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Occurrence of Hermaphroditic Plants of *Carica papaya* L. (Caricaceae) in Southwestern Nigeria

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Abstract: Morphological studies of the three sex types of *Carica papaya* L. were carried out in order to elucidate the floral differences of the sex types and compare the germination ability of the hermaphroditic and female plant seeds. Floral characteristics that are taxonomically important in delimiting the three sex types include, type of inflorescence, petal size, presence or absence and size of corolla tube, size of ovary and fruit shape. Among the fruiting forms, the seeds from female plants germinate faster and have a higher germination index than the seeds from hermaphroditic plants. Nutritive value studies revealed that the fruits on female plants are comparatively more nutritious than the hermaphroditic fruits.

Key words: Hermaphroditic, unisexual, *Carica papaya* L., sex type, floral structure

Introduction

Carica papaya L. belongs to the family Caricaceae, a small family of dicotyledonous plants with four genera. Three are of tropical American origin (*Carica, Jarilla, Jacaratia*) and one, *Cylicomorpha* is from equatorial Africa. Approximately 71 species in the family Caricaceae have been described although Badillo (1993) reduced the number to 30 species with the following distribution, *Carica* 21 species, *Cylicomorpha* 2 species, *Jacaratia* 6 species and *Jarilla* 1 species.

Papaya (*Carica papaya*) is the most important economic species of the 21 species in *Carica* (Nakasone and Paull, 1999). Common names include papaya, pawpaw or papaw (Australia), mamoeiro (Portuguese) and mugua (Chinese). According to Nakasone and Paull (1999), in tropical America, *Carica* species is dioecious, except for the monoecious *C. monoica* (Desf.) and some *C. pubescens* and the polygamous *C. papaya*.

Carica is the only genus of the family Caricaceae in Nigeria with *Carica papaya* being the only species (Hutchinson and Dalziel, 1958). Since then, there has been no newer record in literature on the state of this species in Nigeria. It is a large herbaceous plant with a single erect stem which can attain heights up to 9m terminating with a crown of large leaves. The stem is semi-woody and hollow. The bark is smooth, greyish in colour, with large prominent leaf scars. When the stem is wounded, a thin milky sap oozes from the wound.

Problems in pollination, fruit set and production are intimately associated with sex expression resulting from genotype-environment interactions. Cultivar and environmental differences have produced a wide array of modified forms of the flowers so that the number and types of modifications have varied in reports by various researchers (Nakasone and Paull, 1999). According to Khan *et al.* (2002), papaya plants are either hermaphrodite (flowers with both sexes), pistillate (flowers with female sex only) or staminate (flowers with male sex only). Staminate plants flowerearlier and produce male flowers in large numbers (Singh, 1990).

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Sex inheritance in papaya is determined by a single gene locus with three alleles. M is dominant for maleness; M^H for hermaphroditism and m is recessive for femaleness (Samson, 1980). The diploid zygote may carry any one of the following six possible allelic combinations: MM, M^HM^H, MM^H, Mm, M^Hm and mm. First three homozygous dominant combinations are lethal. Progeny with these alleles do not survive. From the three heterozygous combinations: Mm-produces male (staminate) plants, M^Hm-gives rise to hermaphrodite (bisexual) plants and homozygous recessive combination mm results in female (pistillate) plants (Samson, 1980).

Papaya fruit pulp is the basic component of many facial creams, salves and shampoos. Papaya culls are ground into a puree that can be used for cosmetic purposes. Papain is one of two proteolytic enzymes found in papaya latex (the other is chymopapain). Papain is extremely useful since it retains proteolytic activity over a wide pH range, unlike other proteases. Young leaves can be cooked and eaten as a green vegetable. Green or unripe papaya is used as a vegetable or salad garnish as well, but must be boiled first to denature the papain in the latex. Papaya seeds are edible, tasting like nasturtium, watercress and pepper (Rieger, 2005).

There has been no detailed study of this mono-species genus *Carica* in Nigeria. Occasional observation of sparse fruits in a supposedly male plant of *Carica papaya* in Ile-Ife, Osun State Nigeria, necessitated a close study of the floral differences of the sex forms. It is hoped that this will enhance the taxonomic status of this mono-species genus in Nigeria.

Materials and Methods

The Three Sexual Forms of Carica papaya

The female, male and hermaphrodite plants were identified, monitored and studied in Ile-Ife (7°33'N 4° 34' E) Osun State, Nigeria over a 2 year-period (2002-2004)

Morphological Studies

Flowers were collected and examined from the three sex types. Flowers were picked fresh from those that dropped from already identified and marked plant stands (male and hermaphroditic plants) while the female flowers were collected directly from the inflorescence of standing marked plants From hermaphroditic plants, approximately 2,000 flowers were examined in the year 2002-2003 flowering season and about the same number of flowers were equally studied in the year 2003-2004 to deduce the sex ratio on the plants. In female and male plants, at least 1,000 flowers per sexual form were examined in each of the seasons. Length and diameter were measured for corolla tube, petal, ovary and fruit. Number of seeds per fruit from female and hermaphroditic plants were counted. To allow for uniformity of background, fruits were selected from females and hermaphrodite plants of similar age, size and within the same environment. One hundred and fifty fruits were studied (per sexual form that produced fruits) for number of seeds. Fruit shapes were also observed and documented. Photographs of the different plant/sex forms, fruits and flowers were taken.

Proximate Analysis (Nutritive Value) Studies

Moisture, ash, crude protein, crude fibre and Nitrogen contents were determined by the appropriate AOAC methods (1980). Standard errors of the mean values were calculated.

Germination Studies

Seeds were removed from mature ripened papayas of female and hermaphroditic fruits and rinsed to get rid of the gelatinous covering. They were then sun dried. Plastic pots containing garden soil were prepared in replicates of three for each of the two sex types that produces fruits. Thirty seeds were planted in each pot and kept moist in the open. Germination observations were recorded for up to thirty days. The entire experiment was repeated thrice at different intervals to ascertain the reliability of the results. Germination Index was calculated by the formula:

$$\text{Germination Index} = \frac{\Sigma[(\text{n days to germination})(\text{Number of seeds germinated})]}{\text{Total number of seeds}}$$

where:

n: is the number of days elapsed between imbibition and time of counting germinated seeds
Σ: is the sum of the daily counts of germinated seeds multiplied by n.

This index integrates rate and percentage germination (Scott and Jones, 1982)

Results

Inflorescence and Flowers

Three flower types were observed; the male (♂), hermaphrodite (⚥) and female (♀). A typical male plant bears male unisexual flowers only and the female plant bears female unisexual flowers only. The hermaphrodite plant bears male unisexual and hermaphroditic flowers. The classification of these floral categories is shown in Table 1 and Fig. 1.

On male plants, flowers are borne in clusters on long pendulous racemes (Fig. 2A). The individual flower is tubular with ten epipetalous stamens arranged alternately to form two sets of fives attached to the upper portion of the inner wall of the corolla tube. Five small anthers are borne on filaments while the other five are comparatively bigger and sessile (Fig. 1E). Flowers from male plants have rudimentary ovaries and styles. Female flowers are arranged in cymose inflorescence without any pendulous axis as found in the male (Fig. 2D). Individual flowers are tubular with no stamen. Ovary is large (Fig. 1D), with a feathery stigma that is located directly on it. No style is observed in the female flowers.

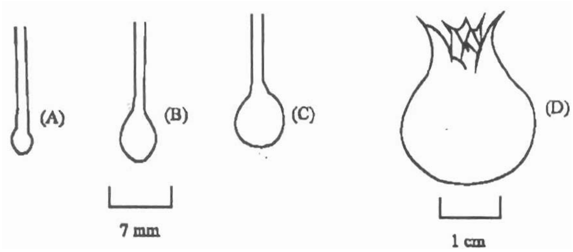
In hermaphroditic plants, flowers are borne at the apical region of the stem and branches in a cymose inflorescence fashion. Individual flowers are tubular (Fig. 3A) with ten stamens arranged like those in the male flowers (Fig. 1F). Staminate flowers from hermaphroditic plants have non-functional rudimentary ovaries and style while hermaphroditic flowers have functional ovaries, style and stigmatic surface. However, the ovaries are much smaller than those of typical females (Fig. 1B and C).

Corolla

There are five petals per flower for all the various sex forms. The female flowers have the largest petals while the typical males have the smallest. Hermaphroditic petals are of intermediate sizes (Fig. 3A and Table 2). Corolla tube is absent in the pistillate flowers but present in the hermaphrodite and staminate flowers. It is short and broad in the hermaphroditic flowers but long and narrow in the male flowers (Fig. 3A and Table 2).

Table 1: Classification of floral types in *Carica papaya*

Staminate (♂)	Hermaphrodite (⚥)	Pistillate (♀)
Functional stamen + rudimentary ovary/no ovary	Functional stamen + functional small ovary	Large functional ovary without any stamen



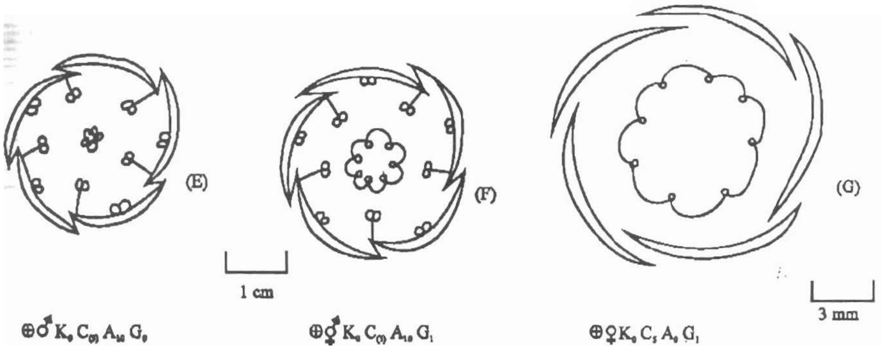


Fig. 1A-D: Variation in ovary size in *Carica papaya*: A: male flower ovary size, B-C: hermaphrodite flower ovary sizes, D: female flower ovary size, E-G: Floral diagrams and formulae of the different floral types in *Carica papaya*, E: male floral formula, F: hermaphrodite floral formula, G: female floral formula

Table 2: Floral morphological attributes of the three sexes/plant types

Variable	Male Plant				Female Plant				Hermaphroditic Plant			
	Mini-Mum	Maxi-mum	Mean	Std. error	Mini-mum	Maxi-mum	Mean	Std. error	Mini-mum	Maxi-mum	Mean	Std. error
Corolla tube Length (mm)	21.00	27.00	22.85	1.33	-	-	-	-	8.50	17.00	11.79	2.48
Corolla tube diameter (mm)	1.90	2.30	2.02	0.09	-	-	-	-	4.00	14.00	8.06	1.79
Petal Length (mm)	16.00	20.00	17.94	0.98	39.00	52.50	44.90	1.69	16.50	29.00	22.70	2.80
Petal Breadth (mm)	4.80	6.00	5.18	0.36	11.50	16.20	13.40	0.54	4.78	11.50	8.04	1.45
Ovary Length (mm)	1.50	6.00	3.67	0.47	25.00	30.50	28.20	0.61	2.00	13.00	7.65	1.39
Rudimentary Ovary Diameter (mm)	0.70	0.80	0.78	0.05	13.00	18.00	16.50	0.50	1.00	5.00	3.15	0.44

Key: -absent

Fig. 2: Plant forms in *Carica papaya:*

A: Male plant (arrow indicate pendulous inflorescence)

B: Hermaphroditic plant (1 fruit plus clusters of flowers)

C: Hermaphroditic plant (arrow indicates stalk of a detached/fallen fruit)

D: Female plant showing many fruits and flowers

Fruit

Fruits from female and hermaphroditic plants do not show appreciable difference in size. Fruits are variously shaped (Fig. 3B-C; Fig. 4A and D) in the hermaphroditic plant. They could be oval, pyriform, elongated or sickle but rarely round (Fig. 3B-C) while it is largely round or spherical in the female (Fig. 4C) and only occasionally elongated. Flesh colour is largely orange-yellow in ripe fruits for both hermaphroditic and female plants.

Seed

Seed colour for mature fruits is dark-grey to black. The number of seeds for typical female fruit examined ranged from 44-715 while in hermaphrodite the range is between 408 and 621.

Table 3: Germination Index of the Seeds

Pots	Hermaphroditic seeds	Female seeds
1	3.27 (n = 1,500)	8.00 (n = 1,500)
2	2.17 (n = 1,500)	7.20 (n = 1,500)
3	2.80 (n = 1,500)	10.40 (n = 1,500)

n = number of seeds

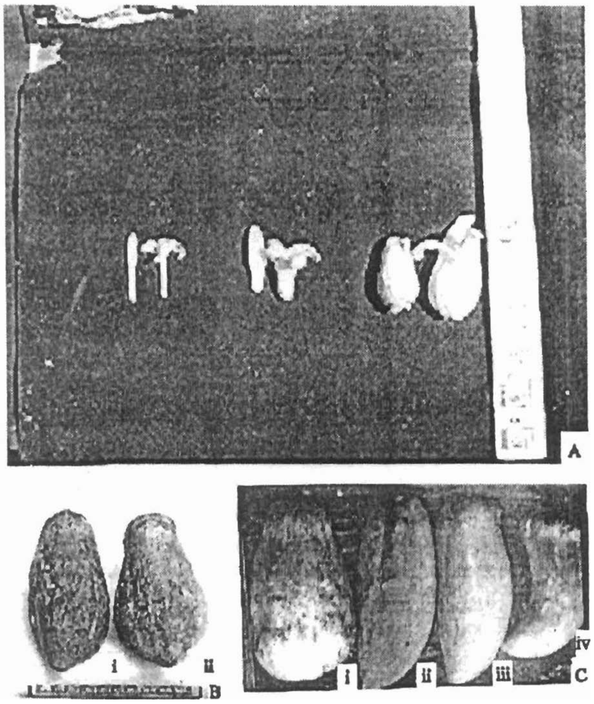


Fig. 3A: Variations in the flower of *Carica papaya* plant forms (flower bud on the left and open flower on the right for each sex)
Male flowers (on the left)
Hermaphroditic flowers (in the middle)
Female flowers (on the right)
B-C: Variations in Fruit Shapes from Hermaphroditic plant
Elongated-Bi, Cii, Ciii
Pyriform-Bii
Oval-Ci
Sickle-Civ

Sex-Distribution

A total of 4000 flowers from the hermaphroditic plants were examined over 24 months for sex type based on presence/absence of functional ovary and were classified following Table 1. Of theseonly 5 flowers possessed both male and female reproductive structures in a functional capacity. Thus only five flowers were true hermaphrodites.

Table 4: Proximate analysis of the fruit mesocarp

Sex/Plant Type	Crude protein (%)	Moisture (%)	Crude fibre (%)	Ash (%)	Nitrogen (%)
Hermaphrodite	0.86±0.02	87.93±1.58	0.32±0.08	0.40±0.02	0.14±0.01
Female	1.18±0.23	88.32±0.86	0.44±0.01	0.49±0.08	0.20±0.04

Seed Germinability

Seeds from fruits in pure female plants consistently germinated earlier than those from hermaphroditic plants. The female seeds also showed a higher germination index than the hermaphroditic seeds (Table 3).

Nutritive Parameters

Proximate analysis of the fruit mesocarp revealed that female *C. papaya* have a higher percentage of the nutritive parameters considered than the hermaphroditic fruits (Table 4).

Discussion

Variation in essential floral parts is a primary determinant of sexual forms in flowering plants. This has been stressed by several workers including Hutchinson and Dalziel (1958), Akinwusi (1992) and Adedeji and Illoh (2005).

There is sexual dimorphism in petal size in *Carica papaya*. Female petals are generally larger than the male and hermaphroditic petals. This is contrary to the report of Campbell (1989) that male petals are always or nearly always larger than female petals in most temperate plants. According to him, selection intensities through male function favoured wide petals, whereas narrow petals were favoured via female function. However, Delph (1996) reported that contrary to popular belief, male flowers are not always larger than female flowers. He reiterated that the past belief in larger male flowers was probably caused by a bias toward considering temperate species, as these are significantly more likely to have relatively large male flowers, whereas in the tropics neither sex is more likely than the other to be the larger of the two. In this study however, the petals of the female flowers are larger than those of the male flowers. According to Delph (1996), this suggests that even though pollen has been shown to produce hormones that affect the growth and expansion of the petals either (1) this is not the case in most species or more likely, (2) selection is able to uncouple the response from the signal in such a way as to modify the developmental tie between the presence of pollen and growth of the petals. As pointed out by Stanton and Galloway (1990), any additive genetic variation for the response to or production of hormonal signals would allow selection to alter the developmental relationship between pollen and petal growth.

In *Carica papaya,* female flowers are more or less polypetalous while male and hermaphroditic flowers are gamopetalous forming a corolla tube from the base of which the ovaries (whether rudimentary or not), arise. Thus, the absence of a corolla tube conveniently differentiates the female flower from the male and hermaphroditic flowers. On the other hand, the size of the corolla tube can be used to delimit the staminate flower from a truly male plant and staminate flower from the hermaphroditic plant, the tube being long and narrow in the typical male but short and broad in the staminate flowers from hermaphroditic plants (Fig. 3A). According to Nakasone and Paull (1999), the hermaphroditic forms in the Pacific region is between the two unisexual flower types and exhibits numerous deviations which agrees with the finding from the present investigation.

All males and almost all hermaphroditic flowers examined had rudimentary ovaries while the female unisexual flowers have bigger and functional ovaries. According to Delph (1996), the need to enclose a larger volume of reproductive parts (ovaries) has influenced the size of the petals where by the petals are larger in the female flowers than in the male flowers. Sex distribution of flowers on the hermaphrodite plants examined showed a paucity of truly hermaphroditic flowers. Only five out of the 4,000 flowers examined on hermaphrodite plants over two years had both male and female reproductive parts. The ovaries of such hermaphroditic flowers are much bigger than the rudimentary forms in the typical male flowers, but smaller than those found in typical female flowers. This is a significant report of this research work.

It is plausible to assume that these functional ovaries of the hermaphroditic flowers were fertilized to produce fruits which are sometimes found on hermaphroditic plants. What may not be so clear is the reason for prolific fruit production noticed on some hermaphrodites which have been observed to fruit as heavily as typical female plants, if not more. Such confusion may be understandable considering that truly hermaphroditic flowers are produced in very low frequency as observed in this study. However, this situation can be explained thus: usually at early sexual maturity, for most fruit producing trees, fruit production is not optimal; production increases with time (years) and decline sets in as the plant ages. Fruit production is an anabolic process that requires the expenditure of metabolic energy. It is thus likely that those heavily fruiting hermaphroditic forms are in their middle years (optimal years) when lots of energy have been devolved to fruit production. The implication therefore is that more hermaphrodite flowers will be encountered on hermaphroditic trees of middle age than on a tree in its first few years of flowering/fruiting. Indeed, the hermaphroditic plants from which flowers were obtained for this study were within the first three years of flowering (at the time of flower collection).

The evolution of hermaphroditic forms in pawpaw could be a genetic response to fluctuating environmental conditions. Environmental sex determination is well documented in the plant kingdom (Charnov and Bull, 1977; Bull, 1981; Guillon and Fievet, 2003). Such sexual transformation has been reported in *Carica papaya* (Simon, 1986). Change of sex may occur temporarily during high temperatures in mid summer. Male or bisexual plants may change completely to female plants after being decapitated/decapped. The hermaphroditic plant appears to be a reservoir of such transformation gene (s) with adverse conditions favouring more staminate flower productions, favourable conditions resulting in true hermaphrodite flowers or even females.

Fruit shape in the female is largely spherical (Fig. 4C), occasionally elongated, whereas fruits from hermaphrodites exhibit diverse shapes (Fig. 3B,C). This supports the findings of Nakasone and Paull (1999). According to these authors, the variety of shapes depends upon modifying factors affecting flower morphology during ontogeny. From this study, pyriform, sickle, elongated and oval fruit shapes were observed for the hermaphrodites.

That fruit form is under genetic control is made apparent in Fig. 4B where an hermaphrodite and a female tree are growing and fruiting under similar environmental situation but displaying clearly distinct fruit shapes.

Seed production appears to vary between the female and the hermaphrodite fruits but with occasional lower numbers in the female. Though the range is wider in female than hermaphrodite, some female fruits were observed to be very low in seed production while hermaphrodites generally had high number of seeds. According to Nakasone and Paull (1999), seedless fruits are sometimes produced on female trees. This observation might make economic sense in biological terms when seed production is compared with germinability success in these two fruiting forms. Another major finding from this study is that seeds from females have significantly higher germination index while hermaphrodite seeds have lower index of germination. The implication is that females devote their reproductive energy towards the production of quality seeds that have guaranteed survival (in terms of seed germination). As a result, females produce less of such quality seeds; the hermaphrodite on its own part compensates for the lower survival rate of its seeds by increasing their numerical strength.

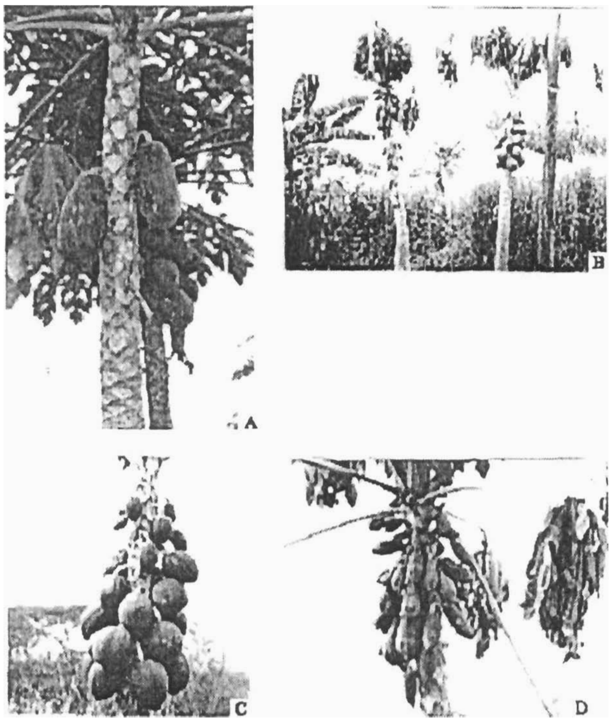


Fig. 4: Plant Forms in *Carica papaya*

A: Hermaphroditic plant (in front, with 2 elongated fruits, a female plant partly showing at the back)

B: Hermaphroditic (on the left) and Female (on the right)

C: Female plant (with spherical-shaped fruits)

D: Hermaphroditic plant (with elongated fruits)

This argument of production of quality seeds may be extended to explain the results of proximate analysis value with the fruit of female being comparatively more nutritious than the hermaphroditic ones. This is the first comprehensive report on the floral differences of the three sex types of *Carica papaya* in Nigeria. It is also the first formal report of the variations in fruit shape in the hermaphrodite *Carica papaya* sex type occurring in Nigeria.

One line of inquiry for the future that should greatly aid our understanding of flower dimorphism in *Carica papaya* is a study of the pollens to see if the hormones produced affect the growth and expansion of the petals. It would also be interesting to study the chromosome behaviours (meiosis and mitosis) as this may give insight into the possible reasons for low seed production in the female sex type. A study of how selection is operating on floral characters would also be necessary.

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