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Heterosis and inbreeding depression analysis for yield and its component traits in Black × Amber Wheat Crosses

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Abstract

Wheat (*Triticum aestivum* L.) is a major staple crop, and improving its productivity under changing climatic conditions remains a key breeding objective. The present study was undertaken to estimate heterosis and inbreeding depression for yield and its component traits in six Black × Amber wheat crosses involving the cultivars Black wheat, HD 3059, WH 1124, WH 1270, DBW 303, WH 1184 and HD 3086. Six generations (P₁, P₂, F₁, F₂, BC₁ and BC₂) were evaluated during the *rabi* season 2022–23 in a randomized block design with three replications. Heterosis was estimated as mid-parent and better-parent heterosis, while inbreeding depression was calculated by comparing F₁ and F₂ generations. Grain yield per plant exhibited low heterosis, and none of the crosses surpassed the better parent, indicating limited scope for direct exploitation of hybrid vigour. However, significant positive mid-parent heterosis was observed for key yield-contributing traits such as number of grains per spike, spike length, and effective tillers per plant. Among the crosses, Black wheat × WH 1124 exhibited maximum heterosis for grains per spike, whereas Black wheat × HD 3086 showed the highest heterosis for effective tillers per plant. Most crosses displayed negative heterobeltiosis for grain yield and contributing traits. Moderate to high inbreeding depression observed for several traits indicated the predominance of non-additive gene effects. Overall, the results suggest that recombination breeding coupled with delayed selection would be an effective strategy for improving yield and its component traits in wheat, particularly in nutritionally enriched genetic backgrounds such as black wheat.

Keywords: Wheat, heterosis, inbreeding depression, crosses, yield

1. Introduction

Wheat (*Triticum aestivum* L.) is a major cereal crop and a staple food for a large proportion of the global population, contributing significantly to food and nutritional security, particularly in countries like India. With increasing demand driven by population growth and changing dietary patterns, improving grain yield and quality remains a key challenge for plant breeders (Shewry and Hey, 2015) [12]. In addition, there is growing interest in developing nutritionally enriched wheat varieties, such as black wheat, which is rich in anthocyanins and exhibits antioxidant properties beneficial to human health (Sharma *et al.*, 2018) [11].

Heterosis, or hybrid vigour, is an important breeding approach for enhancing yield and its component traits. It refers to the superior performance of F₁ hybrids over their parents and is governed by genetic mechanisms such as dominance, overdominance, and epistasis (Shull, 1908) [13]. Although commercial hybrid wheat development is limited, the study of heterosis provides valuable insights into the genetic architecture of complex traits and helps identify superior parental combinations (Longin *et al.*, 2012) [7]. Since grain yield is a complex polygenic trait influenced by traits such as grain number per spike, spike length and tiller number, improvement in these traits can indirectly enhance yield. Previous studies have reported significant heterosis for yield components, suggesting the effectiveness of indirect selection (Fonseca and Patterson, 1968; Singh *et al.*, 2004) [3, 14].

Inbreeding depression, defined as the reduction in vigour from the F₁ to F₂ generation due to the breakdown of favourable gene combinations, provides insights into the nature of gene action. High inbreeding depression indicates the importance of non-additive effects, whereas low values

suggest additive gene action (Allard, 1999) ^[1]. Therefore, the combined assessment of heterosis and inbreeding depression is essential for designing effective breeding strategies.

The present study was undertaken to estimate heterosis and inbreeding depression for yield and its component traits in six Black × Amber wheat crosses, with the aim of identifying suitable breeding strategies for developing high-yielding and nutritionally enriched wheat varieties.

2. Materials and Methods

The present investigation was conducted during the *rabi* seasons of 2020–23 at the Research Farm, Wheat and Barley Section, Department of Genetics and Plant Breeding, CCS Haryana Agricultural University, Hisar, India. The experimental material comprised six crosses derived by crossing black wheat with six amber wheat varieties, namely HD 3059, WH 1124, WH 1270, DBW 303, WH 1184 and HD 3086. Each cross consisted of six generations, viz., P₁, P₂, F₁, F₂, BC₁ and BC₂. The evaluation of all six generations was carried out during *rabi* 2022–23 under field conditions. The experiment was laid out in a randomized block design with three replications.

Controlled hybridization was carried out using standard emasculation and pollination techniques in wheat. Data were recorded for yield and its component traits, including grain yield per plant (g), biological yield per plant (g), harvest index (%), thousand grain weight (g), spike length (cm), number of grains per spike and number of effective tillers per plant.

Statistical analysis was carried out using analysis of variance (ANOVA) to test the significance of differences among generations and crosses, following standard procedures described by Snedecor and Cochran (1967) ^[15] and evaluated by Panse and Sukhatme (1954) ^[8].

Heterosis was estimated as percentage increase or decrease of F₁ over mid-parent and better parent values:

Heterosis over mid parent (Relative heterosis): H₁ (Turner, 1953) ^[16]

$$H_1(\%) = \frac{\bar{F}_1 - \bar{MP}}{\bar{MP}} \times 100$$

$$\bar{MP} = \frac{\bar{P}_1 + \bar{P}_2}{2}$$

Where,

$\bar{P}_1$ = Mean performance of first parent i.e.(female)

$\bar{P}_2$ = Mean performance of second parent i.e.(male)

$\bar{F}_1$ = Mean value of F₁ hybrid i.e., F₁

Heterosis over better parent (Heterobeltiosis): H₂ (Fonseca and Patterson, 1968) ^[3]

$$H_2(\%) = \frac{\bar{F}_1 - \bar{BP}}{\bar{BP}} \times 100$$

Where,

$\bar{BP}$ = Mean performance of better parent

Test of significance

The test significance for heterosis and heterobeltiosis were carried out following ‘t’ test as under

$$t = \frac{\bar{F}_1 - \bar{BP}}{S.E.(F_1 - \bar{BP})} \text{ (For better heterobeltiosis)}$$

$$t = \frac{\bar{F}_1 - \bar{MP}}{S.E.(F_1 - \bar{MP})} \text{ (For relative heterosis)}$$

Standard errors (S.E.) and critical differences were estimated using the following relation

$$S.E. \text{ For } H_1 = \frac{\sqrt{3Me}}{2r} \text{ C.D} = S.E.(H_1) \times t$$

$$S.E. \text{ For } H_2 = \frac{\sqrt{2Me}}{r} \text{ C.D} = S.E.(H_2) \times t$$

Where,

Me = Error mean sum of square

r = Number of replications

The test of significance of relative heterosis and heterobeltiosis were carried out by comparing calculated values of ‘t’ with tabulated values of ‘t’ at 5% and 1% level of significance.

Estimation of inbreeding depression

Inbreeding depression was compared by using the following formulae:

$$\text{Inbreeding depression (\%)} = \frac{\bar{F}_1 - \bar{F}_2}{\bar{F}_1} \times 100$$

The standard error and ‘t’ value for test of significance for inbreeding depression were calculated as under:

Standard error for inbreeding depression

$$S.E. (\bar{F}_1 - \bar{F}_2) = \sqrt{\frac{Me_1 + Me_2}{r}}$$

‘t’ test for inbreeding depression

$$t(\bar{F}_1 - \bar{F}_2) = \frac{\bar{F}_1 - \bar{F}_2}{S.E.(\bar{F}_1 - \bar{F}_2)}$$

Where,

$\bar{F}_1$ = Mean value of F₁ hybrid

$\bar{F}_2$ = Mean value of F₂ generation of respective F₁

Me₁ = Error mean square of F₁ generation

Me₂ = Error mean square of F₂ generation

r = Number of replications

The test of significance of inbreeding depression was performed by comparing, calculated ‘t’ value with table ‘t’ value at 5% and 1% level of significance.

3. Results and Discussion

Heterosis was estimated in terms of mid-parent heterosis (H₁), better-parent heterosis (H₂) and inbreeding depression (ID) across six crosses (Table 1). Heterosis and inbreeding depression were estimated to assess the relative importance of non-additive genetic effects in the inheritance of yield and its component traits. Mid-parent heterosis (MPH) reflects the performance of hybrids relative to the parental mean, whereas better-parent heterosis (BPH) indicates the extent to which hybrids surpass the superior parent. Inbreeding depression (ID), on the other hand, measures the decline in performance from F₁ to F₂ generations due to segregation and breakdown of favourable heterozygous

gene combinations (Allard, 1999) ^[1]. The magnitude and direction of these parameters varied across traits, indicating differences in the underlying genetic control.

For grain yield per plant, the highest value of mid-parent heterosis was observed in the cross Black wheat × WH 1124 (2.19%), while the lowest value was recorded in Black wheat × HD 3086 (-0.77%). Heterobeltiosis ranged from -9.34% (Black wheat × WH 1124) to -16.27% (Black wheat × DBW 303). Significant inbreeding depression was observed only in Black wheat × WH 1124 (3.32%). The presence of both positive and negative MPH, while BPH remained consistently negative across all crosses. The presence of positive MPH suggests partial expression of hybrid vigour; however, the absence of positive BPH indicates that hybrids failed to outperform the best parent. The generally low magnitude of inbreeding depression further suggests limited exploitation of heterosis for this trait. Such a pattern is indicative of the predominance of additive effects, where favourable alleles are dispersed among parents and recombination is required to achieve improvement. Similar findings have been reported in wheat by Fonseca and Patterson (1968) ^[3], Singh *et al.* (2004) ^[14] and Raza *et al.* (2025) ^[9], who

observed limited heterobeltiosis for grain yield despite moderate mid-parent heterosis.

In case of biological yield per plant, the highest value of mid-parent heterosis was observed in the cross Black wheat × HD 3086 (2.49%), while the lowest value was recorded in Black wheat × HD 3059 (0.81%). Heterobeltiosis ranged from -7.21% (Black wheat × HD 3059) to -11.56% (Black wheat × WH 1270). Significant negative heterobeltiosis was recorded in all the crosses. Significant negative inbreeding depression was recorded in Black wheat × WH 1270 (-2.63%) and Black wheat × DBW 303 (-2.80%). The predominance of positive MPH suggests improved biomass accumulation in hybrids relative to the parental mean; however, the consistently negative BPH reflects limited superiority over the best parent. The low to moderate magnitude of inbreeding depression, including negative values in some crosses, indicates the involvement of both additive and non-additive gene effects. Comparable results have been reported by Yadav *et al.* (2025) ^[17] and Kumar *et al.* (2024) ^[6], highlighting the complex inheritance of biomass-related traits.

Table 1: Mid-parent heterosis (H₁), better-parent heterosis (H₂) and inbreeding depression (ID) for yield and its contributing traits in six Black × Amber wheat crosses

Cross	H ₁ (MPH%)	H ₂ (BPH%)	ID (%)
Grain yield per plant			
Black wheat x HD 3059	-0.53	-11.38**	1.85
Black wheat x WH 1124	2.19*	-9.34*	3.32*
Black wheat x WH 1270	1.96*	-14.08**	2.16
Black wheat x DBW 303	0.33	-16.27**	2.58
Black wheat x WH 1184	1.06	-10.63**	2.82
Black wheat x HD 3086	-0.77	-15.60**	1.41
Biological yield per plant			
Black wheat x HD 3059	0.81	-7.21**	0.74
Black wheat x WH 1124	1.10	-9.41*	-1.05
Black wheat x WH 1270	2.07*	-11.56**	-2.63*
Black wheat x DBW 303	1.62	-11.43**	-2.80*
Black wheat x WH 1184	1.91	-9.97**	2.06
Black wheat x HD 3086	2.49	-7.50**	-0.45
Harvest Index			
Black wheat x HD 3059	-1.05	-5.26*	0.96
Black wheat x WH 1124	0.31	-3.09*	1.81
Black wheat x WH 1270	1.81*	-2.12*	4.80*
Black wheat x DBW 303	2.01*	-2.53*	3.59*
Black wheat x WH 1184	1.56	0.30	2.09
Black wheat x HD 3086	-0.54	-5.38*	3.13*
No. of grains per spike			
Black wheat x HD 3059	7.70**	-1.62	9.29**
Black wheat x WH 1124	9.81**	4.10*	5.88*
Black wheat x WH 1270	7.10**	-5.46*	7.83**
Black wheat x DBW 303	7.37**	-5.26*	9.97**
Black wheat x WH 1184	1.25	-6.97*	9.02**
Black wheat x HD 3086	-1.81	-7.55**	6.97**
Thousand Grains Weight			
Black wheat x HD 3059	-0.34	-2.48	-2.16
Black wheat x WH 1124	-0.52	-6.80**	-8.36**
Black wheat x WH 1270	6.95**	-4.69*	-1.54
Black wheat x DBW 303	4.38**	-5.22*	-3.30*
Black wheat x WH 1184	2.35	-4.10*	-5.22*
Black wheat x HD 3086	1.50	-6.11*	-4.87*
Spike Length			
Black wheat x HD 3059	4.34*	-1.12	-5.39*
Black wheat x WH 1124	13.59**	9.11**	7.59*
Black wheat x WH 1270	10.33**	8.33*	1.79
Black wheat x DBW 303	10.69**	7.52**	4.69*
Black wheat x WH 1184	9.05**	3.53	4.12*
Black wheat x HD 3086	7.08**	3.85	1.17

Effective Tillers per Plant			
Black wheat x HD 3059	10.49**	-1.69	6.31*
Black wheat x WH 1124	9.88**	-8.45**	3.74*
Black wheat x WH 1270	11.21**	-9.77**	2.34*
Black wheat x DBW 303	14.60**	-1.93	5.35*
Black wheat x WH 1184	12.86**	-4.39*	3.89*
Black wheat x HD 3086	15.86**	-3.20*	1.84

In case of harvest index, the highest value of mid-parent heterosis was observed in the cross Black wheat × DBW 303 (2.01%), while the lowest value was recorded in Black wheat × HD 3059 (−1.05%). Heterobeltiosis ranged from −5.26% (Black wheat × HD 3059) to −2.12% (Black wheat × WH 1270). Significant positive inbreeding depression was recorded in Black wheat × WH 1270 (4.80%), Black wheat × DBW 303 (3.59%) and Black wheat × HD 3086 (3.13%). The presence of both positive and negative MPH reflects moderate hybrid expression; however, the consistently negative BPH indicates limited scope for heterosis exploitation for this trait. The moderate magnitude of inbreeding depression suggests the involvement of non-additive gene effects, particularly dominance. Similar observations were reported by Kumar *et al.* (2017) [4] and Longin *et al.* (2012) [7], emphasizing the complex genetic architecture of harvest index in wheat.

Considering the number of grains per spike, the highest value of mid-parent heterosis was observed in the cross Black wheat × WH 1124 (9.81%), while the lowest value was recorded in Black wheat × HD 3086 (−1.81%). Heterobeltiosis ranged from −7.55% (Black wheat × HD 3086) to 4.10% (Black wheat × WH 1124). Significant positive better-parent heterosis was observed only in Black wheat × WH 1124 (4.10%), whereas significant negative heterobeltiosis was recorded in remaining crosses. Significant positive inbreeding depression was observed in all the crosses, ranging from 5.88% (Black wheat × WH 1124) to 9.97% (Black wheat × DBW 303). The predominance of positive MPH along with occasional positive BPH indicates strong heterotic expression for this trait. However, the moderate to high positive inbreeding depression suggests that the superior performance of F₁ hybrids is not fully retained in subsequent generations due to the breakdown of favourable gene combinations. This pattern reflects the involvement of additive, dominance and epistatic gene effects. These findings are in agreement with earlier reports by Kumar *et al.* (2024) [6], Raza *et al.* (2025) [9] and Burdak *et al.* (2023) [2], who also reported significant heterosis and inbreeding depression for this trait.

In thousand grain weight, the highest value of mid-parent heterosis was observed in the cross Black wheat × WH 1270 (6.95%), while the lowest value was recorded in Black wheat × WH 1124 (−0.52%). Heterobeltiosis ranged from −2.48% (Black wheat × HD 3059) to −6.80% (Black wheat × WH 1124). Inbreeding depression ranged from −1.54% (Black wheat × WH 1270) to −8.36% (Black wheat × WH 1124). The presence of both positive and negative MPH along with predominantly negative BPH suggests limited heterotic advantage for this trait. The low to negative magnitude of inbreeding depression indicates relative stability across generations and reflects the predominance of additive gene action with minimal influence of dominance and epistasis. These findings are consistent with earlier reports by Singh *et al.* (2004) [14] and Kumar *et al.* (2017) [4], indicating that this trait can be effectively improved through selection.

For spike length, the highest value of mid-parent heterosis was observed in the cross Black wheat × WH 1124 (13.59%), while the lowest value was recorded in Black wheat × HD 3059

(4.34%). Significant positive better-parent heterosis was recorded in Black wheat × WH 1124 (9.11%), Black wheat × WH 1270 (8.33%), and Black wheat × DBW 303 (7.52%). Inbreeding depression ranged from −5.39% (Black wheat × HD 3059) to 7.59% (Black wheat × WH 1124). Significant positive inbreeding depression was observed in Black wheat × WH 1124 (7.59%), Black wheat × DBW 303 (4.69%) and Black wheat × WH 1184 (4.12%), whereas significant negative inbreeding depression was recorded in Black wheat × HD 3059 (−5.39%). The predominance of positive MPH along with the presence of significant positive BPH in some crosses indicates strong heterotic expression for spike length. However, the occurrence of moderate inbreeding depression suggests that the superior performance of F₁ hybrids is not fully fixable in subsequent generations due to the breakdown of favourable gene combinations. This pattern indicates the involvement of non-additive gene effects, particularly epistasis. Similar results have been reported by Yadav *et al.* (2025) [17] and Raza *et al.* (2025) [9].

For effective tillers per plant, the highest value of mid-parent heterosis was observed in the cross Black wheat × HD 3086 (15.86%), while the lowest value was recorded in Black wheat × WH 1124 (9.88%). All the crosses exhibited significant positive mid-parent heterosis. Heterobeltiosis ranged from −1.69% (Black wheat × HD 3059) to −9.77% (Black wheat × WH 1270). Inbreeding depression ranged from 1.84% (Black wheat × HD 3086) to 6.31% (Black wheat × HD 3059). The consistently high positive MPH reflects substantial hybrid vigour for this trait; however, the absence of positive BPH suggests limited superiority over the best parent. The moderate magnitude of inbreeding depression indicates the involvement of non-additive gene effects, particularly dominance and epistasis. These findings are consistent with earlier studies by Kumar *et al.* (2024) [6], Burdak *et al.* (2023) [2] and Kumar *et al.* (2017) [4], which also highlighted the importance of non-additive gene effects for tiller-related traits.

4. Conclusion

The study revealed variable heterosis and inbreeding depression across traits in six Black × Amber wheat crosses, indicating differences in genetic control. Grain yield per plant showed low heterosis with consistently negative better-parent heterosis and low inbreeding depression, suggesting the predominance of additive gene action and limited scope for direct heterosis exploitation. In contrast, traits such as number of grains per spike, spike length and effective tillers per plant exhibited substantial heterosis along with moderate to high inbreeding depression, indicating the involvement of non-additive gene effects. Thousand grain weight and phenological traits showed low heterosis and inbreeding depression, suggesting their amenability to selection. Overall, recombination breeding with selection in later generations would be effective for developing high-yielding and nutritionally enriched wheat varieties.

References

1. Allard RW. Principles of plant breeding. 2nd ed. New York:

- John Wiley and Sons; 1999.
2. Burdak A, Prakash V, Kakralya BL, Gupta D, Choudhary R. Heterotic performance and inbreeding depression for yield and component traits in bread wheat (*Triticum aestivum* L.). International Journal of Plant and Soil Science. 2023;35:120-140.
 3. Fonseca S, Patterson FL. Hybrid vigor in a seven-parent diallel cross in common winter wheat (*Triticum aestivum* L.). Crop Science. 1968;8(1):85-88.
 4. Kumar J, Kumar A, Kumar M, Singh SK, Singh L, Singh GP. Heterosis and inbreeding depression in relation to heterotic parameters in bread wheat (*Triticum aestivum* L.) under late sown condition. Journal of Wheat Research. 2017;9(1):32-41.
 5. Kumar P, Singh G, Kumar S, Kumar A, Ojha A. Genetic analysis of grain yield and its contributing traits for improvement of bread wheat cultivars. Journal of Applied and Natural Science. 2016;8(1):350-356.
 6. Kumar S, Singh L, Yadav RK, Mishra A, Babu K, Dixit R, Kuswaha C. Heterosis and inbreeding depression for yield and yield-attributing traits in maize (*Zea mays* L.). International Journal of Plant and Soil Science. 2024;36(10):93-102.
 7. Longin CFH, Mühleisen J, Maurer HP, Zhang H, Gowda M, Reif JC. Hybrid breeding in autogamous cereals. Theoretical and Applied Genetics. 2012;125(6):1087-1096.
 8. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. New Delhi: ICAR; 1954.
 9. Raza H, Khan SA, Afridi K, Ali N, Hussain I, Ali S, *et al.* Heterosis and inbreeding depression in F1 and F2 populations of bread wheat for quantitative traits. SABRAO Journal of Breeding and Genetics. 2025;57(4):1422-1432.
 10. Satish Kumar SK, Bains NS. Heterosis in wheat hybrids derived from *Triticum timopheevii*-based cytoplasmic male sterility system. Journal of Wheat Research. 2013;5(1):27-32.
 11. Sharma S, Chunduri V, Kumar A, Kumar R, Khare P, Kondepudi KK, *et al.* Anthocyanin biofortified colored wheat: nutritional and functional characterization. PLoS ONE. 2018;13(4):e0194367.
 12. Shewry PR, Hey SJ. The contribution of wheat to human diet and health. Food and Energy Security. 2015;4(3):178-202.
 13. Shull GH. The composition of a field of maize. Journal of Heredity. 1908;1:296-301.
 14. Singh H, Sharma SN, Sain RS. Heterosis studies for yield and its components in bread wheat over environments. Hereditas. 2004;141(2):106-114.
 15. Snedecor GW, Cochran WG. Statistical methods. 6th ed. Ames: Iowa State University Press; 1967.
 16. Turner JH. A study of heterosis in upland cotton. II. Combining ability and inbreeding effects. Agronomy Journal. 1953;45:487-490.
 17. Yadav V, Yadav RK, Maurya CL, Singh L. Estimation of heterotic performance and inbreeding depression for grain yield and contributing traits in bread wheat (*Triticum aestivum* L.). Electronic Journal of Plant Breeding. 2025;16(1):210-221.