AcademicPres

Ahmodu PB *et al.* (2020)
Notulae Scientia Biologicae 12(3):658-672
DOI:10.15835/nsb12310731
Research Article

Notulae Scientia Biologicae

Determination of the relatedness, ease of hybridization and gene exchange among members of the genus *Capsicum* in Nigeria

Paul B. AHMODU*, Joseph A. MORAKINYO,
Catherine T. AHMODU

*University of Ilorin, Faculty of Life Sciences, Department of Plant Science, Ilorin, Kwara State, Nigeria; babs.paul@live.com (*corresponding author); jamorakinyo@gmail.com; ptosin49@gmail.com*

Abstract

The fruit of *Capsicum* plants have a variety of names depending on place and type. This research was focused at studying the exchange of genes amongst members of the genus *Capsicum* in Nigeria. The process of interspecific and intervarietal hybridization of two (2) species of the genus *Capsicum; C. annuum and C. frutasense* were carried out and the results show that most of the studied attributes like arrangement of leaves, shape of leaves, leaf density were undetermined while majority with distinct changes follow maternal inheritance. There were less successes among the interspecific crosses and high successes between varietal crosses ranging from 19.5% to 2.4% for the inter-varietal cross and 9.3% to 2.4% for interspecific crosses. This indicates that there are more hybridization barriers among interspecific hybridization than inter-varietal hybridization. The closely related species and varieties had higher percentage success of hybridization and vice versa. Characters such as Hypocotyl colour had partial dominance. Erect flower position is dominant in W and hybrid T*W while pendant is recessive. Red fruit colour at maturity, green fruit stalk colour was dominant while yellow was recessive. A good knowledge of how related species of the genus *Capsicum* are, the easier it will enable researchers to hybridize and improve the genus.

Keywords: *Capsicum*; crosses; dominance; exchange of genes; hybridization; maternal inheritance; recessive

Introduction

Capsicum commonly known as peppers is a genus of flowering plants in the nightshade family Solanaceae, which includes tomato, potato, tobacco, and petunia. According to International Institute of Tropical Agriculture (IITA, 2005), in Nigeria peppers are used in stew and some local dishes all over the country although the types and quantities utilized vary in different areas. The following varieties are widely grown in this country. Bird peppers 'Atawere' (*Capsicum frutescens*), Cayenne pepper or red pepper 'Sombo' (*Capsicum frutescens*), 'Atarodo' (*Capsicum annum*), 'Tatase' (*Capsicum annum*). The fruits of these types of pepper vary in size, color, shape, and pungency. They are all hot to varying degrees. *Capsicum frutescens* is generally hotter than *Capsicum annum* and there is variation within each species in terms of hotness, fruit size

Received: 09 May 2020. Received in revised form: 23 Sep 2020. Accepted: 25 Sep 2020. Published online: 29 Sep 2020.

and shape. These variations suggest natural exchange of genes, at least within each species which can be determined through artificial intra specific and inter specific hybridization.

Interspecific hybridizations allow a transfer of specific genes of interest between different species, most often those involved in disease resistance (Bosland and Votava, 2000), allowing breeders to develop genetically superior genotypes. However, for the good success of such a transfer, the species must be genetically close or related, minimizing problems of incompatibility and thus enabling hybridization. As a general rule, the closer the species involved in the cross are genetically, the easier it will be to breed hybrids and the more fertile the progenies (Singh, 2002). Thus, the existence of barriers in interspecific crosses indicates the genetic distance of species and probable chromosome pairing problems within the genus. This necessitated this research in order to; determine the mode of inheritance among varieties of the genus *Capsicum annum* and *Capsicum frutesence* in Nigeria.

Materials and Methods

The study was carried out at University of Ilorin (UNILORIN) Botanical Garden between June, 2015 and December 2017. The UNILORIN Botanical Garden lies between latitude 8°30′N and longitude 4°33′E latitude 8.50° N and 4.550° E, Ilorin, Kwara State, Nigeria. The first planting was done between June and November 2015 for the crosses of the parent plants to get the first generation (F_1) seeds while the first generation (F_1) seeds were planted between April and August, 2017 to get the second generation (F_2) seeds, and the F_2 generation were planted between September to December, 2017.

Dried seeds of three (3) varieties of *Capsicum annum* (varieties namely, *abbreviatum* ('Rodo'), *grossom* ('Tatase') and *acumunatum* ('Shombo') and *Capsicum frutescence* (varieties namely, *baccatum* ('wewe') were collected. Seven seeds of various varieties of *Capsicum* were obtained from local markets and were used as the parent lines. The varieties are 3 varieties of Ata of Rodo (*Capsicum. annuum* var. *abbreviatum*), Tatase (*C. annuum* var. *grossum)*, Shombo (*C. annuum* var. *acuminatum)*, Ata wewe (*C. frutascens* var. *baccatum*), Ata Jere (*C. frutascens* var. *baccatum*). Each variety on ridges with a dimension of 30 feet * 20 feet. The seeds were sown in a nursery and the seedlings were transplanted with uniform spacing of 1foot each. All varieties are sown same day; 22nd June, 2015. The seedlings were transplanted to cultivated ridges on 20th July, 2015. Plants were characterized using pepper descriptors at maturity. Single crosses and reciprocal crosses were carried out to attain the F1 seeds from the parent plants based on $n(n-1)/2$, when n=4, Single and reciprocal crosses =12. A total of 6 single crosses and 6 reciprocal crosses. Crosses of flowers were done at the early hours of the day at about 6.00 am to 9.00 am before the sunrise each day before the flower opens fully and get selfed by insects and other agents of pollination. Crosses were also done in the late hours of the day for flowers just before anthesis but mature. This was done at sunset, around 6.00 pm. Cross pollinated flowers were tagged accordingly with codes such as R*T (being Rodo*Tatase) with rodo (R) as the female plant while Tatase (T) as the male plant and bagged using tissue papers to avoid pollination by insects, wind or other pollinating agents.

Crosses (hybridization) were made among all four (4) in all possible combinations by physical or hand emasculation and pollination. Emasculation is the removal of stamen or anthers or killing the pollen grains of a flower without affecting the female reproductive organs and prevent self-fertilization. Pepper flower, being bisexual, hand emasculation was used. The stamens were removed using forceps. The corolla and other parts of the flower covering the androecium were cut off using scissors and proper care was taken to avoid damaging the gynoecium. Mature and viable pollen were freshly collected from the male parent plants and scooped to the mature receptive stigma of the female plant after the anther surrounding the stigma have been carefully removed. The crossed pollinated flowers were emasculated and bagged with tissue paper to ensure fertilization as crossed. Bagging was done immediately after emasculation using tissue paper bags to enclose the emasculated flowers to prevent random cross pollination; the bags are tied to the base of the flower or the flower stalk with threads. The choice of using tissue paper as bagging material was to reduce moisture and temperature inside the bag, which might promote fungi growth and the bags are removed within a day or two at most after pollination, during which fertilization might have taken place and fruit formation. Tagging was done immediately after bagging.

Results

Table 1 shows the percentage and successes of the parent plant crosses. Twelve (12) possible combinations were made, all were successful. It was observed that the crosses between R×S, 12 were successful with a percentage success of 25.53%. 27.45% successes were observed for R×T, with a total cross of 51 and successes of 14. in R×W, it was observed that 89 crosses were made, 42 were successful, 47 got aborted with a percentage success of 47.19%. S×R had a percentage success of 37.14%, a total of 70 crosses was done for the combination, 26 were successful and 44 were aborted. In S×T combination, 33 crosses were done, 18 were successful, giving a percentage success of 54.55%. 40 crosses were observed for S×W, 17 of it were successful, 23 were failed crosses, giving a percentage success of 42.50%. The cross T×R had 11 successes out of 58 crosses with a percentage success of 18.97%, while T×S had 19 successes out of 30 crosses with a percentage success of 63.33%. The cross T×W had 9 successes out of 29 crosses with a percentage success of 31.03%, while W×R had 38 successes out of 115 crosses with a percentage success of 33.04%. The crosses between W×S had 10 successes out of 33 crosses with a percentage success of 30.30 % while W×T had 26 successes out of 46 crosses and a percentage success of 56.52%.

Genetic exchange of characters was noticed during the crosses. Gene exchange between groups or individual organisms can be influenced by several factors which may include physical barriers against cross pollination. Such barriers are overcome through artificial land pollination. However, there are other post-pollination barriers which artificial land pollination cannot remove. In all cases the effectiveness of these barriers depends on the genetic relationship between individuals and groups.

From the quantitative data of hybrids and reciprocals studied in the research. The hybrids and reciprocals exhibited segregation of characters in the F_1 and independent assortment of characters in F_2. 9 quantitative characters were studied and mean values were analyzed using analysis of variance (ANNOVA) and the Duncan of plant height (PH), leaf length (LL), leaf breadth (LB), stem girth (SG), laminar leaf length (LLL), anthal length (AL), style length (SL), petal length (PL) and petal width (PW).

The variation in PH between the varieties and hybrids show that the different varieties of pepper have varying gene alleles for the character. There was drastic increase in variation of PH in the hybrid R*W_2 (36.20±4.39) which is an increase from the hybrid parents R (27.22±3.62) and W (39.30±2.21). There was a decrease in the PH of hybrid S*W (35.86±0.80) compared to the variation in PH of parent plants S (35.20±1.48) and W (39.30±2.21).

There was variation in LL among the hybrids. Notably in W*R (7.80±0.29) relative the parent plants W (12.64±0.92) and R (17.14±0.71). This was also noted in S*T (8.06±0.31) from the parents S (13.30±0.45) and T (15.30±0.45). This can be attributed to variation in alleles of the genes responsible for LL between parents. No dominance nor recessiveness of this trait among the parents.

With hybridization there was an increase in SG in the hybrid offspring of the cross. T*R, T*W, W*S and S*T had drastic increase in SG. There was variation of LLL among hybrid plants and their parents. This can be attributed to the random pairing of the alleles of the genes that regulate these characters.

Majorities of the data followed maternal inheritance. This can be found in tables 9 to 20. While few amongst the characters followed paternal inheritance. Majority of the characters could not be determined since both parents showed similar attributes for the same character. Examples of these characters are, calyx pigmentation, Leaf type, Leaf venation, leaf arrangement, e.t.c.

From plate 2, it was noticed that hybrid fruits are smaller in size in size when compared to their parent fruits. About 70% of the fruits were discovered to have shrinked.

Based on interspecific crosses, it was seen that crosses between *C. frutasense * C. annuum* are higher at an average percentage than crosses between *C. annuum and C. frutasence*. Both at an average percentage. This means reciprocal successes are few.

Most plants crossed with W at their orientation of flower and fruits showed alternation of the character of flower orientation as some plants had either erect flowers like W while others had pendant flowers. Plants crossed with W had similar erect flowers which were not shown in W parent plants and this implies that erect flower orientation could be said to be coded by a heterogenous pair of chromosomes. This is found in table 15. Similar result was observed in the work done by Nwankiti (1976); and Odland and Porter (1941).

Table 1. Percentage cross pollination success among varieties of *Capsicum* sp.

SN	Crosses	Freq.	Success	Failure	Percentage success (%)	Success groups
1	R*S	47	12	35	25.53	B
2	R*T	51	14	37	27.45	B
3	R*W	89	42	47	47.19	B
4	S*R	70	26	44	37.14	B
5	S*T	33	18	15	54.55	A
6	S*W	40	17	23	42.50	B
7	T*R	58	11	47	18.97	C
8	T*S	30	19	11	63.33	A
9	T*W	29	9	20	31.03	B
10	W*R	115	38	77	33.04	B
11	W*S	33	10	23	30.30	B
12	W*T	46	26	20	56.52	A

Key 1
A = Groups 1; 50% and above
B = Groups 2; 25% - 49%
C = Groups 3; 10% - 24%
D = Groups 4; 0% - 09%

Key 2
R = Rodo (*C. annuum* var. abbreviatum)
S = Shombo (*C. annuum* var. *acuminatum*)
T = Tatase (*C. annuum* var. *grossum*)
W = Ata wewe (*C. frutascens* var. *baccatum*)

Table 2. Percentage success group

S/N	Group	*C. annuum x C. annuum*	*C. annuum x C. frutescens*	*C. frutescens x C. frutescens*	*C. frutescens x C. annuum*
1	A (50%<)	19.5	7.3	2.4	4.9
2	B (25-49%)	14.6	12.2		14.6
3	C (10-24%)	14.6	2.4		2.4
4	D (0-9%)	2.4			2.4

The different groups, i.e. 1-4 denotes the grouping of the different percentage successes of hybridization from the crosses

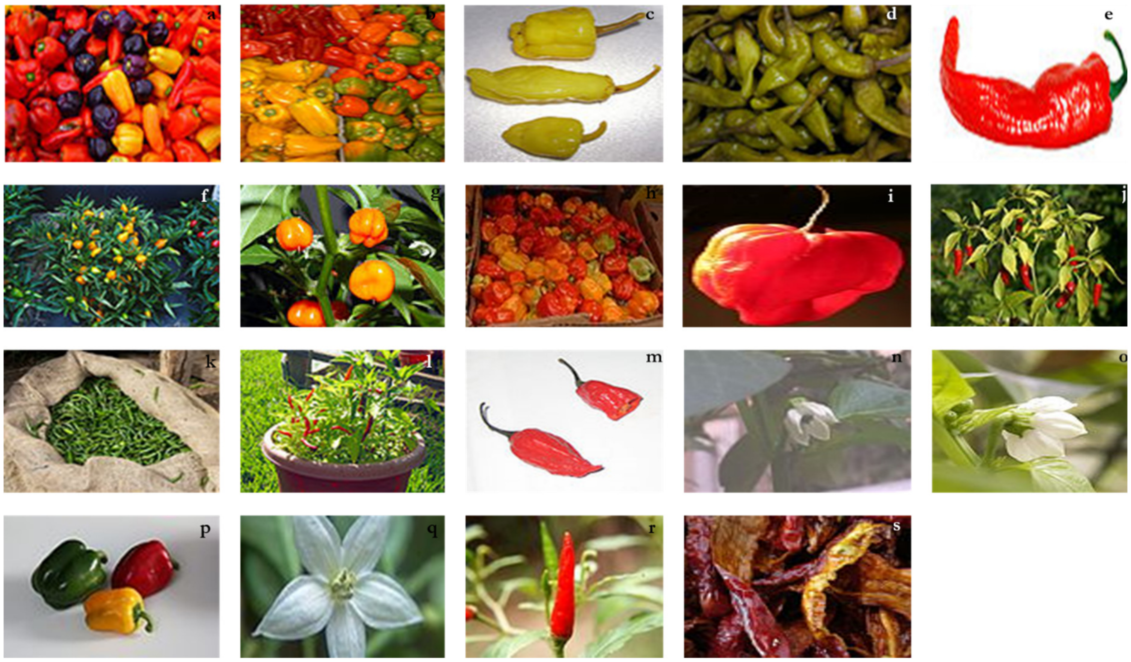

Figure 1. *C. annuum* cultivars

a: A variety of coloured *Capsicum*; b: Peperoncini (*C. annuum*); c: Peperoncini in kebab restaurant; d: Cayenne pepper (*C. annuum*); e: Compact plant of orange *Capsicum;* f: Habanero chili (*C. chinense* Jacquin) - plant with flower and fruit; g: Scotch bonnet (*C. chinense*) *in a* Caribbean market; h: Scotch bonnet; i: Thai peppers (*C. annuum*); j: Fresh Indian green chillies in Bangalore market; k: Piri piri (*C. frutescens* African Devil'); l: Naga jolokia pepper (bhut jolokia) (*C. chinense* x *C. frutescens*); m: *C. annuum* flower; n: *C. annum* flower close-up; o: Green, yellow, and red peppers; p: The flower of red hot *bangi* pepper, Malaysia; q: A small but very hot *Capsicum* in Malaysia; r: Dried and crunchy *Capsicum* from Basilicata; s: *Capsicum* in Bangladesh

Source: https://en.wikipedia.org

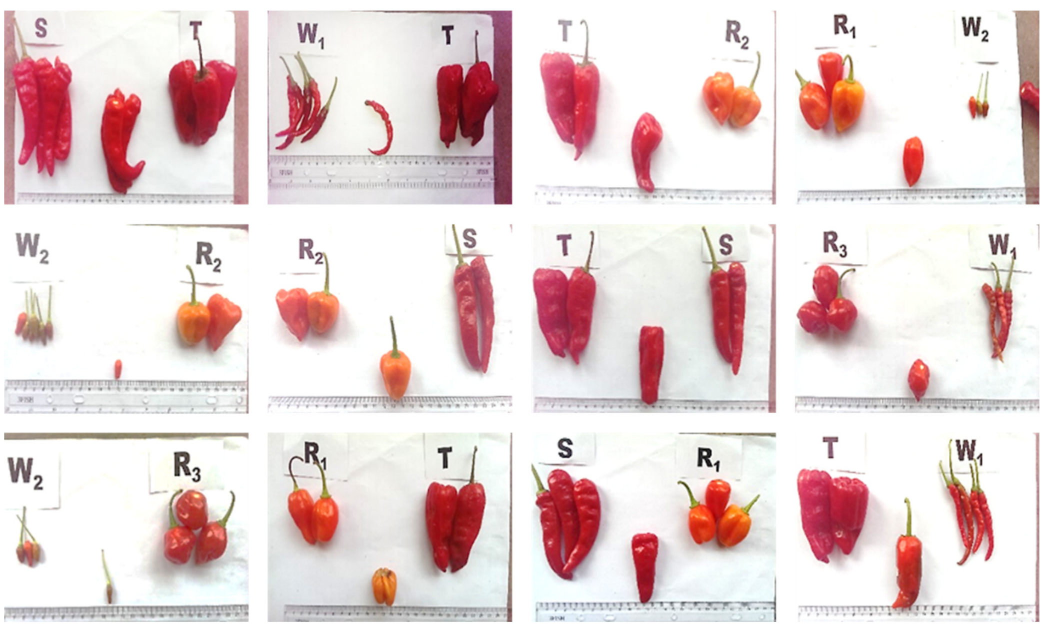

Figure 2. F_0 hybrid fruits

Table 3. Means and standard deviation of quantitative characters in all the parents and their crosses

Varieties and hybrids	Plant height	Leaf length	Leaf breadth	Stem girth	Laminar leaf length	Anthal length	Style length	Petal length	Petal width
R	27.22±3.62^{bcd}	17.14±0.71^{gh}	5.80±0.40^{ghij}	1.02±0.22^{a}	10.12±1.76^{bcde}	0.24±0.19^{a}	0.32±0.01^{a}	0.80±0.03^{g}	0.31±0.00^{ab}
S	35.20±1.48^{fgh}	13.30±0.45^{def}	4.30±0.07^{cde}	0.60±0.09^{a}	9.64±0.31^{bcd}	0.28±0.14^{b}	0.51±0.01^{ef}	0.84±0.02^{g}	0.72±0.01^{h}
T	41.48±1.82^{ghi}	15.3±0.45^{ef}	4.65±0.09^{cdefg}	0.86±0.09^{a}	10.58±0.30^{bcdef}	0.31±0.06^{bc}	0.42±0.01^{c}	1.14±0.04^{i}	0.51±0.00^{g}
W	39.30±2.21^{fgh}	12.64±0.92^{cde}	2.74±0.06^{a}	0.98±0.12^{a}	7.52±0.85^{ab}	0.31±0.00^{bc}	0.51±0.01^{ef}	0.96±0.19^{h}	0.41±0.00^{ef}
R*W	36.20±4.39^{efgh}	12.52±1.63^{cde}	6.30±0.90^{ij}	1.84±0.16^{bc}	10.40±1.86^{bcdef}	0.30±0.03^{bc}	0.30±0.01^{a}	0.87±0.18^{g}	0.40±0.01^{ef}
R*S	33.34±1.84^{defg}	15.72±1.29^{fgh}	9.460.35^{k}	1.64±0.40^{b}	13.18±1.33^{f}	0.31±0.00^{bc}	0.46±0.03^{cde}	0.67±0.03^{def}	0.36±0.02^{cd}
R*T	21.86±2.21^{ab}	12.74±1.42^{cde}	5.32±0.56^{efghij}	1.96±0.39^{bcd}	8.64±1.10^{b}	0.30±0.00^{bc}	0.48±0.02^{def}	0.64±0.04^{cde}	0.35±0.02^{cd}
S*R	36.88±3.28^{efgh}	11.20±1.62^{bce}	4.28±0.33^{cde}	1.90±0.14^{bc}	8.84±0.21^{b}	0.30±0.01^{bc}	0.52±0.10^{ef}	0.54±0.02^{ab}	0.31±0.00^{ab}
S*T	42.24±3.29^{hi}	8.06±0.31^{a}	3.52±0.28^{abc}	3.32±0.42^{f}	5.08±0.29^{a}	0.40±0.00^{e}	0.52±0.04^{f}	0.84±0.04^{g}	0.44±0.02^{f}
S*W	35.86±0.80^{efgh}	12.02±1.05^{bcd}	4.38±0.49^{cdef}	2.74±0.35^{e}	10.31±0.99^{bcdef}	0.41±0.01^{e}	0.60±0.00^{g}	0.80±0.01^{g}	0.30±0.00^{a}
T*R	18.62±2.09^{a}	13.98±0.70^{def}	3.86±0.43^{abcd}	1.84±0.23^{bc}	12.76±0.80^{ef}	0.31±0.01^{bc}	0.33±0.03^{ab}	0.57±0.02^{bc}	0.31±0.01^{ab}
T*W	35.88±0.92^{efgh}	12.04±0.71^{bcd}	4.36±0.19^{cdef}	3.92±0.10^{f}	9.48±0.58^{bc}	0.32±0.20^{c}	0.40±0.10^{bc}	0.49±0.01^{a}	0.41±0.01^{ef}
W*R	38.94±0.97^{fgh}	7.80±0.29^{a}	2.92±0.09^{ab}	2.46±0.16^{cde}	4.88±0.20^{a}	0.30±0.01^{bc}	0.39±0.01^{bc}	0.72±0.01^{cd}	0.34±0.02^{bc}
W*S	36.58±0.86^{efgh}	11.18±0.30^{bcd}	4.72±0.10^{cdefg}	3.44±0.02^{f}	7.56±0.24^{ab}	0.40±0.01^{e}	0.60±0.03^{g}	0.80±0.03^{g}	0.40±0.01^{e}
	S	S	S	S	S	S	S	S	S

Figure 3. F_0 hybrid fruits

Table 4. Qualitative/quantitative fruit characters of F_1 plants

Fruit characters						
Hybrids	Pedicel length (cm)	Fruit width (cm)	Fruit length (cm)	Fruit weight with pedicel (mg)	Fruit weight without pedicel (cm)	Fruit colour
R*S	3.40	5.65	5.65	7.30	7.10	Red
R*T	3.30	4.9	2.90	6.06	6.02	Orange
R*W	4.20	4.8	40.00	9.16	8.52	Red
S*R	5.10	3.75	7.10	10.40	10.05	Red
S*T	3.65	2.4	11.25	10.61	10.29	Red
S*W	4.10	3	8.20	6.70	6.50	Red
T*R	4.90	4.15	3.95	6.20	6.00	Red / Variegated
T*S	5.70	2.9	6.80	12.54	12.17	Red
T*W	4.55	4.95	8.55	10.50	10.30	Red
W*R	3.20	1.6	7.20	1.30	1.22	Red
W*S	3.43	1.62	8.57	1.83	1.63	Red
W*T	3.90	1.10	7.97	1.56	1.44	Red

Table 5. Quantitative and floral data of F_1 hybrid plants

F_1 hybrids														
Quantitative characters						Floral characters								
	Flower position	Pollen sac colour	Style colour	Stigma colour	Stigma position	Flower stalk lenth (cm)	Petals length (cm)	Calyx length (cm)	Style length (cm)	Pollen -sac length (cm)	Leaf breadth (cm)	Leaf length (cm)	Stem girth (cm)	Plant height (cm)
r*w	pendant/ pointing upward	green	green	green	same level	2.7	0.5	0.4	0.5	0.3	5.3	10.52	1.84	23.12
s*r	pendant	purple	purple	light green	protruding	2.8	0.5	0.4	0.5	0.3	4.28	9.38	1.9	24.42
t*r	pendant	purple	green	green	submerged	2.6	0.6	0.5	0.34	0.34	3.86	11.98	1.84	16.62
r*s	pendant /upward curvy	green/ purple	green	purple	protruding	2.8	0.5	0.4	0.5	0.32	9	18.2	1.7	25.4
t*s	pendant	green/ purple	purple	green	protruding	2.15	0.8	0.45	0.5	0.39	3.52	8.06	3.32	33.6
s*w	pendant	green	purple	green	submerged	1.8	0.8	0.4	0.6	0.4	4.38	10.36	2.74	27.58
r*t	conical pendant	green	purple	green	protruding	1.8	0.7	0.5	0.5	0.4	5.35	12.2	1.925	20.85
w*r	pendant	purple	green	green	submerged/ protruding	1.8	0.7	0.38	0.4	0.3	2.9	7.51	2.8	40.9
w*s	erect	purple	green	green	protruding	0.8	0.5	0.3	0.4	0.4	4.4	10.6	3.4	35.7

Table 6. Comparison of R and T

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		R	**T**	**T x R**	
1	Stem colour	Green	Purple	Green/Purple	No dominance
2	Stem pubescence	Intermediate	Sparse	Sparse	Resembles male parent
3	Leaf colour	Light green	Dark green	Green	No dominance
4	Fresh fruit colour	Yellow	Green	Green	Resembles male parent
5	Fruit pubescence	Sparse	Sparse	Sparse	Not determined
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to germination	7	6	7	Quantitative
8	Hypocotyl colour	Purple	Purple	Purple	Not determined
9	Hypocotyl pubescence	Intermediate	Sparse	Sparse	Resembles female parent
10	Anthocyanin on the nodes	Green	Dark purple	Green	Resembles female parent
11	Stem pubescence	Dense	Sparsed	Dense	Resembles female parent
12	Plant growth habit	Erect	Erect	Erect	Not determined

13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Green	Dark green	dark green	Resembles male parent
16	Leaf venation	Parallel	Pinnate	pinnate	Not determined
17	Leaf type	Compound	Compound	compound	Not determined
18	Leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Intermediate	Intermediate	Intermediate	Not determined
20	Pedicel position at anthesis	Intermediate	Pendant	Pendant	Resembles male parent
21	Filament colour after anthesis	Green	Purple	Green	Resembles female parent
22	Flower position	Pendant	Pendant	Pendant	Not determined
23	Fruit shape	Sunken	Sunken	Sunken	Not determined
24	Fruit surface	Semi-wrinkled	Semi wrinkled	Semi-wrinkled	Not determined
25	Stigma position at anthesis	Exserted	same level	Exserted	Resembles female parent
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at immature stage	Yellow	Green	Green	Resembles male parent
28	Fruit colour at maturity	Lemon	Red	Red	Resembles male parent
29	Pedicel with fruit	Persistent	Persistent	Persistent	Not determined

Table 7. Comparison of R and W

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		R	W	W X R	
1	Stem colour	Green	Purple	Green	Resembles female parent
2	Stem pubescence	Intermediate	Sparse	Sparse	Resembles male parent
3	Leaf colour	Light green	Dark green	Green	Not dominance/Reccessiveness
4	Fresh fruit colour	Yellow	Green	Green	Resembles male parent
5	Fruit pubescence	Sparse	Non	Non	Resembles male parents
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to germination	7	8	7	Quantitative
8	Hypocotyl colour	Purple	Dark green	Green	No dominance
9	Hypocotyl pubescence	Intermediate	Sparse	Sparse	Resembles male parents
10	Anthocyanin on the nodes	Green	Purple	Green	Resembles female parents
11	Stem pubescence	Dense	Dense	Dense	Not determined
12	Plant growth habit	Erect	Erect	Erect	Not determined
13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Green	Dark green	Green	Resembles female parents
16	Leaf venation	Parallel	Parallel	Parallel	Not determined
17	Leaf type	Compound	Compound	Compound	Not determined
18	leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Intermediate	Intermediate	Intermediate	Not determined
20	Pedicel position at anthesis	Intermediate	Pendant	Pendant	Resembles male parents
21	Filament colour	Green	White	White	Resembles male parents

22	Flower position	Intermediate	Pendant	Intermediate	Resembles female parents
23	Fruit shape	Sunken	Elongated	elongated	Resembles female parents
24	Fruit surface	Semi-wrinkled	Wrinkled	wrinkled	Resembles male parents
25	Stigma position at anthesis	Exserted	Exserted	Exserted	Not determined
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at immature stage	Yellow	Green	Green	Resembles male parents
28	Fruit colour at maturity	Red	Red	Red	Not determined
29	Pedicel with fruit	Persistent	Persistent	Persistent	Not determined

Table 8. Comparison of T and R

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		R	**T**	**T X R**	
1	Stem colour	Green	Purple	Green/purple	No dominance
2	Stem pubescence	Intermediate	Sparse	Sparse	Resembles male parent
3	Leaf colour	Green	Dark green	Green	Resembles female parents
4	Fresh fruit colour	Yellow	Green	Green	Resembles male parent
5	Fruit pubescence	Sparse	Sparse	Sparse	Not determined
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to germination	7	6	7	Quantitative
8	Hypocotyl colour	Light green	Purple	Purple/green	No dominance
9	Hypocotyl pubescence	Intermediate	Sparse	SPARSE	Resembles male parent
10	Anthocyanin on the nodes	Green	Dark purple	Green	Resembles female parents
11	Stem pubescence	Dense	Sparse	Sparse	Resembles male parent
12	Plant growth habit	Erect	Erect	Erect	Not determined
13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Green	Dark green	Green	Resembles female parents
16	Leaf venation	Parallel	Pinnate	Pinnate	Resembles male parent
17	Leaf type	Compound	Compound	Compound	Not determined
18	leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Sparse	Intermediate	Intermediate	Resembles male parent
20	Pedicel position at anthesis	Intermediate	Pendant	Intermediate	Resembles female parents
21	Filament colour	Green	Purple	Purple	Resembles male parent
22	Flower position	Intermediate	Pendant	Pendant	Resembles male parent
23	Fruit shape	Pointed	Sunken	Sunken	Resembles male parent
24	Fruit surface	Semi-wrinkled	Semi wrinkled	Semi wrinkled	Not determined
25	Stigma position at anthesis	Same level	same level	Same level	Not determined
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at Immature stage	Yellow	Green	Green	Resembles male parent
28	Fruit colour at maturity	Red	Red	Red	Not determined
29	Pedicel with fruit	Persistent	Persistent	Persistent	Not determined

Table 9. Comparison of R and S

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		R	**S**	**R X S**	
1	Stem colour	Green	Purple	Green	Resembles the female parent
2	Stem pubescence	Intermediate	Sparse	Sparse	Resembles the male parent
3	Leaf colour	Green	Dark green	Green	Resembles the female parent
4	Fresh fruit colour	Yellow	Green	Yellow	Resembles the female parent
5	Fruit pubescence	Sparse	Sparse	Sparse	Not determined
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to germination	7	6	7	Quantitative
8	Hypocotyl colour	Light green	Purple	Green	Partial dominance
9	Hypocotyl pubescence	Intermediate	Sparse	Sparse	Resembles the male parent
10	Anthocyanin on the nodes	Green	Dark purple	Green	Resembles the female parent
11	Stem pubescence	Dense	Dense	Dense	Not determined
12	Plant growth habit	Erect	Erect	Erect	Not determined
13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Green	Dark green	Green	Resembles the female parent
16	Leaf venation	Parallel	Pinnate	Parallel	Resembles the female parent
17	Leaf type	Compound	Compound	Compound	Not determined
18	leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Sparse	Sparse	Sparse	Not determined
20	Pedicel position at anthesis	Intermediate	Pendant	Pendant	Resembles the male parent
21	Filament colour after anthesis	Green	Purple	Green	Resembles the female parent
22	Flower position	Intermediate	Pendant	Pendant	Resembles the male parent
23	Fruit shape	Pointed	Elongated	Pointed	Resembles the female parent
24	Fruit surface	Semi-wrinkled	Semi wrinkled	Semi wrinkled	Not determined
25	Stigma position at anthesis	Same level	Exserted	Same level/ Excerted	No dominance
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at Immature stage	Yellow	Green	Green	Resembles the male parent
28	Fruit colour at maturity	Red	Red	Red	Not determined
29	Pedicel with fruit	Persistent	Persistent	Persistent	Not determined

Table 10. Comparison of T and S

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		T	S	S X T	
1	Stem colour	Purple	Purple	purple	Not determined
2	Stem pubescence	Sparse	Sparse	Sparse	Not determined
3	Leaf colour	Dark green	Dark green	Green	No dominance nor recessiveness Leaf colour green
4	Fresh fruit colour	Green	Green	Green	Not determined
5	Fruit pubescence	Sparse	Sparse	Sparse	Not determined
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to flowering	6	6	6	Quantitative
8	Hypocotyl colour	Purple	Purple	Purple	Not determined
9	Hypocotyl pubescence	Sparse	Sparse	Sparse	Not determined
10	Anthocyanin on the nodes	Dark purple	Dark purple	purple	No dominance nor recessiveness
11	Stem pubescence	Sparse	Dense	Dense	Resembles male parent
12	Plant growth habit	Erect	Erect	Erect	Not determined
13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Dark green	Dark green	Green	No dominance nor recessiveness
16	Leaf venation	Pinnate	Pinnate	Pinnate	Not determined
17	Leaf type	Compound	Compound	Compound	Not determined
18	leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Intermediate	Sparse	Sparse	Resembles male parent
20	Pedicel position at anthesis	Pendant	Pendant	Pendant	Not determined
21	Filament colour	Purple	Purple	Purple	Not determined
22	Flower position	Pendant	Pendant	Pendant	Not determined
23	Fruit shape	Sunken	Elongated	Sunken	Resembles female parent
24	Fruit surface	Semi wrinkled	Semi wrinkled	Wrinkled	No dominance nor recessiveness
25	Stigma position at anthesis	same level	Exserted	Exserted	Resembles male parent
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at immature stage	Green	Green	Green	Not determined
28	Fruit colour at maturity	Red	Red	Red	Not determined
29	Pedicel with fruit	Persistent	Persistent	Persistent	Not determined

Table 11. Comparison of T and W

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		T	W	T X W	
1	Stem colour	Purple	Green	Green	Resembles male parent
2	Stem pubescence	Sparse	Dense	Sparse	Resembles female parent
3	Leaf colour	Dark green	Dark green	Green	No dominance/recessiveness
4	Fresh fruit colour	Green	Green	Green	Not determined
5	Fruit pubescense	Sparse	Sparse	Sparse	Not determined
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to flowering	6	6	7	Quantitative
8	Hypocotyl colour	Purple	White	White	Resembles female parent
9	Hypocotyl pubescence	Sparse	Intermediate	Sparse	Resembles female parent

10	Anthocyanin on the nodes	Dark purple	Purple	Purple	Resembles male parent
11	Stem pubescence	Sparse	Dense	Non	No inheritance
12	Plant growth habit	Erect	Erect	Erect	Not determined
13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Dark green	Green	Green	Resembles male parent
16	Leaf venation	Pinnate	Parallel	pinnate	Resembles female parent
17	Leaf type	Compound	Compound	Compound	Not determined
18	leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Intermediate	Intermediate	Intermediate	Not determined
20	Pedicel position at anthesis	Pendant	Erect	Erect	Resembles male parent
21	Filament colour	Purple	Purple	Purple	Not determined
22	Flower position	Pendant	Erect	Erect	Erect is dominant over pendant
23	Fruit shape	Sunken	Pointed	Pointed	Resembles male parent
24	Fruit surface	Semi wrinkled	Smooth	Semi wrinkled	Resembles female parent
25	Stigma position at anthesis	same level	Exserted	Exserted	Resembles male parent
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at immature stage	Green	green/variegated	Green	Resembles female parent
28	Fruit colour at maturity	Red	Red	Red	Not determined
29	Pedicel with fruit	Persistent	Persistent	Persitant	Not determined

Table 12. Comparison of S and W

Determination of dominance between parents					
s/n	Character	Parent 1	Parent 2	Hybrid	Inference on mode of inheritance
		S	**W**	**S X W**	
1	Stem colour	Purple	Purple	purple	Not determined
2	Stem pubescence	Sparse	Sparse	sparse	Not determined
3	Leaf colour	Dark green	Dark green	Green	No dominance nor recessiveness
4	Fresh fruit colour	Green	Green	Green	Not determined
5	Fruit pubescence	Sparse	Non	Non	Resembles the male parent
6	fruit stalk colour	Green	Green	Green	Not determined
7	Days to flowering	6	8	7	Quantitative
8	Hypocotyl colour	Purple	Dark green	Green	Green is dominant over purple
9	Hypocotyl pubescence	Sparse	Sparse	sparse	Not determined
10	Anthocyanin on the nodes	Dark purple	Purple	purple	Not determined
11	Stem pubescence	Dense	Dense	Dense	Not determined
12	Plant growth habit	Erect	Erect	Erect	Not determined
13	Branching habit	Dense	Dense	Dense	Not determined
14	Leaf density	Dense	Dense	Dense	Not determined
15	Leaf colour	Dark green	Dark green	Green	Not determined
16	Leaf venation	Pinnate	Parallel	Pinnate	Resembles female parent
17	Leaf type	Compound	Compound	Compound	Not determined
18	leaf arrangement	Alternate	Alternate	Alternate	Not determined
19	Leaf pubescence	Sparse	Intermediate	Non	No inheritance from either parent
20	Pedicel position at anthesis	Pendant	Pendant	Pendant	Not determined
21	Filament colour	Purple	White	White	Resembles male parent
22	Flower position	Pendant	Pendant	Pendant	Not determined

23	Fruit shape	Elongated	Elongated	Elongated	Not determined
24	Fruit surface	Semi wrinkled	Wrinkled	Semi wrinkled	Resembles female parent
25	Stigma position at anthesis	Exserted	Exserted	Exserted	Not determined
26	Calyx pigmentation	Present	Present	Present	Not determined
27	Fruit colour at immature stage	Green	Green	Green	Not determined
28	Fruit colour at maturity	Red	Red	Red	Not determined
29	Pedicel with fruit	Persistent	Persistent	Persistent	Not determined

Discussion

In this study, closely related members of the genus *Capsicum* had the highest successful percentage crosses. For example, T*S, W*T and S*T had the highest percentage success from the crosses carried out; i.e.; 63.33%, 56.52% and 54.55% respectively (being different types of Pepper plants). This implies that intra-varietal hybridization is easier in *Capsicum* spp than inter-varietal hybridization and this agrees with the research of Morakinyo and Falusi (1992).

The high degree of fertilization can be attributed to the high pollen fertility, compatibility between the species and genetic similarities since all the plants are of the same species. This is in accordance with the law of genetic distance between both the species (Geleta *et al*., 2005).

The species with the lowest hybridization are T*R which had a successful fertilization of 18.97%. R*S had a percentage fertilization of 25.53%, R*T had a percentage fertilization of 27.45% while W*S had a percentage fertilization of 30.30%. The low percentage of fertilization could be as a result of genetic incompatibility, failure of the pollen tube to germinate on the stigma. Failure of the pollen tube to germinate to reach the tube or abortion of same (Zhang, 2010).

There was no hybridization with zero percentage cross success. This further enforces how closely related and compatible species of Pepper are. In the study carried out by Morakinyo and Falusi (1992), on the chromosome behavior of some selected species of *Capsicum*, this was also discovered, and it enforces how closely related species of Pepper are due to the chromosomal behavior.

Genetic exchange of characters was noticed during the crosses. Gene exchange between groups or individual organisms can be influenced by several factors which may include physical barriers against cross pollination. Such barriers are overcome through artificial land pollination. However, there are other post-pollination barriers which artificial land pollination cannot remove. In all cases the effectiveness of these barriers depends on the genetic relationship between individuals and groups. Personal success of artificial land pollination is an indicator of this genetic relatedness and possibility of the crosses occurring in the wild. This accounts for the numerous varieties of Pepper in cultivation all around the world. This was ascertained by Morakinyo and Falusi (1992). The higher the percentage success from the crosses carried out, the higher the genetic relatedness or the closer the genetic relationship of the individuals (Falusi and Morakinyo, 1994).

Pathogenesis was also discovered in some F_1 fruits as they developed without seeds in them. Some seeds gotten from the F_1 generation were not viable. This led to a reduction in the number of F_1 plants. This is in correlation with the work of Hundal and Dhall (2005).

From the Quantitative data of hybrids and reciprocals studied in the research. The hybrids and reciprocals exhibited segregation of characters in the F_1 and independent assortment of characters in F_2. 9 quantitative characters were studied and mean values were analyzed using analysis of variance (ANNOVA) and the Duncan of plant height (PH), leaf length (LL), leaf breadth (LB), stem girth (SG), laminar leaf length (LLL), anthal length (AL), style length (SL), petal length (PL) and petal width (PW).

The variation in PH between the varieties a hybrid show that the different varieties of pepper have varying gene alleles for the character. There was drastic increase in variation of PH in the hybrid R*W_2 (36.20±4.39) which is an increase from the hybrid parents R (27.22±3.62) and W (39.30±2.21). There was a decrease in the PH of hybrid S*W (35.86±0.80) compared to the variation in PH of parent plants S (35.20±1.48) and W (39.30±2.21).

There was variation in LL among the hybrids. Notably in W*R (7.80±0.29) relative the parent plants W (12.64±0.92) and R (17.14±0.71). This was also noted in S*T (8.06±0.31) from the parents S (13.30±0.45) and T (15.30±0.45). This can be attributed to variation in alleles of the genes responsible for LL between parents. No dominance nor recessiveness of this trait among the parents.

With hybridization there was an increase in SG in the hybrid offspring of the cross. T*R, T*W, W*S and S*T had drastic increase in SG. There was variation of LLL among hybrid plants and their parents. This can be attributed to the random pairing of the alleles of the genes that regulate these characters.

Majorities of the data followed maternal inheritance. This can be found in Tables 2 to 10. While few amongst the characters followed paternal inheritance. Majority of the characters could not be determined since both parents showed similar attributes for the same character. Examples of these characters are; calyx pigmentation, leaf type, leaf venation, leaf arrangement, e.t.c.

From Figure 2, it was noticed that hybrid fruits are smaller in size in size when compared to their parent fruits. About 70% of the fruits were discovered to have shrinked especially when crossed with species of smaller sizes.

Based on interspecific crosses, it was seen that crosses between *C. frutasense * C. annuum* are higher at an average percentage than crosses between *C. annuum and C. frutasence*. Both at an average percentage. This means reciprocal successes are few.

Most plants crossed with W at their orientation of flower and fruits showed alternation of the character of flower orientation as some plants had either erect flowers like W while others had pendant flowers. Plants crossed with W had similar erect flowers which were not shown in W parent plants and this implies that erect flower orientation could be said to be coded by a heterogenous pair of chromosomes. This is found in table 15. Similar result was observed in the work done by Nwankiti (1976) and Odland and Porter (1941).

Conclusions

Based on these results, it can be concluded crosses between varieties of the same species (intervarietal crosses) are more successful than interspecific crosses. There are minimum successes of interspecific crosses among the genus *Capsicum* in Nigeria. Furthermore, characters follow maternal inheritance than paternal inheritance. Therefore, there is natural gene exchange. This could be used as a baseline for the genetic improvement of *Capsicum* plants.

Authors' Contributions

Methodology: JAM and CTA, Supervision: JAM, Writing - review and editing: JAM, OTM. Project administration: KSO. All authors read and approved the final manuscript.

Acknowledgements

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Bosland PW, Votava EJ (2000). Peppers: vegetable and spice *Capsicums.* CAB International, England, pp 233. *https://doi.org/10.1080/01140671.2012.745161*

Falusi OA, Morakinyo JA (1994). Intra and inter specific hybridization in the genus *Capsicum*. African Crop Science Journal 2(2):169-171. *https://doi.org/10.4314/acsj.v2i2.54703*

Geleta LF, Labuschagne MT, Viljoen CD (2005). Genetic variability in pepper (*Capsicum annuum* L.) estimated by morphological data and amplified fragment length polymorphism markers. Biodiversity and Conservation 14:2361-2375. *https://doi.org/10.1007/s10531-004-1669-9*

Hundal JS, Dhall RK (2005). Breeding for hybrid hot pepper. Journal of New Seeds 2(2):1-22. *https://doi.org/10.1300/J153v06n02_03*

Nwankiti OC (1976). Cytogenetics of some Nigerian peppers – genus *Capsicum*. II. Hybrid origin of *C. frutescens*. Nigerian Journal of Science 10:61-75.

Odland ML, Porter AM (1941). A study of natural crossing in peppers (*Capsicum frutescens*). Proceedings of the American Society for Horticultural Science 38:585-588.

Reilly CA, Crouch DJ, Yost GS (2001). Quantitative analysis of capsaicinoids in fresh peppers, oleoresin capsicum and pepper spray products. Journal of Forensic Sciences 46:502-509.

Singh RJ (2002). Plant cytogenetics. CRC Press, London, pp 488.

Singh RJ (2002). Genetic resources, chromosome engineering and crop improvement: vegetable crops. Volume 3, CRC Press.

Zhang BX, Wang LH, Mao SL, Zhang ZH (2010). Research progress on pepper breeding and genetic during China's Eleventh Five-year Plan. China Vegetables 24:1-9.