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Hybrid Vigour and Combining Ability in Biofortified Maize (*Zea mays* L.)

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ABSTRACT

The study was conducted during *winter* season of 2020–2021 and *rainy* season of 2021 at Maize Research Station, Sardarkrushinagar Dantiwada Agricultural University, Bhiloda, Gujarat, India. The aim of the study was to assess magnitude of heterosis and combining ability of forty-five single cross hybrids developed by half-diallel mating design involving ten parents and two standard checks. The field experiment was laid out in randomized block design with three replications. The heterosis, combining ability and components of genetic variance were studied for diverse thirteen characters. The analysis of variance revealed that mean square values of genotypes were significant for all the characters which indicated the existence of considerable amount of genetic variation in genotypes for all the characters. Among single crosses, IMR-76×IMR-58 exhibited maximum mean and desired SCA effect and standard heterosis for β-carotene and IMR-53×IMR-72 for kernel yield. The general and specific combining ability variances observed highly significant for all traits except days to tasseling (only additive gene action), anthesis-silking interval and shelling percentage (only non-additive gene action). The σ^2_A/σ^2_D ratio indicated that preponderance of non-additive gene action for the inheritance of these characters suggesting due weightage should be given to heterosis breeding for genetic improvement of these traits. The crosses namely IMR-52×IMR-72 and IMR-51×IMR-58 presented significant heterosis for days to maturity, grain yield, iron and β-carotene content.

KEYWORDS: β-carotene, biofortified, combining ability, half-diallel mating, heterosis, maize

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Data Availability Statement: Legal restrictions are imposed on the public sharing of raw data. However, authors have full right to transfer or share the data in raw form upon request subject to either meeting the conditions of the original consents and the original research study. Further, access of data needs to meet whether the user complies with the ethical and legal obligations as data controllers to allow for secondary use of the data outside of the original study.

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1. INTRODUCTION

Maize (*Zea mays* L.) is the most important food grain in India after wheat and rice. Increased demand from diverse sectors such as human food, animal feed, and also services, maize has gained significant importance globally as a source of fundamental raw material for a variety of businesses. (Bisen et al., 2017). From semi-desertic conditions to tropical rainforests, maize can be grown widely upto 3000 m altitude mean sea level which constitute it as key staple food crop in underdeveloped nations (Fonteyne et al., 2021, Ram et al., 2017). Among the cereals, it has advantage of being the only crop that contains appreciable amount of carotenoid, in particular β-carotenoid content about 6 to 11 ppm (Trono, 2019, Yang et al., 2018) with wide range of variability in maize breeding for improved nutritional quality (Darshan and Marker, 2019). Prolamine (Zein) is the primary protein found in maize. (Khan et al., 2016, Larkin et al., 2017, Tripathy et al., 2017) Vitamin A deficiency can cause symptoms such as, night blindness, fatigue, skin issues, and a weakened immune system. Severe vitamin A problems can lead to blindness. (Debelo et al., 2017, Wiseman et al. 2017) Carbohydrate (71.88 g), protein (8.84 g), fat (4.57 g), and fiber (4.57 g) make up the nutritional content of a 100 g edible quantity of maize (Shah et al., 2016).

Micronutrients are important in a well-balanced diet that contains a range of fruits, vegetables, and animal products. (Lal et al., 2020, Gush et al., 2021, Martiniakova et al., 2022). Micronutrient deficits not cause visible hunger consequences but cause undesirable physiologic manifestations. As a result, these micronutrient deficiencies are referred to as "hidden hunger." (Lowe, 2021, Harding et al., 2018, Masuda et al., 2020) Iron (Fe) and zinc (Zn) deficiencies have been claimed to be the most prevalent, affecting more than two billion people globally, mainly in underdeveloped nations. (Webb et al., 2018, Kramer and allen, 2015) Balanced and appropriate nutrition intake and metabolism offer the substrates for the human body's regular physiological activities, which can be fulfilled by the higher amount of macronutrients like carbohydrates, proteins and fats supplemented in a moderate quantity and minuscule amount of micronutrients like Fe, Zn, Cu, I and Se are most important (Kiani et al., 2022). Nevertheless, millions of people, mostly in underdeveloped nations, rely on basic foods to keep their tummies full. These foods do not provide them enough micronutrients. Micronutrient deficiencies continue to be a problem in developing nations, particularly in Sub-Saharan Africa and Southeast Asia. Micronutrient deficiency affects around two billion people worldwide, or one out of every three people (Anonymous, 2015). The ultimate measure of maize breeding success is the demand for and acceptance of novel varieties by end users (Ekpa at al., 2018). Biofortification focus on improving the mineral nutritional properties of crops at the source, which include procedures that enhance mineral content and bioavailability in staple crops' edible parts (Singh et al., 2016, Dhaliwal et al., 2022, Butari et al., 2021). It is a way of improving the nutritional content of crops through breeding. The purpose of biofortification is to reduce the high frequency of specific nutritional deficiencies, such as iron, zinc, and Vitamin-A particularly in low-income communities (Wakeel et al., 2018, Ohanenye at al., 2018). This will be accomplished by increasing the micronutrient density of staple food crops grown and consumed by these communities, as well as enhancing the adequacy of micronutrient intakes if bioavailability can be established. Biofortification is meant to help avoid micronutrient deficiencies by reaching all members of the household.

2. MATERIALS AND METHODS

2.1. Field experiment

The study was conducted during *rabi* 2020-2021 and *kharif* 2021 at Maize Research Station, Sardarkrushinagar Dantiwada Agricultural University, Bhiloda, Gujarat, India. Ten parental lines viz. IMR-66, IMR-76, IMR-51, IMR-58, IMR-52, IMR-53, IMR-71, IMR-72, IMR-65 and IMR-61 available at Maize Research Station, S. D. Agricultural University, Bhiloda were crossed in a half diallel mating design to produce 45 single cross hybrids during *rabi* of 2020–21. The parents, hybrids and standard checks viz., APQH-5 and GDYMH-101 were evaluated in complete randomized block design with three replication during *kharif* 2021 at Maize Research Station, S. D. Agricultural University, Bhiloda, Gujarat, India. Different traits like days to tasseling, days to silking, anthesis silking interval, days to maturity, plant height, primary ear height, cob weight plant^{-1}, shelling percentage, seed index, kernel yield plant^{-1}, iron, zinc and β-carotene content were studied.

2.2. Statistical analysis

The data were analyzed using RBD analysis. The diallel analysis was done using method 2, on model 1 (Griffing, 1956) for combining ability of parents and hybrids, followed by relative heterosis (Turner, 1953) and heterobeltiosis (Fonseca and Patterson, 1968). Standard heterosis estimated using mean of the standard checks.

3. RESULTS AND DISCUSSION

The result of analysis of variance for different characters under study is presented in Table 1. The results revealed that mean square value due to genotypes found significant for all the characters. This indicated that materials had adequate genetic variability and this might

Table 1: Analysis of variance for characters under study in maize

Source of variation	Mean sum of square							
	Degree of freedom	Days to tasseling	Days to silking	Anthesis -Silking Interval	Days to maturity	Plant height	Primary ear height	Cob weight plant^{-1}
Replications	2	10.71	4.11	0.16	1.70	443.82	102.17	299.13
Genotypes	56	6.55*	5.51**	0.90**	31.60**	687.47**	427.23**	818.34**
Parents	9	3.63	2.09	0.55	25.94**	875.51**	379.00**	2310.18**
Hybrids	44	5.02	4.43**	0.89**	28.54**	421.62**	323.24**	494.61**
Parents vs. Hybrids	1	1.56	1.29	0.51	131.94**	9744.14**	3392.44**	2856.70**
Checks vs. Hybrids	1	66.99*	54.16**	4.54**	100.62**	1224.91*	1584.98**	250.86
Between checks	1	42.67*	37.50*	0.67	66.67**	400.17	864.00*	291.21
Error	112	4.11	2.27	0.45	0.72	167.89	99.59	188.65
Total	170	4.99	3.36	0.59	10.90	342.29	207.55	397.38

Table 1: Continue...

Source of variation	Mean sum of square						
	Degree of freedom	Shelling percentage	Seed Index	Kernel yield plant^{-1}	Iron content	Zinc content	β- carotene content
Replications	2	0.85	19.20	234.52	46.04	6.48	0.08
Genotypes	56	28.47**	12.89**	557.88**	608.81**	164.71**	7.70**
Parents	9	6.38	22.98**	1391.06**	108.08**	50.83**	6.33**
Hybrids	44	32.16**	11.21*	353.47**	740.33**	195.40**	7.85**
Parents vs. Hybrids	1	71.21*	17.05	2747.91**	158.31**	11.39	11.01**
Checks vs. Hybrids	1	60.94	1.44	426.93	422.90	144.12	8.58
Between checks	1	0.20	4.17	161.20	5.90	19.37	10.44*
Error	112	12.19	7.26	130.91	22.37	4.75	0.25
Total	170	17.42	9.26	272.78	215.83	57.46	2.70

*, **: indicate level of significance at (p=0.05) and (p=0.01), respectively

be attributed to diverse parents. The genotypic variance was further partitioned into Parents, hybrids, Parent *vs* hybrids, Checks vs. Hybrids and between checks. The variance due to parents were found significant for the characters like; days to maturity, plant height, primary ear height, cob weight, seed index, kernel yield plant^{-1}, iron, zinc and β-carotene. These findings indicated that significant variability was existed in parents for these traits.

The mean square due to hybrids indicated significant difference for all the traits under study except days to tasseling. These differences may be due to better combination of genes derived from the diverse parents for maximization of hybrid vigour in respect of kernel yield and its components and quality traits. The analysis of variance for parents *vs* hybrid revealed significant difference among them for all the characters under study except days to tasseling, days to silking, anthesis- silking interval, seed index and zinc content which suggested the existence of differences between parents and hybrids for the characters leading to manifestation of heterosis.

The mean square due to checks *vs* hybrids indicated significant difference for the traits like days to tasseling, days to silking, anthesis silking interval, days to maturity, plant height and primary ear height. The analysis of variance between checks revealed significance for days to tasseling, days to silking, days to maturity, primary ear height and β-carotene content in seed. In present study, two standard checks were used in which GDYMH-101 is local check for kernel yield while, APQH-5 is recommended for Gujarat condition with enhanced pro-vitamin A content, which is clearly reflected in the present study.

The analysis of variance for combining ability of different traits presented in following Table 2. Here, for days to tasseling estimates of only σ^2_{gca} was significant, hence only

Table 2: Analysis of variance components (Mean sum of square) of combining ability for different characters

Source of variation	Mean sum of square							
	Degree of freedom	Days to tasseling	Days to silking	Anthesis -Silking Interval	Days to maturity	Plant height	Primary ear height	Cob weight plant^{-1}
GCA	9	2.57*	1.94*	0.28	17.25**	494.504**	259.85**	470.83**
SCA	45	1.38	1.21*	0.28**	8.56**	169.08**	103.78**	242.21**
Error	108	1.38	0.75	0.15	0.24	56.54	33.3	60.73
σ^2_{gca}		0.099*	0.099*	0.011	1.417**	36.496**	18.879**	34.175**
σ^2_{sca}		-0.003$^{\#}$	0.453*	0.130**	8.318**	112.540**	70.474**	181.484**
$\sigma^2_{gca}/\sigma^2_{sca}$		-33.00	0.218	0.082	0.170	0.324	0.268	0.188
σ^2_A		0.198	0.197	0.021	2.834	72.974	37.758	68.349
σ^2_D		-0.003	0.453	0.130	8.318	112.540	70.474	181.484
σ^2_A/σ^2_D		-66.00	0.43	0.16	0.34	0.65	0.54	0.38

Table 2: Continue...

Source of variation	Mean sum of square						
	Degree of freedom	Shelling percentage	Seed Index	Kernel yield plant^{-1}	Iron content	Zinc content	β-carotene content
GCA	9	6.10	7.37**	288.75**	325.42**	96.69**	1.95**
SCA	45	10.22**	3.84*	170.55**	184.59**	47.82**	2.67**
Error	108	4.18	2.40	42.84	7.53	1.59	0.08
σ^2_{gca}		0.160	0.415**	20.492**	26.491**	7.925**	0.155**
σ^2_{sca}		6.032**	1.442*	127.711**	177.054**	46.228**	2.591**
$\sigma^2_{gca}/\sigma^2_{sca}$		0.026	0.287	0.160	0.150	0.171	0.060
σ^2_A		0.320	0.829	40.985	52.982	15.850	0.310
σ^2_D		6.032	1.442	127.711	177.054	46.228	2.591
σ^2_A/σ^2_D		0.05	0.57	0.32	0.30	0.34	0.12

*, **: indicate level of significance at (p=0.05) and (p=0.01), respectively; #: Negative estimates not used for analysis

additive gene action for the trait. For anthesis-silking interval and shelling percentage only σ^2_{sca} was significant indicating role of only non- additive gene action for inheritance. While, for remaining all the traits, days to silking, days to maturity, plant height, cob weight, seed index, kernel yield plant^{-1}, iron, zinc and β-carotene content both σ^2_{gca} and σ^2_{sca} were significant indicating role of both additive and non-additive gene action. In such cases, ratio of σ^2_A/σ^2_D was indicative to study the greater role of either gene action. Which depicted less than 1.0 indicating greater role of non-additive gene action for inheritance of these traits. The presence of only non-additive gene action or prime role of non-additive genetic variance for inheritance of these traits indicating greater amount of heterosis and adoption of heterosis breeding methodology for improvement of these traits. Above results are similar to the findings of Rajitha et al. (2014), Abdulazeez et al. (2021) and Dhanawade (2021) in maize.

Based on the study of all forty-five hybrid with their parents for various traits, the three combination namely, IMR-53×IMR-72, IMR-52×IMR-72 and IMR-51×IMR-58 (Table 3) showed significant heterosis over mid parent, better parent and both the checks except for IMR-51×IMR-58 over better parent for kernel yield plant^{-1}. In addition to these, three hybrids were top three for *per se* performance and depicted significant SCA effect in desired direction for the trait. Based on classification of parents it can be concluded that top yielding combinations involve Average×Poor and Average×Good interactions. The parent, IMR-72 was common in two crosses which ranked on top three on the basis of specific combining ability effects for kernel yield. Also, these three crosses found to have significant standard heterosis for days to maturity, cob weight, shelling percentage, iron and β-carotene content in seed. The characters like β-carotene, iron and zinc content

Table 3: Promising crosses for kernel yield plant^{-1} with heterosis over standard check hybrids, better parent and mid parent, their SCA effects and component traits showing significantly desired standard heterosis

Sl. No.	Promising hybrids	Mean of Kernel yield plant^{-1} (g)	Per cent heterosis over				SCA effects	Classification of parents for kernels yield	Other traits found with desirable direction for standard heterosis over both the checks
			Mid parent	Better parent	Standard check : APQH-5	Standard check : GDYMH-101			
1.	IMR-53×IMR-72	106.73	71.18**	44.89**	34.99**	55.36**	19.50**	A×G	Days to maturity, cob weight
2.	IMR-52×IMR-72	103.47	51.27**	40.45**	30.86**	50.61**	17.35**	A×G	Days to maturity, shelling percentage, iron content, β-carotene
3.	IMR-51×IMR-58	97.87	30.55**	-6.32	23.78*	42.46*	13.10*	G×A	Days to maturity, iron content, β-carotene

*, **: indicate level of significance at (p=0.05) and (p=0.01), respectively

in seed are important quality characters, in which β-carotene content is the trait which is a precursor to Vitamin A and through biofortification it can be exploited.

For β-carotene content, three crosses combination *viz,* IMR-76×IMR-58, IMR-52×IMR-53 and IMR-51×IMR-72 (Table 4) recorded maximum *per se* performance. They also presented significantly desirable all three types heterosis and specific combining ability effect for β-carotene content. Here, these crosses combination showed significantly standard heterosis over both the checks for other components traits also viz, days to maturity, shelling percentage iron and zinc content. Based on classification of parents it can be concluded that parents either poor or poor and average general combiner for β-carotene content gave superior good SCA effects. These results are accordance with the findings of Muthuswamy et al., 2016 and Ambikabathy et al., 2019

The potentiality of a parent in hybridization may be assessed by its *per se* performance and GCA effects while, for hybrid it assessed by *per se* and SCA and heterotic effects. For the present study, three top ranking parents for *per se* performance and GCA effects and three best hybrids selected on basis of *per se* performance, SCA and heterosis over mid parent, better parent and standard check for different characters have been presented in Table 5. A perusal of this revealed that the best performing hybrids were found to be different from the best heterobeltiosis hybrids for all most all the characters. Therefore, while selecting a cross, one has to look both aspects *i.e.* degree of heterosis exhibited and *per se* performance of the cross.

Looking, the performance of top three parents, the parent, IMR-61 and IMR-71 depicted good *per se* performance for days to tasseling, days to silking and anthesis-silking interval. While, based on GCA effect IMR-65 (days to tasseling and days to silking) and IMR-51 (anthesis-silking interval) were good general combiners. The parent, IMR-72 depicted desirable mean performance for days to maturity and zinc content in seed. While, based on GCA effect, IMR-66 found significant for days to maturity, plant height, primary ear height and iron content. The parent, IMR-52, possesses good *per se* performance for β-carotene and iron content in the seed. For hybrid, IMR-51×IMR-52, IMR-65×IMR-61 and IMR-66×IMR-65 were good for days to tasseling for mean performance and standard heterosis. The crosses, IMR-58×IMR-65, IMR-52×IMR-65 and IMR-71×IMR-61 were good for mean performance, relative heterosis and standard heterosis for days to silking. The GCA effects of parents involved in combinations, expressed significant SCA effects for most traits had at least one parent as good general combiner. Therefore, it can be concluded that in order to get high frequency of significant SCA effects at least one parent should possess good GCA effects particularly for kernel yield plant^{-1}. Nine crosses depicted positive desirable significant SCA effects for grain yield and eighteen crosses for β-carotene in seed.

Table 4: Promising crosses for β-carotene content in seed with heterosis over standard check hybrids, better parent and mid parent, their SCA effects and component traits showing significant desired standard heterosis

Sl. No.	Promising hybrids	Mean of β carotene content (ppm)	Per cent heterosis over: Mid parent	Per cent heterosis over: Better parent	Per cent heterosis over: Standard check : APQH-5	Per cent heterosis over: Standard check : GDYMH-101	SCA effects	Classification of parents for β-carotene content	Other traits found with desirable direction for standard heterosis over both the checks
1.	IMR-76×IMR-58	9.39	31.09**	25.25**	36.45**	121.30**	2.96**	P×A	Days to maturity
2.	IMR-52×IMR-53	9.34	55.38**	23.63**	35.79**	120.24**	2.3**	G×P	Days to maturity, shelling percentage, zinc content
3.	IMR-51×IMR-72	9.27	125.02**	96.33**	34.70**	118.46**	2.81**	P×A	Days to maturity, iron content, zinc content

*, **: indicate level of significance at (*p*=0.05) and (*p*=0.01), respectively

Table 5: Top three of the parents and F_1s for *per se* performance, combining ability effects and heterosis estimates for various traits

Characters	Parents: *Per se* performance	Parents: GCA effects	F_1s: *Per se* performance	F_1s: SCA effects	F_1s: Per cent heterosis over: Mid parent	F_1s: Per cent heterosis over: Better parent	F_1s: Per cent heterosis over: Standard check : APQH-5	F_1s: Per cent heterosis over: Standard check : GDYMH-101
Days to tasselling	IMR-61 IMR-76 IMR-71	IMR-65**	IMR-51×IMR-52 IMR-65×IMR-61 IMR-66×IMR-65	-	IMR-51×IMR-52*	-	IMR-65×IMR-61** IMR-51×IMR-52** IMR-66×IMR-65**	-
Days to silking	IMR-71 IMR-61 IMR-53	IMR-65**	IMR-58×IMR-65 IMR-52×IMR-65 IMR-71×IMR-61	-	IMR-51×IMR-52* IMR-52×IMR-65*	-	IMR-58×IMR-65** IMR-52×IMR-65** IMR-71×IMR-61**	IMR-58×IMR-65
Anthesis silking interval	IMR-51 IMR-61 IMR-71	IMR-51**	IMR-76×IMR-65 IMR-76×IMR-72 IMR-66×IMR-76	IMR-76×IMR-65**	IMR-76×IMR-72*	-	IMR-76×IMR-65** IMR-76×IMR-72** IMR-66×IMR-76**	-

Table 5: Continue...

Characters	Parents		F_1s					
			Per se performance	SCA effects	Per cent heterosis over			
	Per se performance	GCA effects			Mid parent heterosis	Better parent heterosis	Standard check over APQH-5	Standard check over GDYMH-101
Days to maturity	IMR-72 IMR-65 IMR-71	IMR-66** IMR-65** IMR-71**	IMR-66×IMR-65 IMR-66×IMR-53 IMR-66×IMR-52	IMR-66×IMR-52** IMR-76×IMR-58** IMR-58×IMR-61**	IMR-66×IMR-52** IMR-66×IMR-53* IMR-66×IMR-65**	IMR-66×IMR-52** IMR-66×IMR-53** IMR-66×IMR-65**	IMR-66×IMR-65** IMR-66×IMR-52** IMR-66×IMR-53**	IMR-66×IMR-65** IMR-66×IMR-52** IMR-66×IMR-53**
Plant height (cm)	IMR-71 IMR-53 IMR-61	IMR-66**	IMR-66×IMR-58 IMR-66×IMR-51 IMR-66×IMR-61	IMR-76×IMR-61** IMR-51×IMR-52** IMR-58×IMR-72**	-	-	IMR-66×IMR-58** IMR-66×IMR-51* IMR-66×IMR-61	IMR-66×IMR-58** IMR-66×IMR-51* IMR-66×IMR-61*
Primary ear height (cm)	IMR-61 IMR-65 IMR-71	IMR-66**	IMR-76×IMR-61 IMR-66×IMR-71 IMR-51×IMR-52	IMR-76×IMR-61** IMR-58×IMR-72** IMR-51×IMR-52**	-	-	IMR-76×IMR-61** IMR-66×IMR-71** IMR-51×IMR-52**	IMR-76×IMR-61** IMR-66×IMR-71* IMR-51×IMR-52*
Cob weight plant^{-1} (g)	IMR-76 IMR-51 IMR-66	IMR-76** IMR-51** IMR-72**	IMR-53×IMR-72 IMR-51×IMR-58 IMR-76×IMR-53	IMR-58×IMR-61** IMR-53×IMR-72** IMR-51×IMR-58**	IMR-58×IMR-61** IMR-53×IMR-71** IMR-58×IMR-52**	IMR-53×IMR-71** IMR-58×IMR-61** IMR-58×IMR-53**	IMR-53×IMR-72*	IMR-53×IMR-72** IMR-51×IMR-58** IMR-76×IMR-53**
Shelling percentage	IMR-71 IMR-58 IMR-61	-	IMR-52×IMR-53 IMR-76×IMR-61 IMR-52×IMR-72	IMR-76×IMR-61** IMR-52×IMR-53** IMR-52×IMR-72*	IMR-52×IMR-53** IMR-52×IMR-72** IMR-76×IMR-61**	IMR-52×IMR-53* IMR-52×IMR-72*	IMR-52×IMR-53** IMR-76×IMR-61** IMR-52×IMR-72*	IMR-52×IMR-53** IMR-76×IMR-61** IMR-52×IMR-72*
Seed index	IMR-51 IMR-76 IMR-52	IMR-52** IMR-51**	IMR-52×IMR-72 IMR-52×IMR-65 IMR-52×IMR-61	IMR-52×IMR-72** IMR-52×IMR-65* IMR-53×IMR-65*	IMR-53×IMR-65** IMR-58×IMR-53** IMR-52×IMR-65**	IMR-58×IMR-53* IMR-53×IMR-65*	-	IMR-52×IMR-72* IMR-52×IMR-65* IMR-52×IMR-61*
Kernel yield plant^{-1} (g)	IMR-76 IMR-51 IMR-66	IMR-51** IMR-76** IMR-72**	IMR-53×IMR-72 IMR-52×IMR-72 IMR-51×IMR-58	IMR-58×IMR-61* IMR-53×IMR-72** IMR-52×IMR-72**	IMR-58×IMR-61** IMR-53×IMR-71** IMR-53×IMR-72**	IMR-53×IMR-71** IMR-58×IMR-53** IMR-58×IMR-61**	IMR-53×IMR-72** IMR-52×IMR-72** IMR-51×IMR-58*	IMR-53×IMR-72** IMR-52×IMR-72** IMR-51×IMR-58**

Table 5: Continue...

Characters	Parents		F$_1$s					
			Per se performance	SCA effects	Per cent heterosis over			
	Per se perfor-mance	GCA effects			Mid parent heterosis	Better parent heterosis	Standard check over APQH-5	Standard check over GDYMH-101
Iron content (ppm)	IMR-52 IMR-71 IMR-53	IMR-66** IMR-71** IMR-72**	IMR-66×IMR-51 IMR-71×IMR-72 IMR-53×IMR-71	IMR-66×IMR-51** IMR-76×IMR-51** IMR-72×IMR-61**	IMR-66×IMR-51** IMR-76×IMR-51** IMR-76×IMR-53**	IMR-76×IMR-51** IMR-66×IMR-51** IMR-65×IMR-61**	IMR-66×IMR-51** IMR-71×IMR-72** IMR-53×IMR-71*	IMR-66×IMR-51** IMR-71×IMR-72*
Zinc content (ppm)	IMR-72 IMR-71 IMR-51	IMR-51** IMR-52** IMR-72**	IMR-52×IMR-71 IMR-51×IMR-72 IMR-51×IMR-52	IMR-52×IMR-71** IMR-51×IMR-72** IMR-72×IMR-61**	IMR-52×IMR-71** IMR-51×IMR-52** IMR-72×IMR-61*	IMR-52×IMR-71** IMR-51×IMR-52** IMR-51×IMR-72**	IMR-52×IMR-71** IMR-51×IMR-72** IMR-51×IMR-52**	IMR-52×IMR-71** IMR-51×IMR-72** IMR-51×IMR-52**
β-carotene content (ppm)	IMR-52 IMR-76 IMR-71	IMR-61** IMR-52**	IMR-76×IMR-58 IMR-52×IMR-53 IMR-51×IMR-72	IMR-76×IMR-58** IMR-51×IMR-72** IMR-51×IMR-53**	IMR-51×IMR-72** IMR-51×IMR-53** IMR-51×IMR-58**	IMR-51×IMR-53** IMR-51×IMR-72** IMR-72×IMR-65**	IMR-76×IMR-58** IMR-52×IMR-53** IMR-51×IMR-72**	IMR-76×IMR-58** IMR-52×IMR-53** IMR-51×IMR-72**

*, **: indicate level of significance at (p=0.05) and (p=0.01), respectively

4. CONCLUSION

For β-carotene, exhibited exceptional amounts of positive directional standard heterosis (IMR-76×IM2R-58, IMR-52×IMR-53 and IMR-51×IMR-72) and kernel yield (IMR- 53×IMR-72, IMR-52×IMR-72 and IMR-51×IMR-58). IMR-76, IMR- 51 and IMR- 72 for kernel yield; IMR-52 for β-carotene, iron, zinc content were recorded as good general combiners. IMR-52×IMR-72 and IMR-51×IMR-58 showed significance of heterosis for days to maturity, grain yield, iron and β-carotene which could be evaluated extensively and advanced to obtain desirable segregants for β-carotene content, grain yield and its component traits simultaneously.

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