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## Research Note

# Combining ability for yield and yield-associated traits in wheat (*Triticum aestivum L.*)

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**Abstract**

The current breeding effort aims to develop new wheat genotypes with higher genetic potential, thereby contributing to food security. Ten wheat genotypes were crossed in a half-diallel mating design. The $F_1$ progeny from the 45 crosses, along with their ten parents, were evaluated in a randomized block design to estimate combining ability and the nature of gene action. Analysis of variance for combining ability revealed significant mean squares for both general and specific combining abilities across all studied traits. This indicates the importance of both additive and non-additive gene effects in the inheritance of these traits. The GCA/SCA ratio suggested the predominance of non-additive genetic action for all studied traits. Only five parents (HD3086, UP 2748, WH 1105, UP 2565, and HD 2967) exhibited good general combining ability for yield and associated traits. However, but none of them were found good combiners for all traits. Twenty-one crosses exhibited significant specific combining ability for yield and associated traits. The crosses UP 2748 x HD 3059, UP2565 x HD3086, WH 1105 x UP 2526, WH 1105 x WH 1021, and HD 2967 x WH 1021 were identified as good specific combiners for higher grain yield and associated traits. Utilizing these crosses in breeding programs that exploit heterosis can lead to the creation of new wheat genotypes with a broader genetic base. This approach, which involves crossing high-performing parents for some traits with low-performing parents for others, has the potential to produce offspring with superior characteristics in the next generation due to interactions between dominant genes.

**Keyword:** General combining ability, Specific combining ability, half diallel, and Wheat.

Wheat (*Triticum aestivum* L.) is a major cereal crop, occupying the largest cultivated area globally. In some Asian countries, wheat is grown for both grain and straw (Beres *et al.,* 2020). It serves as a versatile ingredient in various food products like bread, pasta, and baked goods. Additionally, it has industrial uses in animal feed and biofuels production (Ficco & Borrelli, 2023). The demand for processed wheat products is expected to rise significantly due to population growth, rapid urbanization, and evolving lifestyles (Anonymous, 2015). However, projections indicate a potential decline of 5 to 6 million hectares in wheat cultivation by 2050 due to factors like off-farm diversification and competition from alternative crops (Chaudhary *et al.,* 2023). Combining ability analysis is a widely used technique in wheat breeding. It helps identify promising parental genotypes and their hybrids by evaluating parental performance in hybrid combinations. This method provides insights into the genetic mechanisms involving numerous major and minor genes that influence wheat yield and related traits (Din *et al.,* 2020).

Some of the major challenges for future wheat production in India include the increasing impact of climate change, particularly rising temperatures and water scarcity, the emergence of new and potentially devastating crop diseases, maintaining sustainable agricultural practices, including reducing dependence on the continuous rice-wheat cropping system, meeting the demands of a growing population with changing urbanization patterns and a preference for higher quality wheat. Despite these challenges, wheat breeders have opportunities to improve yields by eliminating yield-limiting factors and enhancing the inherent yield potential of wheat varieties (Kumar *et al*., 2022). Identifying suitable parents for high-yielding breeding programs is crucial. Diallel breeding methods, such as half-diallel crosses, are valuable tools for evaluating general and specific combining abilities for desired traits (Bao *et. al.,* 2009). These methods enable breeders to study genetic variation and inheritance patterns in the hybrid offspring. The present study aims to investigate the combining ability of different wheat genotypes and their crosses with respect to yield and yield-related traits using a half-diallel breeding approach.

The current experiment aimed to investigate the genetic basis of yield and associated traits in ten bread wheat genotypes. These genotypes were: HD 2967, WH 1105, UP 2748, UP 2565, UP 2572, UP 2628, UP 2526, HD 3059, HD 3086, and WH 1021. Selection criteria for these genotypes included morphological characteristics, maturity time, and yield-contributing traits. The experiment was conducted at the research farm of Janta Vedic College in Baraut (Baghpat), Uttar Pradesh, India. During the Rabi season of 2018-19, a half-diallel mating design was employed. Ten wheat lines were crossed to generate 45 hybrid combinations. The resulting $F_1$ progenies, along with their parental lines, were evaluated during Rabi 2019-20 in a randomized block design with three replicates. Each plot consisted of three rows, each one meter long, with a spacing of 22.5 cm between rows and 10 cm between plants. Data on 11 yield and yield-related namely days to heading, days to maturity, flag leaf area ($cm^2$), plant height at maturity (cm), number of productive tillers per plant, spike length (cm), number of grains per spike, 1000-grain weight, biological yield per plant, grain yield per plant, and harvest index (HI) were collected. For each entry (genotype or cross), five competitive plants were randomly selected, and their average values for all traits (except days to heading and days to maturity) were used for analysis. Data for days to heading and days to maturity were recorded for the entire plot. Combining ability analysis was performed using Griffing's Method 2, Model I (Fixed) (1956).

This study highlights the importance of understanding both general combining ability (GCA) of parents and specific combining ability (SCA) of progeny for developing high-yielding bread wheat varieties. Analysis of variance between parents, hybrids, and parents versus hybrids revealed the significance of all $F_1$ traits. As shown in **Table 1**, the mean square for all traits was significantly influenced by both GCA and SCA. This suggests the importance of both additive and non-additive gene action in the inheritance of these traits. The estimated value of SCA variance ($\sigma^2 s$) was higher than GCA variance ($\sigma^2 g$) for all traits, indicating the predominance of non-additive genes. The ratio of $\sigma^2$ GCA/$\sigma^2$ SCA was less than one for all studied traits, further supporting the major role of non-additive gene action. These findings, consistent with previous reports by Singh *et al.* (2012)**,** Nawaz *et al.*(2015), Kumar *et al.* (2017), Gautam *et al.* (2016), Arya *et al.* (2018), Patel (2017), Nassar *et al.* (2020) and Haridy *et al.* (2021) imply that non-additive gene action significantly contributes to the inheritance of all studied traits.

Analysis of GCA for yield and yield-related characteristics (**Table 2**) revealed that only five out of the 10 parents (HD3086, UP 2748, WH 1105, UP 2565, and HD 2967) were good general combiners but none of them were good combiners for all traits. However, some parents showed promise for specific traits: UP2748 and HD 3086 for early flowering and maturity, UP2748 and UP2565 for short stature, WH 1105 and UP2748 for more productive tillers and flag leaf area, UP2748 and HD 3086 for spike length, WH 1105 and HD 3086 for more grains per spike, UP2565 and HD 3086 for 1000-grain weight, HD 2967 and HD 3086 for biomass production, UP2748 and HD 3086 for harvest index and grain yield. These parents (HD3086, UP 2748, WH 1105, UP 2565, and HD 2967) with favorable GCA effects for

**Table 1 Analysis of variance (ANOVA) of combining ability analysis for grain yield and yield contributing traits in bread wheat.**

| Source of variation | d.f. | Mean squares | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days to heading | Days to maturity | Plant height (cm) | Productive tillers/ plants | Flag leaf Area (cm) | Spike length (cm) | Grains per spike | 1000-grain weight | Biological yield/ Plant | Harvest Index | Grain yield/ Plants |
| GCA | 9 | 36.68** | 11.78** | 152.97** | 3.97** | 70.52** | 2.20* | 183.37** | 18.87** | 138.97** | 47.31** | 67.15** |
| SCA | 45 | 5.76** | 9.06** | 31.86** | 2.38** | 27.61** | 2.09** | 59.65** | 16.83** | 164.88** | 52.44** | 56.25** |
| Error | 108 | 0.495 | 0.959 | 0.236 | 0.128 | 0.261 | 0.038 | 0.471 | 0.063 | 0.351 | 0.936 | 0.152 |
| $\Sigma g^2_i$ | | 1.809 | 0.541 | 7.637 | 0.192 | 3.513 | 0.108 | 9.145 | 0.940 | 6.931 | 2.319 | 3.350 |
| $\Sigma s^2_{ij}$ | | 5.262 | 8.104 | 31.625 | 2.255 | 27.345 | 2.052 | 59.183 | 16.772 | 164.528 | 51.500 | 56.093 |
| $\Sigma g^2_i / \Sigma s^2_{ij}$ | | 0.344 | 0.067 | 0.241 | 0.085 | 0.128 | 0.053 | 0.155 | 0.056 | 0.042 | 0.045 | 0.060 |

*, ** Significant at 0.05 and 0.01 levels of probability, respectively

**Table 2. Evaluation of overall General Combining Ability (GCA) effects and performance, including a ranking (of desired traits only) for parental contributions to yield**

| Parents | Days to heading | | Days to maturity | | Plant height (cm) | | Productive tillers/ plants | | Flag leaf Area (cm | | Spike length (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gca | *Per se* | Gca | *Per se* | Gca | *Per se* | gca | *Per se* | Gca | *Per se* | gca | *Per se* |
| HD- 2967 | 1.11 ** | 86.33 | 0.76 ** | 125.33 | -0.30 ** | 98.06 | 0.15 ** | 7.60 | -1.35 ** | 27.89 | -0.20 ** | 10.89 |
| UP2748 | -1.51 ** | 81.67 | -0.52 ** | 124.33 | -3.69 ** | 84.80 | 0.36 ** | 6.60 | 1.94 ** | 25.32 | 0.32 ** | 11.47 |
| WH 1105 | 0.02 ns | 83.67 | 0.48 ** | 124.67 | -0.97 ** | 91.37 | 0.39 ** | 7.53 | 2.28 ** | 29.82 | 0.23 ** | 11.44 |
| UP2565 | -0.59 ** | 82.33 | -0.24 ns | 123.67 | -1.19 ** | 90.27 | 0.07 ns | 6.40 | 0.51 ** | 25.03 | -0.03 ns | 10.49 |
| UP2572 | 1.58 ** | 87.67 | 0.64 ** | 125.33 | 3.55 ** | 100.23 | -0.36 ** | 7.63 | -1.24 ** | 23.83 | -0.40 ** | 10.87 |
| UP 2628 | 0.88 ** | 85.67 | -0.36 * | 123.33 | -0.31 ** | 98.31 | 0.09 ns | 7.80 | -0.92 ** | 27.67 | -0.02 ns | 12.77 |
| UP2526 | 0.19 ns | 85.67 | -0.08 ns | 125.33 | 0.17 * | 90.53 | -0.32 ** | 6.70 | 0.74 ** | 28.40 | 0.06 * | 11.80 |
| HD3059 | 0.08 ns | 85.33 | 0.31 * | 125.00 | 0.67 ** | 93.74 | -0.54 ** | 5.65 | -1.90 ** | 23.14 | -0.30 ** | 11.30 |
| WH1021 | -0.39 ** | 84.33 | 0.09 ns | 125.00 | 2.88 ** | 99.07 | -0.19 ** | 6.50 | -0.11 ns | 26.24 | 0.03 ns | 12.11 |
| HD3086 | -1.37 ** | 79.67 | -1.08 ** | 119.33 | -0.81 ** | 85.47 | 0.35 ** | 8.83 | 0.04 ns | 29.85 | 0.31 ** | 12.90 |
| Good general combiner | UP2748, HD 3086, UP 2565, WH 1021 | | HD 3086, UP2748, UP2628 | | UP2748,UP2565, WH 1105, HD 3086, UP 2628, HD 2967 | | WH 1105, UP2748, HD 3086, HD 2967 | | WH 1105, UP2748, UP 2565 | | UP2748, HD 3086, WH 1105 | |
| High *per se* performance | HD3086, UP 2748, UP 2565, WH 1021 | | HD3086, UP 2748, | | UP2748, HD 3086,UP2565, WH 1105, UP 2628, HD 2967 | | HD 3086, HD 2967 WH 1105, UP2748, | | WH 1105, UP2748, UP 2565 | | HD3086, UP2748, WH 1105 | |
| Common parent | HD3086, WH 1021 | | HD3086 | | UP2748, UP 2565, WH 1105, UP 2628, HD 2967 | | WH 1105, HD 3086, HD 2967, UP 2748 | | WH 105, UP2748, UP 2565 | | HD3086, UP2748, WH 1105 | |

| Parents | Grains per spike | | 1000-grain weight | | Biological yield/ Plant | | Harvest Index | | Grain yield/ Plants | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Gca | *Per se* | gca | *Per se* | Gca | *Per se* | Gca | *Per se* | Gca | *Per se* |
| HD 2967 | 0.79 ** | 53.67 | -0.60 ** | 41.71 | 3.12 ** | 64.90 | -0.59 ** | 44.07 | 0.78 ** | 28.60 |
| UP2748 | -0.21 ns | 40.43 | 0.52 ** | 38.33 | 0.79 ** | 43.26 | 1.22 ** | 42.30 | 1.36 ** | 18.30 |
| WH 1105 | 3.74 ** | 57.73 | 0.10 * | 39.30 | 1.85 ** | 56.60 | 0.28 ns | 43.29 | 1.27 ** | 24.50 |
| UP2565 | 0.49 ** | 44.64 | 1.35 ** | 41.40 | 0.48 ** | 46.70 | 0.97 ** | 41.78 | 1.05 ** | 19.51 |
| UP2572 | -2.00 ** | 48.60 | -0.23 ** | 44.23 | -1.82 ** | 54.67 | -1.58 ** | 39.67 | -1.64 ** | 21.68 |
| UP 2628 | -1.51 ** | 45.10 | 0.34 ** | 42.30 | -0.00 ns | 58.32 | -1.04 ** | 47.29 | -0.30 ** | 27.58 |
| UP2526 | -0.64 ** | 48.10 | -0.80 ** | 39.20 | -1.31 ** | 50.00 | -0.39 * | 41.40 | -0.94 ** | 20.51 |
| HD3059 | -2.65 ** | 42.30 | -0.75 ** | 38.30 | -1.88 ** | 48.23 | -1.26 ** | 39.24 | -1.94 ** | 18.83 |
| WH1021 | -1.77 ** | 39.37 | -0.63 ** | 38.42 | -3.00 ** | 48.01 | 0.57 ** | 40.62 | -1.26 ** | 19.50 |
| HD3086 | 3.75 ** | 56.20 | 0.69 ** | 42.17 | 1.78 ** | 65.60 | 1.82 ** | 44.46 | 1.62 ** | 29.17 |
| Good general combiner | WH 1105, HD 3086, UP 2565 | | UP2565, HD 3086, UP2748, UP 2628, WH 1105 | | HD 2967, WH 1105, HD 3086, UP 2748,UP 2565 | | HD 3086, UP2748, UP 2565, WH 1021 | | HD 3086, UP2748, WH 1105,UP 2565, HD 2967 | |
| High *per se* performance | WH 1105, HD3086, HD 2967 | | UP 2572, UP 2628, HD 2967, UP 2565, | | HD 3086, HD 2967, UP 2628, WH 1105, UP 2572 | | UP 2628, HD 3086, HD 2967, WH 1105 | | HD 3086, HD 2967, UP 2628, WH 1105, UP 2572 | |
| Common parent based on GCA | WH 1105, HD 3086 | | UP2565, UP 2628 | | HD 3086, HD 2967 | | HD 3086 | | HD 3086, WH 1105 | |

*, ** Significant at 0.05 and 0.01 levels of probability, respectively

grain yield and associated traits are considered good general combiners and could be used in future breeding programs to improve grain yield. Based on the overall study, parent HD 3086 exhibited superior performance, making it suitable for recombination programs to produce superior offspring. Similar findings were reported earlier by Singh *et al.* (2013), Singh *et al.* (2014), Kumar *et al.* (2015), Nagar *et al.* (2018), Kumar *et al.* (2017), Hammam *et al.* (2020) and Tariq and Al-Jubouri (2023).

Since SCA effects are often associated with non-additive genes, they are less relevant in self-pollinated crops like wheat because complementary or linkage effects cannot be easily fixed in pure lines. However, SCA can be beneficial for producing transgressive segregants, which are offspring with traits exceeding those of the parents. SCA analysis of 45 crosses revealed that 21 hybrids exhibited significant SCA effects on grain yield and other associated traits (**Table 3**). The combinations UP 2748 x HD 3059, UP 2565 x HD 3086, WH 1105 x UP 2526, WH 1105 x WH 1021, UP 2748 x UP 2628, UP 2748 x UP 2572, UP 2748 x UP 2565, HD 3059 x WH 1021, UP 2748 x HD 3086, HD 2967 x UP 2572, UP 2565 x WH 1021, UP 2565 x UP 2572, WH 1105 x UP 2628, WH 1105 x HD 3086, UP 2526 x HD 3059, UP 2628 x UP 2526, WH 1105 x UP2565, HD- 2967 x HD3059, UP2748 x UP2526, and UP 2565 x UP 2526 **(Table 4)** were identified as superior combinations for grain yield and yield associated traits but none of the crosses consistently showed better SCA effect for all traits. Notably, the cross UP 2748 x HD 3086 was the best cross for days to heading, HD 2967 x WH 1105 for days to maturity, HD 2967 x UP 2572 for plant height, HD 2967 x WH 1021 for productive tillers per plant, UP 2565 x UP 2526 for flag leaf area, UP 2748 x UP 2572 for spike length, WH 1105 x UP 2526 for grains per spike, UP 2748 x UP 2572 for thousand grain weight, UP 2748 x HD 3059 for biological yield per plant and UP 2572 x WH 1021 for harvest index. Interestingly, most successful crosses involved parents with contrasting GCA effects (high x low), except for UP 2565 x HD 3086, UP 2748 x UP 2565, and WH 1105 x HD 3086 (high x high). This suggested that high specific combining ability was not always linked to high parental GCA effects, potentially due to the importance of intrallelic interaction or additive x additive gene action in high x high combinations.

The current study demonstrates that high x high GCA parents may not always produce the best recombinants.

**Table 3 Best cross combinations with significant and desirable SCA effects for yield and yield-associated traits**

| S. No. | Crosses | SCA effects | GCA effects | | GCA effects of parent | Nature of gene action | Yield contributing traits |
|---|---|---|---|---|---|---|---|
| | | | $P_1$ | $P_2$ | | | |
| 1 | UP 2748 x HD 3059 | 7.86 | 1.36 | -1.94 | H x L | Non-additive | DH, PT, FLA, SL, GS, TGW, BY |
| 2 | UP 2565 x HD 3086 | 7.63 | 1.05 | 1.62 | H x H | Additive | DH, DM, PT, FLA, SL, GS, TGW, BY, HI |
| 3 | WH 1105 x UP 2526 | 6.99 | 1.27 | -0.94 | H x L | Non-additive | PH, PT, FLA, SL, GS, TGW, BY, HI, |
| 4 | WH 1105 x WH 1021 | 6.87 | 1.27 | -1.26 | H x L | Non-additive | PH, PT, FLA, SL, GS, TGW, BY, HI |
| 5 | HD 2967 x WH 1021 | 6.75 | 0.78 | -1.26 | H x L | Non-additive | DH, PT, FLA, SL GS, BY, HI |
| 6 | UP 2748 x UP 2628 | 4.91 | 1.36 | -.30 | H x L | Non-additive | DH, DM, PH, FLA, PT, TGW, SL, GS, BY, HI, |
| 7 | UP 2748 x UP 2572 | 4.11 | 1.36 | -1.64 | H x L | Non-additive | PH, FLA, PT, TGW, SL, GS, BY, HI, |
| 8 | UP 2748 x UP 2565 | 4.16 | 1.36 | 1.05 | H x H | Additive | PH, FLA, SL, GS, BY, HI |
| 9 | HD 3059 x WH 1021 | 3.42 | -1.94 | -1.26 | L x L | Non-additive | PH, PT, SL, GS, TGW, BY, |
| 10 | UP 2748 x HD 3086 | 3.26 | 1.36 | 1.62 | H x L | Non-additive | DH, PT, FLA, SL, GS, TGW, BY |
| 11 | HD 2967 x UP 2572 | 3.02 | 0.78 | -1.64 | H x L | Non-additive | DM, PH, PT, FLA, SL, TGW, HI, |
| 12 | UP 2565 x WH 1021 | 2.70 | 1.05 | -1.26 | L x L | Non-additive | DM, PH, PT, GS, TGW, BY, HI |
| 13 | UP 2565 x UP 2572 | 2.13 | 1.05 | -1.64 | H x L | Non-additive | PH, PT, FLA, SL, TGW, BY, HI |
| 14 | WH 1105 x UP 2628 | 2.13 | 1.27 | -.30 | H x L | Non-additive | PH, PT, FLA, SL |
| 15 | WH 1105 x HD 3086 | 1.48 | 1.27 | 1.62 | H x H | Additive | PT, SL, GS, TGW, HI |
| 16 | UP 2526 x HD 3059 | 1.15 | -0.94 | -1.94 | L x L | Non-additive | DH, DM, PT, GS, TGW, BY, |
| 17 | UP 2628 x UP 2526 | 0.63 | -0.30 | -0.94 | L x L | Non-additive | DH, PH, PT, FLA, SL |
| 18 | WH 1105 x UP2565 | 0.44 | 1.27 | 1.05 | H x H | Additive | DH, SL, GS, TGW, HI |
| 19 | HD- 2967 X HD3059 | 0.41 | 0.78 | -1.94 | H x L | Non-additive | DH, FLA, SL, GS, HI, |
| 20 | UP2748 X UP2526 | 0.21 | 1.36 | -0.94 | H x L | Non-additive | DM, PT, FLA, TGW, |
| 21 | UP 2565 x UP 2526 | 0.22 | 1.05 | -0.94 | H x L | Non-additive | PH, FLA, BY, |

DH= Days to heading, DM = Day to maturity, PH = Plant height, FLA = Flag leaf area, PT = Productive tillers per plant, SL = Spike length, GS= Grains per spike, TGW = Thousand-grain weight, BY = Biological yield per plant, HI = harvest index.

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**Table 4. Elite cross combinations for each trait identified based on SCA effects**

| Character | Cross combination | SCA effects | GCA effects | | GCA effects on parents | Nature of gene action |
|---|---|---|---|---|---|---|
| | | | $P_1$ | $P_2$ | | |
| Days to heading | UP 2748 x HD 3086 | -1.74 | -1.51 | -1.37 | H x H | Additive |
| Days to maturity | HD 2967 x WH 1105 | -3.92 | 0.76 | 0.48 | L x H | Non-additive |
| Plant height (cm) | HD 2967 x UP 2572 | -8.55 | -0.30 | 3.55 | H x L | Non-additive |
| Productive tillers per plant | HD 2967 x WH 1021 | 2.15 | 0.15 | -0.19 | H x L | Non-additive |
| Flag leaf area (cm) | UP 2565 x UP 2526 | 7.63 | 0.51 | 0.74 | H x H | Additive |
| Spike length (cm) | UP 2748 x UP 2572 | 1.38 | 0.32 | -0.40 | H x L | Non-additive |
| Grains per spike | WH 1105 x UP 2526 | 7.80 | 3.74 | -0.64 | H x L | Non-additive |
| 1000-grain weight | UP 2748 x UP 2572 | 3.87 | 0.52 | -0.23 | H x L | Non-additive |
| Biological yield per plant | UP 2748 x HD 3059 | 18.56 | 0.79 | -1.88 | H x L | Non-additive |
| Harvest index | UP 2572 x WH 1021 | 7.73 | -1.58 | 0.57 | L x L | Non-additive |
| Grain yield per plant | UP 2748 x HD 3059 | 7.86 | 1.36 | -1.94 | H x L | Non-additive |

Conversely, crosses involving parents with contrasting GCA effects (high x low) can generate transgressive segregants due to dominance gene interactions. These findings align with previous research by Singh *et al.* (2007), Singh *et al.* (2012), Singh *et al. (*2013), Rahul *et al.* (2017), Kumar *et al.* (2017), Rania A. R. El-Said (2018), Khokhar *et al.* (2019), Nagar *et al.* (2020), Joshi *et al.* (2020) and Bilgin *et al*., (2022).

The study identified five parents-HD3086, UP2748, WH1105, UP2565, and HD2967 – as promising due to their good general combining ability for yield and related traits. These parents can be directly used in breeding programs to enhance grain yield in wheat. Furthermore, specific crosses, such as UP2748 x HD3059 and UP 2565 x HD 3086, showed significant potential for improving grain yield and associated characteristics in future bread wheat breeding efforts. These promising crosses likely benefit from both additive and non-additive gene effects. Breeding approaches like bi-parental mating and diallel selective mating could be particularly effective in improving bread wheat characteristics. These methods allow for crosses between selected parents in multiple cycles, maximizing the utilization of both additive and non-additive genetic effects.

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