

Compatibility and fruit-set in cashew (*Anacardium occidentale* L.)

Olawale Mashood Aliyu

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Abstract Understanding complex factors controlling yield is very crucial to the improvement of cashew in major producing countries currently experiencing very low yield and consequently making cashew farming unprofitable and the whole industry unsustainable. Eleven cashew clones were evaluated for their compatibility and fruit set between 2000 and 2002 seasons, in a diallel cross using randomized complete block design with three replications. Data collected on number of fruit set at 6 weeks after pollination were statistically analyzed. Significant differences between the parents at the 1% level, revealed the existence of variability for compatibility and fruit set, with 34% cross-compatibility, 51% partial cross-compatibility and 15% cross-incompatibility recorded, while 37% of the parents were self-compatible. Parents sharing the same apples colors tend to be highly cross-compatible, while some clones showed evidence of unilateral compatibility. Maximum value of 55% fruit set obtained from cross-pollination probably indicates upper limit for fruit set

in cashew. Significant correlation between compatibility and variation in fruit yield suggests the important role of parental compatibility in selection of planting materials for the establishment of cashew plantation.

Keywords Allogamous · Breeding · Cashew · Fruit-set · Cross-compatibility · Self-compatibility

Introduction

Cashew nut is a high-value export crop and is the main source of cash income for millions of smallholders farmers in southern Tanzania (Shomari 1988) and north-central Nigeria (Topper et al. 2001). It is an emerging tree crop in northern Australia with its imports valued at US\$30 month per year (Blaikie et al. 2002). Today, cashew nut is produced in about 32 countries with world total production reaching about 2.7 millions tons in 2005 (FAO 2005). According to production statistics (FAO 2005), major raw nuts producing countries in 2005 are Vietnam (960,800 tonnes), Nigeria (594,000), India (460,000 tonnes), Brazil (147,629 tonnes) and Indonesia (122,000 tonnes). World's total area under the cultivation of cashew is around 35,100 km²; India ranking first with 730,000 ha of land utilized for its production, though her yields are relatively low. World's average yield of cashew raw nuts is still as low as 780 kg/ha (FAO 2005). Despite the importance of

O. M. Aliyu (✉)
Department of Cytogenetics and Genome Analysis,
Institute for Plant Genetic Research and Cultivated Crops
(IPK), Correnstrasse 3, 06466 Gatersleben, Germany
e-mail: aliyu@ipk-gatersleben.de

O. M. Aliyu
Department of Plant Breeding and Genetics,
Cocoa Research Institute of Nigeria, P M B 5244,
Ibadan, Nigeria

cashew as a commodity crop with increasing cultivation in major producing countries in South America, Africa, Asia, and Australia, the crop is threatened with problem of low yield. Chacko et al. (1990) remarked that, in country such as Australia with intensive production, competitiveness of cashew industry might only be sustained through substantial increases in productivity of trees. Available literatures showed that little is known about the factors controlling yield in cashew (Chacko et al. 1990) and in particular the extent to which pollination and compatibility influenced yield. However, several factors have been described to be closely related to yield potential of cashew trees, ranging from poor genetic potential of the available plant material (Chacko et al. 1990; Foltan and Ludders 1995), plant architecture to floral biology and its interaction with environmental conditions seems to be of major importance (Nambiar 1977; Parameswaran et al. 1984). In addition to poor fruit set, excessive premature fruit drop has been reported in the crop (Nawale et al. 1984; Patnaik et al. 1985). Studies by Wunnachit and Sedgley (1992) showed wide variation in yield performance of cashew genotypes in Australia. Similar works on the yield in Tanzania and Nigeria have shown that only 30% of the tree population in an hectare produced 80% of the nut yield, while the remaining 20% yield comes from the 70% of the trees (Martins and Kasuga 1995; Aliyu 2004). Several reports also showed that percentage fruit-set in cashew is very low with initial fruit-set ranging from 3 to 40% but with final fruit-set dropping to between 0.7 and 4.1%. Rao (1956) observed 3% fruit set on the West Coast of India, and 6–12% fruit set was recorded on the East Coast by Murthy et al. (1975). It was evident that the number of fruits that attained maturity in cashew was often very low compared to initial fruit set. Several authors attributed number of hermaphrodite flowers to be closely related to fruit set (Rao and Hassan 1957; Murthy et al. 1984; Parameswaran et al. 1984). However, Masawe et al. (1996) and Aliyu and Awopetu (2003) have reported between 50 and 416 hermaphrodite flowers/panicle in Tanzania and Nigeria; suggesting that number of hermaphrodite flowers is unlikely to limit fruit set in cashew. Foltan and Ludders (1995) uphold the same view with studies in Australia. Subaiah (1983), Nawale et al. (1984), and Ghosh (1989) emphasized effect of resources or inadequate pollination (Heard et al. 1990) on fruit yield. Cashew has

hitherto been described as out-crossing plant, but studies have shown some degree of self-pollination (Westergaard and Kayumo 1970; Wunnachit et al. 1992; Foltan and Ludders 1995) and self-incompatibility (Wunnachit et al. 1992). Available data showed conflicting results and evidence of poor understanding of reproductive aspect of factors (pollination, fertilization, and fruit development) controlling yield that are required for developing a long-term breeding strategy in cashew. Nevertheless, important way to increase the productivity of the crop and improve on the quality of nuts is to select desirable genotypes from germplasm of wide genetic diversity (Chacko et al. 1990) and use identified superior materials in the breeding programs. Consequently, successful utilization of promising genotypes in breeding program would require adequate knowledge of compatibility (pollination and fruit set) of the crop species.

In this study, eleven selected cashew clones were evaluated for compatibility and fruit set through cross- and self-pollinations, to provide quantitative information into understanding compatibility and fruit set in cashew and possibly provide evidence that could guide in the selection of planting materials for use in the establishment of cashew orchards and future breeding works.

Materials and methods

The trial was carried out at the Cocoa Research Institute of Nigeria (CRIN), Ibadan, Latitude of 07°10'N and Longitude 03°52'E with average annual rainfall ranging between 1,100 mm and 1,500 mm. Data on the monthly summary of the weather variables (rainfall, temperature, and relative humidity) at the trial site were collected through the period of study, but not presented because it was relatively stable and within ranges for optimum growth and fruiting in cashew. Cashew trees used for this study are eleven clones (CC01-CC11) selected by the Institute (CRIN) from Farmers' field in Ochaja area, north-central region of Nigeria and established at Institute's headquarters, Ibadan in 1988 (Akinwale and Esan 1989). The trees are the progenies of early Indian Introductions in the country, which have been grown and adapted over a long planting period (Sanwo 1974; Akinwale and Esan 1989). Each clone was planted in a single row at spacing of $9.1 \times 9.1 \text{ m}^2$ with a clone represented by

three entries. A full diallel cross among the eleven clones was carried out using randomized complete block design experimental layout with tree canopy marked on the four cardinal positions (north, south, west, and east) using a compass according to Masawe et al. (1996) and Aliyu and Awopetu (2003). There were sixty pollinations for each kind of cross (i.e., 15 pollinations/cross/side) and replicated on the three entries for each clone. The trial started in November 1999 and repeated for another 2 years (2001 and 2002 fruiting seasons) to evaluate the influence of environment on the experimental lots. Although flowering commences as early as September, pollination is often delayed until the peak of flowering between October and January in the region (Akinwale 1992; Aliyu and Awopetu 2003), to ensure availability of enough hermaphrodite flowers for all kind of crosses. It is important to mention that studies on pollen fertility, floral characteristics, and pollen-style compatibility of these clones have been reported (Aliyu 2007). Standard procedure for cashew hybridization is yet to be developed in the region, however, a modified method of Sedgley and Attanayake (1988) described below produced appreciable results. Perfect flowers selected for pollination were emasculated a day before anthesis by removing all the petals and pistillate parts and enclosed in cotton-made pollination bags. Selection of perfect flowers prior to anthesis was possible following description by Ohler (1979) and Akinwale (1990). Hand pollination was carried out the next day between 9.00 a.m and 12.00 noon by dusting/rubbing pollen grains of desired male (pollen) parent on the stigma of the emasculated hermaphrodite flower (female parent) (Sedgley and Attanayake 1988). Thereafter, other flowers on the same laterals were removed and pollination bag was closed. Pollinated inflorescence/panicles were properly labelled for: (a) date of pollination, (b) number of flowers pollinated per panicle, and (c) Identity of the cross on each

lateral. At 7 days after pollination, the bags were opened and successful crosses were recorded. Subsequently, the number of pollinated flowers that finally set fruits were recorded at 3 and 6 weeks after pollination according to Ohler (1979) and Aliyu and Hammed (2000). Percentage fruit set were later calculated for each cross (number of fruit-set/number of flowers pollinated) using data collected at 6 weeks after pollination. Data collected on percentage fruit-set at 6 weeks after pollination were summarized and subjected to statistical analysis using computer softwares of SAS packages.

Results

Analysis of variance of the fruit set for the two types of crosses (within and among clones) presented in Table 1 showed highly significant ($P < 0.01$) for crosses and year, suggesting wide variation in number of fruit-set probably due to compatibility of the selected parents. The interaction of these two factors was statistically not significant indicating non-dependence of one on the other. Variation across the 3 years of study showed that fruit-sets in first year (2000) was the highest and least recorded in 2001 (Table 2). Pattern of variation in fruit set across the 3 years was similar for both cross- and self-pollinations. Mean values for fruit-set for the diallel cross of the selected clones presented in Table 3 showed average of 32.98 fruits/cross, i.e., 18% fruit set. Corresponding percentages for number of fruit set were presented in italics in the same Table 3. Crosses among clonal parents, i.e., cross-pollination gave average fruit set ranging from 7.79 (4%) for CC02 $\times$ CC09 to 100.33 (56%) for CC05 $\times$ CC06. This range is an indication of wide variability in compatibility among the selected trees. Summary of fruit set recorded on each parent (clone) showed mean values ranging from 23.78 (13%) for CC09 to 55.74 (31%) for CC06 when used

Table 1 Analysis of variance of the compatibility crosses over 3 years

Source of variance	Degree of freedom	Mean squares	<i>F</i> -values	Probability <i>F</i>
Replication	2	150.2562	5.56	0.0040
Crosses	120	4637.3772	171.46	<0.0001
Year	2	7287.0826	269.42	<0.0001
Crosses x Year	240	21.4567	0.79	0.9837
Error	724	27.0472		

Table 2 Variation in fruit set across the 3 years

Year	Crosses among clones (cross)	Crosses within clones (self)
1 (2000)	37.19a (20.66)	8.48a (4.71)
2 (2001)	28.27c (15.71)	3.48c (1.93)
3 (2002)	33.49b (18.61)	6.42b (3.57)
LSD (0.05)	0.758	0.869

Figures with the same letters in a column are not significantly different

Values in parentheses represent percentage fruit-set

as pollen donors, however the values were between 21.09 (12%) for CC09 and 63.40 (35%) for CC06 as female parents in the crosses. It suggests that CC09 had

least cross-compatibility as both pollen and female parents among the tested clones. However, the data showed that, CC06 was the best cross-compatible clone with highest fruit-set as both pollen (male) and pistillate (female) parents (Table 3). Self-pollinated crosses gave fruit set ranging from 0.33 (0%) for CC07 to 20.11 (11%) for CC06. This range was low compared to cross-pollinated crosses thus confirming preference for out-breeding system in cashew. Some paired clones tend to show high fruit sets when crossed in both directions, i.e., both as female and male parents. This observation was recorded in the following paired clones; between CC08 and CC01, CC02 and CC04, and CC05 and CC06. Interestingly, these compatible paired clones shared the same apple colors, with CC08 and CC01; CC02 and CC04; and CC05 and CC06 produc-

Table 3 Mean and percentage (%) fruit-set in the diallel cross among eleven selected cashew clones

Pollen parents												
Female parents	CC01	CC02	CC03	CC04	CC05	CC06	CC07	CC08	CC09	CC10	CC11	Mean
CC01	1.22	51.56	45.22	38.78	44.00	87.44 ^a	20.44	76.33 ^a	20.11	28.22	13.89	38.84
	<i>1</i>	<i>29</i>	<i>25</i>	<i>22</i>	<i>24</i>	<i>49</i>	<i>11</i>	<i>42</i>	<i>11</i>	<i>16</i>	<i>8</i>	<i>22</i>
CC02	41.56	5.00	88.33 ^a	71.68 ^a	10.67	60.33 ^a	40.00	20.44	22.44	24.78	19.78	36.73
	<i>23</i>	<i>3</i>	<i>49</i>	<i>40</i>	<i>6</i>	<i>34</i>	<i>22</i>	<i>11</i>	<i>12</i>	<i>14</i>	<i>11</i>	<i>20</i>
CC03	24.78	83.00 ^a	12.11	32.33	27.00	65.67 ^a	32.78	25.89	33.78	13.89	21.00	33.84
	<i>14</i>	<i>46</i>	<i>7</i>	<i>18</i>	<i>15</i>	<i>36</i>	<i>18</i>	<i>14</i>	<i>19</i>	<i>8</i>	<i>12</i>	<i>18</i>
CC04	24.56	83.22 ^a	21.89	9.67	45.44	55.22	31.56	20.56	18.44	26.33	23.78	32.79
	<i>14</i>	<i>46</i>	<i>12</i>	<i>5</i>	<i>25</i>	<i>31</i>	<i>18</i>	<i>11</i>	<i>10</i>	<i>15</i>	<i>13</i>	<i>18</i>
CC05	31.22	31.44	16.78	33.78	1.00	90.11 ^a	21.78	47.33	22.67	25.56	19.89	31.05
	<i>17</i>	<i>17</i>	<i>9</i>	<i>19</i>	<i>1</i>	<i>50</i>	<i>12</i>	<i>26</i>	<i>13</i>	<i>14</i>	<i>11</i>	<i>17</i>
CC06	95.78 ^a	64.67 ^a	86.22 ^a	68.67 ^a	100.33 ^a	20.11	53.56	57.11 ^a	46.78	63.00 ^a	41.22	63.40
	<i>53</i>	<i>36</i>	<i>48</i>	<i>38</i>	<i>56</i>	<i>11</i>	<i>30</i>	<i>32</i>	<i>27</i>	<i>35</i>	<i>23</i>	<i>35</i>
CC07	13.22	21.33	25.78	28.67	16.56	64.00 ^a	0.33	27.11	22.78	16.33	38.78	274.89
	<i>7</i>	<i>12</i>	<i>14</i>	<i>16</i>	<i>9</i>	<i>36</i>	<i>0</i>	<i>15</i>	<i>13</i>	<i>9</i>	<i>22</i>	<i>14</i>
CC08	79.89 ^a	12.67	27.44	27.33	56.67 ^a	70.89 ^a	28.11	11.56	29.11	35.22	19.89	24.99
	<i>44</i>	<i>7</i>	<i>15</i>	<i>15</i>	<i>31</i>	<i>39</i>	<i>16</i>	<i>6</i>	<i>16</i>	<i>20</i>	<i>11</i>	<i>20</i>
CC09	7.89	7.78	19.33	11.67	29.22	48.11	11.33	36.89	1.22	27.67	30.89	36.25
	<i>4</i>	<i>4</i>	<i>11</i>	<i>6</i>	<i>16</i>	<i>27</i>	<i>6</i>	<i>20</i>	<i>1</i>	<i>15</i>	<i>17</i>	<i>12</i>
CC10	15.44	17.33	19.78	15.44	21.33	21.11	28.67	46.11	18.22	2.89	28.78	21.09
	<i>9</i>	<i>10</i>	<i>11</i>	<i>9</i>	<i>12</i>	<i>12</i>	<i>16</i>	<i>26</i>	<i>10</i>	<i>2</i>	<i>16</i>	<i>12</i>
CC11	11.11	9.33	31.67	21.44	27.67	30.11	26.11	20.44	26.11	36.78	6.33	22.46
	<i>6</i>	<i>5</i>	<i>18</i>	<i>12</i>	<i>15</i>	<i>17</i>	<i>15</i>	<i>11</i>	<i>15</i>	<i>20</i>	<i>4</i>	<i>12</i>
Mean	31.42	35.21	35.86	32.68	34.53	55.74	26.79	35.43	23.78	27.33	24.02	32.98
	<i>17</i>	<i>20</i>	<i>20</i>	<i>18</i>	<i>19</i>	<i>31</i>	<i>15</i>	<i>20</i>	<i>13</i>	<i>15</i>	<i>13</i>	<i>18</i>

Figures in italics represent percentage fruit set

^a Indicates 20 best crosses

ing red, yellow and orange–red apples, respectively. However, some paired crosses gave a unilateral cross-compatibility and typical is CC10 × CC06 with high fruit-set (35%), while its reciprocal gave low fruit-set (12%). Paired crosses such CC01 and CC07; CC02 and CC08; CC08 and CC11; CC09 and CC01; CC11 and CC02; and CC04 and CC09 equally showed very low cross-compatibility.

Table 4 showed the analysis of both cross- and self-compatibility among the selected clones following Drewlow et al. (1973) and Jacob and Atanda (1972) for the classification of compatibilities in cross- and self-pollinated crosses, respectively. There was variation among the clones in terms of compatibility as female and pollen parents (Table 4). According to the Drewlow et al. (1973) 34% of the cross-pollinated crosses were highly cross-compatible

(+ +), 51% partially cross-compatible (+ −) and 15% cross-incompatible (− −) (Table 4). Similar trend was recorded for the clones as pollen parents. However, the ratios of compatibility (+ + or + −) to incompatibility (− −) among individual clone varied on the respective positions, i.e., male or female. While some clones exhibit high degree of femaleness, few showed evidence of maleness, i.e., high compatible pollens e.g., CC09 and CC07. This observation has implication in production and yield improvement. CC06 however showed evidence of broad compatibility as both pollen and female parents. Fruit set data from self-pollinations showed that, four clones (37%) were self-compatible (+ +) with fruit-set above 5%, two (18%) were partially self-compatible (+ −) and remaining five (45%) were self-incompatible (− −) (Jacob and Atanda 1972) (Table 4).

Table 4 Analysis of compatibility among the clones

Clone	Cross-compatibility						Self-compatibility		
	Female parents			Pollen parents					
	++	− +	− −	++	− +	− −	++	− +	− −
CC01	6	3	1	3	3	4	0	0	1
CC02	5	4	1	4	2	4	0	1	0
CC03	2	7	1	3	6	1	1	0	0
CC04	3	7	0	3	5	2	1	0	0
CC05	2	7	1	4	4	2	0	0	1
CC06	10	0	0	8	2	0	1	0	0
CC07	2	5	3	2	7	1	0	0	1
CC08	3	6	1	5	5	0	1	0	0
CC09	2	4	4	1	9	0	0	0	1
CC010	1	6	3	2	6	2	0	0	1
CC011	1	7	2	2	7	1	0	1	0
Total	37	56	17	37	56	17	4	2	5
Percentage (%)	34	51	15	34	51	15	37	18	45

+ +: Highly compatible, − +: Partially compatible and − −: Incompatible

Cross among the parents

− − : Cross-incompatible (CI) ($\leq 10\%$ fruit-set)

+ −: Partially cross-compatible (PC) (≥ 10.01 – 20.00% fruit-set)

+ +: Cross-compatible (CC) ($>20.0\%$ fruit-set)

(Drewlow et al. 1973)

Cross within parents (selfing)

− − : Self-incompatible (SI) ($\leq 2.0\%$ fruit-set)

+ −: Partially self-compatible (PS) (≥ 2.01 – 4.99% fruit-set)

+ +: Self-compatible (SC) ($>5.0\%$ fruit-set)

(Jacob and Atanda 1972)

Discussion

Cottoned pollination bag with ventilation was found most suitable in this study due to high temperatures prevailing during cashew flowering and fruit development (November–March) in the region. Pollinations carried out with Kraft paper resulted into withering of pollinated flowers probably due to poor aeration. The choice of aerated materials for pollination agrees with Foltan and Ludders (1995) that used perforated plastic bags for pollination in Darwin, Australia. Non-development of fruit without pollination, probably suggest absence of parthenocarpy in cashew. Free and William (1976) and Akinwale (1990) have reported no fruit set in bagged cashew inflorescences without pollination. Fruit set from all crosses involving the eleven parental clones as both paternal and maternal parents indicates absence of strong compatibility barrier among the selected clones (Leonardi et al. 1994; Aliyu 2007). Hybrid nuts obtained from both crosses were normal and viable with well-developed embryos and cotyledons, indicating that incidence of fruit drop and abnormal fruit development may probably be due to nutritional, physiological or environmental factors (Subbaiah 1983; Nawale et al. 1984; Ghosh 1989). Leonardi et al. (1994) opined that high rate of fruit abscission during the early stage of development is probably an indication of post-fertilization incompatibility, but should not be considered as only reason for fruit abscission because resource allocation might also play a vital role. Stability of the haploid chromosome number and regularity of the behavior of chromosomes at meiosis probably accounts for the normal fruit development observed in the crosses (Morakinyo and Adebola 1991; Aliyu and Awopetu 2007).

The study showed wide variability in genotype compatibility in both cross- and self-pollination. Foltan and Ludders (1995) and Sankaranarayanan et al. (1996) reported similar significant variation in genotype compatibility in Australia and India, respectively. The heterogeneity of the parental clones in their compatibility would make it possible for the implementation of selective practices in breeding programs. A non-significant difference of crosses $\times$ year interaction indicates stable nature of the trait and probably high-heritability value, which offers potential for selection of compatible cashew genotypes for breeding and production purposes. Parentage origin of the clones being progenies of Indian introductions

that have adapted over a long period of planting may accounts for absence of the interaction (cross $\times$ year) effects (Sanwo 1974). Mariano and Bartley (1981) opined that accessions tend to exhibit relative uniformity and similar behavior, due to a high degree of parentage. Slight reduction in fruit set in 2001 may be attributed to variation in the physiological factor or available resources across the years. Northwood (1966) and Pillai and Pillai (1975) opined that variation in auxin production across years may accounts for low fruit set. Stephenson (1981) opined that the available resource for reproduction might vary in different reproductive episode. Consistency in fruit-set pattern for all the crosses, across the 3 years suggests that the trait (compatibility) under investigation is stable and probably ruled out biennial fruiting habit in cashew. Selection of superior genotypes in cacao with regard to yield is usually based on successive harvest for two or more years (Atanda 1972).

The study confirms allogamous nature of cashew with about 98% fruit-set from cross-pollination. Significant variation between fruit set from cross- to self-pollination agrees with Northwood (1966), Rao and Hassan (1957), Ohler (1979), Thimmaraju et al. (1980) and Wunnachit et al. (1992; but in contrast to Foltan and Ludders 1995, that recorded no significant difference between self- and cross-pollination. Nevertheless, the authors (Foltan and Ludders 1995) recorded the least fruit set in selfing of H-3-13' cultivar. However, part of the evolutionary success of angiosperms has been attributed to out-breeding system (Sedgley 1994; Wiersma 2003). Low fruit set recorded from self-pollination in this study supports Wunnachit et al. (1992) that reported reduction in yield from self- as compared with cross-pollination in cashew. Previous studies have suggested post-zygotic mechanisms for the self-incompatibility or poor fruit set in selfed cashew trees, as no evidence of barrier in pollen germination and tube growth to the ovule between self- and cross-pollination has been observed (Wunnachit et al. 1992; Aliyu 2007). Sedgley and Griffin (1989) opined that plants of the same species might exhibit variation in the strength of out-crossing as observed in apple and pear.

Data from this work gave a quantitative evidence of the relationship between pollination and fruit set in cashew. Fruit set as high as 56% was recorded in this study as against 3–8% normally recorded in natural open pollination. Rao and Hassan (1957) reported

increased fruit set to 55% from hand pollination in India. Similarly, Sapkal et al. (1994) and Narayan and Ghosh (1996) reported retention rates of 5–18% from India. Chacko (1990) found that only 25% of successfully pollinated flowers produced mature nuts in Darwin, NT region in Australia. Although, this study show direct relationship between pollination/compatibility and fruit set, however, other limiting factors such, pollinator efficiency/abundance and resource allocation, must be taken into consideration to achieve optimum fruit set under natural conditions in cashew farms. Subbaiah (1983), Nawale et al. (1984), and Ghosh (1989) remarked that, rather than by the number of fertile ovules, fruit set in cashew appears to be limited by maternal resources. Nutritional state of the cacao tree has been reported as one of the critical factors limiting fruit set in cacao (Lachenaud 1991). The problem of low yield in cashew can therefore be approach from many ways ranging from selection of compatible parents, nutrition improvement to enhanced pollination (insect or hand). The wide range of fruit set (4–56%) recorded for cross-pollination in this study also throw light into the variability in cashew yield from such plantations planted to parental materials with wide gap in cross-compatibility (Wunnachit et al. 1992; Martins and Kasuga 1995; Aliyu 2004). Maximum fruit set of 52, 55, and 56% recorded by Foltan and Ludders (1995) in Australia, Rao and Hassan (1957) in India and data from this study (Nigeria), respectively, tends to suggest the upper limit to fruit set in cashew. Leonard et al. (1994) corroborates Stephenson (1981) that resource allocation rather than the number of pollinated female flowers usually determine an upper limit to the number of fruit set. This observation is very important to the farmers and breeders in their efforts to improve on fruit set in cashew. Data from this study however provide a quantitative evidence of inefficient pollination and probably planting of incompatible trees as major reproductive factors responsible for low yield in cashew (Wunnachit et al. 1992).

Fruit-set of between 0 and 11% recorded through self-pollination confirms the existence of partial- to self-compatibility in cashew. However, inbreeding depression, which is the expression of recessive deleterious mutation (Lande and Schemske 1985; Campbell 1988), may accounts for low fruit set recorded from self-pollination. About 11% fruit set from self-compatible clone recorded in this work is among

quantitative evidence of self-compatibility in the crop. This study corroborates Ohler (1979), Heard et al. (1990), and Holand-Neto et al. (2002) that have reported occurrence of self-pollination for cashew in Tanzania, Australia, and Brazil, respectively. The occurrence of self-compatibility in allogamous plants like cashew has been attributed to partial breakdown of the self-incompatibility mechanism, which was attributed to increase selection for high-fruit set over long period of cultivation (Wiersma 2003). Thompson and Taylor (1966) attributed increased self-compatibility in out-breeding plants to increase frequencies of the recessive S-alleles in a population. Lanaud et al. (1987) however, reported selfing in cacao when the amount of incompatible pollen is very small compare to compatible pollen. Reports on the occurrence of self-compatibility in some clones across cashew growing regions, suggests further studies into the molecular basis of increasing self-compatibility vis-à-vis inbreeding depression in the crop species.

High fruit set recorded from cross-pollination among clones (trees) that share the same apple color requires further investigation into the genetic linkage between compatibility and fruit (apple) color in the crop. Such investigation will provide information that will be useful in the development of high-yielding varieties of different fruit colors. The results of this study however throw caution on the sole use of pollen fertility and pollen-style compatibility as criteria for selecting high yield in tree crop breeding. While some clones are good in producing highly compatible pollens and as well serve as broad pollen receivers from other trees, it was evident that some clones tend to displayed unilateral compatibility. Some sort of unilateral cross-incompatibility (reciprocal effects) observed in this study is supported by the work of Onus and Pickergill (2004) on *Lycopersicon*. Martin (1963) quoted by Onus and Pickergill (2004) remarked that unilateral incompatibility may occur within species and the example was cross between northern race of *L. hirsutum* which, its pollens was inhibited by styles of most of other *L. hirsutum* accessions, but reciprocal crosses set fruit. The unilateral compatibility recorded in some parents poses challenge to breeders in the choice of parents in breeding work. Parents with no evidence of reciprocal effects may be used as either male or female parent in breeding work while clones with such effect need to be carefully selected as male or female parent depend on

the direction of compatibility. Studies by Foltan and Ludders (1995) showed superiority in combining ability of some cashew cultivars as either male or female parent, thus corroborating this work. This approach would definitely have positive impacts on breeding and overall yield improvement in cashew. About 34% cross-compatibility and 51% partial cross-compatibility recorded on maternal plants further demonstrate sparsely fruiting peculiar to a typical cashew plantation, where only about 30% of the trees in an hectare produce over 80% of the nuts (Martins and Kasuga 1995; Aliyu 2004). Hence, the selection of parental materials for orchard establishment should take into consideration the cross-compatibility status of such genetic materials as suggested by Wunnachit et al. (1992). Paired parental clones that recorded high fruit-set in their crosses and reciprocals (CC08 and CC01; CC02 and CC04; CC05 and CC06) would be good candidates for the establishment of high yielding cashew fields. It is important to note that selection of high-yielding materials only based on fruit-set by the mother trees may turn out to be an incomplete/ineffective strategy to achieve yield improvement without recourse to identifying compatible pollen parents/trees. This simple but important step will go a long way to enhance nut yield improvement in cashew and consequently increase farmer's outputs.

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References

- Akinwale SA, Esan EB (1989) Advances in cashew breeding in Nigeria. In: Progress in Tree Crop Research, 2nd edn. Cocoa Research Institute of Nigeria (CRIN), Ibadan, Nigeria, pp 166–174
- Akinwale SA (1990) Biological characterization of cashew (*Anacardium occidentale* L.). Ph.D Thesis submitted to the Department of Botany, Obafemi Awolowo University, Ile – Ife, Nigeria, 211 pp
- Akinwale SA (1992) Implications of pollen characters to systematic delimitation of cashew (*Anacardium occidentale* L.). Plant Cell Incompatibility News 24:1–6
- Aliyu OM, Hammed LA (2000) A study of nut and apple development in cashew (*Anacardium occidentale* L.). Niger J Tree Crop Res 4(2):1–10
- Aliyu OM, Awopetu JA (2003). Studies on flowering pattern in cashew (*Anacardium occidentale* L.). Niger J Genet 18:29–35
- Aliyu OM, Awopetu JA (2007) Chromosome studies in cashew (*Anacardium occidentale* L.). Afr J Biotechnol 6(2): 131–137
- Aliyu OM (2004) Characterization and compatibility studies in Cashew (*Anacardium occidentale* L.). Ph.D Thesis, University of Ilorin, Nigeria, 266 pp
- Aliyu OM (2007) Pollen-style compatibility in cashew (*Anacardium occidentale* L.) Euphytica (on-line) <http://dx.doi.org/10.1007/s10681-007-9447-x>
- Atanda OA (1972) Correlation studies in *Theobroma cacao* L. Turrialba 22:81–89
- Blaikie S, O'Farrell P, Muller W, Wei X, Scott N, Skyes S, Chack E (2002) Assessment and selection of new cashew hybrids. A report for the Rural Industries Research and Development Corporation (RIRDC). RIRDC Publication No. 01/177. 21pp
- Campbell RR (1988) Mating structure and cost of deleterious mutation I. Postponing inbreeding. J Hered 78:179–183
- Chacko EK, Baker I, Downton JWS (1990) Towards a sustainable cashew industry for Australia. J Aust Inst Agric Sci 3:39–43
- Chacko EK (1990) Summary of research work by CSIRO. Working papers of the 3rd Annual Research and Development Workshop; February 21, 1990; Darwin, Northern Territory, Australia, pp 14–18
- Drewlow LW, Ascher PD, Widmer RE (1973) Genetic studies of self-Incompatibility in the garden Chrysanthemum, *Chrysanthemum morifolium* Ramat. Theor Appl Genet 43:1–5
- FAO (2005) Food and Agriculture Organization production statistics (2005) website<<http://faostat.fao.org/site/DesktopDefault.aspx?PageID=340>>
- Foltan H, Ludders P (1995) Flowering, fruit set and genotype compatibility in cashew. Angew Bot 69:215–220
- Free BB, Williams IH (1976) Insect pollination of *Anacardium occidentale* L., *Mangifera indica* L., *Blighia sapida* Koeing, and *Persea Americana* Mill. Trop Agric 53:125–139
- Ghosh SN (1989) Effect of nitrogen, phosphorus and potassium on flowering duration, yield and shelling percentage of cashew (*Anacardium occidentale* L.). Indian Cashew J 19:19–23
- Heard TA, Vithanage V, Chacko EK (1990) Pollination biology of cashew in the Norther Territory of Australia. Aust J Agric Res 41(6):1101–1114
- Holanda-Neto JP, Freitas BM, Bueno DM, Araujo ZB (2002) Low seed/nut productivity in cashew (*Anacardium occidentale*): effects of self incompatibility and honey bee (*Apis mellifera*) foraging behaviour. J HortSci Biotechnol 77:226–231
- Jacob VJ, Atanda OA (1972) Compatibility and fruit setting in *Theobroma cacao* L. Proceedings of the Genetic Society of Nigeria, University of Ibadan, pp 98–106
- Lachenaud P (1991) Facteurs de la fructification chez le cacaoier (*Theobroma cacao*). Influence sur le nombre de graines par fruit. Doctoral dissertation, Institut National Agronomique Paris-Grignon, Paris
- Lanaud CO, Sounigo YK, Amefia D, Paulin PH, Lachenaud P, Clememt D (1987) Nouvelles donnees sur le fonctionne-

- ment du systeme d'incompatibilite du cacaoyer et ses consequences pour la selection. *Café Cacao The'* 31(3):267–277
- Lande R, Schemske DW (1985) The evolution of self-fertilization and inbreeding depression in plants. I. Genetic Models. *Evolution* 39:24–40
- Leonardi J, Chacko EK, Vithanage V, Turnbull CGN (1994) Studies on premature flower and nut abscission in cashew (*Anacardium occidentale* L.). Working papers of the 7th Annual Cashew Research and Development Workshop; May 17, 1994; Cairns, North Queensland, Australia, pp 52–59
- Mariano AH, Bartely BGD (1981) Comportamento das selecoes baianas na producao de cacaueiro: In Proceedings of 7th International Cocoa Research Conference. J de Lafforest Transla-Inter, Douala, pp 527–533
- Martin FW (1963) The genetic control of unilateral incompatibility between two tomato species. *Genetics* 56:391–398
- Martins PJ, Kasuga LJ (1995) Variation in cashew tree yield in South east Tanzania and the implication for management of cashew smallholder farmers in Tanzania. *Exp Agric* 72:261–268
- Masawe PAL, Cundall EP, Caligari PDS (1996). Distribution of cashew flower sex-types between clones and sides of tree canopies in Tanzania. *Ann Bot* 78:553–558
- Morakinyo JA, Adebola PO (1991) Karyotypic analysis and meiotic chromosome behaviour in *Pennisetum americanum*, *P. purpureum* and *P. pedicellatum*. *Niger J Bot* 4:127–134
- Murthy KN, Yadava RBR, Bigger J (1975) Increasing fruit set in cashew by hormone spraying. *J Plantat Crops (India)* 3(2):81–82
- Murthy KN, Vijayakumar K, Pillai RSN, Kumaran PM (1984) Aspects of flowering behaviour and correlation studies in cashew tree (*Anacardium occidentale* L.). In: Proceedings of the International Cashew Symposium, Cochin, Central Plantation Crop Research Institute (ICAR), Kerala, India, pp 279–280
- Nambiar MC (1977) Cashew. In: Avim PT, Kozlowski TT (eds) *Ecophysiology of tropical crops*. Academic Press, New York, pp 461–478
- Narayan C, Ghosh SN (1996) Fruit set and fruit drop in cashew in Jhargram conditions. *Environ Ecol* 14:144–146
- Nawale RN, Salvi MJ, Limaye VP (1984) Studies on fruit set and fruit drop in cashew (*Anacardium occidentale* L.). *Cashew Causerie* 6:5–7
- Northwood PJ (1966) Some observations on flowering and fruiting-setting in cashew (*Anacardium occidentale* L.). *Trop Agric (Trinidad and Tobago)* 43:35–42
- Ohler JG (1979) Cashew. Koninklijk instituut voor de Tropen; Teskin. Zutphen Co. Amsterdam, The Netherlands
- Onus NA, Pickergill B (2004) Unilateral incompatibility in *Capsicum* (Solanaceae): occurrence and taxonomic distribution. *Ann Bot* 94:289–295
- Parameswaran NK, Daramodaran VK, Prabhakaran PV (1984) Factors influencing yield in cashew (*Anacardium occidentale* L.). *Indian Cashew J* 16:15–19
- Patnaik HP, Das MS, Panda JM (1985) Studies on fruit set and fruit drop in cashew (*Anacardium occidentale* L.) under Orissa conditions. *Cashew Causerie* 7:7–8
- Pillai PKT, Pillai GB (1975) Note on the shedding of immature fruits in cashew. *Indian J Agric Sci* 45:233–234
- Rao VNM (1956) Multiply the better yielding cashew nut. *Indian Farming (India)* 6(3):19–23
- Rao VNM, Hassan MV (1957) Preliminary studies on the floral biology of cashew (*Anacardium occidentale* L.). *Indian J Agric Sci (India)* 27:277–288
- Sankaranarayanan R, Ahmadshah H, Sambandamoorthy S (1996) Hybridization in cashew. *Cashew J* 10(3):18–23
- Sapkal BB, Hulamani NC, Nalwadi UG (1994) Flowering and sex ratio in some cashew (*Anacardium occidentale* L.) selections. *Cashew* 8:7–10
- Sanwo JO (1974) Gerplasm collections. 1973/74 Annual Report of Cocoa Research Institute of Nigeria, pp 100–110
- Sedgley M, Attanayake DPSTG (1988) The breeding system of rubber (*Hevea brasiliensis*): an evaluation of controlled hand pollination methods. *Euphytica* 39:83–91
- Sedgley M, Griffin AR (1989) *Sexual reproduction of tree crop*. Academic Press, London
- Sedgley M (1994) Self-incompatibility in woody horticultural species. In: Williams EG, Clarke AE, Knox RB (eds) *Genetic control of self-incompatibility and reproductive development in flowering plants*. Kluwer Academic, Dordrecht, pp 141–163
- Shomari SH (1988) A review on cashew research in Tanzania. In: Tanzania Agricultural Research Masterplan Conference, Arusha, Agricultural Research Institute, Naliende, Tanzania
- Stephenson AG (1981) Flower and fruiting abortion: proximate causes and ultimate functions. *Ann Rev Ecol Syst* 12:253–279
- Subbaiah CC (1983) Fruiting and abscission patterns in cashew. *J Agric Sci (Cambridge)* 100:423–427
- Thimmaraju KR, Reddy MAN, Reddy BGS, Sulladmath UV (1980) Studies on the floral biology of cashew (*Anacardium occidentale* L.). *Mysore J Agric Sci* 14:490–497
- Thompson KF, Taylor JB (1966) The breakdown of self-incompatibility in cultivars of *Brassica oleracea*. *Heredity* 21(4):637–648
- Topper CP, Calidari PDS, Camara M, Diaora S, Djaha A, Coulibay F, Asante AK, Boamah A, Ayodele EA, Adebola PO (2001) West African regional cashew survey covering Guinea, Guinea Bissau, Cote d'Ivoire, Ghana and Nigeria. Sustainable Tree Crop Programme (STCP) Report No. BHA-01109. Biohybrids Agrisystem Ltd. P. O. Box 2411, Earley, Reading RG6 5FY, UK
- Westergaard PW, Kayumbo HY (1970) The Cashew nut industry in Tanzania. Economic Research Bureau, University of Dar es Salam (Tanzania), p 104
- Wiersma PA (2003) Reproductive barriers in tree fruit crops and nuts. Proceedings of xxvi International Horticultural Congress: genetics and Breeding of Tree Fruit and Nuts. *Acta Hortic* 622:369–377
- Wunnachit W, Pattison SJ, Giles L, Millington AJ, Sedgley M (1992) Pollen tube growth and genotype compatibility in cashew in relation to yield. *J Hortic Sci* 67:67–75
- Wunnachit W, Sedgley M (1992) Floral structure and Phenology of cashew in relation to yield. *J Hortic Sci* 67:769–777