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Effect of gibberellin treatment on parthenocarpic ability and promotion of fruit swelling in papaya

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Abstract

To improve the productivity of vegetable papaya in subtropical regions, 1) fruit setting rate (parthenocarpic ability) and fruit productivity between sex types (females and hermaphrodites) and among cultivars; and 2) effect of gibberellins (GAs) on fruit swelling, was studied. In both sex types, the number of fruits per tree correlated more closely with fruit yield than with individual fruit weight. Females produced higher number of fruits per tree, thus attaining a higher fruit yield than hermaphrodites. A variation in parthenocarpic ability was observed among cultivars, and this ability was higher in female plants than in hermaphrodites. These results suggest that it is possible to grow female cultivars with high parthenocarpic ability. However, parthenocarpic fruits were significantly smaller than those produced by pollination. GA treatment was found to be effective for promoting fruit swelling under greenhouse conditions. Thus, in the greenhouse production of papaya, GA treatment was more efficient than hand pollination. Based on these results, we suggest that in subtropical regions, efficient production of papaya fruit for use as a vegetable may be realized by selection and cultivation of female cultivars with high parthenocarpic ability and promotion of fruit swelling by GA treatment.

Key words: Fruit swelling, gibberellins, papaya (*Carica papaya*), parthenocarpy, sex types.

Introduction

Papaya (*Carica papaya* L.) is a polygamous species with three sex types: male, female, and hermaphrodite (Hofmeyr, 1938; Storey, 1938). The ripe fruits from female and hermaphrodite trees are used commonly as a dessert, and in Southeast Asia the green fruits are also cooked as vegetables (Manshardt, 1992; Nakasone and Paull, 1998). Recently, the demand for green papaya fruits has increased in the Okinawa Islands, Japan (L26˚12'51", N127˚40'28").

The hermaphroditic Hawaiian 'Solo' variety of papaya is preferred in the international market, however, this variety is not highly productive under Okinawa Islands conditions. This low productivity may be related to sexual reversal in the flowers of hermaphrodites (Hofmeyr, 1939; Manshardt, 1992; Nakasone and Paull 1998; Ray, 2002). In contrast, female trees remain stable in their sexual expression throughout the year (Hofmeyr, 1939; Manshardt, 1992; Nakasone and Paull, 1998; Ray, 2002).

Male plants are usually intercropped with females to allow pollination and increase fruit yield (Allan, 1976; Samson, 1986; Aquilizan, 1987; Nakasone and Paull, 1998). However, intercropping is not practiced in the Okinawa Islands, where papaya plants are grown in greenhouses to protect them from typhoon damage and virus infections. Pollination does not occur naturally under greenhouse conditions, even when male or hermaphrodite trees are intercropped with females. Although hand pollination can be done to promote fruit swelling in greenhouses, it is labour-intensive and costly. Therefore, an alternative to hand pollination is needed to improve fruit productivity.

Nakasone and Paull (1998) and Ray (2002) described natural parthenocarpy in papaya. Rodriquez-Pastor *et al.* (1990) also reported variation in parthenocarpic ability among female cultivars. Although the enhancement of parthenocarpic ability will be vital for increasing productivity of the female plants, the parthenocarpic nature of papaya has not been investigated in detail. Moreover, plant growth regulators such as synthetic auxins, gibberellins, and cytokinins, have been successfully used to promote fruit swelling in other horticultural crops (Lurie, 2000), artificial induction of parthenocarpy may provide another route to fruit yield improvement. In order to improve the productivity of vegetable papaya under subtropical conditions, we investigated differences in fruit yield and parthenocarpic ability between sex types among cultivars, and tested the potential of gibberellin treatment for the promotion of fruit swelling.

Materials and methods

Difference in fruit yield between females and hermaphrodites: Female and hermaphrodite trees of the cultivars 'Dantesu', 'Fruit tower' and 'Kansen' (Wakaba Seed Co., Okinawa, Japan) were investigated. Seeds were sown in black plastic pots on 10 October, 2002 and plants were transplanted to 3 m-wide ridges, 2.5 m apart, in a greenhouse on 3 December, 2002. The surface of the ridges was covered with straw mulch and fertilizer (N: 5.4, P: 7.7, P: 4.7 kg per 10 m^2) was applied to the soil before planting. Five to 6 plants per cultivar (2 to 3 plants per sex type) were used for the study.

Female and hermaphrodite flowers were left unbagged. Fruits were harvested from 3 August to 28 November, 2003 (2 months post-flowering) and at every harvest times, the presence of seeds in the fruits was confirmed. The number of fruits per tree, fresh weight per fruit, and fruit yield per tree, were recorded. Regression analyses were performed between fruit yield and number of fruits per tree, and between fruit yield per tree and individual fruit weight, for both females and hermaphrodites of cultivars tested.

Variation in parthenocarpic ability of sex types and cultivars: Seven cultivars, 'Dantesu', 'Fruit Tower', 'Kansen', 'Perfect', 'Tropicana' (Wakaba Seed Co., Okinawa, Japan), 'Taino-2' and 'Taino-5' (Noyu Seed Co., Taipei, Taiwan) were used. Six plants each of females and hermaphrodites from each cultivar were used in the experiment, with the exception of 'Taino-2', for which only female plants were available. Sowing and transplantation dates, as well as cultivation conditions, were as described above.

Two experimental plots (pollination and non-pollination) were established to evaluate differences in fruit-setting rates (percentage of flowers that set fruit: parthenocarpic ability) between sex types and among cultivars. To prevent natural pollination, all flowers of female and hermaphrodite plants were covered with paper bags 2 days before flowering. In both plots, the anthers of hermaphrodite flowers were emasculated before bagging. In the pollination plot, female and hermaphrodite flowers were hand-pollinated on the day of flowering with fresh pollen collected from male plants cultivated in another greenhouse. In the non-pollination plot, female and emasculated hermaphrodite flowers were left bagged for a week, until the stigmatic lobes turned brown.

Data for fruit weight were collected 60 days after bagging, from 16 September to 31 October, 2003. Number of fruits per sex type per cultivar varied from 8 to 29 in the hand-pollination and from 6 to 23 in the non-pollination plots. Differences in fruit weight between the plots were analysed using the Mann-Whitney U-test. Fruit-setting rates were determined for both sex types of 'Dantesu', 'Fruit tower', 'Kansen', and 'Taino-5' and for females of 'Taino-2'. Ten to 30 flowers per sex type were used, and parthenocarpic ability was compared between females and hermaphrodites using the chi-square test on summed data of each sex type.

Promotion of fruit swelling by GA treatment: The cultivar, 'Fruit Tower', was used for the experiment. Seedlings were raised from 12 October to 1 December, 2003. From the seedling population, only female plants were selected using a sex-specific DNA molecular marker (Urasaki *et al.*, 2002). Cultivation conditions were as described above.

Three experimental plots (pollination, non-pollination, and GA treatment) were established and treatments were conducted from 30 April to 2 September, 2004. In the pollination plot, fresh pollen collected from male plants raised in another greenhouse was used; in the non-pollination plot, flowers were not pollinated. In the GA treatment, a commercial GA lanolin paste with 2.7% GAs (containing 85% active GA_3; Kyowa hakko, Co. Tokyo, Japan) was applied to flower peduncles with a soft brush. Approximately 100 mg paste per peduncle was applied to flowers 1 day before flowering (-1), flowering day (0), 1 or 2 days after flowering. Fruits were harvested 37 days after the treatment, and their weight was recorded and analysed by the Scheffe's test. All statistic analyses were conducted using a computer program, StaView (ver. 4.5, SAS Institute Inc., 1998).

Results

Difference in fruit yield between females and hermaphrodites: In all the three cultivars, female fruits contained few seeds, but the hermaphrodite ones had abundant seeds (data not shown). In the 'Dantesu', fruits from hermaphrodites were heavier than those from females, although there was little difference in the number of fruits per tree between the sexes (Fig. 1). Thus, the hermaphrodites produced a greater fruit yield per tree than female plants. In the 'Fruit Tower' and 'Kansen', fruits from hermaphrodites were heavier than those from females. However, in both cultivars, females produced a higher number of fruits per tree than hermaphrodites; thus, fruit yield per tree was higher in the former as compared to the latter.

In the three cultivars, fruit yield per female tree was positively correlated with number of fruits per tree (R^2= 0.904, P= 0.001), and with individual fruit weight (R^2= 0.615, P= 0.036). In hermaphrodite trees, fruit yield per tree also correlated with the number of fruits per tree (R^2= 0.747, P= 0.0056), but not with individual fruit weight (R^2= 0.006, p= 0.850). These results suggest that an increase in the number of fruits per tree predominantly contributed to the improvement of fruit yield per tree.

Variation in parthenocarpic ability of sex types and cultivars: Female plants exhibited a significantly higher fruit-setting rate than hermaphrodites in both pollination (x^2= 8.959, P= 0.0028) and non-pollination treatments (x^2= 10.338, P= 0.0013) (Table 1). There were differences in the fruit-setting rates between females and hermaphrodites and among the cultivars (Fig. 2). In the pollination plot, the fruit-setting rate of female plants varied from 80 % ('Kansen') to 100 % ('Dantesu', 'Fruit tower', and 'Taino-2'), whereas hermaphrodites varied from 37.5 % ('Fruit Tower') to 94.7 % ('Taino-5'). In the non-pollination plot, the rate in females ranged from 60 % ('Kansen') to 100 % ('Dantesu' and 'Fruit tower'); the hermaphrodites ranged from 20 % ('Fruit tower') to 81.3 % ('Kansen').

Table 1. Fruit setting rates between female and hermaphrodite papaya in pollinated and non-pollinated flowers

Sex type[1]	Pollinated				Non-pollinated			
	Number of flowers used	Number of fruits developed	Number of flowers abscised	Fruit setting rate (%)**	Number of flowers used	Number of fruits developed	Number of flowers abscised	Fruit setting rate (%)**
Female	95	79	16	83.2	90	65	25	72.2
Hermaphrodite	145	95	50	65.5	92	45	47	48.9

[1] Data from female or hermaphrodite cultivars were summed up. ** Significant at P<0.0028

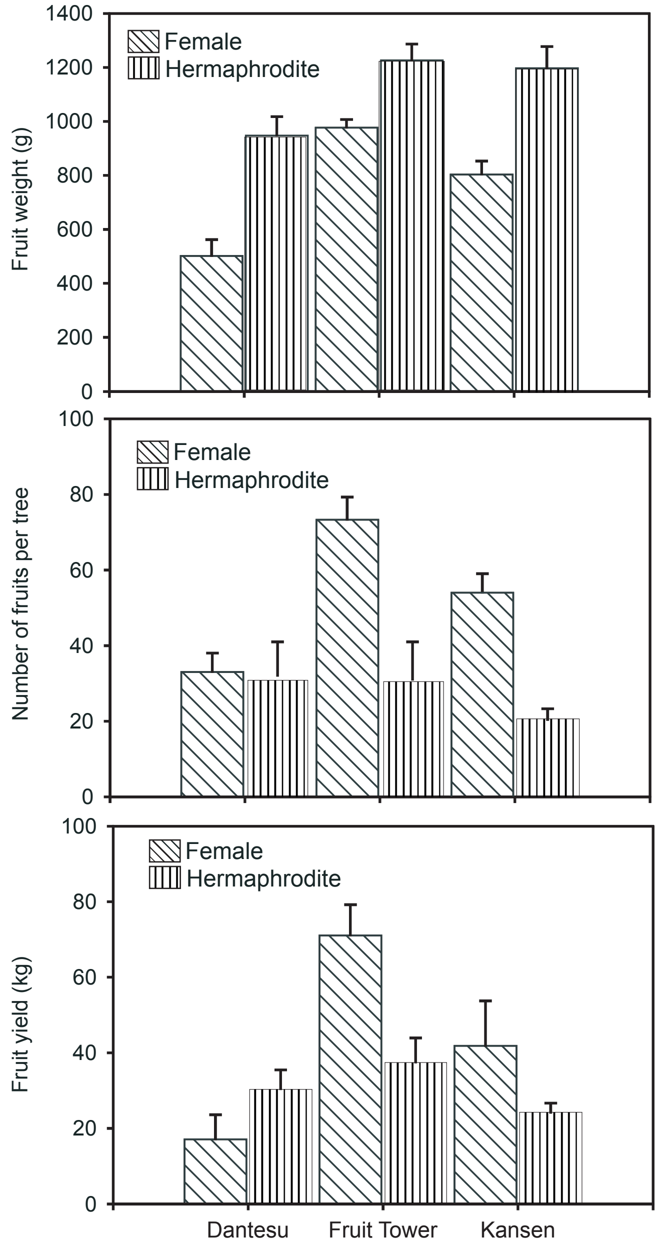

Fig. 1. Number of fruits per tree, fruit weight, and fruit yield per tree in female and hermaphrodite plants

The pollinated fruits were significantly heavier than non-pollinated ones in both sex types of all the cultivars, *i.e.*, pollinated fruits were twice as heavy as non-pollinated ones in both sex types (Fig. 3). Among cultivars, the females of 'Fruit tower' and 'Tropicana' yielded the heaviest fruits from pollinated flowers. In addition, pollinated fruits had thicker flesh than non-pollinated in both sex types (data not shown).

Promotion of fruit swelling by GA treatment: GA treatment effectively promoted fruit swelling (Fig. 4). The pollinated fruits were twice as heavy as the non-pollinated ones. The GA treatment further increased fruit weight, *i.e.*, the fruits were 3 times as heavy as the non-pollinated fruits and 1.5 times of the pollinated ones.

The optimal flower age for the GA treatment ranged from flowering day to 2 days after flowering (Fig. 4). Flowers treated 2 or 3 days after flowering yielded significantly heavier fruits than those treated 1 day before flowering.

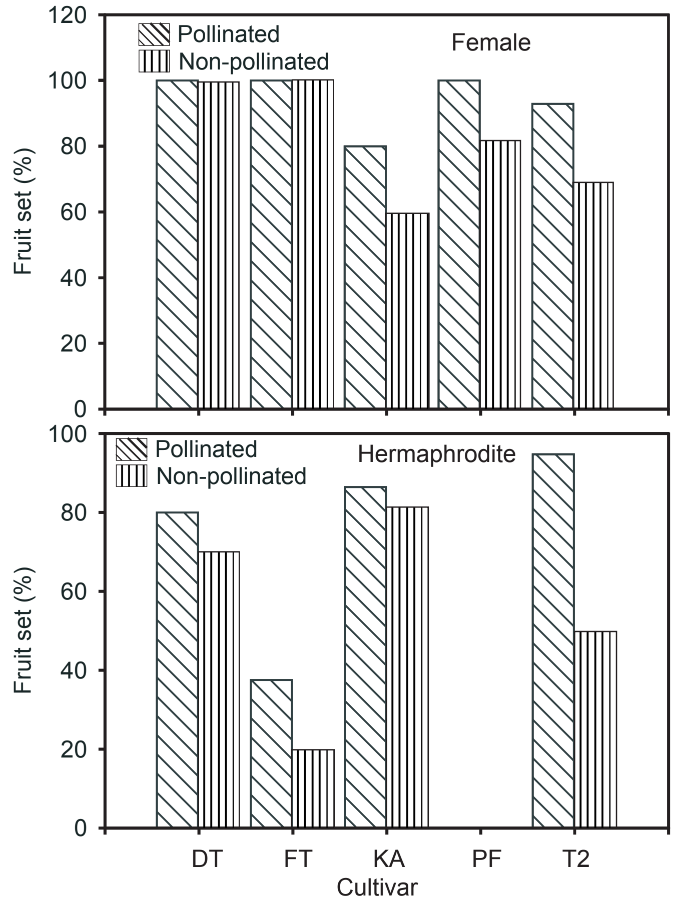

Fig. 2. Fruit-setting rates in pollinated and non-pollinated female and hermaphrodite plants

Discussion

The primary determinant of fruit yield in the papaya plants was the number of fruits per tree; the secondary determinant was individual fruit weight. Thus, increasing the number of fruits per tree appears to be a critical factor in improving fruit yield. In addition, female plants were superior to hermaphrodites at increasing the number of fruits per tree during the hot summer season. This is likely due to the stability of female flowers with respect to sex changes. Therefore, in subtropical regions such as Australia (Aquilizan, 1987) and Okinawa, female papaya plants are considered to be better suited to fruit production than hermaphrodites.

In subtropical regions, the breeding of female cultivars with high fruit-setting rates (parthenocarpic ability) will be important for the improvement of fruit productivity. In this study, we confirmed that both female and hermaphrodite plants exhibit parthenocarpic ability and that female plants possess significantly higher parthenocarpic ability than hermaphrodites. This ability varied among cultivars. The intraspecific variation of this trait suggests a potential possibility of improving papaya genotypes with high parthenocarpic ability. Recently, Rimberia *et al.* (2005) reported an anther culture technique for papaya, by which only female plants were produced from microspores. Such *in vitro* techniques may prove useful in raising female genotypes with high parthenocarpic ability.

As observed in this study, parthenocarpic fruits were smaller than pollinated fruits. However, GA treatment resulted in a

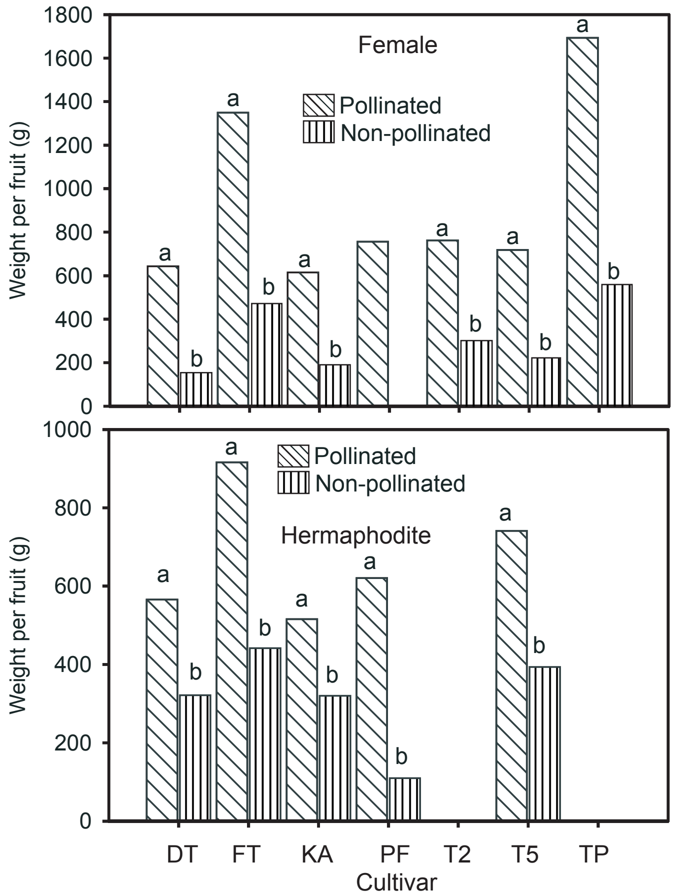

Fig. 3. Differences in fruit weight between hand-pollinated and non-pollinated fruits in female and hermaphrodite cultivars. DT: 'Dantesu', FT: 'Fruit tower', KA: 'Kansen', PF: 'Perfect', T-2: 'Taino-2', T-5: 'Taino-5', and TP: 'Tropicana'. Bars having different letters indicate significant differences between pollination and non-pollination by Mann-Whitney's U-test ($P<0.03$).

significant increase in parthenocarpic fruit size, when compared to either non-pollination or pollination treatments. Moreover, the GA paste could be applied over a range of flower ages, from day of flowering through to 3 days post-flowering, whereas optimal results for fruit development from hand pollination are restricted to the day of flowering itself (Ray, 2002). These results suggest that GA treatment provide greater flexibility than a conventional hand pollination schedule, and may represent a feasible alternative for fruit production from female papaya plants, under greenhouse conditions.

Based on the results obtained, we propose that an efficient production system of vegetable papaya can be realized by: 1) selection of females with high parthenocarpic ability; 2) cultivation of only female plants separated by sex-diagnostic PCR techniques; and 3) promotion of fruit swelling by GA treatments.

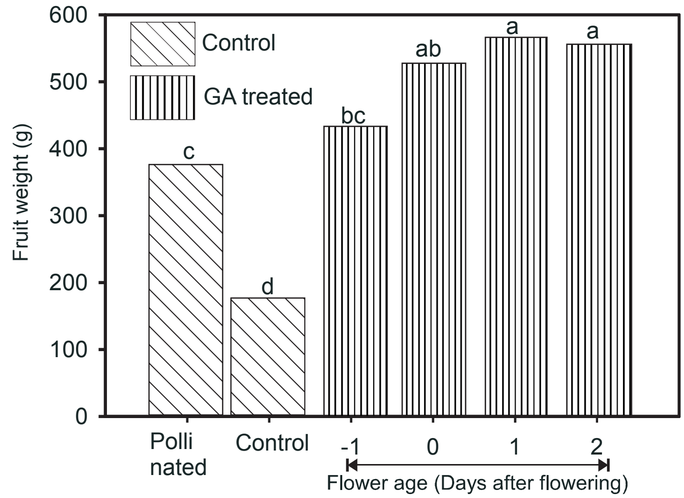

Fig. 4. Effect of GA on fruit swelling. Bars having different letters indicate significant differences by Scheffe's test ($P<0.015$).

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