



Combining Ability and Heterosis for Some Yield Component Traits in a 10x10 Diallel Cross of Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. Author GOSO wrote the protocol and first draft of the manuscript. Authors TV and GOSO managed the analysis and literature searches. Author AML performed the experiment as part of his M.Sc. research under the supervision of authors TV and GOSO. All authors read and approved the final script.

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ABSTRACT

A ten – parent diallel experiment was carried out at the Teaching and Research Farms of the Federal University of Agriculture, Makurdi, Nigeria, to estimate combining ability and heterosis in rice. The design was a 10x10 alpha lattice with three replications and data was collected on plant height (PH), tiller numbers/plant (TN), leaf length (LL) and width (LW), days to flowering (DF), panicle length (PL), panicle exertion (PE), spikelet numbers/panicle (SN), 100 seed weight (100SW) and days to maturity(DM). A preponderance of both additive and non – additive gene action with both negative and positive GCA, SCA and % heterosis was observed in the control of yield component traits in the studied rice varieties and their hybrids. Non – additive variance was higher, except for DF, SN and DM where additive variance was higher compared to non – additivity. Six parents, namely MGD 101, FARO 44, FARO 52, FARO 57, STRASSA 58 and IR 72 recorded the highest GCA values for most of the traits and the least values in terms of days to flowering and maturity. These parents were the most frequent in crosses with the

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highest SCA effects and % heterosis for Tiller number, Leaf length, leaf width, panicle length and Spikelet numbers/panicle. Crosses involving these six parents also recorded the least SCA effects and % heterosis for days to flowering and maturity. Based on the results of GCA, SCA and % heterosis, backcross breeding of F_1 s to their respective parents (the six parents), was recommended for improvement of yield component traits.

Keywords: Additive; GCA; gene action; heterobeltiosis; non-additive; SCA.

1. INTRODUCTION

Rice is generally a very important staple food crop in the developing countries in general and particularly in Sub-Saharan Africa. Garg et al. [1] therefore proposed rice as a cereal crop that could be used to stem the problem of global malnutrition. It is an annual crop which can survive as a perennial crop for several years via ratoons in the tropics [2]. Farmers prefer to produce rice because of ease of adaptability and low input requirement compared to maize [3]. The average annual per capita consumption of 24.8 kg of rice provide 9% of the total calorie requirements of Nigerians [4]. Thus, developing high yielding varieties will directly increase the quantity of food available to poor households and will subsequently benefit others by keeping its price low.

Adequate selection of planting material and use of appropriate mating design is a prerequisite towards a good success in any breeding programme [5] for yield maximization.

The low grain yield of 2.2 t ha^{-1} observed for the rain fed crop and 3.5 t ha^{-1} recorded for the irrigated system in previous studies [6] cannot sustain the rapidly growing population of Nigeria. The need for a 40% increase in rice production by the year 2025 has been proposed by FAO [7]. There is need for annual increase of 2 million metric tonnes via innovative approaches like heterosis breeding [8]. The exploitation of heterosis breeding strategies would lead to the emergence of new line(s) with more diverse genetic base and yield higher than the average recorded so far.

The ethical problem of rejection of GMOs and the challenge of adequate resources to access novel techniques, coupled with inconsistent supply of electricity, leaves the third world countries of sub-saharan Africa with no other option, but conventional plant breeding.

The concept of combining ability is very useful in identifying parent with maximum benefit and

complementarity in hybrid combinations. The general combining ability (GCA), which indicates the additive nature of a trait, identifies superior parental genotypes; while specific combining ability (SCA) is relevant to a cross combination. SCA indicates the dominant nature of a trait and helps in the identification of good hybrid combinations that will ultimately lead to the development of new lines for release to farmers as cultivars.

Previous studies [9; 10; 11; 12] have observed high GCA to SCA ratio due to preponderance of additivity to non – additivity in gene action for grain yield/plant, plant height and days to 50% flowering in rice.

Heterosis or hybrid vigour measures the performance of the hybrid, relative to the parents. Three types of heterosis have been identified, namely; high parent heterosis (heterobeltiosis), mid – parent heterosis and standard heterosis. While mid – parent heterosis measures the performance of the hybrid relative to the average performance of its parents, heterobeltiosis compares the hybrid with the better parent. Standard heterosis evaluates the performance of the hybrid relative to the adapted/improved variety in production within the environment of evaluation. While some researchers use any or all the three in analysis, Chopra [13], recommended the use of heterobeltiosis.

The objective of this research was to estimate combining ability, heterosis and gene action of some yield component traits in rice with a view of identifying genotypes to be selected for the improvement of these traits.

2. MATERIALS AND METHODS

2.1 Sources of the Germplasms

A total number of ten (10) varieties/lines of rice were used as parents for the diallel experiment. Seeds of nine (9) varieties were obtained from the National Cereals Research Institute (NCRI),

Table 1. Names of parental lines used in the 10x10 diallel experiment and their sources

S/No.	Parental number	Genotype	Variety name	Source
1	P1	WAB-450-1-B-P-103-HB	MGD 101	IITA, Kano
2	P2	SIPI	FARO 44	NCRI, Badeggi
3	P3	WITA 4	FARO 52	NCRI, Badeggi
4	P4	Tox 4004-43-1-2-1	FARO 57	NCRI, Badeggi
5	P5	NERICA L19	FARO 60	NCRI, Badeggi
6	P6	NERICA L34	FARO 61	NCRI, Badeggi
7	P7	STRASA 11	Treatmt 11	NCRI, Badeggi
8	P8	STRASA 58	Treatmt 58	NCRI, Badeggi
9	P9	IR 72	IR 72	NCRI, Badeggi
10	P10	WAB-759-55-2-HB	Kano line	NCRI, Badeggi

Key: IITA-International Institute for Tropical Agriculture; NCRI-National Cereals Research Institute

Badeggi, Niger State, Nigeria, while seeds of one (1) variety, namely MGD 101(WAB-450-1-B-P-103-HB) was obtained from IITA sub-station in Kano, Nigeria. The varietal name, genotypic name and parental number (given specifically for this research) of each genotype is presented in Table 1. FARO 44 is popularly referred to as SIPI and it's a long grain rice that is favoured by farmers and consumers in the Southern Guinea Savanna ecology of Nigeria. FARO 44, FARO 52 (WITA 4) and FARO 57 are all high yielding lowland varieties in Nigeria. MGD 101 is a semi-dwarf (100-110cm) variety that is resistant to leaf and neck blast. FARO 60 (NERICA L19) and FARO 61 (NERICA 24) are long grain high yielding (6tha^{-1}), late maturing varieties developed from *Oryza sativa* x *Oryza glaberrima* crosses. STRASSA 11 and STRASSA 58 are stress tolerant varieties developed for Africa and South Asia. IR 72 is a high yielding (6.55tha^{-1}) slender grain rice. WAB-759-2-HB (Kano line) is an improved variety adapted to the Sudan Savanna ecology of Kano, Nigeria.

2.2 Location of the Experiment

Development of genetic materials for diallel experiment and field evaluation of the parents and the hybrids were all carried out at the Teaching and Research Farm of the Federal University of Agriculture, Makurdi, Nigeria (Longitude $08^{\circ}37'N$, Latitude $07^{\circ}45'E$ and 108m asl).

2.3 Development of Genetic Materials

The first phase of this research, involves the planting of the parental lines in pots and monitoring them to the time of flowering, emasculation and pollination to generate all the possible set of crosses (excluding reciprocals).

$$\text{The total number of crosses} = \frac{n(n-1)}{2} = 45$$

$$\text{The number of entries} = \frac{n(n+1)}{2} = 55;$$

Where; n = number of parental lines = 10.

Seeds of the 10 parents along with 45 F_1 (total of 55 genotypes) were harvested, dried and stored for evaluation in the next rain fed cropping season.

2.4 Field Experiment

The forty-five (45) F_1 s along with their ten (10) parents were treated with seed dressing chemical (Dress Force™) and sown separately, each on 30 x 30cm nursery beds. The seedlings from the nursery beds were transplanted to the main field at 14DAP using Randomized Complete Block Design (RCBD) with three replications. Each of the fifty-five (55) genotypes was assigned to a plot of 1m x 1m (1m^2). Two seedlings/hill were transplanted to the main plot at an inter and intra row spacing of 20cm x 20cm [14] and maintained to maturity. The inter-plot distance was maintained at 0.5m with a distance of 1m between replications. NPK 20:10:10 was broadcasted to the seedlings at one week after transplanting. Urea fertilizer (46% N) was broadcasted to the field at 4 and 6 WAT (weeks after transplanting). The field was weeded with hoe and on some occasions with hands as at when due. No herbicide was used.

2.5 Data Collection

Data from each plot was collected on plant height, tiller numbers/plant, leaf length and width, days to flowering, panicle length, Panicle exertion, Spikelet numbers/panicle, 100 seed weight and Days to maturity.

Table 2. Mean squares of analysis of variance for yield component traits in a 10 x 10 diallel cross of rice

SOV	DF	Plant Height	Tiller numbers/plant	Leaf length	Leaf width	100 seed weight	Days to flowering	Panicle length	Panicle exertion	Spikelet numbers/panicle	Days to maturity
Rep.	2	543.62**	691.15**	76.63**	0.04**	0.00	5.86	4.67	15.73**	5763.08**	2.62
Entries	54	202.69**	59.39*	30.20**	0.016**	0.067**	81.02**	9.00**	5.57**	5424.44**	127.32**
Error	108	34.20	37.20	9.80	0.004	0.00	3.10	3.40	1.79	380.02	1.93

Table 3. Mean squares of combining ability analysis of variance for yield component traits in a 10 x 10 diallel cross of rice

SOV	DF	Plant Height	Tiller numbers/plant	Leaf length	Leaf width	Days to flowering	Panicle length	Panicle exertion	Spikelet numbers/panicle	Days to maturity
GCA	9	236.66**	46.93**	29.76**	0.02**	95.67**	9.03**	5.42**	7310.06**	162.32**
SCA	45	33.74**	14.37	6.13**	0.003**	13.28**	1.79**	1.14**	707.76**	18.47**
Error	108	11.66	12.40	3.27	0.001	1.03	1.13	0.60	126.67	0.64
σ^2_A :	-	1:0.9	1:2	1:1.4	2:3	1:0.9	1:4	1:1.3	1:0.6	1:0.8
σ^2_D										

Table 4. GCA effects for yield component traits in a 10 x 10 diallel cross of rice

Parent	PH	TN	LL	LW	DF	PL	P.Exs	SN	DM
P ₁	2.19	-5.07	1.32	0.03	-1.98	-1.36	0.26	44.47	-2.46
P ₂	-3.24	1.75	0.57	0.01	-0.39	0.04	0.09	-4.55	-1.98
P ₃	3.08	-0.02	0.15	-0.02	2.66	0.38	0.97	15.08	2.91
P ₄	7.38	-0.32	1.93	0.02	1.91	1.65	0.54	2.79	2.68
P ₅	-3.98	0.68	1.11	0.02	0.91	0.06	-0.25	-13.77	-0.15
P ₆	-5	1.6	-3.58	-0.06	-0.67	-0.66	-0.34	-29.48	-1.79
P ₇	2.6	1.04	0.12	0.01	0.69	-0.06	-0.27	15.77	1.41
P ₈	4.6	0.71	0.36	0.07	4.55	0.86	0.86	-1.16	7.18
P ₉	-3.4	0.73	-1.43	-0.02	-2.56	0.03	-1.08	12.96	-1.79
P ₁₀	-4.23	-1.09	-0.54	-0.05	-5.23	-0.94	-0.78	-42.11	-6.01

Key: PH-Plant height; TN-Tiller numbers/plant; LL-Leaf length; LW-Leaf width; DF-Days to flowering; PL-Panicle length; P.Exs-Panicle exertion; SN-Spikelet numbers/panicle; DM-Days to maturity

2.6 Data Analysis

The data generated from the study were subjected to analysis of variance while model I, method 2 (parents + F₁s) of Griffing [15] was used to analyse for combining ability.

Components of variance and their genetic interpretation were also estimated from the additive – dominance ratio (σ^2_A : σ^2_D) and GCA and SCA variance (σ^2_g and σ^2_s)

Where,

$$\sigma^2_A = 2 \sigma^2_g \quad \sigma^2_D = \sigma^2_s$$

σ^2_g and σ^2_s were estimated from the GCA, SCA and error mean squares.

Heterosis (heterobeltiosis) was estimated according to Chopra [13].

Heterobeltiosis is mathematically expressed as

$$= \frac{F_1 - BP}{BP} \times 100$$

Where,

F₁ = mean value of the F₁s of the cross

BP = mean value of the better parent in the cross.

3. RESULTS

3.1 Analysis of Variance for Yield Component Traits in Rice

Mean squares of Analysis of variance for Plant height (PH), Tiller numbers (TN), Leaf length (LL), leaf width (LW), days to 50% flowering (DF), panicle length (PL), Panicle Exsertion (P.Exs) Spikelets numbers/panicle

(SN), 100 seed weight (100SW) and days to maturity (DM) is presented in Table 2. Significant difference (P < 0.01) in replications was observed for all the traits except 100SW, DF, PL and DM. However, genotypes were significantly different (P < 0.05 and P < 0.01) for all the traits studied.

3.2 Combining Ability Analysis of Variance for Yield Component Traits in Rice

Significant difference (P < 0.01) in GCA and SCA were observed for all the traits studied, except for TN where SCA was not significant (Table 3). Non – additive variance was higher, except for DF, SN and DM where additive variance was higher compared to non – additivity.

3.3 GCA Effects for Yield Component Traits in Rice

Table 4 summarizes the GCA effects for yield component traits. The best parent, with high positive GCA value (7.38) for plant height was P₄, followed by P₈ (4.60) and P₃ (3.08). Parents with the highest GCA value in tiller numbers were P₂ (1.75), P₆ (1.60) and P₇ (1.04). Parents with the highest GCA value for leaf length were P₄ (1.93), P₁ (1.32) and P₅ (1.11). Parents P₈ (0.07) and P₁ (0.03) recorded the highest values of GCA effect for leaf width. Parents P₈ (4.55) and P₃ (2.66) recorded the highest GCA effects while P₁₀ (-5.228) and P₉ (-2.56) recorded the least GCA effects for days to 50% flowering. Parents P₄ and P₈ shows the highest GCA value in panicle length with 1.65 and 0.86 respectively. The highest GCA value for panicle exertion was observed in P₃ (0.97), P₈ (0.86) and P₄ (0.54). The highest GCA effects for the

number of spikelets/panicle were observed in parents P₁ (44.47), P₇ (15.77) and P₃ (15.08). Parents P₈ (7.18), P₃ (2.91), P₄ (2.68) had the highest GCA effect while P₁₀ (-6.01), P₁ (-2.46) and P₂ (-1.983) recorded the least GCA effect in days to maturity.

3.4 SCA Effects for Yield Component Traits in Rice

The best hybrid combinations with high positive values of SCA effect for PH were P₄ x P₈, P₃ x P₄, P₁ x P₄, P₄ x P₇, P₃ x P₈, and P₃ x P₇; whereas those with high negative values were P₅ x P₆ and P₆ x P₁₀ (Table 5). For SCA on tillering ability (TN), P₂ x P₆, P₂ x P₇, P₂ x P₉, P₂ x P₅ and P₂ x P₈ were observed as the best hybrids with positive value. Hybrids with the highest SCA effects for LL were P₁ x P₄, P₄ x P₅, P₂ x P₄, P₄ x P₈ and P₃ x P₄. The best hybrid combinations with positive value of SCA effects for LW were P₁ x P₂, P₁ x P₄, P₄ x P₈, P₂ x P₈, P₅ x P₈ and P₇ x P₈. The best hybrid combinations in respect of SCA effects for DF were P₃ x P₈ (4.45), P₅ x P₈ (2.65) and P₇ x P₈ (2.51) while P₉ x P₁₀, P₁ x P₆, P₆ x P₉ and P₁ x P₁₀ recorded the least (negative) SCA effects of -5.55, -5.08, -4.88 and -4.22 respectively. For SCA effect on panicle length, the best hybrids with high positive values were P₄ x P₈ (2.32), P₃ x P₄ (2.22), P₄ x P₅ (1.63), P₂ x P₈ (1.58) and P₂ x P₄ (1.55). The hybrids with the highest SCA effects on panicle exertion were P₁ x P₃ (2.54), P₁ x P₂ (1.76), P₄ x P₅ (1.49), P₈ x P₁₀ (1.12) and P₄ x P₈ (1.04). Hybrid combinations P₁ x P₃ (47.01), P₁ x P₇ (41.445), P₇ x P₉ (41.28), P₁ x P₉ (39.67) and P₃ x P₇ (37.60) recorded the highest SCA effect for the number of spikelets/panicle. Hybrids P₃ x P₈ (5.40), P₄ x P₈ (4.26), P₃ x P₄ (4.65) recorded the highest SCA effects while SCA effects were negative in P₂ x P₁₀ (-6.80), P₆ x P₁₀ (-6.71), P₅ x P₁₀ (-6.07), P₁ x P₁₀ (-5.55), P₁ x P₉ (-5.24), P₁ x P₆ (-5.02), P₉ x P₁₀ (-4.96), P₁ x P₂ (-4.740) for days to maturity.

3.5 Estimates of Heterosis (%) for Yield Component Traits in Rice

Positive and negative heterosis (heterobeltiosis) were observed for all the traits studied (Table 6). Percent heterosis ranged from -20.00% (P₁ x P₅) to 18.99% (P₂ x P₉) for plant height, with most of the crosses involving P₂, P₄ and P₇ recording positive values. In terms of number of tillers per plant (TN), 20 cross combinations had positive heterosis with the highest value of 55.86% observed for P₂ x P₃. Most of the hybrids showed negative heterosis for Leaf-length with

all crosses involving P₆ and P₁₀ recording negative heterosis. Hybrid P₆ x P₁₀ (-18.46%) had the least heterosis while P₂ x P₅ (11.49%) recorded the highest heterosis for leaf length. Most crosses were also negative for leaf width with P₆ x P₈ showing the least value of -17.80%. As expected, almost all the crosses involving P₆ and P₁₀ were negative. Most crosses involving P₇ were however negative, except P₂ x P₇ and P₇ x P₈. Almost all the crosses involving P₃ and P₄ had positive heterosis for 100 seed weight, with the highest value of 23.53% (P₃ x P₄ and P₄ x P₉). All crosses involving P₈ were however predominantly negative. Almost all the hybrids (93.33%) and all the hybrids (100%) expressed hybrid vigour for earliness for days to flowering and days to maturity respectively. More than 60% of the hybrids had negative heterosis while two crosses involving P₉, P₁ x P₉ (15.19%) and P₁ x P₉ (11.87%) recorded the highest heterosis for panicle length. Heterosis for panicle exertion was predominantly negative (70%). However, crosses involving P₃ and P₄ recorded positive heterosis, with P₁ x P₃ (57.07%), P₃ x P₄ (37.53%) and P₄ x P₅ (31.33%) recording the highest % heterosis for panicle exertion. Crosses P₅ x P₈ (43.52%), P₂ x P₆ (31.16%), P₂ x P₈ (30.19%) and P₆ x P₈ (29.94%) exhibited the highest heterosis for spikelet numbers/panicle (SN).

4. DISCUSSION

The highly significant and significant differences in entry obtained for all the traits in the current study was due to variability among the genotypes (parents + F₁ hybrids) evaluated and it's consistent with previous findings [8; 10; 11;16; 17; 18].

The preponderance of additive gene action observed for four traits (plant height, days to flowering days to maturity and spikelet number/panicle) in the current study had been previously observed. The preponderance of additive gene action for plant height, is consistent with the previous findings [11; 17; 19; 20]. It is also consistent with previous results [11; 16; 18] on days to flowering and days to maturity. The inconsistency in the results of these authors with the current findings for tiller numbers/plant, leaf length, leaf width, panicle length and panicle exertion in terms of gene action, could be attributed to differences in parental genotypes used for the diallel study. The preponderance of non-additive gene action in the expression of these traits could be

Table 5. SCA effects for yield component traits in a 10 x 10 diallel cross of rice

Cross	Plant Height	Tiller numbers/plant	Leaf length	Leaf width	Days to flowering	Panicle length	Panicle exertion	Spikelet numbers/panicle	Days to maturity
P ₁ xP ₂	-0.10	-3.35	1.57	0.11	-4.97	0.06	1.76	17.97	-4.74
P ₁ xP ₃	6.45	-4.59	1.53	-0.02	-2.66	0.41	2.54	47.01	-1.85
P ₁ xP ₄	7.70	-5.05	5.92	0.09	-1.66	0.05	-2.26	27.77	-1.40
P ₁ xP ₅	-0.40	-3.70	1.53	0.04	-1.66	0.03	-0.34	17.88	-4.46
P ₁ xP ₆	-1.00	-0.35	-2.78	0.03	-5.08	0.47	0.52	15.33	-5.02
P ₁ xP ₇	4.60	-3.29	1.11	0.06	-2.19	-1.81	0.11	41.45	-0.55
P ₁ xP ₈	5.39	-2.88	2.43	0.07	-2.79	-0.64	-1.02	16.12	-0.30
P ₁ xP ₉	3.64	-0.77	-1.64	0.02	-3.99	-0.80	0.76	39.67	-5.24
P ₁ xP ₁₀	-1.22	-5.13	-1.28	-0.07	-4.22	0.57	-2.04	16.12	-5.55
P ₂ xP ₃	3.01	1.05	0.18	0.002	-0.85	0.69	-0.52	10.04	2.43
P ₂ xP ₄	0.71	1.67	4.30	0.04	-1.10	1.55	-1.19	10.33	1.79
P ₂ xP ₅	-1.50	4.81	1.34	0.03	-0.44	0.52	-0.63	-19.40	-2.10
P ₂ xP ₆	-3.36	8.45	-0.11	0.02	-1.44	-0.76	-0.51	-22.58	-4.24
P ₂ xP ₇	-0.52	7.38	0.001	0.03	0.13	-0.50	-0.38	19.82	-0.46
P ₂ xP ₈	3.36	4.76	0.19	0.09	0.26	1.58	-0.95	-14.50	-0.10
P ₂ xP ₉	-2.99	5.57	-2.43	-0.04	-2.35	0.47	0.59	4.40	-2.18
P ₂ xP ₁₀	-3.68	-1.70	-1.38	-0.01	-5.77	-0.15	-0.37	-27.40	-6.80
P ₃ xP ₄	9.98	-4.01	3.74	0.03	2.37	2.22	0.60	27.77	4.65
P ₃ xP ₅	-1.14	-1.17	0.39	0.01	1.81	0.82	0.55	8.44	-0.74
P ₃ xP ₆	-1.12	0.74	-2.45	-0.06	-3.52	-0.51	-0.03	9.20	-0.91
P ₃ xP ₇	6.28	0.47	-0.01	0.01	1.42	-0.44	0.40	37.60	2.12
P ₃ xP ₈	7.16	-0.04	-0.04	-0.03	4.45	1.24	-0.06	-12.80	5.40
P ₃ xP ₉	2.61	-1.13	-2.59	-0.06	0.42	0.58	0.38	21.18	0.43
P ₃ xP ₁₀	1.91	-4.75	-0.82	-0.08	0.56	-0.39	-0.19	8.99	0.12
P ₄ xP ₅	1.05	-2.62	5.31	0.04	1.56	1.63	1.49	-1.68	-1.10
P ₄ xP ₆	0.61	-1.33	-1.06	-0.01	0.09	-0.43	1.01	-13.14	-0.74
P ₄ xP ₇	7.27	0.48	2.85	0.04	1.10	-0.15	1.00	21.46	2.72
P ₄ xP ₈	11.56	-2.33	3.91	0.09	1.67	2.32	1.04	-11.02	4.26
P ₄ xP ₉	5.42	-1.02	-0.03	-0.05	-0.33	0.99	0.48	31.19	-0.57
P ₄ xP ₁₀	1.02	-4.02	-0.14	-0.02	-0.69	-0.21	0.01	10.46	-2.38
P ₅ xP ₆	-10.02	2.34	-1.91	0.01	0.01	-0.72	0.36	-42.63	-3.10

Cross	Plant Height	Tiller numbers/plant	Leaf length	Leaf width	Days to flowering	Panicle length	Panicle exertion	Spikelet numbers/panicle	Days to maturity
P₅xP₇	0.47	1.97	0.87	0.03	-2.49	-0.14	-0.04	11.44	-1.88
P₅xP₈	3.12	1.36	0.69	0.08	2.65	1.20	-0.51	-21.71	-0.60
P₅xP₉	-2.49	1.78	-0.98	-0.08	-0.77	0.57	-2.73	9.65	-2.96
P₅xP₁₀	-3.87	0.33	-0.79	-0.08	-0.27	-0.08	0.64	-27.42	-6.07
P₆xP₇	-2.22	4.46	-2.33	-0.08	-2.33	-1.27	0.71	13.14	-1.27
P₆xP₈	3.06	2.73	-1.41	-0.05	0.08	-1.17	-0.02	-16.92	0.12
P₆xP₉	-6.52	2.23	-3.05	0.02	-4.88	-2.36	-0.51	4.61	-3.66
P₆xP₁₀	-9.13	0.34	-2.99	-0.02	-3.61	-1.09	0.89	-47.78	-6.71
P₇xP₈	4.21	2.74	-0.75	0.08	2.51	-1.09	-0.66	13.12	2.46
P₇xP₉	1.20	2.41	-1.35	-0.02	0.70	-1.00	0.12	41.28	1.57
P₇xP₁₀	-1.41	0.05	-0.95	-0.01	1.09	-1.24	-0.52	1.27	0.57
P₈xP₉	1.02	1.57	-0.68	-0.05	-0.44	1.22	0.62	7.18	1.93
P₈xP₁₀	0.09	-2.40	-0.56	-0.02	0.98	-0.01	1.12	-23.29	0.89
P₉xP₁₀	-4.05	-2.40	-2.90	-0.11	-5.55	-0.84	0.46	2.50	-4.96

Table 6. Estimates of Heterobeltiosis (%) for Yield Component Traits in a 10 x 10 Diallel Cross of Rice

Cross	PH	TN	LL	LW	100S W	DF	PL	P.Ex.	SN	DM
P1xP2	-9.62	4.04	-10.24	0.92	5	-9.38	2	12.77	-21.74	-6.99
P1xP3	-1.52	-32.98	-12.24	-6.42	5.26	-18.52	-11.82	57.07	-6.69	-17.89
P1xP4	3.45	-26.16	-7.25	9.17	15.79	-9.71	-15.77	-34.21	-10.26	-8.84
P1xP5	-20	-9.28	9.77	-7.34	-5	-3.13	1.43	-14.49	-18.17	-5.17
P1xP6	-12.2	-44.88	-16.49	-9.17	5.26	-6.25	-3.09	-1.05	-30.51	-8.82
P1xP7	-5.3	-41.37	3.02	1.83	4.76	-9.3	0	-6.98	-2.74	-7.56
P1xP8	-5.84	-22.84	-10.49	-5.08	0	-17.18	-21.3	-25.66	-11.06	-16.54
P1xP9	-3.57	-45.77	-5.74	-4.59	0	-6.25	15.29	-9.77	-7.21	-5.17
P1xP1	-	-	-	-	-	-	-	-	-	-
0	13.41	-18.99	-13.75	14.68	-5.26	-11.46	4.61	-52.91	-34.67	-9.73
P2xP3	1.99	55.86	8.19	6.86	15	14.15	-5.38	-11.23	13.95	-13.01
P2xP4	1.83	33.37	10.83	9.62	15	10.68	-11.42	-28.15	27.32	-16.03
P2xP5	7.34	-2.89	11.49	-2.8	5	3.23	-0.44	-31.85	19.88	-2.43
P2xP6	7.7	3.12	-5.23	-1.96	10	-3.13	3.01	-31.23	31.16	-5.79
P2xP7	5.95	2.29	-3.47	-1.96	0	-7.31	2.2	-28.15	-7.93	-7.85
P2xP8	-1.96	4.07	1.06	11.86	-9.09	-10.74	-14.61	-27.06	30.19	-15.75
P2xP9	18.99	-1.46	11.17	-2.94	-5	-2.15	11.87	-25.69	15.6	-3.7
P2xP1	-	-	-	-	-	-	-	-	-	-
0	9.96	16.02	-8.19	-8.82	0	-3.23	-0.22	-35.85	-0.52	-3.7
P3xP4	8.7	18.62	-1.31	-7.69	23.53	-9.84	-13.41	37.53	1.28	-5.96
P3xP5	-3.16	18	2.9	-9.35	5	-12.31	-9.3	21.95	-1.8	-12.2
P3xP6	-6.91	25.32	-11.9	1.02	5.26	-16.92	-9.14	9.35	-2.18	-15.45
P3xP7	12.52	-14.98	-9.26	12.24	4.76	-12.31	-7.18	18.76	11.78	-12.2
P3xP8	2.28	-5.57	-6.53	-8.47	13.68	-5.52	-16.08	-2.37	-7.4	-7.09
P3xP9	-0.71	-39.12	-8.74	8.16	23.53	-16	-6.99	3.19	15.5	-12.2
P3xP1	-	-	-	-	-	-	-	-	-	-
0	-3.39	-27	-7.18	-4.08	11.11	-19.69	-11.82	-1.88	-9.59	-18.7
P4xP6	12.24	7.7	15.84	1.87	15	-9.71	-4.02	31.33	4.67	-10.5
P4xP6	2.75	-8.44	-8.17	-6.73	10.53	-12.62	-11.75	23.18	-7.5	-14.64
P4xP6	12.24	17.31	7.65	2.88	0	-5.83	-11.57	24.52	-8.47	-7.74
P4xP6	9.25	14.21	1.58	-9.32	-4.55	-7.98	-12.13	6.97	2.62	-6.04
P4xP6	1.03	-23.25	-10.02	11.54	23.53	-12.52	-9.06	-0.96	2.45	-13.81
P4xP6	-6.63	0.5	-6.67	-0.96	5.56	-15.53	-8.22	-4.21	14.47	-17.96
P5xP6	11.96	8	-5.72	-6.54	15	1.74	4.9	-6.19	7.23	0
P5xP7	9.11	16.86	-6.92	0.93	-4.76	-5.31	1.19	-12.38	0.9	-5.82
P5xP8	-0.87	10.14	-4.43	1.69	0	-9.82	-9.83	-25.66	43.52	-11.81
P5xP9	8.65	-34.3	2.01	-8.41	5	0	6.11	-78.05	-24.55	-5.17
P5xP1	-	-	-	-	-	-	-	-	-	-
0	7.67	0.99	-5.38	-5.61	-5	-6.45	0.84	-9.38	-2.19	-9.73
P6xP7	5.57	-4	-13.31	3.13	0	-11.29	5.82	23.38	-8.47	-11.05
P6xP8	-7.74	-2.68	-9.14	-17.8	0	-11.66	-18.68	-20.08	29.94	-9.71
P6xP9	1.24	-18.07	-2.41	-2.08	5.26	-6.25	3.13	-0.9	-28.94	-3.66
P6xP1	-	-	-	-	-	-	-	-	-	-
0	7.64	-13.76	-18.46	-6.25	0	-9.38	-1.86	36.24	13.23	-9.45
P7xP8	-9.7	18.21	-6.01	-7.63	-9.09	-14.12	-20.66	-27.89	-12.32	-4.46
P7xP9	17.59	-35.04	-4.26	10.42	-4.76	-10.3	8.42	-7.41	-0.36	-9.3
P7xP1	-	-	-	-	-	-	-	-	-	-
0	14.05	-18.17	-12.05	5.21	-4.76	-13.29	3.61	-15.05	-24.6	-11.05
P8xP9	-9.91	-18.43	-6.01	-1.69	-9.09	-17.18	-16.41	-21.48	2.45	-14.96
P8xP1	-	-	-	-	-	-	-	-	-	-
0	-7.96	6.53	-4.26	-9.32	-9.09	-14.42	-16.73	-10.32	14.18	-16.01
P9xP1	-	-	-	-	-	-	-	-	-	-
0	2.96	-37.99	-12.05	10.42	-5.56	-3.33	10.93	4.36	0.74	-5.56

Key: PH-Plant height; TN-Tiller numbers/plant; LL-Leaf length; LW-Leaf width; DF-Days to flowering; PL-Panicle length; P.Exs-Panicle exertion; SN-Spikelet numbers/panicle; 100SW-100seed weight; DM-Days to maturity

attributed to the degree of selection, particularly because the parental lines/varieties used in the current study are highly selected genotypes. The wide range in heterosis in the current work has been previously observed [12; 16; 19; 21; 22; 23], and it's an indication of the suitability of the parental lines for heterosis breeding.

Six parents, namely MGD 101 (P₁), FARO 44 (P₂), FARO 52 (P₃), FARO 57 (P₄), STRASSA 58 (P₈) and IR 72 (P₉), recorded the highest GCA values for most of the traits and the least values in terms of days to flowering and maturity. These parents were the most frequent in crosses with the highest SCA effects and % heterosis for Tiller number, Leaf length, leaf width, panicle length and Spikelet numbers/panicle. Crosses involving these six parents also recorded the least SCA effects and % heterosis for days to flowering and maturity.

Back cross breeding of the F₁s to their respective parents, namely, MGD 101, FARO 44, FARO 52, FARO 57, STRASSA 58 and IR 72, concentrating on selection for higher tiller numbers, longer and wider leaves, longer panicles, more spikelet numbers per panicle, dwarfism and earliness will enhance the improvement of these genotypes towards the development of new varieties of rice.

5. CONCLUSION

Both additive and non – additive gene action was involved in the control of yield component traits in the studied rice varieties and their hybrids. The GCA, SCA and % heterosis were considered as selection criteria in the improvement of the identified genotypes (parents and crosses) for yield component traits via backcross breeding.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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