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Evaluation of the parental and hybrid lines- Heterosis and other genetic parameters among *Capsicum annuum* genotypes and their hybrids

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In most parts of the world pepper has become a popular spice that makes food hot in addition to its much needed nutrients of carotenoids and vitamins. This report has its objective to evaluate the parents and hybrid of three Nigerian pepper genotypes (Shombo, Tatase and Nsukka yellow pepper) for growth and yield; and to estimate their genetic parameters. Conventional breeding by hand pollination was adopted. The mean performance of the parents and hybrids for morpho-agronomic characters were evaluated. Heterosis and inbreeding depression were estimated. The F_1 hybrids showed superiority over the parental genotypes with *Sho x Nsky-rw* having significantly (P ≤ 0.05) the highest value in most of the traits. In morphological traits, *Sho x Nsky-rw* hybrid had highest values in canopy diameter, number of leaves, number of nodes and number of branches per plant, while in fruit traits, it also had significantly the highest values in the number of fruits, fruit length and weight of fruits per plant. *Sho* x *Nsky – rw* had positive heterobeltiosis over the better parent in most of the yield and yield component characters. While *Sho* x *Nsky – rw* had the highest yield, *Tat* x *Sho* had the highest fruit wall thickness. The combinations of these traits are important to both the farmers and consumers. Having appropriate parents with genetic variability F_1 pepper plants having distinct superiority above the mid and better parents could be developed.

Key words: *Capsicum annuum,* chili pepper; heterosis, hybrid, inbreeding depression.

INTRODUCTION

Pepper is a vegetable grown by small, medium and large producers or integrated to agro-business with a considerable socio-economic importance. *Capsicum* genus has been reported to be one of the important vegetables cultivated in Nigeria which is ranked in the third position after onion and tomato in the economic market (Maga, 2012). Diverse types of *Capsicum* species are cultivated widely in Africa where they are consumed as traditional vegetable or spice. Due to the great range of pepper products and by-products, uses and forms of consumption, it is an essential spice commodity and has formed an integral part of many diets in the world

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Table 1. Crossed in a complete diallelic mating system without reciprocal crosses to obtain F1 generation.

Correlation	***Nsky - rw***	***Shombo(Sho)***	***Tatase(Tat)***
Nsky - rw	*Nsky-rw* (x)	*Nsky-rw* x *Sho*	*Nsky-rw* x *Tat*
Shombo(Sho)	*Sho* x *Nsky-rw*	*Shombo* (x)	*Sho* x *Tat*
Tatase(Tat)	*Tat* x *Nsky-rw*	*Tat* x *Sho*	*Tatase* (x)

(Bosland and Votava, 2000; Rodrigues et al., 2012). However, due to the absence of dependable statistics and outlined information, it is difficult to measure the real size and importance of pepper market; however, obtaining improved cultivars are very necessary in sustaining the pepper agro-business (Rodrigues et al., 2012).

Capsicum species are usually self-compatible and self-pollinating crop (Raw, 2000; Onus and Pickersgill, 2004). Some percentage of outcrossing is associated with insect pollinators than with wind (Raw, 2000). Genetic advance (GA) under selection refers to the improvement of characters in genotypic value for the new population compared with the base population under one cycle of selection at given selection intensity (Singh, 2001). Therefore, genetic advance (GA) is important to predicting the expected genetic gain from one cycle of selection. Heterosis is one of the most important genetic tools for the manifestation of different cross combinations in crops and determining their potential for commercial exploitation under different environmental conditions (Ashfaq et al., 2013). This breeding method has been used extensively in agriculture to increase yield and to enlarge adaptability of hybrid varieties in a number of crop species (Meyer et al., 2004). The percentage increase or decrease in traits among the hybrids over the mid-parent and better parents' performance is used to assess the overall performance of these hybrids (Inamullah et al., 2006). Heterobeltiosis expresses the betterment over the better parent; likewise, standard heterosis expresses the heterosis over the standard varieties (Shrestha et al., 2011). The major goal of the research was to improve the red fruited pepper genotypes in relation to aroma and β-carotene; however, this report is aimed at evaluating the hybrid field performance as compared to the parents (Shombo, Tatase and Nsukka yellow pepper) and the estimation of heterosis

MATERIALS AND METHODS

The experiment was conducted at the Botanical Garden, University of Nigeria, Nsukka. The seed sources of the parental accessions were from a three year evaluation programme at the Faculty of Agriculture Farms, University of Nigeria, Nsukka. The F_1 hybrids were generated between the highly aromatic genotype, Nsukka Yellow Pepper (*Nsky - rw*) and some red and fat fruited genotypes (*Shombo* and *Tatase*) with a view to improving the red fruited genotypes in relation to aroma from the *Nsky - rw* parent and improving the carotenoid content of the aromatic yellow pepper genotype (*Nsky – rw*) from the red fruited genotypes (*Shombo* and *Tatase*). Hybridization was conventionally done by hand pollination (Morakinyo and Falusi, 1992) (Table 1).

Seeds from successful crosses were used to generate the F_1 plants. The F_1s were evaluated in the subsequent year and the seeds from F_1 plants were used to raise the F_2 plants. The parents, F_1 and F_2 plants were evaluated in the field using randomized complete design (RCBD). Cultural practices were maintained manually. The weeds were removed by manual weeding with small hoe. The data on plant height, mainstem length, mainstem internode length and canopy diameter were metrically measured in centimeters (cm). The parameter on the number of branches per plant, number of leaves per plant, number of nodes per branch, number of nodes per plant, number of nodes on main stem were collected by numerical count at one hundred to one hundred and five days after planting (DAP). The leaf area (cm^2) measurement was taken using the autoamated leaf area meter in the Physiology Laboratory of the Department of Crop Science, University of Nigeria, Nsukka.

The fruit attributes and yield were also studied and data were collected on fruit diameter (cm), fruit length (cm), fruit stalk length (cm) and Pericarp thickness (mm) - measured with Venier Caliper.The number of fruits per plant was by numerical count. Fresh fruit weight (g) per plant was also determined. The fruits were processed and the seeds were sun dried for five days in the Botanical garden; the average of the numerical count of seeds was recorded as number of seeds per fruit. Seed weight / fruit (g) was also determined. The yield in tonnes per hectare was estimated from fruit yield per plant using plant population per hectare.

Statistical and genetic analysis of data

Data collected on the quantitative characters were subjected to analysis of variance (using GenStat Discovery Edition 4 software) to test for significant differences among the treatments, while significant means were separated using Fisher's Least Significant Difference (F-LSD) at $p < 0.05$.

Estimation of Heterosis/ Hybrid vigor was achieved using the formula:

$$\text{Heterosis over the mid parent} = \frac{\bar{F} - \bar{M}P}{MP} X \frac{100}{1}$$

$$\text{Heterosis over the better parent} = \frac{\bar{F} - \bar{B}P}{\bar{B}P} X \frac{100}{1}$$

$\overline{F_1}$ = Mean of F_1

$\overline{MP}$ = Mid parent value

$\overline{BP}$ = Better parent value

Differences between selfed (F_2) and outcrossed (F_1) progeny were

Table 2. Mean performance of parents, F_1 and F_2 populations in morphological and yield component characters.

Category		Canopy spread	No. of leaves/plt	Leaf area	Mainstem length	Mainstem internode length	No. of nodes on mean stem	No. of nodes/ branch	No. of nodes/plt	No. of branches/plt	Plant height
Parent											
Shombo		52.15	241.1	14.22	22.53	1.9	18.50	7.96	392.43	215.18	61.6
Tatase		37.9	64.27	14.11	16.81	1.5	14.33	8.43	83.87	55.65	49.03
Nsky-rw		51.69	127.33	22.96	17.84	1.31	20.82	7.55	265.94	123.97	43.63
Hybrid											
Sho x Nsky-rw	F_1	66.92	337.43	24.77	22.78	0.55	27.33	13.54	608.63	233.33	51.71
	F_2	61.83	144.33	22.13	14.42	0.96	19.00	8.08	216.79	172.85	57.51
Tat x Nsky-rw	F_1	51.69	116.77	23.06	32.33	1.3	21.67	9.21	187.27	188.24	66.11
	F_2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FLSD. 05 (genotype)		9.46	26.54	3.9	1.25	0.26	3.8	2.19	39.05	13.3	9.5

NS = Non-survived.

estimated according to Hedrick and Kalinowski, (2000) using

$D = 1 - w_s / w_o$,
D = Inbreeding effect.
w_s = F_2 value
w_o = F_1 value

RESULTS AND DISCUSSION

The results of the field evaluation of the parents and hybrids are presented in Tables 2 and 3. There were significant variations across the traits among the parents and hybrids. The values for canopy diameter ranged from 37.9- 66.92 cm. Wider canopies could confer advantage in exposing the leaves to sunlight and more production of the fruit. Equally, high number of leaves together with high leaf area among the F_1 plants of *Sho* x *Nsky – rw* is advantageous in attracting more sunlight energy thereby increasing assimilates from photosynthesis. *Shombo* had significantly the highest value in main stem length across the parent and other hybrid. Its hybrid (*Sho* x *Nsky – rw*) equally significantly had the tallest plants with a mean value of 66.11 cm. This value did not, however, vary from *Shombo* parent and F_2 plants of *Sho* x *Nsky – rw.* Tall plants could be disadvantageous in mechanical harvesting but could be preferred in positioning the leaves and tender branches for wider contact with sunlight. *Sho* x *Nsky – rw* F_1 plants had significantly the shortest internodes (0.55 cm). These same F_1 plants (*Sho* x *Nsky – rw*) also had significantly the highest number of nodes on the main stem, number of nodes/ branch, number of nodes/ plt and number of branches/ plt. This seems to suggest that the inheritance of shorter internodes could result in a significant increase in yield component characters that may have direct or indirect effect on fruit yield. These yield components have been shown to contribute to yield by having high correlations with fruit yield (Nandadevi and Hosamani, 2003).

The results of the fruit characters showed that *Tatase* had significantly the fattest fruits (2.03 cm diameter) while *Shombo* had significantly the longest fruits (7.76 cm) across the parents and hybrids (Table 3). *Tatase* parent which had the fattest fruits also had the longest fruit stalk length and the highest number of seeds/ fruits. This fat fruited genotype had the highest single fruit weight; however, it sets few fruits which is evidenced by the significantly low number of fruits per plant (14.83). Equally the F_1 hybrids (*Tat* x *Nsky-rw*) inherited this attribute of low number of fruits per plant (9.33). *Tatase* genotype has its preference in having high single fruit weight and thick pericarp as recorded in fruit wall thickness (3.54 cm) (Table 3). The highly aromatic genotype (*Nsky-rw*) had a relatively high yield (6.64 t/ha) which was significantly higher than the *Tatase* parent and the F_1 hybrids of *Tat x Nsky-rw.*

Table 3. Mean performance of parents, F_1 and F_2 populations in fruit characters.

Category		Fruit diameter	Fruit length	Fruit stalk length	No. of seeds / fruit	Seed wt/ fruit	Single fruit wt	No. of fruits/ plt	Fruit wt/ plt	Fruit yield (t/ha)	Fruit wall thickness
Parents											
Shombo		0.71	7.76	3.85	133.9	0.92	4.26	77.1	333.08	11.1	1.94
Tatase		2.03	3.51	3.95	188.97	0.81	6.65	14.83	97.86	3.26	3.54
Nsky-rw		1.19	3.53	3.24	50.5	0.22	2.87	69.72	199.38	6.64	1.67
Hybrid											
Sho x Nsky-rw	F_1	0.8	5.9	3.32	39.39	0.33	2.16	156.84	338.47	11.28	1.07
	F_2	0.86	4.77	3.32	43.73	0.20	2.75	56.87	128.33	1.56	1.64
Tat x Nsky-rw	F_1	1.24	4.21	3.85	50.37	0.18	3.19	9.33	29.76	1.00	2.20
	F_2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
FLSD. 05 (genotype)		0.23	0.37	0.4	25.62	0.17	0.68	15.76	48.94	2.3	0.4

NS = Non survived.

The higher numbers of fruits recorded in *Shombo* parent and its F_1 hybrids (*Sho* x *Nsky – rw*) were translated to higher cumulative yield of 11.1 and 11.28 t/ha, respectively. The red fruited genotype *Shombo* could be used as one of the parents in breeding programs due to its high yield. Shukri et al (2015) reported that genetic distance between parents used in breeding program is required in developing new parents with high performance in line with the breeders' objectives. It had earlier been reported that *Shombo* has a *frutescens* origin while Nsukka yellow pepper (*Nsky – rw*) is purely *Capsicum annuum* (Morakinyo and Falusi, 1992). This tends to point out the genetic distance between these two parents, thus favouring the observed high performance.

Canopy diameter, number of leaves/ plt, number of nodes/ plt, leaf area and number of branches/ plt showed positive heterosis over the mid-parents in both hybrids, and all except number of leaves/ plt in *Tat* x *Nsky-rw*, showed positive heterobeltiosis over the better parent (Table 4). These traits are the major traits that contribute to yield in peppers. Nandadevi and Hosamani, (2003) reported a high correlation between these traits and pepper yield. It, therefore, implies that the increase in these yield component traits could significantly improve fruit yield among the F_1 plants. The F_1 hybrids of *Tat* x *Nsky-rw* had positive heterosis over the mid and better – parents (+42.69 and +34.84, respectively) in plant height. This peculiarity puts these F_1 plants at advantage in hand harvesting since taller plants are preferred. All the major yield component traits showed inbreeding depression in F_2 among *Sho* x *Nsky – rw* plants. This is expected as there are allelic segregations at F_2 and pepper being predominantly self - pollinating would have high heterozygosity at F_1. High heterozygosity favours heterosis in many plant species. The F_2 seeds of *Tat* x *Nsky-rw* failed in germination; this phenomenon had previously been observed in crosses by some researchers (Silva et al., 2017).

The estimation of heterosis over the mid and better parent and inbreeding depression in F_2 for fruit characters is presented in Table 5. The number of fruits/ plt is a major trait contributing to fruit yield in peppers and it has positive heterosis over both the mid and better – parent in *Sho* x *Nsky – rw* (+113.65 and +103.42, respectively). It has been reported that number of fruits/ plt could predict yield with a high prediction accuracy (Abu et al., 2015).

Fruit weight together with fruit yield also had a positive heterosis over both the average and better parental values in *Sho* x *Nsky – rw*. Superiority over the better parental values (heterobeltiosis) has been reported to be more effective than heterosis, particularly in the breeding of self-pollinating crops (Shukri et al., 2015). It should also be noted that most of the fruit characters had negative heterosis in *Tat* x *Nsky-rw.* Tatase usually sets few fat fruits with high

Table 4. Estimation of heterosis over the mid and better parents and inbreeding depression for morphological traits.

Character	Heterosis % *Sho x Nsky-rw*		Heterosis % *Tat x Nsky-rw*		Inbreeding Depression *Sho x Nsky-rw*	Inbreeding Depression *Tat x Nsky-rw*
	$\overline{MP}$	$\overline{BP}$	$\overline{MP}$	$\overline{BP}$		
Canopy diameter	+28.89	+28.32	+15.38	0.00	0.08	-
No. of leaves/plt	+83.17	+39.95	+21.89	-8.29	0.57	-
Leaf area	+33.24	+7.93	+24.38	+0.44	0.11	-
Mainstem length	+12.83	+1.11	+86.56	+ 81.22	0.37	-
Mainstem internode lenght	-65.84	-71.05	-7.80	-13.33	-0.75	-
No. of nodes on mainstem	+39.01	+31.27	+23.27	+4.08	0.30	-
No. of nodes/branch	+74.48	+70.10	+15.27	+9.25	0.40	-
No. of nodes/plt	+84.89	+55.09	+7.07	+29.58	0.64	-
No. of branches/plt	+37.59	+8.44	+10.60	+51.84	0.26	-
Plant height	-1.73	-16.06	+42.69	+34.84	-0.11	-

Table 5. Estimation of heterosis over the mid and better parents and inbreeding depression for fruit characters.

Character	Heterosis % *Sho x Nsky-rw*		Heterosis % *Tat x Nsky-rw*		Inbreeding Depression *Sho x Nsky-rw*	Inbreeding Depression *Tat x Nsky-rw*
	$\overline{MP}$	$\overline{BP}$	$\overline{MP}$	$\overline{BP}$		
Fruit diameter	-15.79	-32.77	-22.98	-38.92	-0.08	-
Fruit lenght	+2.61	-25.88	+19.60	+19.26	0.19	-
Fruit stalk lght	-6.48	-13.77	+6.94	-2.53	0.00	-
No. of seeds/fruit	-57.27	-70.58	-57.93	-73.34	-0.11	-
Seed wt/fruit	-42.1	-64.13	-65.39	-77.78	0.39	-
Single fruit wt	-32.71	-49.30	-33.26	-52.03	-0.27	-
No. of fruits/plt	+113.65	+103.42	-77.93	-86.62	0.64	-
Fruit wt/plt	+27.13	+1.62	-79.98	-85.07	0.62	-
Fruit yield t/ha	+27.17	+1.62	-79.80	-84.94	0.86	-
Fruit wall thickness	-40.88	-44.85	-15.71	-37.85	-0.53	-

single weight value. Inbreeding depression was positive among the F_2 plants of *Sho* x *Nsky – rw* while in *Tat* x *Nsky-rw*, there were no survivals. Gonza´lez et al. (2014) associated inbreeding depression with embryo mortality and a reduction in plant vigor. This could explain the germination failure of the F_1 seeds of *Tat* x *Nsky-rw* hybrids and the reduction in vigor among the F_2 hybrids of *Sho* x *Nsky – rw.* In conclusion, the very short internode length observed in *Sho* x *Nsky – rw* hybrid was advantageous as it had the highest values in major morphological traits with high weightage to yield and in fruit yield. Equally, while *Sho* x *Nsky – rw* had the highest yield, *Tat* x *Sho* had the highest fruit wall thickness. The combinations of these traits are important to both the farmers and consumers. The genetic distance between the *Shombo* and Nsukka yellow pepper was advantageous in raising F_1 hybrids with high performance above the better parent.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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