International Journal of Genetics and Genomics
2024, Vol. 12, No. 3, pp. 54-67
https://doi.org/10.11648/j.ijgg.20241203.12

Research Article

Combining Ability, Heterosis and Potence Ratio for Yield and Yield Components in Korean Double-Haploid, Progenies and Improved Rice Varieties in Nigeria

Ogba Chinonyelum Somtochukwu, Efisue Andrew Abiodun*

Development of Crop and Science, University of Port Harcourt, Port Harcourt, Nigeria

Abstract

Rice is the most widely consumed staple crop in Africa and consumption continues to grow at a rapid pace with increasing population. Success in breeding programs are largely dependent on the genetic diversity of a crop. Genetic variability occurs due to genetic differences in individuals within a given population, which is the basis of plant breeding. Thus, if the genetic variability is well managed, diversity can result to permanent gains in the performance of the crop. The objectives of this study were to determine the interaction between grain yield and yield components and to conduct genetic studies on selected rice genotypes. The research was carried out at the University of Port Harcourt Faculty of Agriculture teaching and research farm. Thirteen (13) varieties were used which comprised 7 adapted Nigerian varieties and 6 Korean rice varieties in a randomized complete block design (RCBD) in three replications was established. All agronomic practices were carried out at appropriately crop phenology. North Carolina II mating design was used to perform crosses. Data was collected on 10 agronomic traits. All means were subjected to ANOVA, combining ability, Heterosis and Potence ratio were determined. The progenies from UPIA 2 x UPN 234, FARO 52 X UPN 266 and UPIA 3 X UPN 266 had the best phenotypic and genotypic expression and most of the hybrids had heterotic values than their parents. The results also showed ranges of dominance for genotypes. UPIA 1, UPIA 2, UPN 223, UPN 234 and UPN266 should be included in breeding programs because they showed the best GCA's across most traits.

Keywords

Combining Ability, Heterosis, Potence Ratio, Populations, Korean

1. Introduction

Rice (*Oryza sativa* L.) is one of the major food grains consumed by majority of people in the world [1]. Increase in the world population has trigger the consumption rate of this crop, therefore, necessitate the need for increase in the rice production to guarantee food security in the world. This saddled the breeder the responsibility of develop high yielding genotypes with good quality traits for the stakeholders.

The concept of combining ability was defined as the ability of a genotype to transmit superior performance to its progenies [2]. Two types were defined; General combining ability (GCA) and specific combining ability (SCA). According to Sprague and Tatum general combining ability (GCA) is the average performance of a genotype in a series of crosses. It is a measure of additive gene action. Specific Combining Ability

*Corresponding author: andyefisue@yahoo.com (Efisue Andrew Abiodun)

Received: 12 June 2024; **Accepted:** 9 July 2024; **Published:** 31 July 2024

(SCA) is used to evaluate the performance of a genotype in a cross based on what is expected on the average performance of the lines involved. It is a measure of non-additive gene action

Yield is a quantitative trait controlled by many associated factors, one of such factors is ability of the parental lines to combine effectively for higher yield and quality traits. Combining ability is a powerful tool used by breeders to estimate the ability of parents to produce superior hybrid. The knowledge of combining ability is a useful tool to assess ability of gene recombination among genotypes and understanding the nature and magnitude of gene actions involved [3]. It also provides information about the nature and level of gene impacts that regulates grain yields and yields characters, thus enabling the breeders to develop effective and efficient breeding techniques for genetic improvement of grain yields and yields components [4].

Heterosis can be define as a natural phenomenon whereby the offspring or the progeny out-perform their parents in multiple traits such as yield, adaptability and as well resistances to biotic and abiotic stressors [5]. In agricultural production, heterosis is widely exploited for the development of hybrids mostly in cereal crops.

It has been observed that cross-pollinating crops like, maize, and other cereal typically exhibit a higher degree of heterosis than the self-pollinating crops like rice and wheat. However, many hybrid cultivars have also been developed in self-pollinating plant species [6]. Heterosis can manifest by virtue of improvement of several traits during the crop development. The present grain yield of some cereal crops like maize almost in five-times increase as compared to the yield before the development of hybrid.

Maize (*Zea mays*) has huge potential for the manifestation of heterosis and is effectively exploited. The number of hybrids in maize is far higher than any self-pollinated crops, as it is endued with substantial amounts of heterosis for yield and other important agronomic traits thereby enhancing the social and economic benefits of agricultural production [7].

The genetic basis of heterosis has also been exploited in F2 populations of rice mostly the indica types of rice for hybrid production. The results suggest that over-dominance most likely the basis for heterosis which, exhibited in the form of higher tiller numbers, grain weight and, grain yield [8]. This study was therefore conducted to determine combining ability of the genotypes and level of heterosis exhibited by progenies for rice population improvement.

Potence ratios helps show, which are dominance of the inherited traits if the values are greater than ±1, which indicate over-dominance, while values between −1 and +1 indicate partial dominance and values of +1.0 show total dominance and values of 0 indicate there no dominance. Potence ratio was highly exploited in maize breeding in population development [9, 10].

2. Materials and Methods

The research was carried out at the University of Port Harcourt Faculty of Agriculture teaching and research farm, Choba, Rivers State. University of Port Harcourt is located in the southern part of the country along the Niger-Delta coast and lies on latitude 4 °31 to 5 °00N and longitude 6 °45 to 7 °00 E, has an estimated annual rainfall of 2000 – 2680 mm and an average temperature of 28 – 30℃ with an elevation of 20 metre above sea level. This is a potted experiment of 28 entries which, comprised 13 parental lines and their 15 progenies where pre-germinated germinated and seedlings transplanted at the rate of two seedlings per pot in a randomized complete block design in two replications. Normal agronomic practices were carried out as required. Irrigation was applied regularly to maintain the soil field capacity. Inorganic fertilizer (NPK 15:15:15) was applied as basal application of 200 kg ha-^{1}(N_2, P_2O_5 and K_2O) and top-dressed with urea (46% N) 65 kg ha-^{1} at tillering and 35 kg ha-^{1} at booting stages.

Table 1. *Varieties used in this study.*

S/NO	Variety	Origin/Source
1	WBK 114	Uniport Agra germplasm (Improved rice)
2	UPIA 1	Uniport Agra germplasm (Improved rice)
3	UPIA 2	Uniport Agra germplasm (Improved rice)
4	UPIA 3	Uniport Agra germplasm (Improved rice)
5	FARO 52	Uniport Agra germplasm (Improved rice)
6	FARO 57	Uniport Agra germplasm (Improved rice)
7	FARO 61	Uniport Agra germplasm (Improved rice)
8	UPN 223	Double-haploid line from South Korea
9	UPN 266	Double-haploid line from South Korea

S/NO	Variety	Origin/Source
10	UPN 250	Double-haploid line from South Korea
11	UPN 234	Double-haploid line from South Korea
12	UPN 257	Double-haploid line from South Korea
13	UPN 268	Double-haploid line from South Korea
14	FARO 52 X UPN 266	Progeny
15	FARO 52 X UPN 223	Progeny
16	FARO 52 X UPN 268	Progeny
17	FARO 52 X UPN 257	Progeny
18	FARO 61 X UPN 250	Progeny
19	FARO 61 X UPN 234	Progeny
20	UPIA 1 X UPN 250	Progeny
21	UPIA 1 X UPN 266	Progeny
22	UPIA 1 X UPN 234	Progeny
23	UPIA 2 X UPN 266	Progeny
24	UPIA 2 X UPN 234	Progeny
25	UPIA 2 X UPN 257	Hybrid generated from study
26	UPIA 3 X UPN 250	Hybrid generated from study
27	UPIA 3 X UPN 266	Hybrid generated from study
28	WBK 114 X UPN 25O	Hybrid generated from study

2.1. Data Collection

Data was collected at appropriate phenological stages of plant development using the standard evaluation system (SES) for Rice [11]. Data was collected from two plants in each genotype per replication and their means was taken as a representative sample of the population.

Parameters were measured such as plant height from the base of the plant to the tip of the longest leaf, leaf area (LA) was determined using a leaf area meter (li-3100, Lincoln, NE USA), leaf area index (LAI) was calculated as was calculated as follows. LAI = (sum of the Leaf Area of all leaves per unit area where the leaves have been collected [12]. Number of effective tillers, % full seed per panicle was noted, number of seeds per panicle and number of filled seeds per panicle were counted and recorded. Panicle length was measured in centimeters. Panicle weight, 1000 seed weight and yield per plant were all weighed using a sensitive weighing balance in grams.

2.2. Data Analysis

Analysis of variance (ANOVA) using PROC GLM [13], for mean separation.

Variance components were estimated by the method of moments using PROC VARCOMP procedure in SAS computer software version 9.1. General combining ability and SCA effects for the parents and crosses, respectively, were estimated for all traits using the following model:

$$Yijk = m + rk + fi + mj + (fm)ij + eijk;$$

Yijk = phenotypic observation on the progenies;
rk = replication effect;
fi = female parent GCA effects;
mj = male parent GCA effects;
(fm)ij = interaction between female and male parents in the crosses (SCA); and
eijk = experimental error due to environmental effects.

Additive genetic variances (δ^2A) and dominance variance (δ^2 D) and other parameters were estimated from expected mean square equations [14, 15].

Heterosis (mid-parent MPH) and Heterobeltiosis (better parent BPH) of the F1 crosses against their parents were also calculated using the adjusted means [16]. Mid-parent and better parent heterosis were calculated as;

$$MPH = \frac{F_1 - MP}{MP} \times 100$$

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

Where MP (mean of mid-parent) = (P1 + P2)/2 where P1 and P2 are the means of the two inbred parents, BP is the mean of the better parent and F1 is the mean performance of the hybrid.

Potency ratio was calculated according to Mather (1949) [17] and Smith (1952) [18] to determine the degree of dominance as follows:

$$P = \frac{F_1 - MP}{0{\cdot}5(P2 - P_1)}$$

Where, P: relative potency of gene set, F1: first generation mean, P1: the mean of lower parent, P2: the mean of higher parent, M.P.: mid-parent value = (P1 + P2)/2.

3. Results

3.1. Evaluation of Agronomic Characters in Parental Lines and F1 Progenies

The results of this study showed that for plant height 17 varieties performed better than the general mean plant height of 88.04 (Table 2). The cross with the highest plant height was UPIA 2 X 234 (106.01) while the lowest was UPIA 2 X 226 (39.53). the parental line with the highest plant height was UPIA 3 (121.00) followed by FARO 61 (115.5). The parent with the lowest plant height was UPN 223 (67.40). Plant height showed high significant differences (0.05) amongst the analyzed genotypes.

Seventeen (17) varieties performed better than the general mean based on agronomic traits such as LAI of 1.61 (Table 4). The highest leaf area index (LAI) was 3.68 (UPIA 1 X UPN 250), followed by 3.19 (UPIA 1 X UPN 266). And among the parental lines the highest LAI was UPIA (2.53) and significant difference for LAI was observed among the genotypes tested (Table 2).

About 8 varieties performed better than the general mean value (2.67) based on effective tillers number (Table 2). Effective tiller is the number of harvestable tillers at the time of harvest that make up the total grain yield. The cross with the highest effective tiller was UPIA 2 X UPN 234 (7.25) followed by FARO 52 X UPN268 (5.5). The parents with the highest effective tiller were UPN 250 (4.5) followed by UPN 266 (3.0). Effective tillers had high significance among the analyzed genotypes.

About 6 varieties performed better than the general mean based on yield per plant (3.69g) (Table 2). The cross with the highest yield per plant (YPP) was FARO 52 X UPN223 (5.8g) followed by UPIA2 X UPN234 (4.97g). The parents with the YPP were UPN 266 (5.71g) followed by UPIA 1 (4.15g) The yield per plant showed high significance among the analysed genotypes.

Other agronomic trait measured such length of panicles, weight of panicles, NOSPP: Number of seeds per panicle, % FS: % Filled seeds, 1000 SW: 1000 Seed weight NOFSPP: Number of filled seeds per panicle were significant among the genotypes observed in the experiment. (Table 2)

Table 2. Estimation of means for yield and yield related traits in parents and F1 population.

Variety	PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW (g)
FARO52 X UPN266	99.15^{abcdef}	2.33^{ecd}	5^{bc}	25.85^{abcd}	1.04^{a}
FARO52 X UPN223	88.50^{cdedgh}	1.17^{jklm}	3^{def}	23.15^{bcde}	1.38^{a}
FARO52 X UPN268	100.75^{abcdef}	2.24^{cdef}	6^{ab}	25.03^{abcd}	1.25^{a}
FARO52 X UPN257	$96.30^{abcdefg}$	2.43^{cde}	2^{ef}	26.33^{adcd}	1.10^{a}
FARO61 X UPN250	78.50^{efgh}	1.18^{ijklm}	1^{f}	17.90^{e}	0.56^{a}
FARO61 X UPN234	84.50^{defgh}	0.55^{mn}	1^{f}	20.55^{de}	0.79^{a}
UPIA1 X UPN250	100.75^{abcdef}	3.68^{a}	3^{cdef}	28.00^{abc}	1.42^{a}
UPIA 1 X UPN266	91.20^{bcdefg}	3.19^{ab}	2	25.58^{abcd}	1.42^{a}
UPIA 1 X UPN234	75.50^{fgh}	1.33^{hijkl}	2^{ef}	24.75^{abcd}	1.27^{a}
UPIA 2 X UPN266	39.53^{i}	0.63^{lmn}	2^{f}	21.95^{cde}	1.34^{a}
UPIA 2 X UPN234	106.01^{abcd}	2.64^{bcd}	7^{a}	24.78^{abcd}	1.88^{a}
UPIA 2 X UPN257	$91.90^{bcdefgh}$	2.86^{bc}	2^{ef}	25.53^{adcd}	1.15^{a}
UPIA 3 X UPN250	84.40^{defgh}	1.06^{jklm}	1^{f}	20.28^{de}	2.53^{a}
UPIA 3 X UPN266	94.85^{bcdef}	2.27^{cdef}	4^{bcde}	26.55^{abcd}	1.81^{a}

Variety	PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW (g)
WBK114 X UPN250	87.83^{cdefgh}	1.54^{fghij}	1^{f}	17.16^{e}	0.72^{a}
UPN 250	76.10^{fgh}	1.37^{ghijkl}	5^{bcd}	27.45^{abc}	1.24^{a}
UPN 266	99.75^{abcdef}	1.93^{defghi}	3^{cdef}	28.65^{ab}	2.57^{a}
UPN 223	67.40^{h}	0.75^{klm}	5^{bcd}	22.35^{bcde}	1.75^{a}
UPN 234	81.50^{defgh}	1.67^{efghij}	2^{f}	25.80^{bcde}	1.82^{a}
UPN 268	84.50^{defgh}	1.66^{efghij}	3^{def}	25.90^{abcd}	1.35^{a}
UPN 257	72.75^{fgh}	1.41^{ghijk}	2^{ef}	22.25^{bcde}	1.27^{a}
FARO 52	99.00^{abcdef}	2.13^{cdefg}	3^{def}	25.25^{abcd}	1.42^{a}
FARO 57	111.65^{abc}	2.11^{cdefg}	2^{ef}	23.30^{bcde}	1.38^{a}
FARO 61	115.5^{ab}	2.37^{cde}	1^{f}	27.40^{abc}	2.01^{a}
UPIA 1	102.5^{abcde}	2.53^{bcd}	2^{ef}	29.90^{a}	2.43^{a}
UPIA 2	$97.00^{abcdefg}$	2.02^{defg}	1^{f}	26.45^{abcd}	1.59^{a}
UPIA 3	121.00^{a}	2.05^{defg}	2^{ef}	22.50^{bcde}	0.97^{a}
WBK 114	86.65^{cdefgh}	1.50^{fghijk}	1^{f}	24.30^{abcd}	1.26^{a}
Mean	88.04	1.61	2.67	24.02	1.27
S.E	1.720	0.071	0.147	0.319	1.085

Variety	NOSPP	NOFSPP	%FS %	1000SW (g)	YPP (g)
FARO52 X UPN266	108^{bcdefg}	47^{bcdef}	43.52^{efgh}	15.90^{cdefg}	2.14^{ab}
FARO52 X UPN223	$85^{cdefghi}$	59^{bcdef}	69.41^{bcd}	18.44^{bcdef}	5.83^{a}
FARO52 X UPN268	$98^{bcdefgh}$	60^{bcdef}	61.22^{cde}	18.30^{bcdef}	3.72^{a}
FARO52 X UPN257	$97^{bcdefghi}$	48^{bcdef}	49.48^{defg}	19.11^{bcdef}	1.39^{ab}
FARO61 X UPN250	45^{is}	20^{f}	44.44^{efgh}	8.02^{h}	0.42^{ab}
FARO61 X UPN234	46^{hi}	32^{def}	69.57^{bcd}	13.23^{efgh}	0.68^{ab}
UPIA1 X UPN250	$86^{cdefghi}$	51^{bcdef}	59.30^{def}	24.31^{abc}	2.85^{ab}
UPIA 1 X UPN266	74^{defghi}	41^{cdef}	55.41^{def}	23.40^{abcd}	1.94^{ab}
UPIA 1 X UPN234	59^{fghi}	46^{bcdef}	77.97^{a}	24.81^{ab}	1.69^{ab}
UPIA 2 X UPN266	$97^{bcdefghi}$	61^{bcdef}	62.89^{cde}	18.50^{bcdef}	‘1.12^{ab}
UPIA 2 X UPN234	135^{abcde}	85^{abc}	62.96^{cde}	17.85^{bcdefg}	4.97^{a}
UPIA 2 X UPN257	118^{abcde}	47^{bcdef}	39.83^{efghi}	16.4^{bcde}	1.02^{ab}
UPIA 3 X UPN250	58^{fghi}	40^{cdef}	68.97^{bcd}	14.21^{defgh}	0.71^{ab}
UPIA 3 X UPN266	126^{abcd}	90^{ab}	71.43^{ab}	18.53^{bcdef}	4.28^{ab}
WBK114 X UPN250	56^{ghi}	23^{ef}	41.07^{efgh}	10.07^{gh}	0.50^{ab}
UPN 250	$85^{cdefghi}$	50^{bcdef}	58.82^{def}	21.41^{adcde}	2.91^{ab}
UPN 266	144^{ab}	106^{a}	73.61^{ab}	21.91^{abcd}	5.72^{a}
UPN 223	$92^{c0defghi}$	67^{abcde}	72.83^{ab}	24.10^{abc}	3.32^{a}
UPN 234	105^{bcdefg}	77^{abcd}	73.33^{ab}	24.62^{ab}	1.67^{ab}

Variety	NOSPP	NOFSPP	%FS %	1000SW (g)	YPP (g)
UPN 268	$85^{cdefghi}$	59^{bcdef}	69.41^{bcd}	20.31^{abcdef}	1.88^{ab}
UPN 257	71^{efghi}	54^{bcdef}	76.06^{a}	21.21^{abcde}	1.76^{ab}
FARO 52	121^{abcde}	59^{bcdef}	48.76^{efgh}	20.62^{abcde}	2.51^{ab}
FARO 57	107^{bcdefg}	56^{bcdef}	52.34^{defg}	21.63^{abcd}	2.31^{ab}
FARO 61	$88^{cdefghi}$	66^{abcdef}	75.00^{a}	19.51^{bcdef}	1.81^{ab}
UPIA 1	109^{bcdef}	80^{abc}	73.39^{ab}	28.12^{a}	4.15^{a}
UPIA 2	160^{a}	63^{abcdef}	39.38^{efghi}	21.41^{abcde}	1.49^{ab}
UPIA 3	77^{defghi}	30^{ef}	38.96^{efghi}	12.31^{fgh}	1.87^{ab}
WBK 114	81^{defghi}	40^{cdef}	49.38^{efgh}	17.81^{bcdefg}	1.25^{ab}
Mean	90.34	56.69	59.96	18.81	3.69
S.E	2.748	2.179	1.726	0.438	1.476

Means in the same column with different superscripts are significantly (p>0.05) different PHT: Plant height, LAI: Leaf area index, ET: Effective tiller, PL: Panicle length, PW: Panicle weight, NOSPP: Number of seeds per panicle, NOFSPP: Number of filled seeds per panicle, % FS: % Filled seeds, 1000 SW: 1000 Seed weight, YPP: Yield per plant.

3.2. Combining Ability

The mean squares and mean square errors for all traits in the males, females and their progenies all showed significant differences (Table 3). The mean square GCA for both male and female parental lines were significantly different for all traits observed. The mea square SCA (M and F) for all observed traits were significant (Table 3).

The results showed negative GCA values for both male and female parents, both were significant for the traits, it may be concluding that the traits were governed by additive genes in negative way, thus indicate that it may not be effective for population improvement in the breeding programme. Positive SCA values indicates the presence of non- additive genes in the crosses. This shows that the genes expressed in the phenotype of the hybrids it may be governed by dominant gene combinations (Table 3).

Table 3. *Analysis of variance for combining ability in F1 progenies and parents for various traits.*

Source of variation	Mean Sum of Squares									
	Df	PHT (cm)	FLAI (cm^2)	ET	LP (cm)	WP (g)	NOSPP	NOFSPP	1000 SW (g)	YPP (g)
Male parents	5	255.71**	0.33**	3.20**	13.76**	0.51**	1266.08**	855.33**	1.22^{ns}	4.82**
Female parents	6	284.34**	0.21**	0.78^{ns}	13.06**	0.48**	1651.81**	553.00^{ns}	44.35**	1.81^{ns}
Male x Female	16	2729.33*	4.50*	16.88*	222.48*	1.03*	5524.53*	2155.42*	186.49*	568.54*
Error	106	142.88^{ns}	0.14^{ns}	1.14^{ns}	9.04^{ns}	0.21^{ns}	587.17^{ns}	466.23^{ns}	15.19^{ns}	342.84^{ns}
GCA male (δ^2m)		-178.83*	-0.29*	-0.98*	-14.91*	-0.04*	-304.18*	-92.86*	-13.23*	-40.27*
GCA female (δ^2f)		-203.75*	-0.36*	-1.34*	-17.45*	-0.05*	-332.73*	-133.54*	-11.85*	-47.23*
SCA (δ^2fm)		1293.23*	2.18*	7.87*	106.72*	0.41*	2468.68*	844.59*	85.65*	121.85*
Replication	1									

*, **, significant at 0.01 and 0.05 respectively, ns, not significant. PHT: Plant height, LAI: Leaf area index, ET: Effective tiller, PL: Panicle length, PW: Panicle weight, NOSPP: Number of seeds per panicle, 1000 SW: 1000 Seed weight, YPP: Yield per plant.

3.3. GCA Effects for Parental Lines

The estimates of GCA effects for all traits except PW varied significantly among the lines (Table 4).

UPN 268 and FARO 52 had the highest significantly positive GCA's (12.77 and 8.27) for plant height (Table 4). FARO 61 had the highest GCA (-1.08) for leaf area index. The best GCA's for effective tillers were UPN 268 and UPIA 1 with positive GCA's of (3.20 and 2.53)

The highest GCA effects for Panicle length were in UPN 234 (11.48) and WBK 114 (-6.40), while for panicle weight the highest positive GCA was in UPIA 2 (30.80) and UPN 257 (21.63) while the highest negative was Faro 61 (-40.37) and WBK 114 (-29.87)

UPIA 3 and UPIA 2 had the highest GCA's for number of filled seeds per panicle (15.00 and 14.33) while UPN 268 and UPN 266 had the highest negative values (-17.43 and -13). The results for %Filled seeds showed highest positive was recorded in UPIA 3 and UPN 234 (11.57 and 11.67) while the highest negative values was recorded for WBK 114 (-17.43).

In 1000 seed weight, UPIA 1 (6.76) had the highest positive value while WBK 114 (-7.34) had the highest negative value. UPN 223 had the highest positive (3.61) for Yield per plant while WBK 114 (1.72) had the highest negative value (Table 4).

The varieties with the best GCA are UPN 268, UPN 223, UPN 234, UPIA 1, and UPIA 2 because they had high positive values for most traits. WBK 114 had consistently negative GCA's across all traits (Table 4).

3.4. SCA Effects for F1 Hybrids

The crosses with the highest number of significant positive SCA's were UPIA 1 X UPN 250, UPIA 3 X 266 and WBK 114 X 250 (Table 5).

In Plant height, UPIA 2 X UPN 266 (-32.81) had the highest negative GCA while UPIA 2 X UPN 234 (26.17) had the highest positive GCA (Table 5). Panicle length (cm); UPIA 1 X 234 (-12.84) and UPIA 2 X 234 (-10.76). Panicle weight (g); FARO 52 X UPN 266 (-1.05).

The results for Number of seeds per panicle showed that UPIA 2 X UPN 266(-35.05), WBK 114 X UPN 250 (25.42) and UPIA 2 X UPN 234 (24.2) while in Number of filled seeds per panicle UPIA 1 X 250 (21.5) and UPIA 2 X 234 (16.37). Table 5 also shows that for % Filled seeds UPIA 2 X UPN 234 (16.37) and UPIA 2 X UPN 257 (14.83) and 1000 Seed weight (g); FARO 52 X UPN 266 (3.71) and WBK X 250 (3.26). Yield per plant showed UPIA 2 X 234 (2.31) and FARO 52 X UPN 257 (-2.85) had the highest SCA's.

Table 4. *General combining ability effects for the parental lines.*

	GCA									
	PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW(g)	NOSPP	NOFSPP	%FS (%)	1000 SW (g)	YPP (g)
Males										
UPN 266	-6.81**	0.17**	0.45**	1.42*	0.09ns	15.38**	9.75**	-0.87ns	1.67*	0.15ns
UPN 223	0.52ns	0.77**	0.20ns	-0.41ns	0.07ns	-0.87ns	9.00**	10.91**	1.03*	3.61*
UPN 268	12.77**	0.30**	3.20*	1.47*	-0.06ns	12.13**	10.00**	2.72*	1.70*	1.50*
UPN 257	6.12**	0.71**	-0.80**	-2.37*	-0.19**	21.63**	-2.50*	-13.85**	0.35ns	-0.97ns
UPN 250	-0.11ns	-0.08ns	-1.30*	-2.73*	0.19**	-24.62**	-16.50**	-5.12**	-3.26*	-1.10*
UPN 234	0.69ns	0.32**	0.53**	11.48**	0.01ns	-5.87**	4.30*	11.67**	1.22*	0.29ns
Females										
FARO 52	8.27**	0.10ns	1.20*	1.53*	-0.12**	11.3**	3.50*	-2.59*	0.53ns	1.05*
FARO 61	-6.48**	-1.08*	-1.80*	-4.34**	-0.64**	-40.37**	-24.00**	-1.49*	-6.79**	-1.67*
UPIA 1	1.17*	0.79**	-0.47**	2.55**	0.06ns	-12.87**	-4.00*	5.72**	6.76**	-0.01ns
UPIA 2	-8.83**	0.10ns	2.53*	0.50ns	0.15**	30.80**	14.33**	-3.27*	0.17ns	0.15ns
UPIA 3	1.65*	-0.28**	-0.30ns	-0.14ns	0.86**	6.13**	15.00**	11.57**	1.96*	0.28ns
WBK 114	-0.15ns	-0.40**	-1.80*	-6.40**	-0.59**	-29.87**	-27.00**	-17.43**	-7.34**	-1.72*
MEAN	0.73	0.11	0.14	0.21	-0.01	-1.43	-0.68	-0.17	-0.17	0.13

	GCA									
	PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW(g)	NOSPP	NOFSPP	%FS (%)	1000 SW (g)	YPP (g)
SE	1.74	0.15	0.44	1.23	0.11	6.01	4.02	2.59	1.08	0.41

*, **, significant at 0.05 and 0.01 respectively. ^{ns} not significant. PHT: Plant height, LAI: Leaf area index, ET: Effective tiller, LP: Length of panicle, WP: Weight of panicle, NOSPP: Number of seeds per panicle, NOFSPP: Number of filled seeds per panicle. %FS: % Filled seeds, 1000 SW: 1000 Seed weight, YPP: Yield per plant

Table 5. Specific combining ability effects for the F1 crosses.

Crosses	SCA				
	PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW (g)
FARO 52 X UPN 266	1.71*	0.12^{ns}	0.55**	-0.66^{ns}	-1.05*
FARO 52 X UPN 223	-8.27**	-0.38^{ns}	-1.2*	-1.53*	0.12**
FARO 52 X UPN 268	-8.27**	-1.17*	-1.2*	-1.53*	0.12**
FARO 52 X UPN 257	6.07**	-0.51**	-1.2*	-1.13*	0.10**
FARO 61 X UPN 250	-2.89*	-0.08**	1.3*	1.41*	-0.30**
FARO 61 X UPN 234	2.51*	-0.63**	-0.53**	10.15**	0.12**
UPIA 1 X UPN 250	11.71**	0.78**	1.97*	4.62*	-0.14**
UPIA 1 X UPN 266	8.86**	0.29^{ns}	-0.78**	-1.95*	-0.04**
UPIA 1 X UPN 234	-12.96**	-1.72*	-0.86**	-12.84**	-0.10**
UPIA 2 X UPN 266	-32.81**	-1.58*	-3.78*	-3.53*	-0.21**
UPIA 2 X UPN 234	26.17**	0.28**	-1.22*	-10.76**	0.42**
UPIA 2 X UPN 257	6.63**	0.11^{ns}	-3.86*	-0.90^{ns}	-0.47**
UPIA 3 X UPN 250	-5.12**	-0.68**	-0.2^{ns}	-0.41^{ns}	0.17**
UPIA 3 X UPN 266	6.91**	0.44**	1.95*	1.71*	-0.45**
WBK 114 X UPN 25O	0.11^{ns}	-0.08^{ns}	1.3*	2.73*	-0.16**
MEAN	0.02	-0.32	-0.52	-0.97	-0.12
SE	3.30	0.19	0.44	1.38	0.08

Crosses	SCA				
	NOSPP	NOFSPP	%FS (%)	1000 SW (g)	YPP (g)
FARO 52 X UPN 266	-4.38*	-16.25**	-11.52**	-3.71*	-1.28*
FARO 52 X UPN 223	-11.13**	-3.5*	2.59*	-0.53**	-1.05*
FARO 52 X UPN 268	-11.13**	-3.5*	2.59*	-1.34*	-1.05*
FARO 52 X UPN 257	-21.63**	-3.0*	7.42**	0.82**	-2.85*
FARO 61 X UPN 250	22.99**	10.5**	-7.45**	0.66**	0.97*
FARO 61 X UPN 234	6.37**	1.7*	0.89*	1.39*	-0.16**

Crosses	SCA				
	NOSPP	NOFSPP	%FS (%)	1000 SW (g)	YPP (g)
UPIA 1 X UPN 250	-11.62**	21.5**	0.20ns	3.40*	1.73*
UPIA 1 X UPN 266	-12.38**	-14.75**	7.94**	-2.42*	-0.43**
UPIA 1 X UPN 234	-8.13**	-4.3*	2.08*	-0.58**	-0.62**
UPIA 2 X UPN 266	-35.05**	-13.08**	8.53**	-0.75**	-1.4*
UPIA 2 X UPN 234	24.2**	16.37**	-3.94*	1.2*	2.31*
UPIA 2 X UPN 257	-20.3**	14.83**	-1.55*	-2.38*	-0.38**
UPIA 3 X UPN 250	-9.38**	-8.5**	18.6**	-1.9*	-0.66**
UPIA 3 X UPN 266	18.62**	9.75**	1.93*	-2.51*	1.63*
WBK 114 X UPN 25O	25.42**	16.5**	5.12**	3.26*	1.1*
MEAN	-3.17	1.62	2.23	-0.36	-0.14
SE	4.63	3.10	1.79	0.53	0.35

*, **, significant at 0.05 and 0.01 respectively, ns not significant. Blank superscripts = not significant. PHT: Plant height, LAI: Leaf area index, ET: Effective tiller, LP: Length of panicle, WP: Weight of panicle, NOSPP: Number of seeds per panicle, NOFSPP: Number of filled seeds per panicle. %FS: % Filled seeds, 1000 SW: 1000 Seed weight, YPP: Yield per plant

3.5. Heterosis

Table 6 shows that Plant height has values range from +18.77 to -59.83 for mid-parent heterosis (MPH). The values for better parent heterosis (BPH) ranged from -60.38 to +9.28. UPIA 2 X UPN 266 had the highest negative values while UPIA 2 X UPN 234 had the highest positive values. For Leaf area index, The MPH and BPH values ranged from +88.72 to -72.76 and -76.99 to +48.78 respectively.

The computed heterosis for Effective tillers showed that MPH and BPH values ranged from +480 to -69.23 and +383.33 to -77.78 respectively. UPIA 3 X UPN 250 had the highest negative value while UPIA 2 X UPN 234 had the highest positive value. Heterosis for Panicle length ranged from +10.86 to -37.73 (MPH) and -37.49 to +6.31. FARO 61X UPN 250 had the highest negative value while FARO 52 X UPN 257 had the highest positive value. For Panicle weight, The MPH and BPH values ranged from +10.26 to -65.54 and -104.03 to -72.14 respectively. FARO 61 X UPN 250 had the highest negative value while UPIA 2 X 234 had the highest positive value.

As shown in Table 6 below, heterosis for Number of seeds per panicle values ranged from +14.51 to -47.98 (MPH) and -58 to -16.04 (BPH). FARO 61X UPN 250 had the highest negative value while UPIA 3 X 266 had the highest positive value. MPH and BPH for Number of filled seeds per panicle ranged from +55.53 to -65.88 and -69.70 to +11.11. FARO 61X UPN 250 had the highest negative value while FARO 61 X 250 had the highest positive value. For % Filled seeds, the heterosis values ranged from +41.07 to -33.58 (MPH) and -47.65 to +6.24 (BPH). FARO 61X UPN 250 had the highest negative value while UPIA 3 X 250 had the highest positive value.

1000 Seed weight; 3 crosses performed better than the mean of the parents. The values ranged from +10.51 to -60.88. FARO 61X UPN 250 had the highest negative values while FARO52 X 268 had the highest positive values. For Yield per plant, the values BPH and MPH ranged from +214.54 to -83.05 and -86.25 to +197.60. FARO 61X UPN 250 had the highest negative value while UPIA 2 X 234 had the highest positive value.

Table 6. Mid Parent and Better Parent Heterosis of 15 F1 crosses of upland rice varieties.

Crosses		HETEROSIS VALURS IN %									
		PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW (g)	NOSPP	NOF-SPP	%FS (%)	1000 SW (g)	YPP (g)
FARO 52 X UPN 266	MPH	-0.23	14.5	81.82	-3.99	-47.67	-18.10	42.86	-19.09	-24.89	-47.96

Crosses		HETEROSIS VALURS IN %									
		PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW (g)	NOSPP	NOF-SPP	%FS (%)	1000 SW (g)	YPP (g)
	BPH	-0.60	9.39	66.67	-9.77	-59.53	-24.61	-55.66	-26.01	-25.97	-62.37
FARO 52 X UPN 257	MPH	12.14	37.29	-25	10.86	-18.51	1.04	-15.04	-20.72	-8.65	-35.05
	BPH	-2.73	14.08	-10.00	2.05	-39.56	-19.71	-37.25	-34.95	-22.36	-44.62
FARO52 X UPN 268	MPH	9.80	12.93	100	-2.05	-12.78	-5.1	2.55	3.61	10.51	72.75
	BPH	1.77	5.16	120.00	-3.36	-11.97	-18.88	2.55	-11.80	-11.17	48.21
FARO 52 X UPN 223	MPH	6.37	-18.75	-66.67	-2.61	-19.92	-12.61	-17.51	14.51	-5.68	100.00
	BPH	-10.61	-45.07	-44.44	-8.31	-21.59	-29.23	-11.97	-4.70	-23.49	75.60
UPIA 2 X UPN 234	MPH	18.77	43.24	480.00	-5.17	10.26	1.70	22.30	11.72	-22.39	214.54
	BPH	9.28	31.19	383.33	6.31	3.30	-16.04	11.11	-14.14	-27.44	197.60
UPIA 2 X UPN 257	MPH	8.28	66.56	50	0.048	-19.58	1.29	-19.83	-30.99	-23.72	-36.45
	BPH	-5.26	41.58	50.00	-3.48	-27.67	-26.79	-25.6	-47.65	-23.36	-40.70
UPIA 2 X UPN266	MPH	-59.83	-68.18	-25	-20.31	-35.58	-36.51	-28.19	11.32	-14.55	-52.29
	BPH	-60.38	-68.81	-50.00	-23.39	-47.86	-39.88	-42.94	-14.94	15.53	73.43
UPIA 1 X UPN 250	MPH	12.89	88.72	30.77	2.35	-22.75	-11.08	-21.62	-10.29	-1.62	-19.26
	BPH	-1.71	45.45	-27.78	-6.35	-41.56	-20.87	-36.1	-19.20	-13.21	-31.33
UPIA 1 X UPN 234	MPH	-17.93	36.67	14.29	-11.13	-40.47	-44.96	-41.67	11.32	5.64	-41.75
	BPH	-26.34	-47.43	0	-17.22	-47.74	-46.10	-42.77	6.24	-11.43	-59.04
UPIA 1 X UPN 266	MPH	-9.81	42.91	10	12.64	-43.25	-41.17	55.53	-16.18	-5.26	66.67
	BPH	-11.02	0.26	-25	-14.75	-44.75	-48.20	-61.80	-24.50	-16.43	-53.25
FARO 61 X UPN 234	MPH	-12.44	-72.76	-20.00	-22.74	-58.49	-43.38	-55.79	-6.20	-40.14	-61.20
	BPH	-24.22	-76.79	-33.33	-25.00	-60.45	-58.98	-55.98	-7.24	-46.34	-62.71
FARO 61 X UPN 250	MPH	-16.27	-36.9	-63.64	-37.73	-65.54	-47.98	-65.52	-33.58	-60.88	-83.05
	BPH	-29.60	-50.63	-77.78	-34.79	-72.14	-48.86	-69.70	-40.75	-62.61	-86.25
UPIA 3 X UPN 250	MPH	-14.31	-38.60	-69.23	-18.82	-18.07	-28.05	0.63	41.07	-16.91	-70.65
	BPH	-30.25	48.78	-77.78	-26.12	104.03	-31.44	-20.58	17.27	-34.58	-75.86
UPIA 3 X UPN 266	MPH	-13.18	13.78	70	3.81	-2.69	14.51	32.10	26.91	8.19	11.46
	BPH	-21.61	10.73	41.67	-7.33	-29.57	-12.02	-15.57	-2.96	-15.53	-26.05
WBK 114 X UPN 250	MPH	7.99	7.32	-15.61	-32.57	-42.4	-32.73	-48.22	-24.09	-48.62	-75.96
	BPH	1.36	2.67	-27.01	-37.49	-42.86	-33.12	-53.4	-30.18	-52.94	-82.82

PHT: Plant height, LAI: Leaf area index, ET: Effective tiller, PL: Panicle Length, PW: Panicle Weight, NOSPP: Number of seeds per panicle, NOFSPP: No of Filled seeds per panicle, %FS: %Filled Seeds, 1000 SW: 1000 Seed weight, YPP: Yield per plant, MPH: Mid parent heterosis, BPH: Better parent heterosis.

3.6. Potence Ratio of F1 Progenies

The results in Table 7 shows that for Plant height; the potence ratio Ranged from +42.8 to -0.87 showed complete dominance for (+/-1) or absence of dominance for (0). 7 crosses showed overdominance while 8 showed partial dominance for plant height. While for Leaf area index, the potence ratio values ranged from +31.53 to -5.79. 7 crosses showed overdominance while 8 showed partial dominance. The observations for Effective tiller ranged from +24 to -1.1. 3 crosses (UPIA 1 X UPN 234, FARO 52 XUPN 257 and FARO 61 X 250) showed absence of dominance (0) while FARO 61 x UPN 234 and UPIA 1 X 234 showed complete dominance (+/-1). 7 crosses showed overdominance while 3 showed partial dominance.

Table 7 also showed that the potence ratio for Panicle length ranged from +1.76 to -5.73. 11 crosses showed overdominance while 4 showed partial dominance while Panicle weight ranged from +83.87 to -16.15. 12 crosses showed overdominance while 3 showed partial dominance. Potence ratio for Number of seeds per panicle ranged from +1.51 to -27.67. 11 crosses showed overdominance while 4 showed partial dominance. Number of seeds per panicle ranged from +21.67 to -4.75. 11 crosses showed overdominance while 4 showed partial dominance. 1000 Seed weight ranged from +0.47 to -14.33. 11 crosses showed overdominance while 4 showed partial dominance. Yield per plant ranged from +7.20 to -15.21. 13crosses showed overdominance while 2 varieties showed partial dominance (Table 7).

Table 7. *Potence ratio of 15 F1 crosses of upland rice varieties.*

Crosses	TRAITS								
	PHT (cm)	LAI (cm^2)	ET	PL (cm)	PW (g)	NOSPP	NOFSPP	%FS (%)	1000 SW (g)
FARO 52 X UPN 266	-0.9	3.07	3	1.12	1.66	-2.09	-1.48	-8.23	-1.23
UPIA 2 X UPN 234	2.16	3.52	24	-4.16	0.30	-3.7	2.22	-3.22	-6.07
UPIA 1 X UPN 250	0.87	2.99	0	-0.55	-0.70	-0.89	0.95	-0.42	-1.09
FARO 61 X UPN 234	-0.82	-5.79	-1	-2.02	11.76	-6.09	-7.57	-3.47	-15.21
UPIA 3 X UPN 250	-0.62	-1.92	-1.8	-1.89	10.96	-568	-0.02	-5.29	-3.21
FARO 61 X UPN 250	-0.87	-1.38	0	-3.81	-2.76	-27.67	-4.75	-3.47	-3.58
WBK 114 X UPN 250	1.22	1.68	-1.1	-5.73	83.87	-10.9	-4.33	-5.29	-1.9
FARO 52 X UPN 257	0.79	1.81	0	1.76	3.26	-0.03	-3.2	-6	-1.53
UPIA 1 X UPN 266	7.22	3.24	0.5	-5.92	-16.15	-3.017	-3.77	-0.51	-3.83
UPIA 2 X UPN 257	0.58	3.72	1.5	0.58	-1.80	0.034	-2.56	-49	-5.04
UPIA 2 X UPN266	42.8	31.53	-0.5	-5.09	-1.51	-6.53	-1.09	-12.6	-1.17
FARO52 X UPN 268	1.24	0.97	3	-1.5	-3.67	-0.3	-1.08	-14.33	4.82
UPIA 1 X UPN 234	-1.94	-2.43	1	1.52	-2.82	-21.97	21.67	-0.88	0.98
UPIA 3 X UPN 266	-1.46	11.99	3.5	0.32	0.05	0.48	0.57	0.47	0.26
FARO 52 X UPN 223	0.3	-0.39	0.5	0.44	1.92	1.516	-0.80	-2.24	7.20

PHT: Plant height, LAI: Leaf area index, ET: Effective tiller, PL: Length of panicle, WP: Weight of panicle, NOSPP: Number of seeds per panicle, NOFSPP: Number of filled seeds per panicle. %FS: % Filled seeds, 1000 SW: 1000 Seed weight.

4. Discussion

4.1. Combining Ability of Parental Lines and F1 Progenies

The SCA variances for all traits were all significant ($P \leq 0.01$) and higher than the GCA variances were observed which, suggests that non-additive genes played a significant role in the expression of the traits. This occurrence was also noted by [19-21].

The GCA variances also had significant though negative values. This shows that there was a presence of additive genes. These results were in line with those from those observed by [22-24] who all noted the presence of both additive and non-additive gene action.

High positive GCA effects values are preferable for positive traits associated with yield while low negative GCA is suitable for negative traits for grain yield [25]. The results (Table 4) from this current study were not at corroborated as some scientists who found that all parental lines showed negative GCA's for plant height [26]. Tall plant might be attributed to high diversion of nutrients for vegetative growth to detriments of grain yield of the plant.

The best specific combiners observed in this study were

UPIA 2 X 234 and FARO 52 X 266 (Table 5). Negative SCA is preferred for desirable traits such as plant height, yield per plant, %filled seeds, effective tillers and number of seeds per panicle [26] However, traits with high SCA values indicate non additive gene action and with low heritability, therefore negative SCA would not be preferable for grain yield that could not be inherited by their progenies. The results also showed that the crosses with high SCA for plant height, number of filled seeds per panicle and % filled seeds also showed high SCA's in yield per plant, these results were corroborated previously who observed significant SCA (non-additive gene action) for most of the traits measured [27, 28].

Good combining parents always lead to higher frequency in heterotic hybrids more than the poor combiner parents. However, from the study carried they found that crosses between low GCA and low SCA can give heterotic combinations and therefore it will be wrong to discard the low GCA parental lines as found in this study [29]. Here, selecting the appropriate parents by taking into consideration their combining ability including their heterosis is still remain the best option for maximizing the breeding efficacy in identifying the heterotic hybrids. Analyzing combining ability and estimating the degree of heterosis, gives an understanding on the nature of gene action, desirable parents and important yield traits [30]. Lowland rice breeding program in various countries including Nigeria applied combining ability studies, genetic actions and heterosis studies in identifying the suitable parents for local needs, as this study will assist breeders in selecting good parents for rice population improvement [31-33]. General combining ability (GCA) and Specific combining ability (SCA) effects are extremely important in any rice breeding program because is useful for hybrid rice breeding program by identifying traits that are predominantly governed by non- additive genetic variance such as number of panicles per plant, number of spikelets per panicle, test grain weight, total dry matter accumulation, spikelet fertility and grain yield as some of these Korean rice have been evaluated for good agronomic performance in Nigeria this corroborate this study [33, 34].

4.2. Heterosis in FI Progenies

Heterosis in plants is often attributed to additive gene action and high degree of dominance of the traits [35]. Plants that show high positive heterosis can be selected for heterosis breeding to improve chances of successful transfer of traits as shown in Table 6. It has also been observed that favorable heterosis for traits such as FLAI, NOSPP, GWPP and 1000 SW results in increased YPP [36]. Similar results in heterosis for plant height with values ranging from +15.09 to -15.97 and +3.41 to -32.20, respectively were reported [37] Other scientists observed similar results ranges for panicle length (-39.26 to +56.41) and -40.44 to +8.56 for panicle weight [23, 38].

The results (Table 6) indicates that most of the hybrids performed better heterotic values than the mean of both parents for most of the traits observed. Heterosis in plants is often attributed to additive gene action and high degree of dominance of the traits [35]. Plants that show high positive heterosis can be selected for heterosis breeding to improve chances of successful transfer of traits. It has also been noted that favorable heterosis for traits such as FLAI, NOSPP, GWPP and 1000 SW results in increased YPP [36]

4.3. Potence Ratio For F1 Progenies

Estimation of potence ratio is to observed gene action of different traits. The potence ratio results obtained from this study showed that most of the crosses exhibited overdominance in most of the observed traits (Table 7). This shows that overdominance gene action, played an important role in the expression of the phenotypic traits hence selection based on the physical traits could be effective. It is also evidence from some studies that the values overdominace gene action than epistasis gene action, which is very evidence in this study Table 7 [39].

Studies also showed that overdominance played an important role in the inheritance of most traits including grain yield per plant, there are genotypes that could be used for population improvement in this study due to their high overdominance in some the agronomic traits Table 7 [40]. Similar results were also noted, which that overdominance (> 2) for traits studied showing genes governing the observed traits [41].

5. Conclusion

Based on the desirable mid-parent and better parent heterosis observed in some of the hybrids (UPIA 2 X UPN 234 and FARO 52 X UPN 223), they can be exploited for heterosis breeding for better results. High heritability plus high genetic advance observed in PHT, ET, NOSPP and NOFSPP indicates a high genetic control (gene action) therefore, selection for these traits would be highly effective. The crosses between UPIA 2 x UPN 234, FARO 52 X UPN 266 and UPIA 3 X UPN 266 had the best phenotypic and genotypic expressions. The crosses between FARO 61 X UPN 250 and WBK114 X UPN 250 did not show positive expressions but high yielding UPIA 1, UPIA 2, UPN 223, UPN 234 and UPN266 should be included in breeding programs because they showed the best GCA's across most traits.

Acknowledgments

Authors wish to express their gratitude to KAFAC of RDA Korea for providing the genetic materials used for this study under the project KAR20190112.

Author Contributions

Ogba Chinonyelum Somtochukwu: Data curation, Formal Analysis, Funding acquisition

Efisue Andrew Abiodun: Conceptualization, Software, Supervision, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Zhao, L., Wu, L., Wu, M., & Li, Y. (2011). Nutrient uptake and water use efficiency as affected by modified rice cultivation methods with reduced irrigation. Paddy and Water Environment, 9(1), 25–32.

[2] Sprague, G. F. and Tatum, L. A. 1942. General vs specific combining ability in single crosses of corn. J.American Soc. Agron., 34: 923–932.

[3] Veeresha, B. A., Hanamaratti, N. G., & Salimath, P. M. (2015). Heterosis and combining ability studies for yield and productivity traits in rice: A Review. International Journal of Current Agricultural Research, 4(5),120-126.

[4] Dar, S., Rather, A. G., Ahanger, M. A., Sofi, N. R., & Talib, S. (2014). Gene action and combining ability studies for yield and component traits in rice (Oryza sativa L.): A review. Journal of Plant and Pest Science, 1(3), 110-127.

[5] Hochholdinger, F., and Hoecker, N. (2007). Towards the molecular basis of heterosis. Trends Plant Sci. 12, 427–432.

[6] Rajendrakumar P., Hariprasanna K., Seetharama N. Prediction of Heterosis in Crop Plants—Status and Prospects. Am. J. Exp. Agric. 2015; 9: 1–16. https://doi.org/10.9734/AJEA/2015/19263

[7] Mulualem T., Abate M. Heterotic Response in Major Cereals and Vegetable Crops. Int. J. Plant. Breed. Genet. 2016; 10: 69–78. https://doi.org/10.3923/ijpbg.2016.69.78

[8] Zhou G., Chen Y., Yao W., Zhang C., Xie W., Hua J., Xing Y., Xiao J., Zhang Q. Genetic composition of yield heterosis in an elite rice hybrid. Proc. Natl. Acad. Sci. USA. 2012; 109: 15847–15852. https://doi.org/10.1073/pnas.1214141109

[9] El-Badawy MEIM, 2012. Estimation of genetic parameters in three maize crosses for yield and its attributes. Asian Journal of Crop Sci. 4(4): 127-138.

[10] Alhadi RAA, Hadid ML, AL Ahmad SA, 2013. Potence Ratio and Path Analysis for Yield and Quality Traits in Single Crosses of Maize (Zea mays L.) Produced in Syria. Jordan J. Agri. Sci. 9(2): 153-161.

[11] IRRI (International Rice Research Institute). (2013). Standard Evaluation System (SES) for Rice (5th ed.). Los Banos.

[12] Yoshida S (1981) Fundamentals of rice crop science. International Rice Research Institute, Los Ban˜os, Philippines, p 269.

[13] SAS Institute Inc. 2003. SAS/STAT user's guide, version 9.1. Cary, NC: SAS Institute Inc.

[14] Comstock, R. E. and Robinson H. F. 1948. The components of genetic variance in the populations of biparental progenies and their use in eliminating the average degree degree of dominance. *Biometrics 4*(4): 254-266.

[15] Wolf, D. P., L.A. Peternelli, and A R. Hallauer. 2000. Estimates of genetic variance in an F2 maize population. J. Heredity 91(5): 384–391.

[16] Virmani, S. S., Viraktamath, B. C., Casal, C. L., Toledo, R. S., Lopez, M. T., & Manalo, J. O. (1997). Hybrid rice breeding manual (p. 4). Los Banos, Philippines

[17] Mather K, 1949. Biometrical Genetics. Dover Press, New York

[18] Smith, H. H. (1952). Fixing transgressive vigor in JVicotiana rustica. In Heterosis, pp. 161-174, edited by Gowen, J. W., Iowa State College Press, Ames.

[19] Saidaiah P. 2010. Combining Ability Studies for Development of New Hybrids in Rice over Environments

[20] Singh, R.V., Maurya, D.M., Dwivedi, J.L. & Verma, O.P. (2005). Combining ability studies on yield and its components using CMS lines in rice (Oryza sativa L.). Oryza, 42, 306-309.

[21] Dalvi, V.V. & Patel, D.V. (2009). Combining ability anlysis for yield in hybrid rice. Oryza, 46(2), 97-102.

[22] Zhao, Q. Y., Zhu, Z., Zhang, Y., Zhao, L., Zhang, Q., Xu, L. and Wang, C., 2008, Combining ability and Heterosis of quality characters in japonica hybrid rice. Jiangsu J. Agril. Sci., 24(4): 387-393.

[23] Rahimi, M., Rabiei, B., Samizadeh, H. and Kafighasemi, A., 2010, combining ability and heterosis in rice (Oryza sativa L.) cultivars. J. Agri. Sci. Tech., 12: 223-231.

[24] Swamy, M. H., Gururaja Rao, M. R. and Vidyachandra, B., 2003. Studies on combining ability in rice hybrids involving new CMS lines. Karnataka J. Agril. Sci., 16(2): 228-233.

[25] Franco, M. C., Cassini, S. T., Oliveira, V. R., Vieira, C., Tsai, S. M., & Cruz, C. D. (2001). Combining ability for nodulation in common bean (Phaseolus vulgaris L.) genotypes from Andean and Middle American gene pools. *Euphytica*, *118*(3), 265-270.

[26] Sharma, D., Sanghera, G. S., Sahu, P., Sahu, P., Parikh, M., Sharma, B., ... & Jena, B. K. (2013). Tailoring rice plants for sustainable yield through ideotype breeding and physiological interventions. *African Journal of Agricultural Research*, *8*(40), 5004-5019.

[27] Pradeep-Kumar, V. and Reddy, C. V. C. M., 2011, Study of specific combining ability for yield characters in hybrid rice Plant Archives, 11(1): 449-452.

[28] Pradhan, S. K., Lotan Kumar, B. and Jitendriya, M., 2006, Studies on gene action and combining ability analysis in basmati rice. J. Cent. Eur. Agric., 7(2): 267-272.

[29] Allahgholipour, M. and Ali, A. J. (2006). Gene action and combining ability for grain yield and its components in rice. Journal of Sustainable Agriculture. 28: 39-53.

[30] Can, N. D., Nakamura, S. and Yoshida, T. (1997). Combining ability and genotype × environment interaction in early maturity grain sorghum for summer seeding. Japanese Journal of Crop Science. 66: 698-705.

[31] Moon, H. P. Heu, M. H. and Kim, C. H. (1994). Hybrid rice research in the Republic of Korea. In. Virmani S. S. (Ed.) Hybrid Rice Technology: new developments and future prospects. International Rice Research Institute, Manila, Philippines. P: 217-226.

[32] Gravois, K. A. and McNew, R. W. (1993). Combining ability and heterosis in U.S. southern long-grain rice. Crop Science. 33: 83-86.

[33] Siddiq, E. A. Jachuck, P. J. Mahadevappa, M. Zaman, F. U. Vijayakumar, R. Vidhyachandra, B. Sidhu, G. S. Kumar, I. Prasad, M. N. Rangaswamy, M. Pandey, M. P. Panwar, D. V. S. and Ahmed, I. (1994). Hybrid rice research in India. In Virmani S. S. (Ed.) Hybrid Rice Technology: new developments and future prospects. International Rice Research Institute, Manila, Philippines. P: 157-171.

[34] Exonam Amegan, Andrew Efisue, Malachy Akoroda, Afeez Shittu, Fiot Tonegnikes (2020). Genetic Diversity of Korean Rice (Oryza Sativa L.) Germplasm for Yield and Yield Related Traits for Adoption in Rice Farming System in Nigeria. International Journal of Genetics and Genomics. Vol. 8, No. 1, 2020, pp. 19-28. https://doi.org/10.11648/j.ijgg.20200801.13

[35] Saleem, M. Y. (2008). *Genetic analysis of basmati rice (Oryza sativa L.)* (Doctoral dissertation, Bahauddin Zakariya University, Multan, Pakistan.

[36] Vanaja, T., & Babu, L. C. (2004). Heterosis for yield and yield components in rice (Oryza sativa L.). Journal of Tropical Agriculture, 42(1), 43-44.

[37] Patil, P. P., Vashi, R. D., Shinde, D. A. and Lodam, V. A. 2011. Nature and magnitude of heterosis for grain yield and yield attributing traits in rice (Oryza sativa L.) Plant Archives, 11(1): 423-427.

[38] Tiwari, D. K., Pandey, P., Giri, S. P., & Dwivedi, L. J. (2011). Heterosis studies for yield and its components in rice hybrids using CMS system. Asian Journal of Plant Science, 10(1), 29-42. https://doi.org/10.3923/ajps.2011.29.42

[39] Flint-Garcia SA, Buckler ES, Tiffin P, Ersoz E, Springer NM, 2009. Heterosis is prevalent for multiple traits in diverse maize germplasm. PLoS ONE 4(10): e7433.

[40] Kumar, N. S., & Mudhalvan, S. (2018). Genetic analysis in rice (orzya sativa) for grain yield and its component characters. *Plant Archives*, *18*(2), 1447-1450.

[41] Allah, A. A. (2009). Genetic studies on leaf rolling and some root traits under drought conditions in rice (Oryza sativa L.). *African Journal of Biotechnology*, *8*(22).