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Diallel Analysis for Quantitative Traits in Rice Germplasm (*Oryza sativa* L.) Across Locations

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ABSTRACT: *A diallel cross from seven parents and their F1 hybrids were evaluated across three locations using a Randomized complete block design with three replications for their quantitative traits performance. Parameters assessed include plant heights, days to 50% headings, panicle lengths, panicle weights, number of seeds per panicle, number of productive tillers, number of panicle branches, yield per plots which were extrapolated to yield in tonnes per hectare and 100 grain weights. Results obtained showed a significant difference among parents and F1 hybrids performance across different locations evaluated. GCA and SCA effects were computed, variance components that is additive, dominance, heritability in both narrow sense and broad sense were also computed.*

KEYWORDS: Diallel cross, Quantitative trait, Germplasm, Rice

INTRODUCTION

Diallel cross being a systematic technique in plant breeding refers to mating of selected parents in all possible combinations while the evaluation of a set of diallel crosses is known as diallel analysis. When crosses are made in all possible combinations using the technique, it is possible to produce new genetic combinations that might have improved performances over the parents (Susan *et al.*, 2012).

Quantitative genetics remains useful in practical rice improvement despite advances in molecular breeding. Thus, estimation of genetic parameters such as combing ability gives useful genetic information regarding the selection of parents in terms of the performance of their hybrids indicates the appropriate selection strategy to be applied in the breeding program and allows the identification of the best parents (Torres and Geraldi, 2007).

A successful and efficient hybridization program relies on the knowledge of parental lines or germplasm which is the term used to describe the seeds, plants, or plant parts useful in plant breeding when maintained for the purposes of studying, managing, or using the genetic information they possess. The effectiveness of any rice improvement programme depends on the utilization of different germplasm from different locations (Susan *et al*., 2012.). Hence, this study is aimed at evaluating a set of diallel mating for the purpose of elucidating various quantitative traits in rice germplasm (*Oryza sativa* L.) across three locations.

Theoretical Underpinning

Crop improvement program helps in the development of superior recombinants in which genetic diversity is a prerequisite. Rice (*Oryza sativa* L.) shows great morphological variation, especially in quantitative traits especially in vegetative traits such as plant height and leaf length. The breeders are interested to evaluate genetic diversity based on morphological traits because they are inexpensive, rapid, and simple to score. The study of these traits needs neither sophisticated methods nor complicated equipments, and also these traits can be inherited without either specific biochemical or molecular techniques. Until now scientific classification of plant was based on morphological traits (Din *et al.*, 2010).

A quantitative trait is a measurable phenotype that depends on the cumulative actions of many genes and the environment to improve the production of crops. In other words, they refer to the characteristics of crops that impact their yield, quality, and ability to resist biotic and abiotic stresses. The most important traits in rice include plant height, number of tillers/plant, number of days to 50% flowering/heading, number of panicles/plant, number of grains per panicle, panicle length, panicle weight, number of days to maturity, 1000-grain weight and grain yield (t/ha), as well as the ability to resist pests, diseases, and environmental stressors (Osundare *et al.*, 2017).
Various strategies are being used to improve agronomic traits, such as genetic engineering, marker-assisted selection, and plant breeding to identify and manipulate genes that can be used to develop crops with desirable traits thereby improving the yield and quality of crops while also ensuring that they are resistant to pests and diseases (Kebriyaee *et al.*, 2012).

Another important aspect of agronomic research is testing crops in different environments to determine their suitability for different growing conditions. This involves evaluating crops in different soil types, climates, and elevations to determine which ones are best suited for different regions. This can help to ensure food security and empower farmers to produce enough food to feed their communities and the world (Kebriyaee *et al.*, 2012). This research helps to ensure global food security and empowers farmers to produce more crops and better quality produce.

Collection of the diverse germplasm ensures that plant breeders have the whole range of possible genetic variabilities of a crop plant. These germplasm can only be utilised optimally by breeders if it is well characterized. Selection through breeding is one of the several factors that influence the nutritional content of rice (Das *et al.*, 2020).

The success of any crop improvement program depends on the selection based on actual performance of the parents as well as their combining ability for traits of agronomic importance. Combining ability provides information about inheritance pattern of gene action to breeders for development of hybrids. It also plays a vital role in obtaining the genetic information on a particular trait of interest via fixed and random selection of parental lines in the shortest possible time. Combining ability indicates the expression of a trait, whether additive or non-additive and the appropriate breeding strategy that will efficiently improve the trait. General combining ability (GCA) is mainly attributable to the additive genetic effects, whereas those associated with specific combing ability (SCA) are attributed to the nonadditive effects (dominance and various types of epistasis) (Owusu *et al.*, 2020). Breeding strategies based on hybrid production require a high level of heterosis as well as the specific combining ability (SCA) of crosses. One of the main problems of plant breeders for improving high yielding varieties is to select good parents and crosses. Compared to alternative mating designs, the diallel analysis is an effective method for screening parents for hybrid production. In other words, diallel analysis is one of the most powerful tools for estimating the general combining ability (GCA) of parents and selecting of desirable parents and crosses with high SCA for the exploitation of heterosis (Sarkar *et al.*, 2002; Rahimi *et al.*, 2010).

METHODOLOGY

Seven parents obtained from National Cereal Research Institute Badeggi (NCRI) name (1) FARO 26 (2) FARO 64 (3) FARO 57 (4) FARO 33 (5) FARO 66 (6) FARO 44 (7) FARO 31. The parents were planted and crossed in all possible combinations to obtain F1 hybrids (excluding reciprocals). The parents and 21 F1 hybrids were planted across three locations using a randomized complete block design with three replications to evaluate their performance. The land was cleared and harrowed manually, 3 – 5 seeds were planted and later thinned to 2 seedlings per planting hole at spacing of 20 x 20cm manual weed control with hoe were carried out. Fertilizer application at the rate of 200 kg/ha N, 60kg/ha P_2O_5 and 60kg/ha K_2O (Terres and Geraldi, 2007).

Parameters assessed include plant height, days to 50% heading, panicle lengths, panicle weights, number of seeds per panicle, number of productive tillers, number of panicle branches, yield per plot (also extrapolated to yield in tones per hectare) 100 seed weights. Diallel analysis in line with Griffinga (1956) model II and method II that is parents and F1 hybrids excluding reciprocals.
The three locations include used for the evaluation are: Kura village in Kano state (Latitude 11° 43' 32"N, Longitude 8° 25' 22" E); Makurdi in Benue State (Latitude 7° 41' 01"N, Longitude 08° 37' 17"E); Zuru in kebbi state (Latitude 11° 24' 16"N, Longitude 05° 14' 24"E)

RESULTS AND DISCUSSION

Information and exact study of combining ability can be useful in regards to selection of breeding methods and selection of lines for hybridization (Bagheri *et al*., 2008). Among different methods to assess the nature of generation in the parents, the diallel cross technique is a systematic method (Verma 2003).

Table 2 shows mean performance of parents and their F1 hybrids performance in Kura village Kano state. parent p5= FARO 66 recorded highest plant heights (118.33cm) and hybrids p4*p5, recorded highest plant heights of (125.67) followed by p2*p5(118.67) p3*p5(118.33) p2*p3 (112.33) respectively.

For days to 50% heading, p2=FARO64 recorded lowest days to 50% heading (83) followed by hybrids p1*p2, (88), p2*p6 (88), p2*p4 89), p2*p3(89) and p2*p5 (90)Yield attributes recorded in Kura shows that p5=FARO66 is the highest producing parent (5.23) tonnes per hectare followed by p7 =FARO31 (4.96) tonnes per hectare. Hybrids p4*p5, p5*p6, p3*p5, p3*p4 shows significantly higher yield.

Table 3 shows mean performance of parents and hybrids in Makurdi. P5=FARO66 also showed higher yield in Makurdi followed by p3=FARO57, p4=FARO33. Hybrids p3*p5 shows higher followed by p3*p4, p4*p7, p3*p5 respectively.
In Zuru (Table 4) the mean performance of parents and hybrids showed that parent p5=FARO66 produced higher than other parents followed by p4=FARO33, p2=FARO, 64 respectively. Hybrids p3*p5, p4*p5 p1*p5, p5*p6, p2*p3 shows significantly higher yield in Zuru.

Generally, p5=, FARO66 p4=FARO33 shows consistent performance across locations evaluated. Hybrids p4*p5, p3*p5, p1*p5, p3*p4 shows consistent yield performance across locations studied. Table 5 shows mean square for agronomic traits studied among parents and their F1 hybrids across three locations.

Table 6 shows mean squares for general and specific combining ability of seven parents and their F1 hybrids. Mean squares for general combining ability were found to be significantly higher in almost all the traits studied compared to the specific combining ability in all the locations. This is an indication of prepollence of additive gene effect which suggest that effective selection for such traits could be practiced even in an early generation (Mothilal, 2026).

Table 7 shows genetic parameters for quantitative traits studied. Additive genetic variance was significantly higher than dominance variance except for yield and 100 grain weights. The predominance of additive genetic variance indicates that genetic gain for such traits is achievable. However, level of dominance on yield and 100 grain weights suggest that heterosis might result due to dominance on recessive genes (White *et al*., 2007). Similarly, the findings is in line with the findings of Mckeand *et al*. (2006) They suggested that when dominance contributes to the complex traits, these strategy increase yield when compared to half sib open pollinated families. Heritability in narrow sense (h2) was found to be higher on days to 50% heading, plant heights, panicle lengths, number of productive tillers, and panicle weights. Indicating that selection progress can be made in improving yield based on these traits (Holand *et al*., 2003).

Table 8 shows general combining ability effects across locations studied. There were highly significant effects in almost all the traits in Makurdi and Zuru locations except few traits that shows non significant effects. However, at Kura location, a non-significant effect was observed. These might be attributed to some environmental factors such as disease, wind, temperature, rain etc. These factors can have large impact on Agricultural productivity. (Christine *et al*., 2017)The significant general combining ability effects are evidence of superior parents that can be used in intra-population breeding programs (Viana, 2000).

Tables 9,10 and 11 shows specific combining ability effects across locations which shows positive and negative values indicating high and low values for such traits respectively. Positively higher specific combining ability for a given trait by a hybrid is showing the degree of dominance of the gene controlling such trait in a cross. Suggesting that they might be trustworthy crosses for hybrid production.

CONCLUSION

From the study, parents p5=FARO66 and p4=FARO33 shows consistent performance across all locations. Similarly, hybrids p4xp5, p3xp5, p1xp5, and p3xp4 also showed consistent yield performance across all the locations evaluated. Therefore, these hybrids are recommended for heterosis breeding. Similarly, additive gene effect was found to be highly positive for the consistent parents for most of the traits studied. That indicates that selection for such traits even in early generation will be promising.

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Table 1 passport information on parents used for crosses. (1) FARO 26 (2) FARO 64 (3) FARO 57 (4) FARO 33 (5) FARO 66 (6) FARO 44 (7) FARO 31

Variety Name	National Code	Original Name	Outstanding Characteristics	Origin/Source	Developing Institute
FARO 44	NGOS-91-44	SIPI-692033	• Good cooking qualities • Tolerant to iron toxicity • Stress tolerant • Lower breakage characteristic • Resistant to blast disease	Taiwan	WARDA/IITA/NCRI
FARO 64	NGOS-15-69	ART15-7-16-38-1-B-B-2	• Early maturing • High yielding • Drought tolerance	Africa Rice	Africa Rice Centre and NCRI
FARO 33	NGOS-91-33	FAROX-233-1-1-1	• Long grain type	Nigeria (NCRI)	NCRI, Bida
FARO 66	NGOS-17-71	ART351:2-2-B-5-B	• Submergence tolerant • High yielding • Long and medium slender grains and • Moderately tolerant to iron toxicity	Africa Rice	Africa Rice Centre and NCRI, Badeggi
FARO 31	NGOS-91-31	FAROX-228-3-1-1	• Medium grain type	Nigeria (NCRI)	NCRI, Bida
FARO 57	NGOS-05-57	TOX4004-43-1-2-1	• High yielding • Medium maturing • Long slender grains • Resistant to blast disease • Resistant to drought • Resistant iron toxicity and • Resistance to rice yellow mottle virus disease • Good cooking quality	WARDA/IITA	NCRI, Badeggi, Ibadan
FARO 26	NGOS-91-26	TOS-78	• Medium grain type • High tillering ability	Nigeria (NCRI)	FDAR (NCRI)

Table 2: Mean performances of parents and their F1 hybrids performance in Kura village Kano State

Entry	Plant Height (cm)	Days to 50% Flowering	Panicle Length (cm)	Panicle Weight (g)	Seed per Panicle	Productive Tillers	Panicle Branches	Yield per Plot	Yield per Hectare (t/ha)	Grain Weight (g)
P1	79.33	99.00	24.67	2.93	103.67	25.00	10.00	1709.00	4.28	2.90
P1xP2	92.67	88.33	25.67	2.93	155.33	15.67	12.33	1967.67	4.92	2.80
P1xP3	103.00	103.00	27.67	3.00	183.00	17.00	10.00	2092.67	5.23	3.10
P1xP4	96.00	96.33	28.00	3.00	165.00	15.33	10.00	1877.67	4.69	2.90
P1xP5	99.00	103.67	30.33	3.63	170.33	19.67	11.67	2364.00	5.91	3.00
P1xP6	81.00	98.00	27.67	3.17	159.67	15.67	10.00	1907.00	4.61	2.40
P1xP7	97.33	97.00	28.00	3.37	199.33	15.33	10.00	1743.33	4.36	2.40
P2	98.33	83.00	25.67	3.00	143.67	13.00	12.00	1704.67	4.27	2.80
P2xP3	112.33	89.67	30.00	4.10	187.33	12.00	10.00	2172.67	5.43	2.40
P2xP4	95.00	89.67	27.67	2.97	154.67	15.00	10.00	2261.67	5.65	2.70
P2xP5	118.67	92.00	30.00	3.20	167.67	16.33	12.00	2162.67	5.41	3.00
P2xP6	85.00	88.00	28.00	3.20	156.33	12.00	10.00	1823.00	4.55	2.40
P2xP7	97.67	90.00	27.67	3.47	198.00	14.67	10.00	2362.67	5.92	2.50
P3	112.33	105.00	29.67	4.13	192.00	12.00	9.00	1993.67	4.97	2.80
P3xP4	93.67	95.00	28.33	3.50	170.33	15.00	10.00	2406.67	6.01	2.50
P3xP5	118.33	106.33	30.00	4.40	169.00	16.00	12.00	2647.67	6.62	3.00
P3xP6	90.33	97.00	27.67	3.43	176.67	12.00	9.00	2215.00	5.54	2.60
P3xP7	93.33	95.33	28.67	3.57	196.00	13.67	10.00	2391.00	5.98	2.80
P4	90.67	95.00	27.67	2.90	160.67	15.00	10.00	1925.33	4.82	2.50
P4xP5	125.67	99.33	30.67	3.93	170.33	15.00	11.67	2573.33	6.43	3.00
P4xP6	86.67	95.33	28.00	3.10	160.67	12.33	10.00	2144.00	5.37	2.60
P4xP7	98.67	94.00	28.33	3.20	199.00	12.33	10.00	2476.33	6.19	2.80
P5	118.33	106.00	32.00	4.27	163.33	15.67	12.33	2092.67	5.23	3.00
P5xP6	90.33	97.00	29.33	3.20	168.33	15.00	10.00	2398.00	6.00	3.20
P5xP7	110.00	98.33	30.00	4.07	198.00	15.33	10.00	1903.33	4.77	2.60
P6	81.33	95.00	27.67	3.27	155.33	12.00	9.00	1986.33	4.97	2.80
P6xP7	92.67	91.33	28.00	3.33	190.67	14.00	10.00	1863.33	4.66	2.70
P7	98.33	93.67	28.00	3.37	198.67	13.33	10.00	1982.67	4.96	2.80
Mean	98.43	95.76	28.39	3.42	171.89	14.83	10.39	2112.43	5.28	2.75
Min	79.00	83.00	24.00	2.50	103.00	12.00	9.00	1704.00	4.26	2.40
Max	126.00	107.00	33.00	4.50	202.00	25.00	13.00	2650.00	6.63	3.20
$LSD_{0.05}$	15.01	7.85	3.77	0.23	15.27	3.77	3.36	378.00	0.90	0.42
CV%	17.63	5.47	11.66	4.11	11.87	13.21	12.14	10.94	16.04	14.11

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Table 3: Mean performances of parents and hybrids in Makurdi, Benue State

Entry	Plant Height (cm)	Days to 50% Flowering	Panicle Length (cm)	Panicle Weight (g)	Seed per Panicle	Productive Tillers	Panicle Branches	Yield per Plot	Yield per Hectare (t/ha)	Grain Weight (g)
P1	81.00	103.00	26.00	2.87	99.67	26.00	10.00	1892.00	4.73	3.00
P1xP2	94.67	92.00	26.00	2.90	154.00	17.00	12.33	1993.33	4.99	2.80
P1xP3	105.00	108.00	28.00	3.00	185.00	18.67	10.00	2071.00	5.17	3.00
P1xP4	98.00	99.33	28.00	2.90	168.67	17.67	10.00	1905.33	4.76	2.80
P1xP5	102.33	102.33	30.00	3.93	167.67	20.67	11.67	2406.67	6.01	3.20
P1xP6	82.00	101.33	28.00	3.03	159.00	18.00	10.00	2000.67	5.00	2.50
P1xP7	99.00	100.00	28.00	3.57	198.67	16.00	10.00	1995.00	4.98	2.50
P2	99.67	85.33	26.00	3.00	145.33	14.00	12.33	1890.33	4.72	2.70
P2xP3	115.33	93.67	30.00	4.00	190.00	12.00	10.00	2321.33	5.80	2.50
P2xP4	98.00	93.00	27.67	2.97	154.00	16.67	10.00	2301.67	5.75	2.80
P2xP5	121.67	94.33	30.00	3.17	167.33	16.67	12.00	2341.33	5.85	3.00
P2xP6	88.67	92.00	28.00	3.30	155.67	12.33	10.00	1902.00	4.75	2.50
P2xP7	101.33	94.67	28.00	3.50	198.33	15.00	10.00	2201.33	5.51	2.50
P3	114.67	112.00	30.00	4.23	187.33	12.00	8.67	2105.33	5.26	2.40
P3xP4	95.67	98.00	28.67	3.43	169.33	14.67	10.00	2500.00	6.25	2.50
P3xP5	121.00	110.00	30.00	4.50	168.67	17.33	11.67	2800.00	7.00	2.80
P3xP6	92.00	99.33	28.00	3.40	177.00	12.67	9.33	2333.33	5.83	2.50
P3xP7	94.33	98.00	29.00	3.60	197.33	14.33	10.00	2490.67	6.23	2.50
P4	92.33	98.00	28.00	2.83	156.33	16.00	10.00	2196.67	5.50	2.60
P4xP5	128.00	104.33	30.33	4.00	166.33	18.00	11.67	2602.00	6.51	3.30
P4xP6	88.33	98.33	28.00	3.17	158.00	12.67	10.00	2485.33	6.23	2.80
P4xP7	101.00	98.00	28.00	3.20	198.00	16.00	10.00	2500.67	6.25	2.80
P5	120.33	109.67	32.00	4.53	160.67	16.00	12.33	2500.33	6.25	3.00
P5xP6	91.33	99.67	29.00	3.60	166.33	14.33	10.00	2481.33	6.21	3.30
P5xP7	111.33	98.33	30.00	4.00	196.67	18.00	10.00	2002.33	5.02	2.70
P6	83.33	98.33	28.00	3.13	155.67	12.33	9.00	2008.33	5.02	2.70
P6xP7	93.67	98.33	28.00	3.40	190.67	15.67	10.00	1900.00	4.75	2.70
P7	100.33	98.33	28.00	3.37	199.67	13.67	10.00	2003.33	5.01	2.80
Mean	100.51	99.20	28.52	3.45	171.12	15.87	10.39	2218.99	5.55	2.76
Min	80.00	85.00	26.00	2.80	99.00	12.00	7.00	1890.00	4.72	2.40
Max	130.00	112.00	32.00	4.60	201.00	26.00	13.00	2800.00	7.00	3.30
$LSD_{0.05}$	15.00	7.02	3.13	0.08	3.60	1.89	1.66	240.00	1.08	0.53
CV%	9.96	6.30	6.70	1.45	1.29	3.43	3.89	6.06	11.92	2.36

Table 4: Mean performances of parents and hybrids in Zuru

Entry	Plant Height (cm)	Days to 50% Flowering	Panicle Length (cm)	Panicle Weight (g)	Seed per Panicle	Productive Tillers	Panicle Branches	Yield per Plot	Yield per Hectare (t/ha)	Grain Weight (g)
P1	78.33	98.33	25.33	2.90	101.67	24.33	10.00	1784.33	4.45	3.10
P1xP2	92.33	88.00	26.00	2.93	153.00	15.33	12.00	2008.00	5.00	3.00
P1xP3	102.33	104.00	28.00	3.00	183.33	17.33	10.00	2003.67	5.00	3.00
P1xP4	95.33	96.67	27.67	2.87	166.00	15.00	10.00	1802.00	4.50	3.00
P1xP5	99.33	104.67	30.67	3.17	167.67	20.33	12.00	2651.33	6.50	3.40
P1xP6	80.33	97.33	28.00	2.97	158.00	16.67	10.00	1982.33	4.95	2.70
P1xP7	97.33	96.33	27.67	3.03	199.67	16.67	10.00	1961.33	4.91	2.80
P2	98.00	83.67	26.00	3.00	144.00	12.67	12.00	2090.00	5.22	2.80
P2xP3	111.67	90.67	29.67	4.17	185.00	11.67	10.00	2443.67	6.11	2.80
P2xP4	92.00	89.67	27.67	2.90	154.33	15.33	10.00	2552.00	6.38	2.80
P2xP5	121.00	91.33	30.00	3.43	168.00	16.33	12.00	2532.67	6.33	3.20
P2xP6	84.67	89.00	27.67	3.33	156.00	12.33	10.00	2003.33	5.00	2.80
P2xP7	97.67	89.67	28.00	3.50	198.33	14.33	10.00	2445.00	6.12	2.80
P3	112.00	107.00	29.33	4.17	188.33	12.00	9.00	2022.00	5.05	2.60
P3xP4	91.67	95.00	28.33	3.57	170.00	13.33	10.00	2455.00	6.13	2.80
P3xP5	117.67	106.33	29.67	4.47	172.67	15.67	12.00	2882.33	7.22	2.80
P3xP6	90.00	97.33	28.00	3.47	174.67	12.00	9.00	2284.67	5.70	2.80
P3xP7	92.33	96.00	29.00	3.57	198.67	14.00	10.00	2294.33	5.74	2.80
P4	91.00	95.33	28.00	2.83	158.67	15.33	10.00	2188.00	5.46	2.80
P4xP5	123.67	99.67	30.33	4.03	176.00	17.00	12.00	2667.00	6.67	3.40
P4xP6	85.67	96.00	28.00	3.17	160.67	12.33	10.00	2284.67	5.72	2.90
P4xP7	98.00	94.33	28.00	3.23	199.33	16.00	10.00	2486.33	6.22	2.70
P5	118.33	104.67	31.67	4.17	160.33	16.00	12.33	2449.00	6.10	3.10
P5xP6	89.67	96.33	29.00	3.57	166.00	14.00	10.00	2584.00	6.46	3.40
P5xP7	109.33	96.33	29.67	4.17	197.33	17.33	10.00	1903.33	4.76	2.80
P6	81.00	95.33	28.00	3.17	155.67	11.67	9.00	1929.67	4.81	2.70
P6xP7	91.00	90.00	28.00	3.50	191.33	14.33	10.00	1902.00	4.76	2.80
P7	98.00	93.67	28.00	3.33	199.33	13.67	10.00	1908.00	4.75	3.00
Mean	97.85	95.81	28.40	3.41	171.57	15.11	10.40	2232.14	5.57	2.91
Min	78.00	83.00	25.00	2.80	99.00	11.00	9.00	1780.00	4.45	2.60
Max	125.00	108.00	32.00	4.50	203.00	25.00	13.00	2886.00	7.22	3.40
$LSD_{0.05}$	12.80	10.49	3.64	0.96	15.13	2.95	1.78	468.29	0.78	0.21
CV%	8.04	6.60	4.38	17.20	4.83	5.84	6.50	18.29	14.97	7.63

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Table 5: Mean Squares for 10 agronomic traits of evaluated parental rice lines and their crosses at the three locations considered

Locations	Sources of Variation	Plant Height (cm)	Days to 50% Flowering	Panicle Length (cm)	Panicle Weight (g)	Seed per Panicle	Productive Tillers	Panicle Branches	Yield per Plot	Yield per Hectare (t/ha)	Grain Weight (g)
	Block	0.57	0.58	0.68	0.01	24.25	0.23	0.00	2.39	4.79	0.01
Kura	Entries	454.54	98.42	7.58	0.59	1377.51	22.04	3.01	210956.70	44.05	0.43
	Residuals	3.86	2.75	2.22	0.20	103.86	2.26	0.49	5.34	5.79	0.10
	Block	1.08	1.76	0.01	0.01	4.62	0.01	0.25	17.23	6.29	0.01
Makurdi	Entries	474.04	104.70	5.81	0.73	1463.76	27.32	3.06	205960.40	20.60	0.60
	Residuals	8.49	3.92	0.37	0.03	48.54	2.96	1.64	2.16	4.33	0.11
	Block	0.44	0.58	0.15	0.00	8.82	0.57	0.01	67.00	19.58	0.02
Zuru	Entries	468.48	100.65	5.91	0.68	1437.58	23.06	3.10	280090.50	64.65	0.62
	Residuals	6.13	4.11	1.55	0.04	98.21	3.37	0.12	16.67	20.12	0.12

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Table 6: Mean Square of General and Specific Combining Ability of Seven Rice Parents and their Hybrids for the Ten Quantitative Traits Studied at the three Locations

Locations	Sources of Variation	Plant Height (cm)	Days to 50% Flowering	Panicle Length (cm)	Panicle Weight (g)	Seed per Panicle	Productive Tillers	Panicle Branches	Yield per Plot	Yield per Hectare (t/ha)	Grain Weight (g)
	gca	523.110	134.254	8.942	0.647	1415.551	25.457	3.205	121147.600	0.520	0.121
Kura	sca	45.343	3.820	0.694	0.067	185.917	2.171	0.376	55796.420	0.190	0.033
	error	0.129	0.092	0.074	0.007	3.462	0.075	0.016	1.746	0.092	0.002
	gca	542.880	130.438	7.090	0.861	1471.998	32.479	3.271	177336.600	0.869	0.110
Makurdi	sca	48.050	7.603	0.466	0.068	206.754	2.428	0.378	37601.130	0.251	0.030
	error	0.286	0.131	0.012	0.001	1.615	0.095	0.055	0.722	0.006	0.002
	gca	538.377	132.362	6.966	0.810	1500.015	27.991	3.353	215700.800	1.007	0.132
Zuru	sca	46.956	5.319	0.543	0.062	187.529	1.887	0.369	58409.960	0.291	0.036
	error	0.202	0.137	0.052	0.001	3.262	0.112	0.004	5.556	0.007	0.002

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Table 7: Genetic Parameters for the Ten Quantitative Traits of Seven Rice Lines and their Hybrids at three Locations

Locations	Sources of Variation	Plant Height (cm)	Days to 50% Flowering	Panicle Length (cm)	Panicle Weight (g)	Seed per Panicle	Productive Tillers	Panicle Branches	Yield per Plot	Yield per Hectare (t/ha)	Grain Weight (g)
	VA	106.170	28.985	1.833	0.129	273.252	5.175	0.629	14522.482	0.159	0.019
	VD	45.214	3.729	0.621	0.060	182.455	2.096	0.360	55794.676	0.284	0.030
Kura	h2	0.701	0.884	0.725	0.660	0.595	0.704	0.626	0.207	0.353	0.408
	H2	0.999	0.997	0.971	0.967	0.992	0.990	0.984	1.000	0.985	1.042
	Dominance Ratio	0.923	0.507	0.823	0.965	1.156	0.900	1.070	2.772	1.891	1.903
	VA	109.962	27.297	1.472	0.176	281.165	6.678	0.643	31052.323	0.211	0.018
	VD	47.764	7.473	0.454	0.067	205.139	2.332	0.324	37600.408	0.377	0.028
Makurdi	h2	0.696	0.782	0.760	0.723	0.576	0.733	0.630	0.452	0.468	0.378
	H2	0.998	0.996	0.994	0.997	0.997	0.990	0.947	1.000	1.305	0.965
	Dominance Ratio	0.932	0.740	0.785	0.870	1.208	0.836	1.003	1.556	2.504	1.764
	VA	109.205	28.232	1.427	0.166	291.664	5.801	0.663	34953.524	0.183	0.020
	VD	46.753	5.182	0.491	0.061	184.267	1.774	0.365	58404.406	0.327	0.031
Zuru	h2	0.699	0.841	0.725	0.729	0.609	0.755	0.643	0.374	0.406	0.415
	H2	0.999	0.996	0.974	0.995	0.993	0.985	0.996	1.000	1.132	1.060
	Dominance Ratio	0.925	0.606	0.829	0.855	1.124	0.782	1.049	1.828	2.173	1.937

Table 8: General Combining Ability Effects (gi) of each Parent for the Ten Quantitative Traits at three Locations

Location	Entries	Plant Height (cm)		Days to 50% Flowering		Panicle Length (cm)		Panicle Weight (g)		Seed per Panicle		Productive Tillers		Panicle Branches		Yield per Plot		Yield per Hectare (t/ha)		Grain Weight (g)	
Kura	P1	-0.680	ns	-0.080	ns	-0.200	ns	-0.030	ns	-4.720	ns	0.330	ns	0.020	ns	-70.160	ns	-0.170	ns	-0.170	ns
	P2	-0.050	ns	0.950	ns	0.210	ns	0.010	ns	-1.240	ns	-0.040	ns	0.100	ns	-5.310	ns	-0.010	ns	-0.010	ns
	P3	0.250	ns	-0.790	ns	0.060	ns	0.030	ns	6.130	ns	-0.410	ns	-0.130	ns	60.320	ns	0.150	ns	0.150	ns
	P4	-2.270	ns	-0.490	ns	-0.530	ns	-0.120	ns	-9.090	*	1.040	*	0.060	ns	-164.900	**	-0.410	**	-0.410	**
	P5	1.360	ns	0.030	ns	0.170	ns	0.090	ns	1.690	ns	0.110	ns	-0.050	ns	-9.710	ns	-0.060	ns	-0.060	ns
	P6	2.250	ns	-0.200	ns	0.240	ns	0.090	ns	3.690	ns	-0.960	ns	0.100	ns	115.990	**	0.300	**	0.300	**
	P7	-0.860	ns	0.580	ns	0.060	ns	-0.080	ns	3.540	ns	-0.070	ns	-0.090	ns	73.770	*	0.190	*	0.190	*
	S.Error	**2.479**		**1.012**		**0.298**		**0.086**		**4.123**		**0.506**		**0.213**		**36.993**		**0.094**		**0.094**	
Makurdi	P1	-6.790	**	1.710	**	-0.910	**	-0.280	**	-15.180	**	3.670	**	0.095	ns	-177.323	**	-0.473	**	0.071	**
	P2	1.660	**	-7.030	**	-0.720	**	-0.190	**	-6.550	**	-1.030	**	0.651	**	-101.138	**	-0.122	**	-0.055	**
	P3	5.400	**	4.150	**	0.610	**	0.310	**	10.340	**	-1.480	**	-0.534	**	108.344	**	0.236	**	-0.095	**
	P4	-1.160	**	-0.740	**	-0.170	**	-0.250	**	-4.660	**	0.080	ns	-0.164	*	104.048	**	0.226	**	-0.018	ns
	P5	12.470	**	3.860	**	1.680	**	0.520	**	-1.620	**	1.120	**	0.947	**	209.159	**	0.506	**	0.220	**
	P6	-11.270	**	-0.880	**	-0.350	**	-0.160	**	-5.660	**	-1.850	**	-0.646	**	-70.286	**	-0.203	**	-0.051	**

	P7	-0.310	ns	-1.070	**	-0.130	**	0.050	**	23.340	**	-0.510	**	-0.349	**	-72.804	**	-0.171	**	-0.073	**
	S.Error	**0.164**		**0.111**		**0.034**		**0.009**		**0.393**		**0.097**		**0.072**		**0.262**		**0.025**		**0.013**	
Zuru	P1	-6.570	**	1.910	**	-0.950	**	-0.390	**	-15.730	**	3.238	**	0.085	**	-208.868	**	-0.540	**	-0.190	ns
	P2	1.400	**	-6.760	**	-0.690	**	-0.120	**	-7.767	**	-1.132	**	0.529	**	34.169	**	0.090	**	-0.011	ns
	P3	5.210	**	4.100	**	0.460	**	0.360	**	9.825	**	-1.429	**	-0.471	**	61.169	**	0.160	**	0.168	ns
	P4	-1.600	**	-0.500	**	-0.140	ns	-0.210	**	-3.212	**	-0.132	ns	-0.138	**	85.095	**	0.220	**	-0.459	**
	P5	12.730	**	4.170	**	1.710	**	0.430	**	-0.471	ns	1.312	**	1.048	**	251.280	**	0.620	**	-0.067	ns
	P6	-11.050	**	-1.090	**	-0.290	**	-0.110	**	-6.064	**	-1.762	**	-0.693	**	-106.312	**	-0.260	**	0.336	**
	P7	-0.120	ns	-1.830	**	-0.100	ns	0.040	**	23.418	**	-0.095	ns	-0.360	**	-116.534	**	-0.290	**	0.213	*
	S.Error	**0.140**		**0.114**		**0.070**		**0.011**		**0.557**		**0.103**		**0.019**		**0.727**		**0.001**		**0.105**	

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Table 9: Specific Combining Ability Effects of each Hybrid for the Ten Quantitative Traits at Kura, Kano

Hybrids	Plant Height (cm)		Days to 50% Flowering		Panicle Length (cm)		Panicle Weight (g)		Seed per Panicle		Productive Tillers		Panicle Branches		Yield per Plot		Yield per Hectare (t/ha)		Grain Weight (g)	
P1xP2	-0.70	ns	2.04	ns	0.94	*	0.10	ns	-3.27	ns	-1.13	ns	-0.18	ns	-36.30	ns	-0.10	ns	-0.10	ns
P1xP3	-0.33	ns	0.11	ns	-1.25	**	-0.25	*	9.03	ns	0.91	ns	0.38	ns	-88.93	ns	-0.22	ns	-0.22	ns
P1xP4	-3.81	ns	4.15	**	1.34	**	0.00	ns	7.92	ns	0.46	ns	0.19	ns	172.30	**	0.43	**	0.43	**
P1xP5	2.22	ns	-3.70	**	0.31	ns	-0.01	ns	10.81	*	-1.28	ns	-0.36	ns	25.78	ns	0.10	ns	0.10	ns
P1xP6	0.33	ns	-5.48	**	-0.10	ns	-0.24	*	5.81	ns	0.13	ns	0.16	ns	-42.26	ns	-0.11	ns	-0.11	ns
P1xP7	3.78	ns	3.41	*	0.75	ns	0.46	**	-0.05	ns	-0.76	ns	0.01	ns	308.30	**	0.76	**	0.76	**
P2xP3	1.04	ns	0.07	ns	1.01	*	0.17	ns	12.55	*	-0.39	ns	-0.36	ns	90.56	ns	0.22	ns	0.22	ns
P2xP4	-6.11	ns	-4.89	**	-2.06	**	-0.24	*	-15.56	**	1.50	*	0.12	ns	-182.89	**	-0.45	**	-0.45	**
P2xP5	7.26	*	5.26	**	0.56	ns	0.25	*	0.99	ns	-0.57	ns	-0.10	ns	-93.07	ns	-0.20	ns	-0.20	ns
P2xP6	-9.63	**	-4.19	**	-1.51	**	-0.32	**	-5.01	ns	-0.17	ns	0.08	ns	-243.44	**	-0.61	**	-0.61	**
P2xP7	1.48	ns	3.70	**	0.01	ns	-0.15	ns	-0.19	ns	2.94	**	0.27	ns	-69.22	ns	-0.18	ns	-0.18	ns
P3xP4	2.93	ns	-4.81	**	0.42	ns	-0.23	*	-11.60	*	-1.13	ns	0.34	ns	73.48	ns	0.18	ns	0.18	ns
P3xP5	3.30	ns	1.67	ns	0.05	ns	0.29	*	-0.38	ns	0.80	ns	0.45	ns	308.96	**	0.80	**	0.80	**
P3xP6	2.07	ns	2.22	ns	0.31	ns	0.09	ns	-0.05	ns	0.20	ns	-0.36	ns	103.26	*	0.25	*	0.25	*
P3xP7	-5.81	ns	-0.22	ns	-0.18	ns	-0.10	ns	-5.90	ns	-1.02	ns	-0.18	ns	93.48	ns	0.23	ns	0.23	ns
P4xP5	3.48	ns	-0.96	ns	-0.69	ns	-0.02	ns	-2.49	ns	-2.31	**	-0.06	ns	-63.81	ns	-0.13	ns	-0.13	ns
P4xP6	0.59	ns	3.26	*	1.23	**	0.18	ns	3.51	ns	-1.57	*	0.12	ns	-43.19	ns	-0.11	ns	-0.11	ns
P4xP7	2.04	ns	0.15	ns	-0.92	*	-0.25	*	-2.34	ns	0.20	ns	0.31	ns	-41.96	ns	-0.11	ns	-0.11	ns
P5xP6	6.96	*	-4.93	**	0.53	ns	-0.10	ns	-7.27	ns	0.35	ns	0.23	ns	-19.37	ns	-0.01	ns	-0.01	ns
P5xP7	-6.93	*	-5.04	**	-0.62	ns	-0.02	ns	-2.45	ns	-0.87	ns	-0.25	ns	20.19	ns	0.09	ns	0.09	ns
P6xP7	4.19	ns	0.52	ns	-0.03	ns	-0.02	ns	-2.45	ns	-0.46	ns	0.27	ns	95.81 ns		0.24	ns	0.24	ns
S. Error	7.21		2.94		0.87		0.25		11.99		1.47		0.62		107.59		0.27		0.27	

Table 10: Specific Combining Ability Effects of each Hybrid for the Ten Quantitative Traits at Makurdi, Benue

Hybrids	Plant Height (cm)		Days to 50% Flowering		Panicle Length (cm)		Panicle Weight (g)		Seed per Panicle		Productive Tillers		Panicle Branches		Yield per Plot		Yield per Hectare (t/ha)		Grain Weight (g)	
P1xP2	-0.71	**	-1.88	**	-0.89	**	-0.07	**	4.61	**	-1.51	**	1.19	**	52.81	**	0.10	ns	0.04	ns
P1xP3	5.88	**	2.94	**	-0.22	**	-0.48	**	18.72	**	0.60	**	0.05	ns	-79.01	**	-0.09	ns	0.25	**
P1xP4	5.44	**	-0.84	**	0.56	**	-0.02	ns	17.39	**	-1.95	**	-0.32	*	-240.38	**	-0.57	**	0.04	ns
P1xP5	-3.86	**	-2.44	**	0.70	**	0.24	**	13.35	**	0.01	ns	0.23	ns	155.84	**	0.64	**	0.10	**
P1xP6	-0.45	*	1.31	**	0.74	**	0.02	ns	8.72	**	0.31	*	0.16	ns	29.29	**	0.06	ns	-0.29	**
P1xP7	5.58	**	0.16	ns	0.52	**	0.35	**	19.39	**	-3.03	**	-0.14	ns	26.14	**	-0.07	ns	-0.24	**
P2xP3	7.77	**	-2.66	**	1.59	**	0.43	**	15.09	**	-1.36	**	-0.51	**	95.14	**	0.20	**	-0.09	**
P2xP4	-3.01	**	1.56	**	0.04	ns	-0.04	**	-5.91	**	1.75	**	-0.88	**	79.77	**	0.36	**	0.03	ns
P2xP5	7.03	**	-1.69	**	0.52	**	-0.61	**	4.39	**	0.71	**	0.01	ns	14.32	**	0.01	ns	0.09	**
P2xP6	-2.23	**	0.71	**	0.56	**	0.20	**	-3.24	**	-0.66	**	-0.40	*	-145.56	**	-0.37	**	-0.14	**
P2xP7	-0.53	*	3.56	**	0.33	**	0.20	**	10.43	**	0.68	**	-0.69	**	156.29	**	0.67	**	-0.08	**
P3xP4	-9.08	**	-4.62	**	-0.30	**	-0.08	**	-7.46	**	0.19	ns	0.31	ns	68.62	**	0.20	**	-0.09	**
P3xP5	2.62	**	2.79	**	-0.81	**	0.22	**	-11.17	**	1.82	**	0.86	**	263.51	**	0.74	**	-0.06	*
P3xP6	-2.64	**	-3.14	**	-0.78	**	-0.20	**	1.20	*	0.12	ns	0.12	ns	76.29	**	0.19	**	-0.03	ns
P3xP7	-11.27	**	-4.29	**	0.00	ns	-0.21	**	-7.46	**	0.45	**	0.49	**	236.14	**	0.45	**	0.06	*
P4xP5	16.18	**	2.01	**	0.30	**	0.28	**	1.50	**	0.94	**	0.49	**	69.81	**	0.34	**	0.22	**
P4xP6	0.25	ns	0.75	**	0.00	ns	0.13	**	-2.80	**	-1.44	**	0.42	*	232.58	**	0.28	**	0.03	ns
P4xP7	1.95	**	0.60	**	-0.22	**	-0.04	**	8.20	**	0.56	**	0.12	ns	250.44	**	0.70	**	0.05	ns
P5xP6	-10.38	**	-2.51	**	-0.85	**	-0.21	**	2.50	**	-0.81	**	-0.69	**	123.47	**	0.45	**	0.32	**
P5xP7	-1.34	**	-3.66	**	-0.07	ns	-0.01	ns	3.83	**	1.53	**	-0.99	**	-353.01	**	-0.95	**	-0.25	**
P6xP7	4.73	**	1.08	**	-0.04	ns	0.06	**	1.87	**	2.16	**	0.60	**	-175.90	**	-0.37	**	0.05	ns
S. Error	**0.48**		**0.32**		**0.10**		**0.03**		**1.14**		**0.28**		**0.18**		**0.65**		**0.06**		**0.03**	

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Table 11: Specific Combining Ability Effects of each Hybrid for the Ten Quantitative Traits at Zuru, Kebbi

Hybrids	Plant Height (cm)		Days to 50% Flowering		Panicle Length (cm)		Panicle Weight (g)		Seed per Panicle		Productive Tillers		Panicle Branches		Yield per Plot		Yield per Hectare (t/ha)		Grain Weight (g)	
P1xP2	-0.34	ns	-2.96	**	-0.76	**	0.03	*	4.93	**	-1.88	**	0.98	**	-49.44	**	-0.13	**	-0.11	ns
P1xP3	5.84	**	2.19	**	0.09	ns	-0.38	**	17.67	**	0.42	ns	-0.02	ns	-80.78	**	-0.19	**	-0.25	ns
P1xP4	5.66	**	-0.56	**	0.35	**	0.06	**	13.37	**	-3.21	**	-0.35	**	-306.37	**	-0.76	**	0.48	ns
P1xP5	-4.68	**	2.78	**	1.50	**	-0.28	**	12.30	**	0.68	**	0.46	**	376.78	**	0.84	**	0.11	ns
P1xP6	0.10	ns	0.70	**	0.83	**	0.06	**	8.22	**	0.08	ns	0.20	**	65.37	**	0.18	**	-0.12	ns
P1xP7	6.18	**	0.44	**	0.31	**	-0.03	ns	20.41	**	-1.58	**	-0.13	**	54.59	**	0.16	**	0.85	**
P2xP3	7.21	**	-2.48	**	1.50	**	0.51	**	11.37	**	-0.88	**	-0.46	**	116.19	**	0.29	**	0.25	ns
P2xP4	-5.64	**	1.11	**	0.09	ns	-0.19	**	-6.26	**	1.49	**	-0.80	**	200.59	**	0.50	**	-0.50	ns
P2xP5	9.03	**	-1.89	**	0.57	**	-0.29	**	4.67	**	1.05	**	0.02	ns	15.07	**	0.05	**	-0.22	ns
P2xP6	-3.53	**	1.04	**	0.24	*	0.14	**	-1.74	ns	0.12	ns	-0.24	**	-156.67	**	-0.40	**	-0.68	*
P2xP7	-1.45	**	2.44	**	0.39	**	0.16	**	11.11	**	0.45	ns	-0.57	**	295.22	**	0.74	**	-0.20	ns
P3xP4	-9.79	**	-4.41	**	-0.39	**	0.00	ns	-8.19	**	-0.21	ns	0.20	**	76.59	**	0.18	**	0.20	ns
P3xP5	1.88	**	2.26	**	-0.91	**	0.26	**	-8.26	**	0.68	**	1.02	**	337.74	**	0.87	**	0.90	**
P3xP6	-2.01	**	-1.48	**	-0.57	**	-0.20	**	-0.67	ns	0.08	ns	-0.24	**	97.67	**	0.23	**	0.28	ns
P3xP7	-10.60	**	-2.07	**	0.24	*	-0.25	**	-6.15	**	0.42	ns	0.43	**	117.56	**	0.30	**	0.26	ns
P4xP5	14.69	**	0.19	ns	0.35	**	0.40	**	8.11	**	0.71	**	0.69	**	98.48	**	0.26	**	-0.15	ns
P4xP6	0.47	*	1.78	**	0.02	ns	0.07	**	-1.63	ns	-0.88	**	0.43	**	73.74	**	0.19	**	-0.12	ns
P4xP7	1.88	**	0.85	**	-0.17	ns	-0.01	ns	7.56	**	1.12	**	0.09	*	285.63	**	0.71	**	-0.12	ns
P5xP6	-9.86	**	-2.56	**	-0.83	**	-0.17	**	0.96	ns	-0.66	**	-0.76	**	206.89	**	0.53	**	-0.01	ns
P5xP7	-1.12	**	-1.81	**	-0.35	**	0.29	**	2.81	*	1.01	**	-1.09	**	-463.56	**	-1.14	**	0.10	ns
P6xP7	4.32	**	-2.89	**	-0.02	ns	0.16	**	2.41	*	1.08	**	0.65	**	-107.30	**	-0.26	**	0.27	ns
S. Error	**0.41**		**0.33**		**0.20**		**0.03**		**1.38**		**0.26**		**0.05**		**1.80**		**0.00**		**0.30**	