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Inheritance of Purple Pigmentation in *Carica papaya* Linn. (Caricaceae)

Matthew Oziegbe, Abayomi Ezekiel Folorunso*, Dauda Olarenwaju Ajao

Department of Botany, Obafemi Awolowo University, Ile Ife, Nigeria

Abstract This study was conducted at Ile-Ife to investigate the inheritance of purple colour pigmentation in *Carica papaya*. Seeds of fruits from both female and hermaphroditic purple petiole *Carica papaya* were planted separately and plant populations of purple and green petiole *C. papaya* in Ile-Ife were observed for pigmentations. Plants from both female and hermaphroditic pawpaw segregated for green and purple petiole colour in an equal ratio of 1 purple: 1 green. The study show that there is pleiotropic effect as purple colour pigmentation was noticed on the petal, peduncle, fruit rind, fruit stalk, and on the stem of all male, female and hermaphroditic purple petiole pawpaw investigated. The purple pigmentation is likely to be dominant over green pigmentation which does not explain the prevalence of green petiole over purple petiole in population of *C. papaya* at Ile-Ife.

Keywords Dominance, Petiole colour, Node and stem colour, Pleiotropy, Fruit, Hermaphrodite

1. Introduction

Carica papaya belongs to the family Caricaceae which includes 35 species placed in six genera. Among all species, 32 are dioecious, two triecious and one monoecious [1]. *Carica papaya* is the only genus of the family Caricaceae in Nigeria with *C. papaya* being the only species [2]. *Carica papaya* which is the only Caricaceae species of world economic importance [3] is closely related to *C. petlata* [4] or another wild ancestor within *Caricaceae* [5] which may have arisen, by hybridization. Papaya is grown all over tropics and subtropics regions. However, the main papaya producing countries are India, Brazil, Nigeria, Indonesia and Mexico, in that order [6]. It has now spread to all tropical and subtropical countries. Commonly and erroneously referred to as a "tree", papayas are one of the fastest growing fruit crop. *C. papaya* has a green or deep-purple stem becoming 30-40 cm or more thick at the base and roughened by leaf scars. The leaves emerge directly from the upper part of the stem in a spiral on nearly horizontal petioles 30-105 cm long, hollow, succulent, green or more or less dark purple. The blade is deeply divided into 5 to 9 main segments, each again is irregularly subdivided which varies from 1 to 2 ft (30-60 cm) in width and has prominent yellowish ribs and veins. Leaf morphology changes during development from single lobed juvenile leaves to palmate leaves of mature plants [7]. Generally, papaya cultivars are differentiated by the number of leaf main veins, the number of lobes at the leaf margins, leaf shape, stomata type, wax structure on leaf surface, as well as the colour of the leaf petiole. The sex of the flowers on some plants can undergo changes with age and injury and male plant produce large number of flowers.

In nature, these plants are dioecious or hermaphrodite. Flowers can be produced as early as 4 months after germination of seed [4]. Male flowers are morphologically distinct from female flowers. Male inflorescence is borne in many flowered panicles of cymes on horizontal or pendent stalks up to 1 meter long. The flowers are 2-4 cm long. The petals are fused into a long tube, have 10 fertile stamens, and a rudimentary, non-functional ovary. Female inflorescence is much shorter only 3-4 cm long and has fewer flowers. Female flowers are larger, usually white or cream in colour, with five free petals. There are no stamens, but a large ovary with 5 fan-shaped stigmas is present. The flowers of female plants are usually single whereas the inflorescence of the male plants is cymose [4, 8]. The Caricaceae species including *C. papaya,* contains 2n=18 chromosomes [4, 9]. The male, female and hermaphroditic flowers of papaya are distributed on separate papaya plants and sex types are revealed only after flowering. Methods to identify sex type at juvenile stage have been studied [10, 11]. [12] proposed that the sex of papaya is determined by three homologous gene complexes on sex chromosome. The genes are so tightly linked that no crossing over occurs among them; thus the complexes are transmitted to offspring as if they are single gene alleles with pleiotrophic effects on phenotypic expression. The genotypes of the male, hermaphroditic and female (However, as summarized by [11]), a common hypothesis is that sex is controlled by a single locus with

* Corresponding author:
afolorun@oauife.edu.ng (Abayomi Ezekiel Folorunso)
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three alleles-M_1 (male), M_2 (hermaphrodite) and *m* (female). Male/staminate (M_1m) and hermaphrodite plants (M_2m) are heterozygous whereas female/pistillate plants (mm) are homozygous recessive. Combinations of dominants, namely M_1M_1, M_1M_2, or M_2M_2 are lethal, leading to post-zygotic abortion of such ovules; the lethal effect of these homozygous dominant sex determining alleles is further evidence of the degeneration of the Y chromosome. Accordingly, this hypothesis predicts that viable males can only be M_2m (gynodioecious). A cross of two hermaphrodites normally yields a 2:1 ratio (2 hermaphrodites: 1 female). As might be expected from the variety in flower types, the occurrence of cross-pollination can vary considerably e. g. hermaphrodites can self-pollinate or they can be pollinated from adjacent male plants, while in dioecious plants where males and females are separate, cross pollination is essential.

Carica papaya germplasm shows considerable phenotype variation for many horticultural traits [13]. [14] included morphological traits among the different criteria which can be used to estimate genetic diversity. Plant taxonomy is traditionally dependent upon the comparative external morphological characters [15]. In literatures, there is dearth of information on inheritance of purple pigmentation of organs in *Carica papaya*. In Ile-Ife, the dominant *Carica papaya* is green petiole colour with very few number of purple petiole plants. The aim of this study therefore is to investigate the inheritance of purple colour pigmentation in *C. papaya* populations in Ile-Ife.

2. Materials and Methods

This study was carried out at Ile-Ife Nigeria located within (latitude 7^o 30 N to 7^o 35 N and longitude 4^o 30 and 4^o 35^o E). Fruits of a female purple petiole *C. papaya* 'Solo selection' were collected from Obafemi Awolowo University Teaching Hospital Complex phase two gate in the month of January, 2009 and the fruits of hermaphroditic purple petiole *Carica papaya* were collected from Parks and Garden unit, Obafemi Awolowo University, Ile-Ife, Osun state at the same period. The seeds from each fruit collected were processed to remove mucilaginous covering and air dried for 3-5days to enhance quality of seeds for germination. The numbers of seeds per fruit were counted and seeds from each fruit were planted separately in a plastic bucket of diameter 70.00 cm filled with topsoil collected from the reforestation project unit of the Department of Botany, Obafemi Awolowo University, Ile-Ife. Each plastic bucket was watered to soak the soil followed by the periodic watering. The seeds were allowed to grow in the open field and moved into the screen house after two weeks after germination had been completed. At exactly 4 weeks after germination, seedling from each fruit were transplanted separately into the field of loamy sand soil beside the screen house of the Department of Botany, Obafemi Awolowo University at a spacing of 30 cm x 30 cm and NPK fertilizer was applied to enhance their growth. Individual plants from each fruit were monitored for appearance of purple colour pigmentation on petiole, node and stem. Plants with purple petiole and node, green petiole and node, green petiole purple pigmented node and stem from each fruit were counted. The results obtained were subjected to chi-square analysis to determine the mode of inheritance of purple colour pigmentation on the petiole of *C. papaya*. Plant populations of *C. papaya* at different locations in Ile-Ife were sampled from 2009 - 2011 to examine purple pigmentation on their parts both on Obafemi Awolowo University campus (Parks and Garden unit, white house and spider house) and outside the campus (Opa area, Seventh day Adventist Hospital and Eleyele area). Sampling was done on all the three sex forms in *C. papaya* with green and purple petiole colour.

3. Results

Plants from female and hermaphroditic fruit appeared to be green at the initial stage of germination but later after six weeks of germination purple colour pigmentation became observable in some plants. In fruit A from female plant, 166 plants had purple petiole with purple nodes, 150 plants had green petiole with some showing purple nodes and some showing green nodes. In fruit B from female plant 132 plants had purple petiole with purple nodes; 110 plants had green petiole with some showing purple nodes and some showing green nodes. In fruit A of hermaphroditic pawpaw, 219 plants had purple petiole with purple nodes, 194 plants had green petiole with some showing purple nodes and some showing green nodes. In fruit B of hermaphroditic pawpaw 240 plants had purple petiole with purple, 220 plants had green petiole with some showing purple nodes and some showing green nodes. Table 1 shows the chi square analysis for segregation for purple and green petiole colour, indicating a fit of 1purple:1green in both female and hermaphrodite fruits.

In the population sampled, it was observed that in all purple petiole *C. papaya* purple colour pigmentation was observed on the petiole (Fig. 1A), petal of hermaphroditic flower (Fig. 2A), petal of female flower (Fig. 2C), penduncle of male flower (Fig. 3A), petal of male flower (Fig. 3C), fruit stalk and on the rind of female and hermaphrodotic fruits (Fig. 4A and C). Purple pigmentation was also observed on the nodes and stems of all plants with purple petiole and on some nodes of green petiole pawpaw (Fig. 5B and C).

In all pawpaw plants with green petiole (Fig. 1B) sampled in the population, no purple pigmentation was observed on petal of hermaphroditic flower (Fig. 2B), petal of female flower (Fig. 2D), on the penduncle of male flower (Fig. 3B), petal of male flower (Fig. 3D), on the fruit rind and fruit stalk of female and hermaphroditic fruits (Fig. 4B and D), on the node and stem of some green petiole pawpaw (Fig. 5A).

Table 2 shows the number of purple and green petiole *C. papaya* sampled as well as their sex. Table 3 shows the observed pigmentation data for all the organs in both purple and green petiole pawpaw sampled in the populations studied in Ile-Ife.

Table. 1. Summary of the Chi-square Values for seeds grown from Both Female and hermaphrodite Fruits A and B

	Chi-Square Value For 3:1	Chi-Square Value For 2:1	Chi-Square Value For 1:1
Female fruit A	105.748	27.483	0.810
Female fruit B	55.403	16.806	2.00
Hermaphrodite fruit A	104.099	34.129	1.395
Hermaphrodite fruit B	127.825	42.625	0.869

*p>0.5

Table 2. Number of male, female and hermaphroditic purple petiole pawpaw and green petiole *Carica papaya* sampled in Ile-Ife

	Male	Female	Hermaphrodyte	Total
No of Plant With Petiole Purple Examined	5	4	5	13
No of Plant With Green Petiole Examined	10	10	10	30

Table 3. Inheritance of Pigmentation of Organs in of purple and green petiole colour in *Carica papaya* sampled in Ile-Ife population

	Petiole	Petal	Penduncle	Fruit rind	Fruit stalk	Leaf colour	Sepal	Node colour	Stem
purple petiole pawpaw	13	13	13	13	13	0	0	20	13
green petiole pawpaw	30	30	30	30	30	42	43	23	30

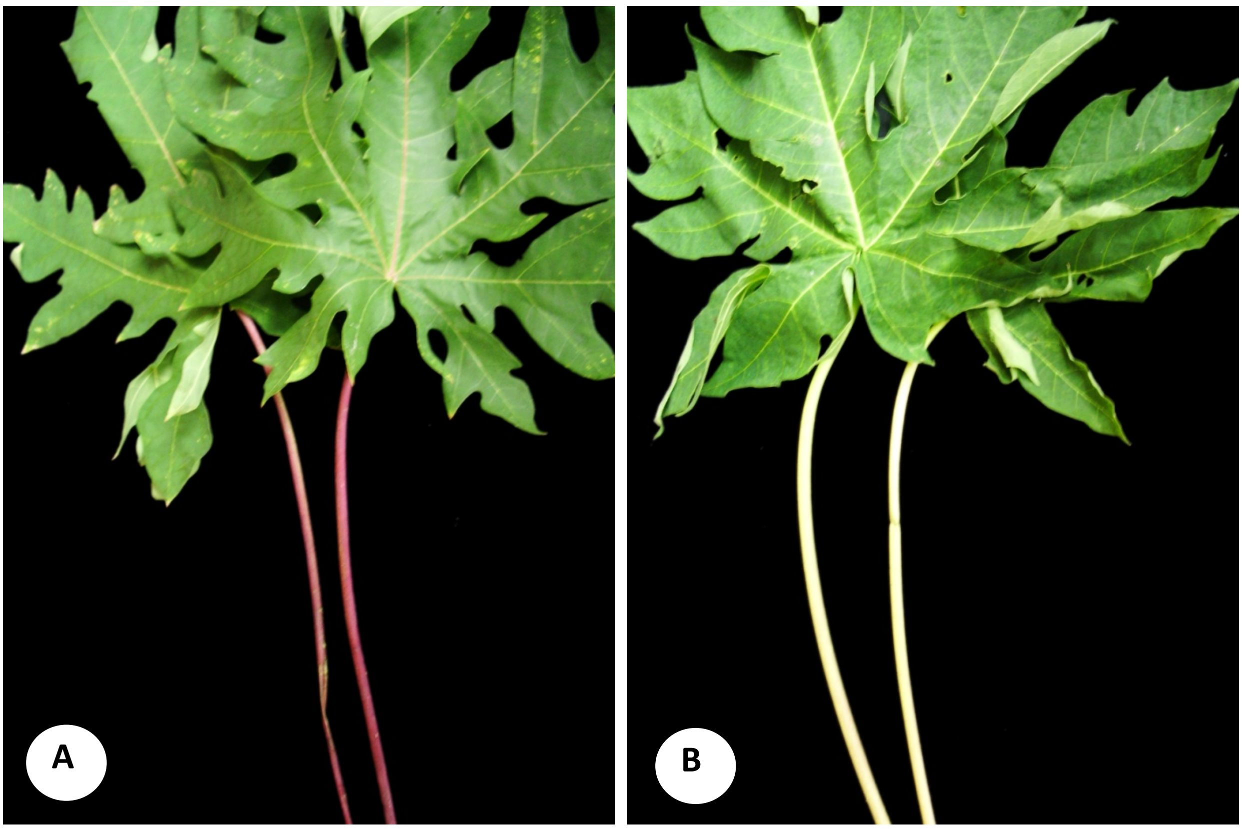
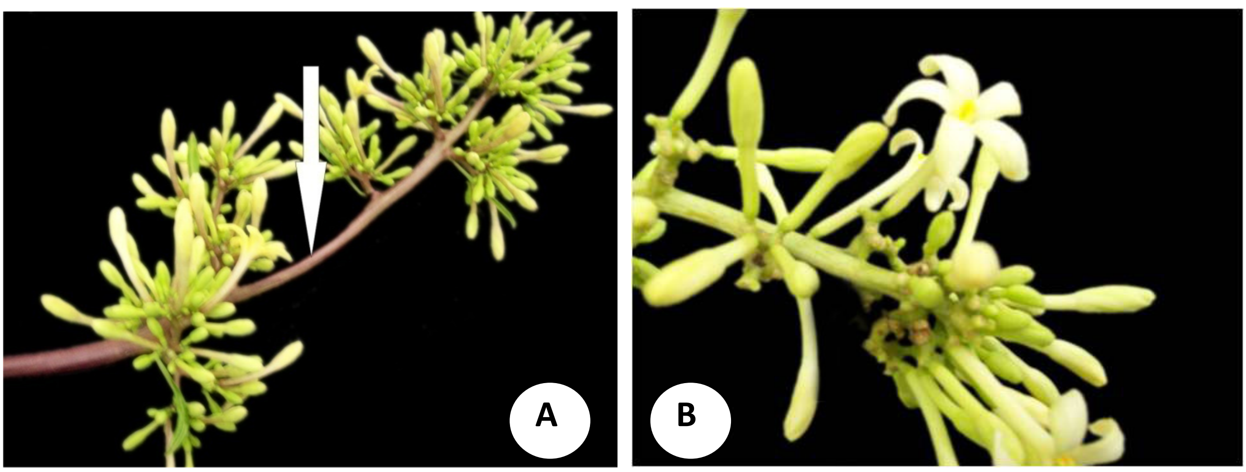


Figure 1. Petiole colour in *carica papaya*. **A.** Purple Petiole, **B.** Green Petiole

Figure 2. Variations in pigmentation on hermaphrodite and female flowers of *Carica papaya* **A** and **C.** Purple Pigmentation on Petal of Hermaphroditic and female Flower, **B** and **D.** Petal of Hermaphroditic and Female flower without pigmentation. Arrow indicate purple pigmentation



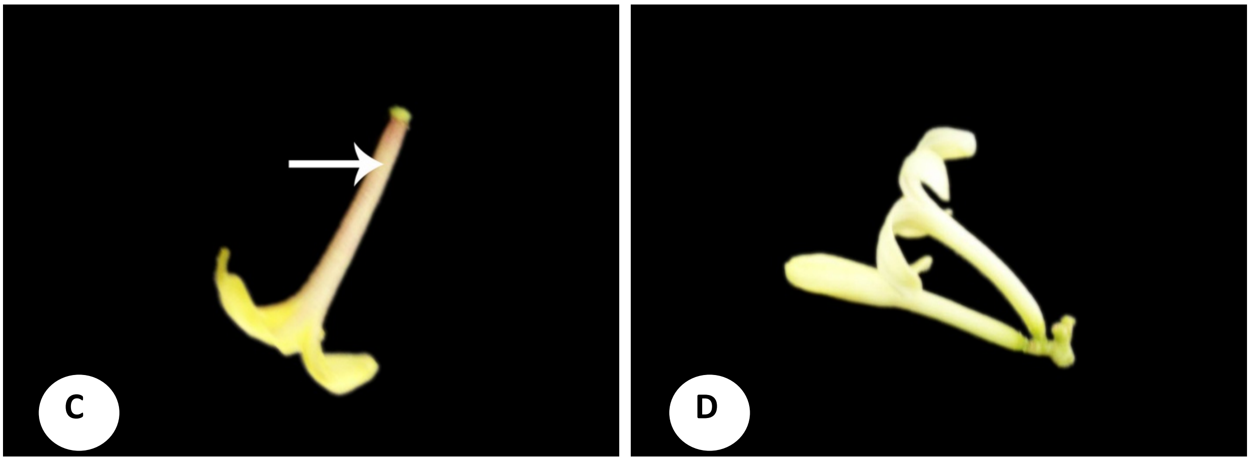


Figure 3. Variation inpigmentation on male flower**. A.** Purple Pigmentation on Penduncle of Male Flower, **B**. Penduncle of Male Flower without pigmentation, **C**. Purple Pigmentation on Petal of Male Flower, **D**. Petal of Male Flower without pigmentation. Arrow indicate purple pigmentation

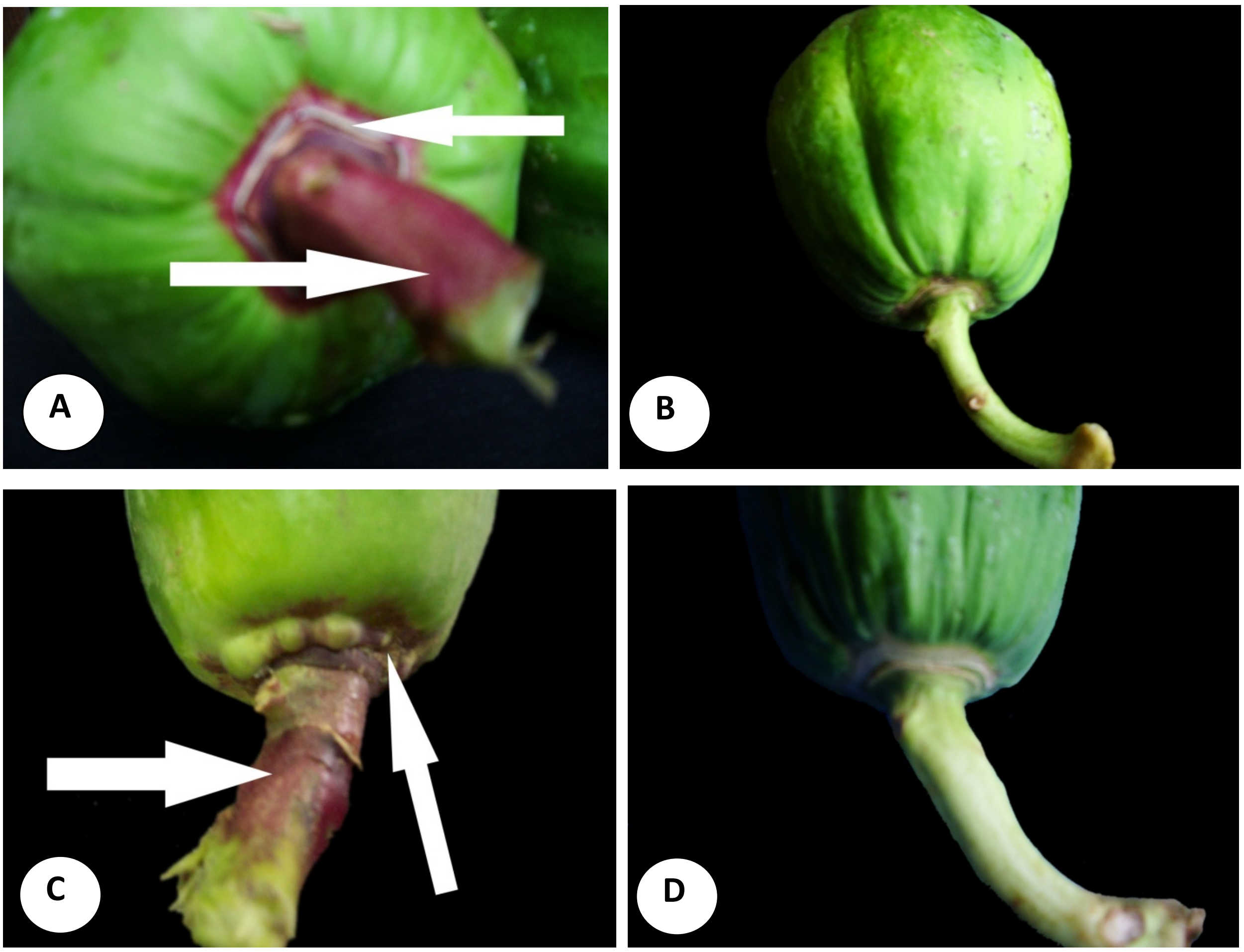


Figure 4. Variation in pigmentation of fruits of Carica papaya. **A and C.** Purple Rind and Stalk of Female and hermaphroditic Fruits, **B and D**. Rind and Stalk of Female and hermaphroditic Fruits without pigmentation. Arrow indicate purple pigmentation

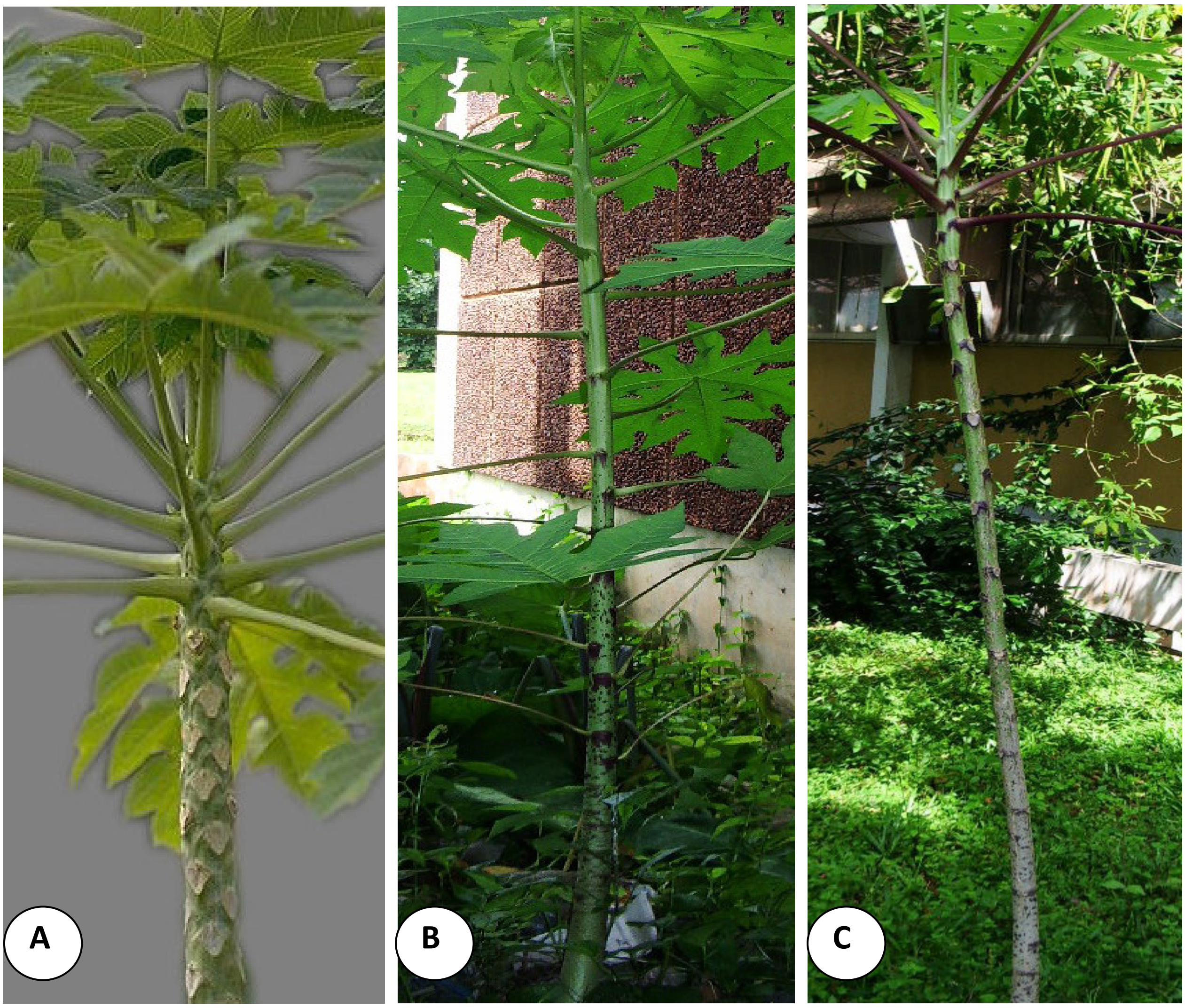


Figure 5. Variation in stem pigmetation of *Carica papaya*. **A.** Green Node and stem of Green Petiole Pawpaw. **B.** Purple pigmented Node and stem of Green petiole pawpaw, **C.** Purple Node of Purple Petiole Pawpaw

4. Discussion

A fit for 1purple petiole: 1 green petiole colour ratio observed in both the seeds of purple petiole female pawpaw and hermaphroditic pawpaw (*Carica papaya*) indicates that purple pawpaw segregated for green and purple petiole colour in an equal ratio. This shows that the gene present in the seed of purple pawpaw does not produce true to type that is it is in a heterozygous form. The hermaphrodite varieties produce true to type seeds if pollinations are controlled, although segregation of sex types does occur (2 hermaphrodites: 1 female). The dioecious papaya cultivars are maintained by means of controlled pollination (sib mating), poly crossing and recurrent selection [16].

The purple petiole female pawpaw of likely genotype (Pp) is likely to have received pollen from a green petiole pawpaw of likely genotype (pp) to segregate in the observed ratio.

The segregation for petiole colour in the purple female pawpaw implies that purple petiole colour might be dominant over green petiole colour but this does not explain the dominance of green petiole pawpaw over the purple petiole pawpaw in populations of *Carica papaya* present in Ile-Ife. [17] reported the dominance of purple petiole over green petiole as well as the dominance of yellow flower colour over white flower colour in *Carica papaya* suggesting a monogenic inheritance and that the variation in intensity of purple petiole colour observed might be due to modifying genes. [18] also reported the dominance of red petiole colour over green petiole colour in *Carica papaya.*

Fruit production in *Carica papaya* plants may occur following cross-pollination (out-crossing), self pollination or parthenocarpy; a form of asexual reproduction in which fruits may be produced without fertilization [19, 20]. As might be expected from the variety in flower types, the occurrence of cross-pollination can vary considerably e. g. hermaphrodites can self-pollinate or they can be pollinated from adjacent male plants, while in dioecious plants where males and females are separate, cross pollination is essential (Organization for Economic Co-operation and Development [21].

The presence of purple pigmentation on the petal, sepal, pendunce, fruit rind and fruit stalk of all purple petiole pawpaw observed indicates that the gene for purple pigmentation exhibit more than one phenotypic effect. The presence of purple pigmentation on the node and stem of some green petiole pawpaw revealed that a separate gene might be responsible for the exhibition of node and stem purple pigmentation.

The results obtained for the inheritance of purple pigmentation of organs in *Carica papaya* examined show that the gene for purple colour pigmentation exhibited pleiotropism thereby putting purple colour on the petal, penduncle, fruit rind and fruit stalk of every plant showing purple colour on its petiole. The explanation for this observation is that the gene responsible for colour pigmentation on the petiole is also responsible for colour pigmentation on the petal, sepal, penduncle, fruit rind and fruit stalk while a different gene might be responsible for the purple colour pigmentation on the node and stem which does not exhibit pleiotropism.

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