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Heterosis and combining ability studies for yield and yield component traits in rice (*Oryza sativa* L.)

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Abstract
The present investigation was carried during *Kharif* 2021 at Navsari Agricultural University, Navsari (Gujarat) to estimate the combining ability and to determine the nature and magnitude of heterosis for yield and yield component traits in rice. The experimental material consisted of 28 hybrids produced by crossing seven lines with four testers in Line x Tester design. Analysis of variance for combining ability revealed that, mean squares of lines, testers and line x testers was highly significant for the traits like productive tillers per plant, grains per panicle, kernel length and 100 grain weight indicated that these traits were governed by both gene actions, among which the predominant gene action was additive for the former three traits while, non-additive for latter last one in pooled over the environments. The other traits *viz*., days to 50 per cent flowering, panicle length, grain yield per plant and straw yield per plant were governed by additive gene action whereas, plant height, kernel breadth, L:B ratio, protein content and amylose content were governed by non-additive gene action. Among the parents; NVSR-418, NWGR-15018, NVSR-6172 and NVSR-494 were good general combiners for grain yield per plant and most of the yield components. The parents *viz*., NVSR-496, NVSR-418, NVSR-2103 and NVSR-494 were good general combiners for earliness whereas, parents *viz*., GNR-3, NVSR-2103, NVSR-496, NVSR-6206 and GR-17 were ideal for dwarf plant stature. In case of heterosis, highly significant and positive heterosis over better parent and standard check for grain yield and its component characters among which, highly significant and standard heterosis suggested that there is ample scope of exploiting heterosis commercially. The hybrid NWGR-15018 x NVSR-418 manifested the highest heterosis over the standard check (37.77%) with high grain yield per plant followed by NVSR-453 x NVSR-418 (33.58%), NVSR-6206 x NVSR-418 (31.47%) and NVSR-494 x NVSR-418 (31.33%) while hybrids, NVSR-453 x NVSR-418 exhibited higher heterobeltiosis (36.30%) followed by NVSR-6206 x NVSR-418 (34.15%), NWGR-15018 x NVSR-418 (33.70%) and NVSR-494 x NVSR-418 (32.79%) over the environments.

Keywords: Heterosis, GCA, SCA, combining ability

Introduction
"Rice is life" was the famous theme of International Year of Rice, 2004 which denoting its importance as an item of food and commerce. Rice (*Oryza sativa* L.) is the world's single most important crop and a primary food source for half of the human kind on the planet. The living and livelihood of majority of the Indian farming population also depends on growing rice. It is the grain that has created and shaped the religions, communities, cultures, diets and economies of millions of people in society as well as occupies a significant position in the culture and heritage of many Asian countries.

Today rice is grown in every continent excluding Antarctica. The world's largest rice producers by far are China and India. Although its area harvested is lower than India's, China's production is greater due to higher yields because nearly all of China's rice area is irrigated, whereas less than half of India's rice area is irrigated.

In breeding point of view, selection of right type of breeding material is crucial step for plant breeder in developing the high yielding varieties or hybrids. The most important is, breeding methods to be adopted for improvement of any crop depends on the nature of gene action involved in the inheritance of economically important traits. The line x tester analysis is a powerful tool in selecting appropriate parental material and predicting type of gene action involved in the inheritance of economically important trait. It also helps in distinguishing good as well as poor combiners.

For the succession in a breeding programme, the method of parental selection for hybridization is considered as a basic factor. Here, line x tester technique which was developed by Kempthorne (1957) [22] is used. Of the various approaches, exploitation of heterosis is considered as one of the desirable and suitable approach. Heterosis reveals the type of gene action involved and it helps in the selection of suitable breeding methodology and parameters, which are employed for crop improvement programme. Heterotic studies can also provide the basis for exploitation of valuable hybrid combinations and their commercial utilization in future breeding programme (Chowdhury *et al*., 2010) [12].

The general combining ability give the information about additive and additive x additive gene action whereas, specific combining ability about the non-allelic interaction and dominance gene action. The knowledge of general combining ability and specific combining ability effects with their variance determines the ability of parent and crosses for involving them in an effective breeding programme (Kamboj *et al*., 2017) [21].

Material and Methods

The present investigation was undertaken during *summer*-2020 to *kharif*-2021 to study the nature and magnitude of heterosis for yield and its component traits, general combining ability of the parental lines as well as specific combining ability of their hybrids 21 hybrids generated from crossing seven lines (NVSR- 494, NWGR- 15018, NVSR-496, NVSR- 453, NVSR- 6172, NVSR- 6206 and NVSR-494) and four testers (GR-17, GNR-3, NVSR-418 and NVSR-6287) in L x T fashion along with eleven parents and one checks "Gurjari'' in a randomized block design with three replications.

One month old seedlings were transplanted in thoroughly puddled main field with a spacing of 20 x 15 cm. All necessary precautions were taken to maintain uniform plant population in each treatment per replication. Observations were recorded on 05 randomly selected plants from each cross for thirteen characters *viz.*, Days to 50% flowering, productive tillers per plant, plant height (cm), panicle length (cm), grains per panicle, grain yield per plant (g), straw yield per plant (g), kernel length (mm), kernel breadth (mm), L:B ratio, 100 grain weight (g), protein content (%) and amylose content (%).

Heterosis was estimated over better parent and standard check and tested for significance as suggested by Fonseca and Patterson (1968) and combining ability analysis was computed using Line x Tester design according to Kempthorne (1957) [22].

Result and Discussion

The analysis of variance for combining ability revealed highly significant differences among the crosses with respect to all the characters studied (Table 1). Analysis of variance for combining ability over the environments revealed that mean sum of squares due to environments were highly significant for all the traits. The mean sum of squares due to females were significant for majority of the traits in the over the environment analysis except plant height, panicle length, grain yield per plant, straw yield per plant, protein content, and amylose content. The mean sum of squares due to males were significant all the traits over the environment analysis except days to 50 per cent flowering, kernel breadth and L:B ratio.

The mean sum of squares due to females x males were manifested highly significant for all traits (except plant height and grains per panicle at Navsari, grain yield per plant at Waghai, kernel length at Navsari and 100 grain weight at Navsari). The interaction of mean sum of square due to hybrids x environments were significant for all characters (except amylose content) indicating that test crosses presented differential performance in the testing environments (Widyastuti *et al*., 2017) [49].

The interaction of mean sum of squares due to females x environments were non-significant for all the traits (kernel length, kernel breadth and L: B ratio). The interaction mean sum of squares due to males x environments were significant for straw yield per plant and protein content only inbred lines performed differently as reflected in their respective test crosses from one environment to another (Widyastuti *et al*., 2017) [49].

On the other hand, the mean sum of squares due to (f x m) x environments were significant for all the characters except amylose content. These findings indicated that these are different ranks of interaction of inbred lines (parental) in their test crosses from one environment to another that appeared in grain yield (Widyastuti *et al*., 2017) [49].

Both σ^2 *gca* and σ^2 *sca* were significant for days to 50 per cent flowering, productive tillers per plant, plant height, panicle length, grains per panicle, straw yield per plant, kernel length, kernel breadth, 100 grain weight and amylose content oner the environments, suggested that, both additive and non-additive variances were important in the expression of these characters. Similar results were reported by, Attia *et al*. (2001), Kamboj *et al.* (2017) and Singh *et al*. (2020) [5, 21, 52].

However, the magnitude of σ2 *gca* /σ2 *sca* ratios depicted greater importance of additive variances in the inheritance of majority traits studied. Similar results were also reported by Akter *et al*. (2010), Bhadru *et al*. (2013), Goswami (2018), Bano and Singh (2019), Ghidan *et al*. (2019), Patel *et al*. (2019), Dianga *et al*. (2020), Kulkarni *et al*. (2020) and Sameer *et al*. (2020) [2, 8, 17, 7, 16, 28, 14, 24, 35].

Analysis of variance for combining ability revealed that, females contributed maximum to parental variation as compared to males for the traits *viz*., days to 50 per cent flowering, productive tillers per plant, plant height, panicle length, grains per panicle, grain yield per plant, straw yield per plant and 100 grain weight while, males contributed more for the traits like, kernel length, kernel breadth, L: B ratio, protein content and amylose content.

General combining ability effects of parents revealed that, out of 11 parents, four parents *viz.*, NVSR-494, NWGR-15018, NVSR-6172 and NVSR-418 recorded highly significant and positive *gca* effects and five parents showed highly significant and negative *gca* effects over the environments. Out of 11 parents, two had recorded the significant and positive *gca* effect (NWGR-15018 and NVSR-418). Hence, they were ideal general combiners. Thus, it exposed that these parents possessed favourable genes for higher grain yield.

The second important criterion for the evaluation of hybrids is the specific combining ability effects which could be related with hybrid vigour. The *sca* effects signify the role of non-additive gene action in trait expression. According to Ping and Virmani (1990) [47], *sca* effects are the index to determine the usefulness of a particular cross combination for exploitation of heterosis. Out of 28 crosses the cross NWGR-15018 x GR-17, NVSR-6172 x GR-17, NVSR-6206 x NVSR-418 and NVSR-6206 x NVSR-6287 recorded significant *sca* effects for majority of the characters *viz.*, days to 50% flowering, productive tillers per plant, panicle length, grains per panicle, grain yield per plant, straw yield, kernel length, kernel breadth, 100 grain weight and amylose content.

The estimates of *sca* effect of hybrids revealed that, for grain yield per plant, out of 28 hybrids, 14 hybrids reported significant and positive *sca* effect which varies from -3.75 (NVSR-6206 x GR-17) to 1.90 (NVSR-6206 x GNR-3). The hybrid NVSR-496 x GNR-3 showed higher desired *sca* effect. The best three hybrids with respect to grain yield per plant based on significant and positive *sca* effect were NVSR-6206 x GNR-3 (1.90), NVSR-496 x GNR-3 (1.79) and NVSR-453 x GR-17 (1.64).

Ranking of parents with respect to general combining ability effects for grain yield and yield component characters in addition to number of hybrids exhibiting significant and desirable *sca* effects for the different traits shown in Table 2. The negative estimates of *sca* effects are desirable for earliness and medium dwarf plant height.

It was interesting to point out that in most of the crosses, the involvement of either or both the parents with significant *gca* effect, did not contributed to significant *sca* effect for the crosses, indicating the occurrence of non-additive gene action in such crosses. Similar results were confirmed by Khute *et al*. (2015) and Chauhan and Patel (2019) [28].

High *sca* effects resulting from crosses where both parents are good general combiners (i.e., good *gca* × good *gca*) may be ascribed to additive × additive gene action (Dey *et al*., 2014 and Verma and Srivastava, 2004) [13, 46]. The high *sca* effects derived from crosses including good × poor general combiner parents may be attributed to favourable additive effects of the good general combiner parent and epistatic effects of poor general combiner, which fulfils the favourable plant attribute (Dey *et al*., 2014 and Verma and Srivastava, 2004) [13, 46]. High *sca* effects manifested by low × low crosses may be due to dominance × dominance type of non-allelic gene interaction producing over dominance thus being non-fixable (Wassimi *et al*., 1986) [50].

A hybrid is commercially valuable only when it exhibits significantly high standard heterosis over the best locally adopted variety or hybrid (Sudeepthi *et al*., 2018) [42]. In general, the crosses which had higher estimates of heterosis for grain yield per plant also had higher heterotic effects for its component traits like, productive tillers per plant, panicle length, grains per panicle and 100 grain weight, kernel length and kernel breadth. Similar results were reported by Roy *et al*. (2009), Singh *et al*., (2011), Bhatti *et al*. (2015), Thorat *et al*. (2017), and Ambikabathy *et al*. (2019) [33, 10, 43, 3]. Therefore, heterotic effects for grain yield per plant could be outcome of direct effects of the above stated component characters. The heterotic effects for grain yield per plant could be a result of combinational heterosis.

Highest heterobeltiotic effect was exhibited by cross NVSR-453 x NVSR-418 (36.30%) and the range of heterobeltiosis was ranged from -10.26 per cent to 36.30 per cent. The spectrum of variation for grain yield per plant for standard heterosis over the check ranged from -16.65 to 37.77 per cent. Out of 28 hybrids, 21 F_1's exposed positive and significant standard heterosis. The four most heterotic hybrids over standard check for grain yield per plant were NWGR-15018 x NVSR-418, NVSR-453 x NVSR-418, NVSR-6206 x NVSR-418, NVSR-494 x NVSR-418.

Considerable significant and positive heterobeltiosis for grain yield per plant was earlier reported by Janardhanam *et al*. (2001), Joshi (2001), Bhandarkar *et al*. (2005), Veni *et al*. (2005), Raj *et al*. (2007), Singh *et al*. (2007), Roy *et al*. (2009), Rahimi *et al*. (2010), Patil *et al*. (2011), Soni and Sharma (2011), Latha *et al*. (2013), Kumari *et al*. (2014), Balakrishna and Satyanaryanan (2015), Bhati *et al*. (2015), Abdel-Moneam *et al*. (2016), Anis *et al*. (2016), Srijan *et al*. (2016), Waza *et al*. (2016), Rumanti *et al*. (2017) and Ghidan *et al*. (2019) [16, 19, 20, 9, 45, 32, 31, 29, 40, 27, 26, 6]. High amount of standard heterosis were similar with the findings of Janardhanam *et al*. (2001), Veni *et al*. (2005), Raj *et al*. (2007), Singh *et al*. (2007), Varpe *et al*. (2011), Waghmode and Mehta (2011), Gulzar and Hussain *et al*. (2012), Latha *et al*. (2013), Kumari *et al*. (2014), Bhatti (2015), Waza *et al*. (2016), Kumar *et al*. (2017) and Rumanti *et al*. (2017) [45, 19, 32, 27, 26].

High *sca* effects alone may not be the appropriate choice for heterosis exploitation because hybrids with low mean values may also possess high *sca* effects. Further, heterosis value alone may also mislead the identity of superior hybrids. Exploitation of hybrids for heterosis breeding is best judged by *per se*, *sca* effects and magnitude of heterosis, characteristics of parents with regards to *gca* effects for grain yield per plant and component characters (Table 4). Based on these criteria the hybrids NWGR-15018 x NVSR-418, NVSR-453 x NVSR-418, NVSR-6206 x NVSR-418, NVSR-494 x NVSR-418 and NWGR-15018 x NVSR-6287 were found to be suitable for heterosis breeding.

Considering the hybrid NWGR-15018 x NVSR-418 and NVSR-494 x NVSR-418 showing non-significant *sca* effect with favourable *gca* effects of parents is suitable for recombination breeding to get desirable segregants in early segregating generations for yield attributes. These results are in support with findings of Sheeba *et al*. (2010) and Sathya and Jebaraj (2015) [37, 36].

In the crosses showing high *sca* effects due to high × low general combiners, simple pedigree breeding would not be effective to improve the characters. Population improvement *i.e.,* mass selection with concurrent random mating in early segregating generations could be a perspective breeding procedure for yield improvement in rice (Sudeepthi *et al*., 2018) [53].

Summary and Conclusion

The maximum value of standard heterosis for grain yield per plant was observed for NWGR-15018 x NVSR-418, NVSR-453 x NVSR-418, NVSR6206 x NVSR-418 and NVSR-494 x NVSR-418. The high heterotic response in these hybrids for seed yield per plant resulted mainly due to substantial heterosis for productive tillers per plant, panicle length, grains per panicle and 100 grain weight, kernel length, kernel breadth etc. The above mentioned highly heterotic crosses also occupied top ranks in *per se* performance for grain yield. Maximum value for heterobeltiosis, exhibited by hybrids, *viz*., NVSR-453 x NVSR-418, NVSR-6206 x NVSR-418, NWGR-15018 x NVSR418 and NVSR-494 x NVSR-418, over the environments. Above mentioned hybrids exhibited superiority for both standard heterosis as well as heterobeltiosis, over the environments. With respect to the quality parameters, the higher magnitude of standard heterosis for protein content recorded in hybrid, NVSR-2103 x GNR-3 (25.13%) and for amylose content, NVSR-6172 x NVSR-418 (8.61%).

Expression of heterosis for grain yield and its components were related to the *gca* effects of parents. The majority of the high-top heterotic hybrids involved at least one parent with a high *gca* effect. *Per se* performance did not always correlate with *gca* effects of parents. It was also observed that good general combiner parents may not produce high with high *sca* effects. For example, hybrids NWGR-15018 x NVSR-418 and NVSR-494 x NVSR-418.

The parent's *viz*., NVSR-418, NWGR-15018, NVSR-6172 and NVSR-494 were good general combiners for grain yield and some of its direct components *viz*., productive tillers per plant, grains per panicle, panicle length, straw yield, kernel length, kernel breadth and 100 grain weight. The parents *viz*., NVSR496, NVSR-418, NVSR-2103 and NVSR-494 were good general combiners for earliness whereas, GNR-3, NVSR-2103, NVSR-496, GR-17 and NVSR6206 were for dwarfness.

Parents NVSR-494, NWGR-15018 and NVSR-6172 were good general combiners for quality traits *viz*., protein and amylose content. The hybrids *viz*., NVSR-6206 x GNR-3, NVSR-496 x GNR-3, NVSR-453 x GR-17 and NWGR-15018 x GR-17 having high *sca* effects for seed yield per plant also registered high and desirable *sca* effects for productive tillers per plant, panicle length, grains per panicle and 100 grain weight. Hybrid NVSR453 x GNR-3 and NWGR-15018 x GNR-3 also recorded a high and desirable *sca* effect for days to 50 per cent flowering. The comparison of the hybrids on the basis of their *sca* effects with their mean performance as well as heterosis revealed that, the ranking on the basis of *sca* effects was not always reflected by the ranking based on *per se* performance and hybrids showing high mean performance may not always shown high *sca* effects. There was no consistent association between *per se* performance of the crosses and their *sca* effects. This suggests that, the estimates of *sca* effects may not always lead to a correct choice of hybrid combination. Hence, the choice of best cross combination on the basis of *per se* performance could be more realistic and useful. The hybrids showing high *sca* effects due to good x poor general combiners, simple pedigree breeding would not be effective to improve the characters. Population improvement *viz.*, mass selection with concurrent random mating in early segregating generations could be a perspective breeding procedure for yield improvement in rice.

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