D-5330
[1 -6]

RESEARCH ARTICLE Agricultural Science Digest

Understanding of Gene Action for Nutritional Traits in Elite Rice (*Oryza sativa* L.) Crosses

N. Lingaiah, Surender Raju, N. Sarla, K. Radhika,
V. Venkanna, D. Vishnu Vardhan Reddy

10.18805/ag.D-5330

ABSTRACT

Background: The nature of inheritance and type of gene action governing nutritional traits are complex, hence a better understanding of the factors that contribute to the overall grain quality of rice will lay the foundation for developing new breeding and selection strategies for combining high quality with high yield. The present investigation was carried out to understand the gene action and inheritance of yield and nutritional quality traits in rice.

Methods: Crosses were effected with ten parents in diallel fashion without reciprocals during *kharif*, 2014, in the next *rabi* 2014-15 itself, all the 45 F_1s without reciprocals along with parents and two check varieties were grown for producing sufficient F_2 seed. The data obtained from F_1s and parents were analysed as per Method II (F_1s + parents) and Model - I (fixed effect) of Griffing (1956) for combining ability.

Result: In the present study, cross combinations *viz.,* WGL-32100 x DRR Dhan-40, Ramappa x RP-Bio-5478-176 for intermediate amylose, WGL-32100 x Ramappa for high protein content, MTU 1010 x RP-Bio-5478-166, WGL-32100 x RP-Bio-5478-166 for iron concentration and RP-Bio-5478-166 x DRR Dhan-40, for zinc concentration were identified as the top ranking ones for further advancement.

Key words: Additive gene action, Iron, Protein, Rice, Zinc.

INTRODUCTION

Along with yield, grain and nutritional quality has also become a primary consideration in rice breeding programs not only in India but also in various rice growing countries across the world. Grain quality and nutritional characteristics are very important in rice breeding as it is predominantly consumed as a whole grain. Like yield, grain quality is not easily amenable to selection due to its complex nature. Lack of clear cut perception regarding the component traits of good quality rice is one of the important reasons for the tardy progress in breeding for rice varieties with fine grain quality. Genetic variation for micronutrients in rice was studied and reported for iron and zinc (Gregario *et al.,* 2000 and Zhang *et al.*, 2004). The range of iron and zinc concentrations in brown rice was 6.3 – 24.4 ppm and 13.5 – 28.4 ppm respectively. Nutritional elements like protein, iron and zinc contents were included as important quality attributes in view of their role in human health maintenance. There is vast genetic potential to increase the concentration of Fe and Zn in rice grains is possible (Gregario, 2002). Incorporation of these nutritional traits into high yielding semi dwarf varieties are essential in this era of quality breeding. Genetic enhancement of key food crops with enhanced nutrients is advocated as the most promising approach to address the problem of malnutrition (Graham *et al*., 2001; Bouis, 2002) which can be possible with understanding the genetic analysis among quality and nutritional traits in rice.

Diallel analysis helps in the selection of suitable parents for use in hybridization programme as well as in the choice of appropriate breeding procedure for the genetic improvement of various quantitative traits. Combining ability analysis helps in the identification of parents with high general combining ability (*gca*) effects and cross combinations with high specific combining effects (*sca*) for commercial exploitation of heterosis and isolation of pure lines among the progenies of the heterotic hybrids. The nature of inheritance and type of gene action governing nutritional traits are many and complex and when genetically manipulated to some extent paved the way for the success in quality improvement through conventional breeding methods. Hence a better understanding of the factors that contribute to the overall grain quality of rice will lay the foundation for developing new breeding and selection strategies for combining high quality with high yield.

Regional Agricultural Research Station, Warangal-506 007, Telangana, India.

Corresponding Author: N. Lngaiah, Department of Genetics and Plant Breeding, Agricultural College, Warangal-506 007, Telangana, India. Email: nlrashi80@gmail.com

How to cite this article: Lingaiah, N., Raju, Ch.S., Sarla, N., Radhika, K. Venkanna, V. and Reddy, D.V.V. (2021). Understanding of Gene Action for Nutritional Traits in Elite Rice (*Oryza sativa* L.) Crosses. Agricultural Science Digest. DOI: 10.18805/ag.D-5330.

Submitted: 24-03-2021 **Accepted:** 15-06-2021 **Online:** 24-07-2021

World Health Organization estimates that nearly 5.6 billion people are suffering from Iron deficiency and that the problem is severe enough to cause anemica to 2 billion people. An estimated 58% of pregnant women in developing countries are anemic and their infants are more likely to be born with low birth weight and depleted Iron stores. Recently more interest is being devoted to developing nutritious rice enriched with essential micro nutrients such as iron and zinc that are associated with major health problems or "hidden hunger". These are the most prevalent micro nutrient deficiencies in humans especially in rural area, and increasing the content of these elements in the polished rice grains could considerably benefit human health.

Keeping in view the above perspectives, the present investigation was carried out to understand the genetics and inheritance of quality and nutritional traits.

MATERIALS AND METHODS

The present investigation was carried out at the Regional Agricultural Research Station, Warangal, Telangana state which is located at an altitude of 304 M above MSL, 17.97°N latitude and 79.60°E longitude during 2 years 2014-15 and 2015-16 utilizing both *Kharif* and *Rabi* crop seasons in each year. The experimental material for combining ability, heterosis and inbreeding depression studies comprised of 10 parents *viz.,* MTU 1010, WGL-32100, Ramappa, RP-Bio-5478-270, RP-Bio-5478-166, RP-Bio-5478-176, DRR Dhan-40, RP-Bio-5478-185, NH-686, NH-787, their 45 F_1 hybrids (generated from ten parents, crossed in diallel fashion without reciprocals during previous *Kharif*, 2014) and corresponding F_2's (seed obtained from F_1 generation raised during successive *Rabi*, 2014-15) and two promising check varieties *viz.* BPT 5204 and Chittimuthyalu.

After the crosses were effected during *kharif*, 2014, in the next *rabi* 2014-15 itself, all the 45 F_1s without reciprocals along with parents and two check varieties were grown for producing sufficient F_2 seed. The material (Parents, F_1s and F_2s) was planted in randomized block design replicating thrice during final season *Kharif,* 2015 in a separate plot for studying combining ability, heterosis and inbreeding depression. Parents, hybrids and check varieties were planted in one row of 3.0 m length adopting a spacing of 20 cm between the row and 15 cm between the plants within a row with single seedling per hill.

Amylose (%) content in the rice sample was estimated as per the procedure given by Jennings *et al*. (1979). Nitrogen content of the rice grain was estimated by following micro-kjeldahl method (AOAC, 1980) to estimate crude protein in rice grains. Grain iron and zinc concentrations were determined by X-Ray fluorescence Spectrometry (XRF) (EDXRF, model-X-supreme8000) at ICAR- Indian Institute of Rice Research (ICAR-IIRR), Hyderabad. The data obtained from F_1s and parents were analysed as per Method II (F_1s + parents) and Model – I (fixed effect) of Griffing (1956) for combining ability to know the gene action governing the nutritional traits inheritance for better understanding.

RESULTS AND DISCUSSION

The success of any breeding programme depends on selection of parents for hybridization and the choice of crosses to be advanced from the several crosses effected. This indicates that prior information on genetic background of the parents to be combined through crossing is very important. One of the techniques, widely used to extract information about the genetic system governing the inheritance of attributes, is the diallel analysis (Arunachalam, 1976). This design gives an idea about the relative magnitude of additive and non-additive components of heritable variance in expression of a trait. In case of diallel analysis developed by Griffing (1956) the additive and dominance components can be studied precisely in the absence of epistasis. Super crosses and parents with high *SCA* effects and *GCA* effects can be picked up.

Analysis of variance for combining ability for nutritional traits (Table 1) indicated that general combining ability (*GCA*) mean squares were significant for all the characters. For specific combining ability (*SCA*), mean squares were significant for all the characters. The results were in accordance with the findings of Lingaiah, *et al.,* (2018). In the present investigation, the magnitude of specific combining ability variances was higher than that of general combining ability for all the traits indicating greater role of non- additive gene action in controlling the traits. (Table 2).

In rice, eating quality is chiefly influenced by amylose and amylopectin in the grain. Rice with intermediate (20-25%) or low to intermediate amylose contents (18-20%) cook dry, pluffy and are softy on cooling. The analysis of gene action for amylose revealed the preponderance of non

Table 1: Mean sum of squares of ten parents and forty five F_1 s in rice for nutritional traits.

Source of variation	d.f.	Amylose content(%)	Protein content(%)	Iron content(ppm)	Zinc content (ppm)
Replications	2	0.16	0.12	0.11**	0.12
Genotypes	54	25.34**	4.34**	6.91**	34.00**
Parents	9	16.07**	4.41**	15.57**	49.59**
Hybrids	44	27.52**	4.42**	5.10**	30.65**
Parent Vs. Hybrids	1	12.46**	0.13**	8.54**	40.79**
Error	108	0.80	0.09	0.17**	0.37

* Significant at 5% level, ** Significant at 1% level.

additive gene action. Belhekar *et al.* (2017) reported similar result of non additive gene action for amylose content. For amylase content, out of ten parents studied, only three parents WGL-32100 (2.655), Ramappa (1.913) and RP-Bio-5478-270 (1.753) had shown significant positive effects where as all the remaining parents had shown significant negative *GCA* effects (Table 3). Thirteen hybrids had shown significant positive *SCA* effects, the highest SCA effect was observed in the cross NH-686 x NH-787 (3.041). The variation ranged from -3.886 (DRR Dhan-40 x NH-787) to 3.041 (NH-686 x NH-787) for amylase content (Table 4).

The present study indicated that the protein content is under the control of non additive gene action. Similar gene effects were observed by Mohammad Naseer (2016). Three parents *viz.,* RP-Bio-5478-270 (0667), NH-787 (0.494) and WGL-32100 (0.450) have highly positive and significant *GCA* effect, which are highly desirable and were found as good general combiners for this trait. The parents *viz.,* RP-Bio-5478-166 (-0.436 and DRR Dhan-40 (-0.436) had significant negative *GCA* effects for protein content. Thirteen hybrids had shown significant positive *SCA* effects, among these three hybrids DRR Dhan-40 x NH-787 (2.179), MTU 1010 x RP-Bio-5478-166 (1.978) and WGL-32100 x NH-686 (1.948) recorded highest *SCA* effects. Eighteen hybrids exhibited significant negative *SCA* effects for amylase content of which the hybrid, Ramappa x RP-Bio-5478-270 (-2.004) recorded highest significant negative *SCA* effect for protein (Table 4).

For iron content, the results indicated that RP-Bio-5478-176 and RP-Bio-5478 -185 have highly positive and significant *GCA* effect, which are highly desirable and were found as good general combiners for this trait. The parents *viz.,* Ramappa and RP-Bio-5478-166 had significant negative *GCA* effects. Out of forty five crosses studied, fourteen crosses had significant positive *SCA* effects where as nineteen crosses manifested significant negative *SCA* effects. Highest positive *SCA* effect was observed in MTU 1010 x DRR Dhan-40 (2.492) followed by RP-Bio-5478-185 x NH-686 (2.368), while highest significant negative *SCA* effect was recorded in the cross, RP-Bio-5478-185 x NH-787 (-1.994) for iron content.

Non-additive gene action was mostly responsible for expression of iron and zinc contents which was in confirmation with the result of Adilakshmi and Upendra (2014). Three parents *viz.,* RP-Bio-5478-176, RP-Bio-5478-185 and DRR Dhan-40 had exhibited significant positive *GCA* effects, among them RP-Bio-5478-176 had highest value and considered as good general combiner for this trait. Highly significant negative GCA effects were observed in WGL-32100 and MTU 1010 (Table 3). Fourteen crosses showed significant positive *SCA* effects, among these, the crosses Ramappa x RP-Bio-5478-166 (5.198), MTU 1010x RP-Bio-5478-270 (4.033), MTU 1010 x RP-Bio-5478-166 (3.828), MTU 1010 x Ramappa (3.701), MTU 1010 x RP-Bio-5478-185 (3.603) and RP-Bio-5478-270 x DRR Dhan-40 (3.224) were the top six cross combinations with higher

Table 2: Gene action and proportions of GCA and SCA variances for grain quality traits

Source of variation	d.f.	Amylose content (%)	Protein content (%)	Iron content (ppm)	Zinc content (ppm)
GCA	*9*	*27.48***	*2.61***	*5.16***	*22.10***
SCA	45	4.63**	1.21**	1.17**	9.18**
Error	108	0.26	0.03	0.05	0.12
σ^2 GCA		2.26	0.21	0.42	1.83
σ^2 sca		4.37	1.18	1.67	9.056
σ^2 GCA / ό^2 sca		0.519	0.182	0.254	0.202

*Significant at 5% level, ** Significant at 1% level.

Table 3: General combining ability (*GCA*) effects of parents for nutritional traits in rice.

Parents	Amylose content	Protein content	Iron content	Zinc content
MTU 1010	-0.579 **	-0.29**	-0.384**	-0.940**
WGL-32100	2.655**	0.450**	-0.461**	-2.940**
WGL-23985	1.913**	0.291**	-0.751**	-0.760**
RP-Bio-5478-270	1.753**	0.667**	-0.310**	-0.652**
RP-Bio-5478-166	-1.407 **	-0.436 **	-0.684**	0.207*
RP-Bio-5478-176	-1.015 **	-0.322 **	1.121**	1.662**
DRR Dhan - 40	-1.460 **	-0.436 **	0.123	1.050**
RP-Bio-5478 -185	-0.858 **	-0.612 **	0.751**	1.128**
NH-686	-0.743 **	0.198 **	0.728**	0.402**
NH-787	-0.260	0.494 **	-0.133*	0.842**
SE (gi) ±	0.321	0.106	0.149	0.218

magnitude. The *SCA* effects for zinc content ranged from -6.085 (Ramappa x RP-Bio-5478-176) to 5.198 (Ramappa x RP-Bio-5478-166). Seventeen crosses showed significant negative *SCA* effects for this trait of zinc content.

Apart from various cooking quality parameters, estimation of amylose content is inevitable in rice, because it plays greater role in texture of cooked rice. Rice with higher amylose content (>25%) will cook dry, pluffy but become hard on cooling whereas, those with low amylose content

Table 4: Specific combining ability (*sca*) effects of crosses for nutritional traits in rice.

Cross	Amylose content	Protein content	Iron content	Zinc content
MTU-1010 x WGL-32100	-0.864	-1.004**	-0.738**	-1.576**
MTU-1010 x Ramappa	0.878	-0.738**	-0.391	3.701**
MTU-1010 x RP-Bio-5478-270	-3.332**	-1.067**	1.378**	4.033**
MTU-1010 x RP-Bio-5478-166	-0.482	1.978**	1.579**	3.828**
MTU-1010 x RP-Bio-5478-176	-2.511**	0.562**	0.333	1.725**
MTU-1010 x DRR Dhan - 40	-1.073*	0.742**	2.492**	1.975**
MTU-1010 x RP-Bio-5478 -185	-1.595**	1.147**	-0.589*	3.603**
MTU-1010 x NH-686	-1.043*	-0.579**	-1.820**	-2.948**
MTU-1010 x NH-787	-0.450	-0.498**	0.184	-3.228**
WGL-32100 x Ramappa	-1.316**	1.299**	0.436	1.274**
WGL-32100 x RP-Bio-5478-270	0.791	0.750**	0.495*	-0.687*
WGL-32100 x RP-Bio-5478-166	2.818**	-0.218	1.649**	-2.009**
WGL-32100 x RP-Bio-5478-176	-0.708	-0.291	-1.267**	-1.971**
WGL-32100 x DRR Dhan - 40	1.273*	0.046	0.702**	-1.809**
WGL-32100 x RP-Bio-5478 -185	0.628	0.075	-0.679**	-0.187
WGL-32100 x NH- 686	2.463**	1.948**	-1.287**	-1.268**
WGL-32100 x NH- 787	-0.340	-0.584**	0.858**	-0.368
Ramappa x RP-Bio-5478-270	-2.337**	-2.004**	0.211	0.623
Ramappa x RP-Bio-5478-166	1.116*	1.492**	2.133**	5.198**
Ramappa x RP-Bio-5478-176	1.361**	-0.639**	-1.443**	-6.085**
Ramappa x DRR Dhan - 40	1.382**	-0.695**	0.259*	-4.835**
Ramappa x RP-Bio-5478 -185	1.743**	-0.326	0.944**	-0.810*
Ramappa x NH-686	-0.198	-1.403**	-1.474**	-0.598
Ramappa x NH-787	0.725	-0.202	-0.499**	-4.434**
RP-Bio-5478-270 x RP-Bio-5478-166	0.210	0.279	1.045**	-4.120**
RP-Bio-5478-270 x RP-Bio-5478-176	1.655**	-0.115	0.662**	2.931**
RP-Bio-5478-270 x DRR Dhan - 40	1.616**	-0.157	-1.589**	3.224**
RP-Bio-5478-270 x RP-Bio-5478 -185	1.487**	-0.015	-1.437**	-3.725**
RP-Bio-5478-270 x NH-686	2.045**	0.181	-0.591*	-1.139**
RP-Bio-5478-270 x NH-787	1.599**	1.336**	-1.703**	0.298
RP-Bio-5478-166 x RP-Bio-5478-176	-0.649	-0.222	-1.203**	-5.174**
RP-Bio-5478-166 x DRR Dhan - 40	-2.201**	-0.732**	-1.114**	2.832**
RP-Bio-5478-166 x RP-Bio-5478 -185	-1.026*	0.840**	-1.066**	0.770*
RP-Bio-5478-166 x NH- 686	-3.318**	-1.406**	-1.713**	0.596
RP-Bio-5478-166 x NH-787	-4.441**	-1.482**	0.318	0.429
RP-Bio-5478-176 x DRR Dhan - 40	1.377**	-1.055**	0.627**	1.633**
RP-Bio-5478-176 x RP-Bio-5478 -185	-2.552**	-1.007**	-0.781**	0.578
RP-Bio-5478-176 x NH-686	-0.517	1.893**	-0.049	1.457**
RP-Bio-5478-176 x NH-787	1.104*	1.985**	1.486**	1.580**
DRR Dhan - 40 x RP-Bio-5478 -185	2.033**	-0.089	-0.733**	-1.403**
DRR Dhan - 40 x NH-686	-0.563	-0.483**	0.343	-2.280**
DRR Dhan - 40 x NH-787	-3.886**	2.179**	-0.746**	1.193**
RP-Bio-5478 -185 x NH-686	-0.704	-0.941**	2.368**	-1.135**
RP-Bio-5478 -185 x NH-787	-1.067*	-0.983**	-1.994**	-0.769*
NH-686 x NH-787	3.041**	-0.396*	-0.425	-1.469**
SE (Sij) ±	0.962	0.329	0.447	0.654

*Significant at 5% level, ** Significant at 1% level.

(<18-20%) will be sticky. Hence, rice with intermediate amylose content which cook dry, pluffy and be soft on cooling would be mostly preferred in India. Accordingly, the 7 crosses with *per se* performance and *SCA* effects falling in intermediate range *viz.,* WGL-32100 x DRR Dhan - 40 Ramappa x RP-Bio-5478-176, Ramappa x DRR Dhan-40 , Ramappa x RP-Bio-5478-185, RP-Bio-5478-270 x RP-Bio-5478-176, RP-Bio-5478-270 x RP-Bio-5478-185 and RP-Bio-5478-176 x DRR Dhan-40 were rated as top ranking ones. As these F_1 hybrids were generated from the parents having high x low *GCA* effects, instead of direct selection alternative population improvement would be more profitable. The crosses *viz.,* RP-Bio-5478-270 x NH-686 and RP-Bio-5478-270 x NH-787, although, have *SCA* effects at desirable level are not suggested for further improvement due to possession of very low amylose content.

Rice varieties with higher protein content (more than 9-10%) are highly desirable from the point of nutritional quality. In the material studied, out of 13 crosses with significant *SCA* effects, three crosses (WGL-32100 x Ramappa, Ramappa x RP-Bio-5478-166 and RP-Bio-5478-176 x NH-686) were considered as most promising ones, when the magnitudes of both *SCA* effects and *per se* performance were taken into consideration. For improvement of protein content, simple direct selection (pedigree method) would be highly useful with respect to one best specific cross *viz.,* WGL-32100 x Ramappa in which parents were of high x high *GCA* effects and prevalence of additive main and interaction effects were noticed. Anyanwu and Obi (2015) reported transgressive segregants with high protein content than the parents in certain hybrids (WATA 4 x IR57689-73, WTA 4 x Max). For such crosses, Manuel and Palaniswamy (1989) were of the opinion that there could be interaction between positive alleles in a cross involving high x high combiners which can be fixed in subsequent generations if no repulsion phase linkage are involved, as in the case of present findings. In remaining two superior crosses (Ramappa x RP-Bio-5478-166 and RP-Bio-5478-176 x NH-787) with *SCA* effects, other methods would be profitable. In general, the *per se* performance of the F_1 hybrids has no relation to the *SCA* effects as per the present study.

In the material studied, although 10 cross combinations registered significant *SCA* effects, three were (MTU 1010 x RP-Bio-5478-166, WGL-32100 x RP-Bio-5478-166 and RP-Bio-5478-185 x NH-686) were designated as superior ones in terms of *SCA* effects as well as mean performance for iron content. Direct selection in one specific cross *viz.,* RP-Bio-5478-185 x NH-686 would be highly fetching as the parents possessed high x high *GCA* effects. Fortunately, highest mean (15.34) was also associated with this cross which is next to DRR Dhan-40 x NH-686 hybrid combination and more than that of best check variety Chittimuthyalu (13.51). In other crosses, where either low x low or low x medium or high x low *GCA* parents were involved, population improvement or hybrid breeding is recommended depending on the cross.

In the study conducted by Adilakshmii and Upendra (2014), superior crosses resulted from high x low, high x

Table 5: Top ranking crosses with high *SCA* and mean for grain nutritional traits.

Character and crosses	Predominant gene action	values of *sca* effects	*per se* performance	Values of *GCA* effects P_1	P_2	*GCA* status of the parents
Amylose content (%)	**Non - additive**					
WGL-32100 x DRR Dhan – 40		1.273*	23.41	2.655	-1.460	high x low
Ramappa x RP-Bio-5478-176		1.361**	23.97	1.913	-1.015	high x low
Ramappa x DRR Dhan – 40		1.382**	23.49	1.913	-1.460	high x low
Ramappa x RP-Bio-5478 -185		1.743**	23.96	1.913	-0.858	high x low
RP-Bio-5478-270 x RP-Bio-5478-176		1.655**	18.51	1.753	-1.015	high x low
RP-Bio-5478-270 x RP-Bio-5478 -185		1.487**	18.29	1.753	-0.858	high x low
Protein content (%)	**Non - additive**					
WGL-32100 x Ramappa		1.299**	10.06	0.450	0.291	high x high
Ramappa x RP-Bio-5478 -166		1.492**	8.38	0.291	-0.436	high x low
RP-Bio-5478-176 x NH-787		1.985**	10.11	-0.322	0.494	low x high
RP-Bio-5478-176 x NH-686		1.893**	7.15	-0.322	0.198	low x high
Iron content (ppm)	**Non- additive**					
MTU 1010 x RP-Bio-5478 -166		1.579**	12.06	-0.384	-0.684	low x low
WGL-32100 x RP-Bio-5478 -166		1.649**	12.25	-0.461	-0.684	low x low
RP-Bio-5478 -185 x NH-686		2.368**	15.34	0.751	0.728	high x high
MTU 1010 x DRR Dhan – 40		2.492**	11.92	-0.384	0.123	low x medium
Zinc content (ppm)	**Non - additive**					
RP-Bio-5478 -166 x DRR Dhan – 40		2.832**	22.02	0.207	1.050	high x high
RP-Bio-5478 -176 x DRR Dhan – 40		1.633**	19.51	1.662	1.050	high x high
RP-Bio-5478 -176 x NH-787		1.580**	20.76	1.662	0.842	high x high
RP-Bio-5478 -270 x DRR Dhan – 40		3.224**	21.76	-0.652	1.050	low x high

high and low x low *GCA* parents and *GCA/SCA* variance less than 1, which is in support of present findings.

Another important micro nutrient after iron is zinc, for which a total of 14 crosses exhibited significant *SCA* effects (Table 4). A perusal of these crosses indicated that high *per se* performance coupled with high *SCA* effects was exhibited by 5 crosses, interestingly, three F_1 hybrids (RP-Bio-5478-166 x DRR Dhan-40, RP-Bio-5478-176 x DRR Dhan-40 and RP-Bio-5478-176 x NH-787) which were generated from high x high *GCA* combinations, suggested that improvement for zinc content would be simple through the common pedigree method.

From the foregoing discussion, the best specific crosses for cooking quality traits including amylase content are WGL-32100 x RP-Bio-5478 -185 (high x low), Ramappa x RP-Bio-5478-176 (high x low), and Ramappa x RP-Bio-5478 -185 (high x low) and interestingly the crosses were highly promosing for cooking quality traits wherever the parent Ramappa was involved.

A total of six specific crosses *viz.,* MTU 1010 x RP-Bio-5478-166 (low x low), WGL-32100 x RP-Bio-5478-166 (low x low) and RP-Bio-5478-185 x NH-686 (high x high) for iron content improvement and for zinc enrichment RP-Bio-5478-166 x DRR Dhan-40 (high x high), RP-Bio-5478-176 x DRR Dhan-40 (high x high) and RP-Bio-5478-176 x NH-787 (high x high) were found to be useful. Among the parents WGL-32100 and Ramappa were graded as top ranking parents because high *SCA* effects, high *per se* performance in desirable direction was noticed in the crosses where these parents were included (Table 5).

Overall, for amylose content, crosses falling in intermediate range *viz.,* WGL-32100 x DRR Dhan–40,Ramappa x RP-Bio-5478-176, Ramappa x DRR Dhan-40 , Ramappa x RP-Bio-5478-185, RP-Bio-5478-270 x RP-Bio-5478-176, RP-Bio-5478-270 x RP-Bio-5478-185 and RP-Bio-5478-176 x DRR Dhan-40 were rated as top ranking ones (Table 5). As these F_1 hybrids were generated from the parents having high x low *GCA* effects, instead of direct selection alternative population improvement would be more profitable. Out of three best crosses (WGL-32100 x Ramappa, Ramappa x RP-Bio-5478-166 and RP-Bio-5478-176 x NH-686), for improvement of protein content, simple direct selection (pedigree method) would be highly useful with respect to one best specific cross *viz.,* WGL-32100 x Ramappa in which parents were of high x high *GCA* effects were involved. Although 10 cross combinations registered significant *SCA* effects, three were (MTU 1010 x RP-Bio-5478-166, WGL-32100 x RP-Bio-5478-166 and RP-Bio-5478-185 x NH-686) were designated as superior ones for iron content. Direct selection in one specific cross *viz.,* RP-Bio-5478-185 x NH-686 would be highly fetching as the parents possessed high x high *GCA* effects. Highest mean (15.34 ppm) was also associated with this cross which is next to DRR Dhan-40 x NH-686 hybrid combination and more than that of best check variety Chittimuthyalu (13.51 ppm) (Table 5). Three F_1 hybrids (RP-Bio-5478-166 x DRR Dhan-40, RP-Bio-5478-176 x DRR Dhan-40 and RP-Bio-5478-176 x NH-787) which were generated from high x high *GCA* combinations, were recommended for improvement for zinc content through the common pedigree method.

REFERENCES

Adilakshmi, D. and Upendra, A. (2014). Combining ability analysis for quality and nutritional traits in rice. International Journal of Farm Sciences. 4: 15-23.

Anyanwu, C.P. and Obi, I.U. (2015). Heterosis and combining ability effects of protein content on rice (*Oryza sativa* L.) genotypes. Journal of Plant breeding and Crop Science. 7: 256-261.

A.O.A.C. (1980). Official methods of analysis, 13th ed. Association of official analytical chemists. Washington, D.C. 376-384.

Arunachalam, V. (1976). Evaluation of diallel crosses by graphical and combining ability methods, Indian Journal of Genetics and Plant Breeding. 36: 358-366.

Belhekar, P.S., Meheta, H.D., Patil, H.M., Bhor T.J., Patil, Y.J and Lende, N.S. (2017). Heterosis and combining ability in aromatic hybrid rice (*Oryza sativa* L.) International Journal of Chemical Studies. 5: 1341-1345.

Bouis, H.E. (2002). Plant breeding: A new tool for fighting micronutrient malnutrition. J. Nutr. 132: 491-494.

Graham, R.D., Welch, R.M., Bouis, H.F. (2001). Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: principles, perspectives and knowledge gaps. Adv. Agron. 70: 77-142.

Gregario, G.B., Senadhira, D., Htut, H and graham, R.D. 2000. Breeding for trace mineral density in rice. Food Nutrition. Bulletin. 21: 382-386.

Gregario, G.B. (2002). Progress in breeding for trace minerals in staple crops. Journal of Nutrition. 132: 500-502.

Griffing, B. (1956). A generilsed treatment of the use of diallel crosses in quantitative inheritance. Heredity. 10: 31-50.

Jennings, P.R., Coffman, W.R., Kaufman, M.H.E. (1979). Grain quality: Rice improvement. International Rice Research institute, Philippines. Chapter. 6: 101-120.

Lingaiah, N., Sarla, N., Venkanna, V., Surender Raju Ch., Radhika, K and Vishnu Vardhan Reddy, D. (2018). Combining ability analysis in Iron and Zinc Rich Rice Genotypes. International Journal of Current Microbiology and Applied Sciences. 7: 3745-3751.

Manuel, W and Palaniswamy, S. (1989). Line x tester analysis of cobining ability in rice. Oryza. 26: 27-32.

Mohammad Naseer, Singh., Surendra, Ahmad., Ekhlaque., Tewari, Salil. (2016). Assessment of combining ability for productivity and quality traits in aromatic rice (*Oryza sativa L.*). International Journal of Bio Resource and Stress Management. 7: 525-532.

Zhang, M.W., Guo, B.J and Peng, Z.M. (2004). Genetic effects of Fe, Zn, Mn and P content in Indica black pericarp rice and their genetic correlations with grain characteristics. Euphytica. 135: 315-323.