Exploring Combining Ability Analysis of Wheat (*Triticum aestivum* L.) using Line × Tester Mating Design

ABSTRACT

This study aimed to evaluate the combining ability (GCA and SCA) and genetic variability among 10 parental wheat lines (7 females and 3 males) and their 21 F1 hybrids using a line × tester mating design. The experiment, conducted at the Research Farm of BRD PG College during the 2021-2022 rabi season, assessed 13 agronomic traits, including plant height, days to flowering, biological yield, and grain yield, using a randomized block design (RBD) with three replications. ANOVA results revealed significant variability among genotypes for all traits except the harvest index, indicating the presence of both additive and non-additive genetic effects. GCA analysis identified PBW-502 and SR-303 as promising parents for early flowering, reduced plant height, and yield-related traits. SCA analysis highlighted hybrids like PBW-502 × DBW-187 and SR-303 × PBW-667 as superior for traits such as early flowering, plant height, and grain yield. These findings provide essential insights for breeders to select suitable parents and hybrids, guiding effective strategies to enhance wheat productivity and agronomic performance.

Keywords: Wheat, Hybrid, Combining ability, Variability

1. INTRODUCTION

Wheat is a major food crop globally and holds a key position in Indian agriculture, second only to rice. As a nutritionally essential cereal, it plays a crucial role in food security, poverty reduction, and livelihoods (Sharma &Duveiller, 2004). Contributing about 30% to the country's food basket, wheat is widely cultivated as a staple crop (Singh*et al*., 2023). Grain yield components often show varied associations with yield and with each other (Edae *et al*, 2014).

Exploiting heterosis is a key strategy for enhancing productivity and combining ability analysis helps breeders select appropriate parents(Begna, 2021). This analysis provides insights into the gene action controlling trait expression, guiding future breeding strategies(Ahmed*et al*., 2020). It assists breeders in identifying desirable genotypes and commercially viable cross combinations. Evaluating genotype performance and compatibility is essential for successful hybridization, with methods like diallel, partial diallel, and line x tester design offering valuable tools. The line x tester design, in particular, assesses specific combining ability (SCA) for individual crosses and general combining ability (GCA) for lines and testers, providing critical insights for refining breeding strategies (Han *et al*., 2020).

2. MATERIALS AND METHODS

The experimental materials for this study consisted of 32 wheat treatments, including 21 F1 hybrids, 10 parental lines (7 females and 3 males), and one standard variety used as a check. The parental lines included 07 lines (females) viz., PBW-502, DBW-14, PBW-343, SR 303, PBW 154, Kundan and CSW-18, with 3 testers (males) viz., DBW187, HD 3226 and PBW 667 during rabi 2019-2020. The experimental hybrids were developed using a line × tester mating design during the 2019-2020 rabi season at the Research Farm of BRD PG College, Deoria (Affiliated with DDU Gorakhpur University, Uttar Pradesh These hybrids, along with their 10 parental lines and the standard check variety HD-2967, were evaluated using randomized block design (RBD) with three replications during rabi seasons in 2021-2022.

3. STATISTICAL ANALYSIS

The analysis of variance (ANOVA) was conducted following Hayman (1954), and combining ability for the line x tester design was analyzed using Kempthorne's method (1957). Data was processed in R using the Agricolae package (Version 1.3-5). Combining ability for each trait was calculated based on Hayes *et al.* (1955).

4. RESULTS AND DISCUSSION

4.1 Analysis of Variance (ANOVA)

Analysis of variance (ANOVA) evaluated differences among parents and hybrids across fifteen traits, revealing significant variability for all traits except the harvest index, which is essential for selecting and breeding superior varieties(Iannucci andCodianni, 2019). Significant genetic differences were observed among parental lines, particularly for traits such as days to 50% flowering, days to maturity, and anthesis duration, emphasizing the importance of choosing the right parents for breeding programs. Hybrids derived from these crosses exhibited notable genetic variation, with traits like plant height, effective tillers per plant, flag leaf area, and the number of grains per spike showing significant mean squares, making these hybrids valuable for breeding. Both additive and non-additive genetic variances were found to play crucial roles in determining trait expression, while interactions between lines and testers highlighted the potential for specific combinations to improve targeted traits. These findings provide vital insights for breeders to select superior genotypes and design effective strategies to enhance wheat yield and its contributing characteristics (Khan*et al*., 2019).

4.4. Combining ability effects

4.4.1 General Combining ability effects (GCA)

The General Combining Ability (GCA) effects provide insights into selecting suitable parent lines for effective breeding. For early flowering and early maturity, PBW-502 displayed significant negative GCA effects, making it a favorable parent (Table 2). Reduced plant height was associated with SR-303 and PBW-502(Fasahat*et al*., 2016). Positive GCA effects for effective tillers were noted in PBW-502 and CSW-18. Larger flag leaf area was significantly influenced by PBW-154, while higher grain yield per spike and test weight were contributed by DBW-187 and DBW-14, respectively. Overall, SR-303 and PBW-502 emerged as key parents for higher biological yield, while PBW-343 stood out for harvest index. These findings enable breeders to leverage specific parents like PBW-502, SR-303, and DBW-14 for enhancing wheat yield and key agronomic traits (Liu*et al*., 2021).

4.4.2 Specific Combining ability effects (SCA)

The Specific Combining Ability (SCA) effects reveal important hybrid combinations for targeted trait improvements(Table 3). For early flowering and early maturity, PBW-502 × DBW-187 showed significant negative SCA effects, making it an ideal cross (Kumar *et al*., 2017). In terms of plant height, hybrids like SR-303 × DBW-187 and CSW-18 × PBW-667 exhibited positive effects, suitable for taller plants, while Kundan × PBW-667 showed desirable negative effects for shorter height. Effective tillers per plant were enhanced by SR-303 × DBW-187, while PBW-343 × PBW-667 contributed to larger flag leaf areas. For grains per spike, hybrids like SR-303 × PBW-667 performed well. Significant combinations such as DBW-14 × DBW-187 enhanced biological yield and harvest index, while PBW-154 × DBW-187 improved grain yield per plant. These SCA findings guide breeders in exploiting specific hybrid crosses to maximize wheat yield and desired agronomic traits (Maan and Yadav 2022; Mohan *et al*., 2023).

CONCLUSION

The study demonstrates the significance of both General and Specific Combining Ability (GCA and SCA) effects in identifying suitable parents and hybrids for wheat improvement.ANOVA results confirmed substantial genetic variability across key traits, except for the harvest index, underlining the importance of parent and hybrid selection. GCA analysis identified parents like PBW-502, SR-303, and DBW-14 as promising for traits such as early flowering, plant height reduction, and yield improvement. SCA findings highlighted hybrids such as PBW-502 × DBW-187 and SR-303 × PBW-667 as ideal for enhancing traits like flowering, maturity, and grain yield. These insights offer valuable guidance for breeders to optimize wheat breeding strategies by selecting high-performing parental lines and hybrid combinations, ultimately contributing to improved wheat productivity and agronomic performance.

Conflict of interest declaration: The authors declare no conflicts of interest.

Ethical issues: None.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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Table 1: Analysis of variance for combing ability

SOV	DF	DFF	DM	PH	ETP	FLA	HL	AD
Replicates	2	9.83*	205.67**	31.73	3.65**	1.94	1.32	0.43
Crosses	20	6.28**	12.34**	48.22**	2.03**	14.77**	20.84**	380.09**
Line Effect	6	5.47	28.81**	36.37	1.11	5.23	37.09	84.82
Tester Effect	2	6.96	9.58	113.8	1.50	12.09	2.74	360.21
Line * Tester Eff.	12	6.57**	4.57	43.21	2.58**	19.98**	15.73**	531.04**
Error	40	2.12	3.96	28.66	0.56	2.91	1.80	41.14
Total	62	3.71	13.17	35.07	1.13	6.70	7.92	149.17

Continue…

SOV	DF	GPS	TW	SL	BYP	HI	GYP
Replicates	2	2.24	2.66	0.13	40.39**	2.69	1.81
Crosses	20	16.23**	4.36**	0.77**	7.21**	30.54**	0.26*
Line Effect	6	11.62	5.49	1.15	8.48	36.90	0.15
Tester Effect	2	28.54	7.84	0.18	8.09	2.424	0.01
Line * Tester Eff.	12	16.48**	3.22*	0.69**	6.43	32.04**	0.35
Error	40	2.27	1.21	0.08	6.27	11.53	1.05
Total	62	6.77	2.28	0.31	7.68	17.38	0.82

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively

Degree of freedom = DF, Days to 50% Flowering = DFF, Days to Maturity = DM, Plant Height = PH, Number of Effective Tillers per Plant = ETP, Flag Leaf Area = FLA, Number of Hairs on Lodicules = HL, Anthesis Duration = AD, Number of Grains per Spike = GPS, Test Weight = TW, Spike Length = SL, Biological Yield per Plant = BYP, Harvest Index = HI, Grain Yield per Plant = GYPP.

Table 2: Estimation of general combining ability with respect to 15 characters in Wheat

Parents	DF	DM	PH	ETP	FLA	HL
PBW-502	-1.58**	-3.04**	-2.08*	0.31	-1.07	-1.70**
DBW-14	-0.14	-0.89	0.43	0.1	0.20	1.53**
PBW-343	0.62	1.69	1.87	-0.51*	0.14	-0.15
SR-303	0.68	0.5	-3.22	0.19	0.59	0.7
PBW-154	-0.22**	-0.75**	0.96	-0.47	0.61	-3.34**
Kundan	0.351	0.16	2.2	0.06	0.6	2.78**
CSW-18	0.289	2.32*	-0.17	0.31	-1.08	0.17
DBW-187	-0.56	-0.63	-2.63*	-0.15	-0.86	0.15
HD 3226	-0.02	-0.07	1.19	-0.15	0.32	0.26
PBW 667	0.59	0.71	1.49	0.30	0.54	-0.41

Continue….

Parents	AD	GPS	TW	SL	BYPP	HI	GYPP
PBW-502	-2.47	-1.37**	-0.78*	-0.19	0.63	-2.06*	0.13**
DBW-14	2.59	1.20**	1.14***	0.75**	-1.38	-0.71	0.12
PBW-343	-5.40**	-1.46**	-0.06	-0.18	0.52	2.75**	-0.04
SR-303	1.51	-0.21	-0.84*	-0.12	1.38	-2.09*	0.15**
PBW-154	0.09	-0.21	0.81*	0.04	-0.79	0.83	-0.13
Kundan	0.19	0.95	0.27	-032**	0.29	-1.14	-0.07
CSW-18	3.48	1.11*	-0.54	0.02	-0.65	2.41*	-0.15
DBW-187	-3.00*	1.33***	-0.026	0.1	-0.68	-0.21	-0.018
HD 3226	-1.71	-0.48	0.62**	-0.05	0.15	0.39	0.013**
PBW 667	4.72	-0.84**	-0.59**	-0.05	0.52	-0.17	0.56**

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively

Degree of freedom = DF, Days to 50% Flowering = DFF, Days to Maturity = DM, Plant Height = PH, Number of Effective Tillers per Plant = ETP, Flag Leaf Area = FLA, Number of Hairs on Lodicules = HL, Anthesis Duration = AD, Number of Grains per Spike = GPS, Test Weight = TW, Spike Length = SL, Biological Yield per Plant = BYP, Harvest Index = HI, Grain Yield per Plant = GYPP.

Table 3: Estimation of specific combining ability with respect to 15 characters in Wheat

Hybrids	DF	DM	PH	ETP	FLA	HL
PBW-502 * DBW 187	-1.88*	-1.58*	3.29*	-0.88	0.39	-1.23
PBW -502 * HD 3226	0.2	-0.31	-1.83	0.23	-1.47	1.29
PBW-502 * PBW 667	1.68	1.89	-1.45	0.64	1.08	-0.06
DBW -14 * DBW 187	-0.61	-0.91	-0.59	1.07*	0.61	-0.68
DBW - 14 * HD 3226	1.57	0.41	0.19	-1.30**	0.62	-0.2
DBW-14 * PBW 667	-0.95	0.5	0.4	0.23	-1.23	0.88
PBW-343 * DBW 187	0.53	0.26	-2.74	0.32	-2.17	0.73
PBW 343 * HD 3226	-0.81	-0.17	3.83	-0.43	-2.02	-2.58**
PBW 343 * PBW 667	0.28	-0.08	-1.09	0.1	4.20**	1.85
SR 303 * DBW 187	0.65	-0.25	3.35*	1.23**	2.99	3.44**
SR 303 * HD 3226	-0.97	0.2	-4.52	-0.01	-2.24	-0.55
SR 303 * PBW 667	0.31	0.23	1.17	-1.22**	-0.74	-2.88**
PBW 154 * DBW 187	-0.43	-0.05	0.9	-1.09*	-2.2	1.77*
PBW 154 * HD 3226	1.02	0.45	1.28	0.65	1.61	-0.19
PBW 154 * PBW 667	-0.59	-0.39	-2.71	0.44	0.59	-1.58
Kundan * DBW 187	1.7	1.84	-2.33*	-0.01	0.43	-3.52**
Kundan * HD 3226	0.45	0.47	5.04	0.11	3.31**	2.66**
Kundan * PBW 667	-2.16	-2.31*	-2.71	-0.1	-3.75**	0.86
CSW - 18 * DBW 187	0.05	0.69	-1.87	-0.63	-0.04	-0.5
CSW- 18 * HB 3226	-1.48	-0.82	-3.99*	0.73	0.18	-0.42
CSW-18PBW 667	1.42	0.17	5.87	-0.1	-0.13	0.93

Continue….

Hybrids	AD	GPS	TW	SL	BYPP	HI	GYPP
PBW-502 * DBW 187	1.92	0.17	-0.17	-0.25	1.53	-3.17	0.11
PBW -502 * HD 3226	0.02	-2.26**	-1.1	-0.25	-2.02	2.94	0.16**
PBW-502 * PBW 667	-1.94	2.08**	1.28*	0.5	0.49	0.22	-0.28**
DBW -14 * DBW 187	-2.34	1.07	0.95	-0.04	1.63	3.96*	-0.46
DBW - 14 * HD 3226	-4.23	1.15	-0.58	-0.22	-0.22	-3.52*	0.27**
DBW-14 * PBW 667	6.58*	-2.23**	-0.36	0.27	-1.41	-0.43	0.18
PBW-343 * DBW 187	9.02**	1.74*	-0.17	0.25	1	-0.02	-0.25
PBW 343 * HD 3226	-27.14**	-2.17**	-0.38	0.24	-0.82	0.67	-0.01
PBW 343 * PBW 667	18.11**	0.43	0.56	-0.49**	-0.18	-0.65	0.26
SR 303 * DBW 187	-6.59*	-3.99**	-0.39	-0.24	-0.24	0.54	0.37
SR 303 * HD 3226	1.68	0.56	-0.77	-0.14	0.8	2.91	-0.34
SR 303 * PBW 667	4.90	3.42**	1.17*	0.38*	-0.55	-3.46*	-0.02
PBW 154 * DBW 187	1.15	1.75*	-0.15	0.02	-0.63	1.68	0.43**
PBW 154 * HD 3226	5.16	0.31	1.19*	0.06	-0.35	-5.02**	0.07
PBW 154 * PBW 667	-6.32	-2.06**	-1.03	-0.08	0.99	3.341	-0.5
Kundan * DBW 187	1.02	-0.92	-0.06	0.63**	-1.52	-2.38	-0.04
Kundan * HD 3226	3.66	1.65*	1.28*	0.31	1.71	-0.19	-0.02
Kundan * PBW 667	-4.68	-0.73	-1.21*	-0.93**	-0.18	2.58	0.07
CSW - 18 * DBW 187	-4.18	0.17	0.02	-0.370*	-1.77	-0.61	-0.14
CSW- 18 * HB 3226	20.83**	0.73	0.37	0.006	0.9	2.2	-0.13
CSW-18PBW 667	-16.65**	-0.9	-0.4	0.36*	0.86	-1.58	0.27**

*, ** indicate significance at the 0.05 and 0.01 probability levels, respectively

Degree of freedom = DF, Days to 50% Flowering = DFF, Days to Maturity = DM, Plant Height = PH, Number of Effective Tillers per Plant = ETP, Flag Leaf Area = FLA, Number of Hairs on Lodicules = HL, Anthesis Duration = AD, Number of Grains per Spike = GPS, Test Weight = TW, Spike Length = SL, Biological Yield per Plant = BYP, Harvest Index = HI, Grain Yield per Plant = GYPP.