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STANDARD HETEROSIS FOR YIELD AND ITS COMPONENT TRAITS UNDER HEAT STRESS IN WHEAT (*TRITICUM AESTIVUM*. L)

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ABSTRACT

The present study was undertaken to estimate standard heterosis for yield and its component traits, namely days to 50% flowering, days to maturity, grain yield (kg/plot), plant height (cm), number of effective tillers per plant, number of grains per earhead, thousand grain weight (g), grain weight per plant (g) and harvest index (%), under early and late sowing conditions at Akola and Niphad, as well as across environments. Forty-five crosses developed through a 10 × 10 half-diallel mating design were evaluated in a randomized block design with three replications to assess the magnitude and direction of heterosis for yield and related traits in wheat. Significant heterosis over the best standard check in the desirable direction was observed for all the traits studied. The results indicated highly significant differences between parents and F_1 hybrids, as well as among parents, for most of the characters. Among the 45 crosses evaluated, QLD 118 × WSM 253 (early sowing, Akola), HS 628 × WSM 253 (early sowing, Niphad), RWP 2018-32 × QLD 118 (late sowing, Akola) and QLD 122 × AKAW 2862-1 (late sowing, Niphad) exhibited superior performance. Across environments, HS 628 × WSM 253 recorded significant and the highest positive heterosis over the best check for grain weight per plant. These promising hybrids should be further evaluated across multiple locations before being recommended for commercial cultivation. The high magnitude of heterosis observed in several hybrid combinations suggests substantial genetic divergence among the parental lines and indicates strong potential for the commercial exploitation of heterosis in wheat.

***Keywords* :** Standard heterosis, F1's, Crosses, Check and Half-diallel.

Introduction

India, the second-largest wheat producer in the world after China, is currently facing significant challenges in maintaining and enhancing wheat productivity. Among the various constraints, abiotic stresses particularly heat stress pose a serious threat to stable production. High temperatures, especially during the grain-filling stage, are of major concern because they hasten crop development, reduce the duration of grain filling and ultimately lead to substantial yield losses (Mitra and Bhatia, 2008). The shortening of the reproductive phase under elevated temperatures limits assimilate accumulation in grains, thereby affecting both grain weight and overall productivity. In the era of global climate change, developing effective adaptation strategies to counteract the adverse effects of rising temperatures has become imperative. One of the most important steps in this direction is the identification and utilization of genetic variability for heat stress tolerance among diverse wheat genotypes. Exploring such variability enables breeders to select resilient germplasm capable of performing well under high-temperature conditions. Moreover, it provides a strong scientific foundation for breeding heat-tolerant cultivars that can sustain productivity under future climatic uncertainties and fluctuating environmental conditions (Jagadish *et al.*, 2015). The development of high-yielding and climate-resilient cultivars largely depends on the effective exploitation of available genetic diversity, particularly through heterosis breeding. Heterosis or hybrid vigour, refers to the phenomenon in which F_1 hybrids exhibit superior performance over their parents in terms of growth, yield or adaptability due to favorable gene interactions under specific environmental conditions (Shull, 1908). Compared to conventional breeding approaches, heterosis-based strategies offer greater potential to overcome yield stagnation and achieve substantial productivity improvements in wheat, especially under stress-prone environments. In self-pollinated crops like wheat, the practical utility of heterosis largely depends on its magnitude and direction (Singh *et al.*, 2004). Cross combinations that demonstrate high and desirable heterotic effects are more likely to produce superior segregants in subsequent generations, thereby enhancing breeding efficiency. Conversely, crosses with poor heterotic performance can be discarded at the F_1 stage, saving time and resources. Therefore, the systematic evaluation of heterosis serves as an effective tool for identifying promising parental combinations. Importantly, the successful exploitation of heterosis relies on the extent of genetic divergence and compatibility among parental lines. Some parents consistently exhibit better combining ability than others, underscoring the importance of careful and strategic parent selection in hybrid breeding programs aimed at improving wheat productivity under changing climatic conditions.

Materials and Methods

The experimental material comprised 10 parental lines which includes AKW 1071, QLD 122, AKAW 3722, AKAW 3717, AKAW 2862-1, HS 628, RWP 2018-32, GW 477, QLD 118, and WSM 253 along with 45 F_1 crosses derived from them. The hybrids were developed during the rabi season of 2023–2024 using a 10 × 10 half-diallel mating design. The evaluation experiment was conducted during rabi 2024–2025 under both early and late sown conditions at the Wheat Research Unit, Dr. PDKV, Akola and the Agricultural Research Station, Niphad, MPKV, Rahuri.

All genotypes, including parents, F_1s and standard checks, were grown in a Randomized Block Design (RBD) with three replications to ensure reliable comparison and minimize experimental error. Each entry was planted in a single-row plot of one-meter length, maintaining a spacing of 30 cm between rows and 5 cm between plants within a row, thereby providing adequate growing space for uniform crop development. Statistical analysis of the data was carried out using the analysis of variance (ANOVA) technique for Randomized Block Design as described by Panse and Sukhatme (1985).

Observations were recorded on five randomly selected, competitive plants from each plot to obtain representative data for most of the traits. However, days to 50% flowering, days to maturity and grain yield per plot were recorded on a whole-plot basis to ensure greater accuracy for these parameters. Data were collected separately for parents, F_1 hybrids and checks in each replication under both early and late sown conditions, enabling a comprehensive assessment of genotype performance across environments.

Estimation of Standard heterosis:

It is estimated as *per cent* increase or decrease over standard commercial check (Meredith and Bridge, 1972) as follows.

(%) Standard heterosis, $H_3 = \frac{\overline{F}_1 - \overline{CHECK}}{\overline{CHECK}} \times 100$

Where,

$\overline{F_1}$ = Mean performance of F_1

$\overline{CHECK}$ = Mean performance of the check variety

Results and Discussion

Analysis of Variance

The analysis of variance (ANOVA) conducted for individual environments, as well as the pooled analysis across all environments, revealed highly significant differences between parents and F_1 hybrids and also among parents for most of the characters studied. These results indicate the presence of substantial genetic variation for the traits under investigation. The pooled ANOVA over the four environments further demonstrated that environmental effects were significant for all the traits, emphasizing the strong influence of environmental conditions on trait expression. This finding justifies the importance of evaluating genotypes across diverse environments to obtain reliable estimates of performance and stability. Multi-environment testing thus becomes essential for identifying genotypes with consistent and superior performance under varying sowing conditions and locations.

The presence of significant variability among parents and their crosses suggests the availability of considerable genetic diversity within the experimental material. Such diversity provides a valuable resource for selection and hybridization in future breeding programs aimed at yield enhancement and stress tolerance. Comparable results highlighting significant genetic variability and environmental influence were also reported by Farooq *et al.* (2015), Chaudhary *et al.* (2023), Kumar *et al.* (2021), Burdak *et al.* (2023) and Santhoshini *et al.* (2023), thereby supporting the findings of the present investigation.

Table 1 : Pooled analysis of variance for experimental design over the environments

Source of variations	df	Mean Sum of Squares					
		Days to 50% flowering	Days to maturity	Grain yield per plot	Plant height	Effective tillers per plant	Grains per earhead
Environments	3	1360.65**	4066.11**	181.59**	8575.90**	2538.68**	5286.03**
Replications within Environments	8	13.61	45.76	7.38	9.09	51.18	1.75
Treatments	54	94.00**	326.21**	71.43**	761.41**	2010.59**	628.92**
Parents	9	85.78**	247.77**	101.38**	789.12**	2571.40**	725.28**
Crosses	44	97.72**	349.30**	66.77**	764.60**	1918.03**	623.23**
Parents vs. Crosses	1	4.15*	16.37*	6.84**	371.38**	1035.92**	12.08**
Treatments * Environments	162	36.15**	8.52**	9.26**	134.84**	195.08**	15.89**
Parents * Environments	27	25.53**	8.04**	11.21**	118.21**	192.57**	17.06**
Crosses * Environments	132	38.65**	8.75**	8.90**	140.30**	198.47**	15.52**
Parents vs. Crosses * Environments.	3	21.73**	3.04**	7.21**	44.36**	68.37**	22.10**
Pooled Error	432	0.79	3.35	0.77	3.83	29.11	0.96

Table. 1.Cont..

Source of variations	df	Mean Sum of Squares		
		Thousand grain weight	Grain weight per plant	Harvest index
Environments	3	2917.08**	446.96**	519.20**
Replications within Environments	8	9.78	3.80	4.61*
Treatments	54	288.51**	95.90**	163.81**
Parents	9	495.59**	109.25**	183.80**
Crosses	44	251.56**	93.78**	163.31**
Parents vs. Crosses	1	50.72**	68.83**	5.95
Treatments * Environments	162	11.70**	4.20**	33.82**
Parents * Environments	27	8.24**	5.00**	25.46**
Crosses * Environments	132	12.58**	4.12**	36.05**
Parents vs. Crosses * Environments.	3	4.05**	0.69**	11.12**
Pooled Error	432	1.12	1.09	1.89

*- significant at 5% level of significance **- significant at 1% level of significance

Estimation of Standard heterosis

The standard heterosis for the 9 characters was studied under early and late sown conditions in Akola and Niphad and over the environments (Table 2.)

Estimation of standard heterosis under early sowing Akola

Under early sowing at Akola, AKAW 3722 × AKAW 2862-1 recorded highest standard heterosis for days to 50% flowering (2.48%), while AKAW 3722 × HS 628 showed the maximum for days to maturity (9.16%). For grain yield per plot (kg), QLD 118 × WSM 253 was superior (30.00%). Plant height (cm) was reduced by AKAW 3722 × GW 477 (−14.86%). Among yield attributes, the best crosses were HS 628 × RWP 2018-32 for effective tillers per plant (13.01%), RWP 2018-32 × QLD 118 for grains per ear head (17.65%), QLD 118 × WSM 253 for thousand grain weight (g) (12.07%) and grain weight per plant (g) (18.48%), while QLD 122 × AKAW 3722 was superior for harvest index (%) (13.73%).

Estimation of standard heterosis under early sowing Niphad

Under early sowing at Niphad, AKAW 2862-1 × GW 477 recorded standard heterosis for days to 50% flowering (−2.75%), while AKAW 3722 × HS 628 showed the highest for days to maturity (6.27%). For grain yield per plot (kg), QLD 118 × WSM 253 was superior (5.26%). Plant height (cm) was reduced by AKAW 3722 × AKAW 3717 (−12.28%). Among yield attributes, the best crosses were AKAW 3717 × GW 477 for effective tillers per plant (26.86%), QLD 118 × WSM 253 for grains per ear head (18.55%), QLD 122 × AKAW 2862-1 for thousand grain weight (g) (8.56%), HS 628 × WSM 253 for grain weight per plant (g) (6.89%) and QLD 122 × RWP 2018-32 for harvest index (%) (33.29%).

Estimation of standard heterosis under late sowing Akola

Under late sowing at Akola, AKAW 3717 × WSM 253 recorded standard heterosis for days to 50% flowering (−15.17%), while AKAW 3722 × QLD 118 showed the highest for days to maturity (6.15%). For grain yield per plot (kg), QLD 118 × WSM 253 was superior (23.81%). Plant height (cm) was reduced by QLD 122 × AKAW 3717 (−10.57%). Among yield attributes, the maximum heterosis was observed in AKW 1071 × WSM 253 for effective tillers per plant (33.90%), RWP 2018-32 × QLD 118 for grains per ear head (18.52%) and grain weight per plant (g) (25.16%), QLD 118 × WSM 253 for thousand grain weight (g) (14.36%), and RWP 2018-32 × WSM 253 for harvest index (%) (16.53%).

Estimation of average heterosis under late sowing Niphad

Under late sowing at Niphad, AKAW 3717 × WSM 253 recorded standard heterosis for days to 50% flowering (−16.76%), while AKAW 2862-1 × WSM 253 showed the highest for days to maturity (6.90%). For grain yield per plot (kg), AKAW 3722 × WSM 253 was superior (11.76%). Plant height (cm) was reduced by AKAW 3722 × AKAW 3717 (−9.96%). Among yield attributes, the maximum heterosis was observed in HS 628 × GW 477 for effective tillers per plant (24.91%), AKAW 3717 × HS 628 for grains per ear head (16.35%), QLD 118 × WSM 253 for thousand grain weight (g) (14.61%), QLD 122 × AKAW 2862-1 for grain weight per plant (g) (−0.46%), and AKAW 3717 × HS 628 for harvest index (%) (27.92%).

Estimation of pooled average heterosis over the environments

In pooled analysis across environments, AKAW 2862-1 × GW 477 showed highest standard heterosis for days to 50% flowering (−3.73%), while AKAW 3722 × GW 477 recorded the highest for days to maturity (8.97%). For grain yield per plot (kg), the best cross was QLD 118 × WSM 253 (27.78%). Plant height (cm) was reduced by AKAW 3722 × AKAW 3717 (−13.80%). Among yield attributes, the maximum heterosis was observed in AKW 1071 × WSM 253 for effective tillers per plant (15.81%), RWP 2018-32 × QLD 118 for grains per ear head (15.92%), QLD 118 × WSM 253 for thousand grain weight (g) (13.73%), HS 628 × WSM 253 for grain weight per plant (g) (13.39%), and AKAW 3717 × HS 628 for harvest index (%) (19.35%).

The observations on standard heterosis under late sown conditions for effective tillers per plant, grains per spike, harvest index, thousand grain weight, protein content and grain yield per plant were consistent with the findings of Kumar *et al.* (2017a), while Thomas *et al.* (2017) also reported similar results for days to maturity and grain yield per plant and Dhoot *et al.* (2020) along with Sharma and Kamaluddin (2020) for proline content. Comparable outcomes for protein content under late sown conditions were further confirmed by Chaudhari *et al.* (2023). Under early sown conditions, Sharma and Kamaluddin (2020) reported significant standard heterosis for protein content, which was further supported by the findings of Chaudhari *et al.* (2023).

Table 3 : Standard heterosis (%) for different characters over the environments

S.No	Genotype	DFF	DM	GY	PH	ETP
1	AKW 1071 x QLD 122	8.15**	21.31**	-11.11**	7.56**	-1.76
2	AKW 1071 x AKAW 3722	-2.58**	10.37**	-33.33**	1.59	-25.85**
3	AKW 1071 x AKAW3717	4.15**	13.46**	-27.78**	19.08**	-28.98**
4	AKW 1071 x AKAW 2862-1	3.73**	13.36**	-16.67**	35.58**	-4.77
5	AKW 1071 x HS 628	10.73**	17.38**	-11.11**	19.10**	-8.28
6	AKW 1071 x RWP 2018-32	5.44**	16.16**	-22.22**	2.21	-26.60**
7	AKW 1071 x GW 477	11.73**	14.20**	-5.56**	9.94**	-10.41*
8	AKW 1071 x QLD 118	1.72*	16.16**	-5.56**	23.75**	1.76
9	AKW 1071 x WSM 253	11.02**	14.95**	11.11**	8.53**	15.81**
10	QLD 122 x AKAW 3722	7.59**	22.89**	5.56**	17.01**	9.54*
11	QLD 122 x AKAW3717	8.02**	22.61**	-38.89**	-1.22	-22.33**
12	QLD 122 x AKAW 2862-1	6.15**	26.07**	0.00	10.63**	3.51
13	QLD 122 x HS 628	15.74**	16.16**	-5.56**	6.47**	-8.28
14	QLD 122 x RWP 2018-32	3.57**	26.35**	-5.56**	8.17**	4.39
15	QLD 122 x GW 477	11.30**	25.32**	-11.11**	-5.46**	3.51
16	QLD 122 x QLD 118	8.02**	22.99**	-5.56**	13.89**	9.41*
17	QLD 122 x WSM 253	12.45**	25.41**	-5.56**	28.16**	-9.79*
18	AKAW 3722 x AKAW3717	-1.58*	12.06**	-16.67**	-13.80**	-29.99**
19	AKAW 3722 x AKAW 2862-1	5.72**	12.80**	-33.33**	2.34	-44.54**

20	AKAW 3722 x HS 628	4.72**	10.93**	-27.78**	23.68**	-29.99**
21	AKAW 3722 x RWP 2018-32	1.29	9.90**	-11.11**	-0.66	-16.31**
22	AKAW 3722 x GW 477	5.87**	8.97**	-11.11**	-13.18**	-16.44**
23	AKAW 3722 x QLD 118	8.72**	8.97**	-11.11**	18.53**	-17.69**
24	AKAW 3722 x WSM 253	1.00	11.30**	16.67**	-4.96**	10.92*
25	AKAW3717 x AKAW 2862-1	6.87**	19.35**	-27.78**	14.41**	-34.50**
26	AKAW3717 x HS 628	6.30**	22.61**	5.56**	19.59**	-21.33**
27	AKAW3717 x RWP 2018-32	9.01**	23.73**	-11.11**	25.09**	-2.51
28	AKAW3717 x GW 477	8.29**	26.16**	-5.56**	18.12**	11.04*
29	AKAW3717 x QLD 118	5.44**	12.99**	-27.78**	28.51**	-18.44**
30	AKAW3717 x WSM 253	0.57	21.21**	-16.67**	15.93**	-16.19**
31	AKAW 2862-1 x HS 628	-1.00	9.81**	-11.11**	9.35**	3.01
32	AKAW 2862-1 x RWP 2018-32	8.88**	16.35**	-5.56**	9.31**	-16.31**
33	AKAW 2862-1 x GW 477	-3.73**	11.02**	-22.22**	9.63**	-46.93**
34	AKAW 2862-1 x QLD 118	-1.85*	10.46**	-27.78**	10.49**	-37.01**
35	AKAW 2862-1 x WSM 253	-1.29	9.99**	-5.56**	26.50**	-13.17**
36	HS 628 x RWP 2018-32	9.58**	22.52**	-11.11**	7.24**	4.52
37	HS 628 x GW 477	7.73**	20.00**	-11.11**	24.35**	13.43**
38	HS 628 x QLD 118	5.72**	22.15**	-5.56**	10.03**	3.64
39	HS 628 x WSM 253	12.15**	22.43**	16.67**	14.92**	-0.38
40	RWP 2018-32 x GW 477	10.16**	18.78**	-5.56**	10.24**	2.76
41	RWP 2018-32 x QLD 118	9.58**	21.49**	5.56**	5.03**	4.52
42	RWP 2018-32 x WSM 253	1.42	14.48**	-5.56**	10.46**	-5.40
43	GW 477 x QLD 118	-0.43	19.24**	-16.67**	9.26**	0.25
44	GW 477 x WSM 253	6.73**	11.11**	-22.22**	10.25**	2.76
45	QLD 118 x WSM 253	1.15	11.02**	27.78**	31.92**	5.65
	SE(m) +/-	0.73	1.49	0.72	1.60	4.41
	CD @5%	1.43	2.93	1.41	3.14	8.66
	CD @ 1 %	1.88	3.86	1.85	4.13	11.40

S.No	Genotype	GPE	TGW	GWP	HI
1	AKW 1071 x QLD 122	-18.10**	-21.03**	-28.96**	1.80
2	AKW 1071 x AKAW 3722	-23.75**	-20.50**	-48.59**	-13.94**
3	AKW 1071 x AKAW3717	-35.32**	-25.15**	-38.41**	-8.89**
4	AKW 1071 x AKAW 2862-1	-5.13**	-14.52**	-29.02**	0.28
5	AKW 1071 x HS 628	-8.55**	-12.89**	-21.14**	2.38*
6	AKW 1071 x RWP 2018-32	-28.79**	-24.85**	-39.92**	-2.93**
7	AKW 1071 x GW 477	-13.98**	-10.68**	-16.28**	6.17**
8	AKW 1071 x QLD 118	-14.72**	-15.24**	-10.31**	10.94**
9	AKW 1071 x WSM 253	4.66**	1.42	4.33**	7.52**
10	QLD 122 x AKAW 3722	3.33**	5.00**	-1.77*	4.03**
11	QLD 122 x AKAW3717	-23.21**	-22.57**	-45.31**	-22.68**
12	QLD 122 x AKAW 2862-1	3.33**	8.21**	7.55**	8.19**
13	QLD 122 x HS 628	-5.31**	-14.08**	-20.22**	5.32**
14	QLD 122 x RWP 2018-32	-6.84**	-8.59**	-14.05**	9.99**
15	QLD 122 x GW 477	-14.75**	-13.59**	-11.62**	5.01**
16	QLD 122 x QLD 118	-7.25**	-7.91**	-15.50**	11.00**
17	QLD 122 x WSM 253	-0.99	-2.91**	-30.53**	9.20**
18	AKAW 3722 x AKAW3717	-33.63**	-33.76**	-45.83**	3.58**
19	AKAW 3722 x AKAW 2862-1	-46.31**	-28.87**	-48.98**	-16.26**
20	AKAW 3722 x HS 628	-38.97**	-24.20**	-46.95**	-9.72**
21	AKAW 3722 x RWP 2018-32	-17.56**	-1.23	-30.53**	2.51*
22	AKAW 3722 x GW 477	3.40**	-6.65**	-19.83**	0.43
23	AKAW 3722 x QLD 118	-5.72**	-10.35**	-15.23**	2.96**
24	AKAW 3722 x WSM 253	4.12**	3.61**	5.12**	11.37**
25	AKAW3717 x AKAW 2862-1	-29.87**	-29.46**	-39.33**	-11.00**
26	AKAW3717 x HS 628	2.75**	-9.66**	-23.70**	19.35**

27	AKAW3717 x RWP 2018-32	-3.24**	-11.89**	-14.51**	3.39**
28	AKAW3717 x GW 477	-16.01**	-9.56**	-19.70**	12.22**
29	AKAW3717 x QLD 118	-34.02**	-29.18**	-50.89**	-10.67**
30	AKAW3717 x WSM 253	-39.53**	-25.31**	-42.81**	-17.60**
31	AKAW 2862-1 x HS 628	-12.49**	-15.57**	-18.12**	4.19**
32	AKAW 2862-1 x RWP 2018-32	-26.52**	-13.94**	-26.13**	13.54**
33	AKAW 2862-1 x GW 477	-35.52**	-31.57**	-46.95**	-3.61**
34	AKAW 2862-1 x QLD 118	-42.77**	-33.90**	-55.61**	-13.14**
35	AKAW 2862-1 x WSM 253	-20.37**	-14.68**	-6.50**	11.61**
36	HS 628 x RWP 2018-32	-12.40**	-7.26**	-4.14**	-1.07
37	HS 628 x GW 477	-10.27**	-4.68**	-15.30**	5.47**
38	HS 628 x QLD 118	-12.34**	-2.72**	-11.88**	7.27**
39	HS 628 x WSM 253	11.44**	-3.23**	13.39**	8.86**
40	RWP 2018-32 x GW 477	-12.49**	-4.61**	-8.08**	11.34**
41	RWP 2018-32 x QLD 118	15.92**	3.96**	7.75**	-8.74**
42	RWP 2018-32 x WSM 253	-6.73**	-10.89**	-24.95**	10.30**
43	GW 477 x QLD 118	-10.20**	-11.87**	-19.24**	1.07
44	GW 477 x WSM 253	-14.61**	-7.86**	-17.73**	-6.88**
45	QLD 118 x WSM 253	12.56**	13.73**	9.98**	8.22**
	SE(m) +/-	0.80	0.86	0.85	1.12
	CD @5%	1.56	1.70	1.67	2.20
	CD @ 1 %	2.06	2.24	2.20	2.90

*- significant at 5% level of significance **- significant at 1% level of significance

DFF: Days to 50% flowering, **DM**: Days to maturity, **GY**: Grain yield (kg/plot), **PH**: Plant height (cm), **ETP**: Effective tillers per plant number, **GPE**: Grains per earhead number, **TGW**: Thousand grain weight (g), **GWP**: Grain weight per plant (g) and **HI**: Harvest index (%)

Conclusion

The maximum standard heterosis for grain weight per plant was observed in different crosses under specific environments. In early sowing at Akola, the cross QLD 118 × WSM 253 recorded the highest standard heterosis (18.48%). Under early sowing at Niphad, HS 628 × WSM 253 exhibited 6.89% heterosis. In late sowing at Akola, RWP 2018-32 × QLD 118 showed the highest heterosis (25.16%), while in late sowing at Niphad, QLD 122 × AKAW 2862-1 recorded 0.46% heterosis over the best check. Across all environments, HS 628 × WSM 253 demonstrated significant and positive standard heterosis (13.39%) over the best check. In addition to superior grain weight per plant, these highly heterotic crosses also exhibited significant heterosis in the desirable direction for one or more yield-contributing traits, indicating their overall agronomic superiority. Such consistent performance across traits enhances their potential value in breeding programs. These promising hybrids should be further evaluated across diverse locations and seasons to confirm their stability and adaptability before being considered for commercial release. The high magnitude of heterosis observed among these hybrid combinations reflects substantial genetic divergence among the parental lines, suggesting strong potential for the effective commercial exploitation of heterosis in wheat improvement programs.

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Author Contributions

Gandhodi Himaja: Designed the model, analysed the data, computational framework original draft preparation and wrote the manuscript. Dr. Swati G. Bharad: Conceived the original idea Designed the model and Project Administration. Dr. R.B. Ghorade: Supervision and Investigation. Dr. N.R. Potdukhe: Visualization and Supervision. Dr. S.S. Hadole, R.D. Walke: Supervision and Methodology. Dr. N.D. Bichewar: Reviewing and Editing.

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