in wheat was reported to be greatly controlled by additive gene action by Bhatt (1972).

For flag leaf area and harvest index greater importance of additive gene action was reported by Singh *et al* (1996), whereas, reported greater importance of non-additive gene action.

4. Conclusion

The material selected (winter and spring wheat) possessed good magnitude of variability for all the Morphological traits. Greater magnitude of GCA variance than sca variance revealed that the traits had predominant role of additive gene action as compared to non-additive gene action. The results were also confirmed from the average degree of dominance that was incomplete to partial for all the traits. Multiline crossing programme is needed to introgress allelic resources from elite genotypes and the progenies showing better early generation performance are further crossed through bi-parental procedure to increase chances of generation of hidden latent variability in heterozygous polygenic blocks. Use of recurrent selection procedure for the identification of superior transgressive segregants before fixation of alleles in homozygous condition.

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