

Prominent Traits of Some F1 Hybrid Papaya Lines in Thailand

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This study identified and compared characteristics of 10 F1 hybrid papayas that were obtained by crossing five cultivars selected for high yield and tolerance to *Papaya ring spot virus* (PRSV). The hybrids were tested at the Papaya Research and Development Center, Maha Sarakham Province, from January to December 2013. The results showed that hybrids No. 1 ('Yellow Krang' × 'Red Krang'), No. 2 ('Yellow Krang' × 'Khaek Dam'), No. 3 ('Yellow Krang' × 'Florida'), No. 4 ('Yellow Krang' × 'Khaek Nuan') and No. 5 ('Khaek Dam' × 'Khaek Nuan') had good yield and fruit qualities but they were more susceptible to PRSV than hybrids No. 6 ('Khaek Dam' × 'Florida'), No. 7 ('Red Krang' × 'Florida'), No. 8 ('Red Krang' × 'Khaek Nuan'), No. 9 ('Khaek Dam' × 'Florida') and No. 10 ('Florida' × 'Khaek Nuan'). Hybrid No. 2 ('Yellow Krang' × 'Khaek Dam') had the lowest tolerance to PRSV, with disease incidence of 3.56 on a scale of 0–4. Hybrids No. 2 and No. 5 produced more fruits than the others, while hybrid No. 3 had the lowest yield with only 16 fruits/plant/year. Hybrids with 'Florida' cultivar as parent tended to have better tolerance to PRSV.

Key Words: *Carica papaya*, conventional breeding, cultivar, *Papaya ringspot virus*, papaya yield

Abbreviations: PRSV – *Papaya ringspot virus*, TSS – total soluble solids

INTRODUCTION

Papaya (*Carica papaya* L.) is easy to grow and propagate. It is an early-bearing tree that produces fruit all year round. The fruit is nutritious, so papaya is a popular crop in the tropics and subtropics, both as a food crop and as a source of papain, which is used in the pharmaceutical and food industries (Janthasri 2007; Somsri 2014). In Thailand, especially in the northeast region, most farmers grow papaya as a backyard crop for home consumption and for marketing. Papaya is most commonly eaten in the form of green papaya salad, or "som tam," which is a staple food in Thailand.

The major problem with papaya growing is prevention of a *Papaya ringspot virus* (PRSV) epidemic. PRSV was first reported in northeastern Thailand in 1975. It quickly spread and by 2003, 80% of the growing areas in Thailand were infected by the disease. The virus had a serious negative effect on the yield and quality of papaya all over the country (Janthasri 2007). Although transgenic papaya with resistance to PRSV has been developed, it has not gained approval for

commercial production in Thailand and many other countries (Drew 2014).

In 1986, Prof. Dr. Dennis Gonsalves of Cornell University, a papaya consultant for Thailand's Department of Agriculture, introduced the 'Florida Tolerant' cultivar, which is tolerant to PRSV, for testing by growers in northeastern Thailand. Its disease-resistance qualities were quite good, but because the fruits are small and round and the flesh is yellow when ripe, it was not popular with Thai consumers. Prasartsee (1997) thus tried crossing 'Florida Tolerant' with the local 'Khaek Dam' cultivar that is very popular in Thailand. 'Khaek Dam' has dark orange flesh when ripe but is very susceptible to PRSV.

Hybridization and selection work carried out from 1987 to 1994 resulted in the introduction of three hybrid cultivars called 'Thaphra 1', 'Thaphra 2' and 'Thaphra 3' that were tested all over the country. 'Thaphra 2' was selected as the most suitable cultivar because it was dwarf (1.3 m tall), had good disease tolerance and high yield. Its tolerance level was 79% compared with that of 'Khaek Dam'. 'Thaphra 2' could also produce fruit

in only 6–7 mo, and the flesh was crispy when unripe, orange-yellow when ripe, sweet and fragrant. In 1997 the Department of Agriculture thus registered the ‘Thaphra 2’ hybrid line as a new recommended cultivar and gave it the name ‘Khaek Dam Thaphra’. The Department produced seeds and seedlings to distribute to farmers and the general public. From 1998 up to the present, ‘Khaek Dam Thaphra’ has spread almost all over the country (to 60 of the 76 provinces). Nevertheless, ‘Khaek Dam Thaphra’ is not 100% PRSV-tolerant and its fruit flesh is light orange-yellow, not the dark orange that most Thai consumers prefer. At present it is mostly sold for unripe fruit consumption. In addition, when the papaya is grown in any area, it has become less resistant to disease, even if new cultivars are used (Prasartsee et al. 2002 unpublished).

The objectives of this research were (1) to study the characteristics of F1 papaya hybrids obtained by making ten reciprocal crosses between ‘Florida’, ‘Khaek Dam’ and ‘Khaek Nuan’ with the local ‘Yellow Krang’ and ‘Red Krang’ from Maha Sarakham Province, and (2) to select promising hybrids that combine disease tolerance with high yield and good eating qualities for future breeding efforts. The hybrids were tested at the Papaya Research and Development Center, Maha Sarakham Province, from January to December 2013.

MATERIALS AND METHODS

Five papaya cultivars with good characteristics were selected as the parents, namely:

- ‘Yellow Krang’: reasonably tolerant to PRSV and suitable for producing fruits with crispy flesh when unripe, and yellow when ripe
- ‘Red Krang’: somewhat tolerant to PRSV and suitable for producing fruits with crispy flesh when unripe and red when ripe
- ‘Florida’: tolerant to PRSV, and suitable for producing fruits with yellow flesh when ripe
- ‘Khaek Dam’: suitable for producing fruits with red flesh when ripe, but very susceptible to PRSV
- ‘Khaek Nuan’: suitable for producing consumable fruits when unripe, but susceptible to PRSV

The seeds for the parent plants to be crossed were obtained from the Papaya Research and Development Center, Maha Sarakham Province.

Every possible pair of parents were crossed using the following hand pollination method:

- Flowers were observed and at the stage when the ends of the petals of the hermaphrodite flowers were beginning to curve but had not fully opened, the whole hermaphrodite flower that would serve as the pollen donor was plucked from the male parent plant, and then the petals were removed, leaving only the fully mature anthers (when tapped onto the palm of one’s hand, light yellow powder was observable).
- Selected hermaphrodite flowers on the female parent plants were emasculated by using forceps to remove all the anthers, and then donated pollen from the male parent plant was brushed lightly onto the stigma. Each hermaphrodite flower was labeled.
- Hand pollination was performed from 7:00 to 10:00 a. m.

Paternal Parent	Maternal Parent	F1 Code	No. of Plants
1 ‘Yellow Krang’	× ‘Red Krang’	RMU 1	10
2 ‘Yellow Krang’	× ‘Khaek Dam’	RMU 2	10
3 ‘Yellow Krang’	× ‘Florida’	RMU 3	10
4 ‘Yellow Krang’	× ‘Khaek Nuan’	RMU 4	10
5 ‘Red Krang’	× ‘Khaek Dam’	RMU 5	10 (Fig. 1)
6 ‘Red Krang’	× ‘Florida’	RMU 6	10 (Fig. 2)
7 ‘Red Krang’	× ‘Khaek Nuan’	RMU 7	10
8 ‘Khaek Dam’	× ‘Florida’	RMU 8	10 (Fig. 3)
9 ‘Khaek Dam’	× ‘Khaek Nuan’	RMU 9	10
10 ‘Florida’	× ‘Khaek Nuan’	RMU 10	10 (Fig. 4)

*RMU stands for “Rajabhat Maha Sarakham University”.

The hybrid trees from each cross that best met the selected criteria were selected and 10 fruits were taken to serve as sources of seeds to obtain the F1 generation for this experiment. The selection criteria were as follows:

1. Higher yield than the parent plants to a statistically significant degree when analyzed by t-test ($p < 0.05$)
2. PRSV tolerance measured at 3–3.5 when grown under northeastern Thailand conditions
3. Tree height no more than 160 cm when the first full set of flowers appeared
4. Unripe fruit weight of approximately 0.8–1.5 kg



Fig. 1. Red Krang × Khaek Dam hybrid papaya

Fig. 2. Red Krang × Florida hybrid papaya

Fig. 3. Khaek Dam × Florida hybrid papaya.



Fig. 4. Florida × Khaek Nuan hybrid papaya.

5. Fruit size suitable for making “som tam” (30–40 cm long and 30–35 cm in circumference)
6. Suitable for unripe fruit consumption (crisp flesh)

To grow seeds from the selected hybrids, peat moss was used as the planting material in containers with good drainage. The seeds were sown in the containers and thoroughly watered. They started to germinate in about 14 d.

To prepare the planting material for seedlings, plastic bags (16 × 10.5 or 10.5 × 10.5 cm) were filled with potting soil that was a 1:1:1 mixture of loam to burned rice husks to dried rice husks. The bags were filled with planting medium and thoroughly watered.

When the papaya seeds had sprouted and had two seed leaves, they were pulled by hand from the peat moss and planted in the prepared seedling bags. After about 30 d, the seedlings were ready to be planted out in the field.

The selected test field was located at least 800 m from any space where other cultivars of papaya were grown in order to prevent cross pollination.

The land was plowed and cultivated to remove weeds. After plowing, the turned-over soil was left to dry for 10–15 d, then berms were made that were 20–30 cm high and 1.5 m wide, with a distance of 2.5–3.0 m between the middle of one berm to the next. Papayas were planted on the berms to promote drainage.

Holes 50 × 50 × 50 cm were dug in the berms and left to dry for 7–10 d, then the soil that had been dug out was broken down to smaller particles. Manure and compost made from rice straw or decomposing leaves were put into the holes first to improve moisture retention, then the soil from the hole was thoroughly mixed with about one shovel full of manure or compost, 100 g of rock phosphate, and 200 g of 15-15-15 or 16-16-16 chemical fertilizer per hole, and then returned to fill the hole. A stake was fixed in the middle of each hole to mark the middle and keep the rows straight.

When the seedlings were 1 mo old, they were planted in the prepared holes, one seedling per hole. For each hybrid line, 30 seedlings were selected to grow 30 trees per row (Fig. 5).

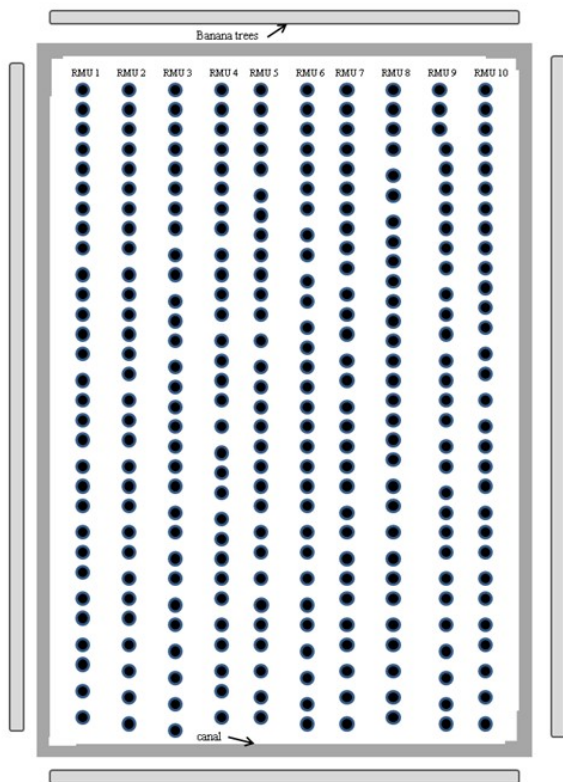


Fig. 5. Experimental field layout with 300 papaya trees in 10 rows surrounded by a canal and banana trees.

The experiment was a randomized complete block design (RCBD) with 10 hybrid lines and three replications of each hybrid line, and with 10 trees per replication.

Chemical fertilizer formula 15-15-15 was applied at the rate of 1 g per tree every 15 d, and after the trees flowered, chemical fertilizer formula 13-13-21 was applied at the rate of 1 g per tree. Manure or compost was applied regularly. The trees were watered twice a day, every morning and evening.

Data were collected from the stage of seed germination up to harvest for an experimental period of 12 mo, from January to December, 2013.

The following parameters were measured on each tree:

1. Height in centimeters, measured with a 2-m ruler. A mark was made on the stem 10 cm from soil level and each time the measurement was made from that mark up to the uppermost shoot apex.
2. Stem circumference in centimeters, measured

10 cm from soil level using a measuring tape.

3. Number of marketable fruits per tree per year (very small, misshapen, non-uniform or otherwise unmarketable fruits were not counted).
4. Fruit weight in kilograms, measured with a digital balance
5. Fruit width at the widest point in centimeters, measured with a ruler
6. Fruit length in centimeters, measured with a ruler
7. Flesh thickness in centimeters, by cutting each fruit lengthwise, measuring with a ruler at the thinnest part and the thickest part, and then taking the average
8. Total soluble solids in degrees Brix, measured by hand refractometer. Measurements of ripe fruits from three points in each fruit – top end, middle and bottom end – were averaged.
9. Number of seeds per fruit
10. Percentage of fruits displaying disease symptoms

Incidence of PRSV was evaluated on a scale of 0–4 as follows:

- Level 0 = no symptoms; very good tolerance
- Level 1 = very mild mottling, meaning yellow areas covering 1–25% of the leaf area, with some ring spots on leaves but no perceptible symptoms on fruit, no bruises or streaks on petioles and stem; good tolerance
- Level 2 = mild to moderate mottling, meaning yellow areas covering 26–50% of the leaf area, fruit mostly smooth with some ring spots, no bruises or streaks on petioles or stem; medium tolerance
- Level 3 = mottling, meaning yellow areas covering 51–75% of the leaf area, clear evidence of ring spots all over the fruit, and bruises or streaks on the petioles and stem; little tolerance
- Level 4 = severe mottling, meaning yellow areas covering 75–100% of the leaf area, deformed or brittle leaves up to severe leaf distortion with only the midrib visible, clearly seen ring spots all over the fruit, scabby spots, deformed fruit, rough outer peel and bitter, grainy flesh; no tolerance (Prasartsee et al. 2009 unpublished)

Data Analysis

Differences between means of the treatments were analyzed by Duncan's Multiple Range Test (DMRT) (Gomez and Gomez 1984) using MSTAT software (Bricket 1989).

RESULTS AND DISCUSSION

Plant Height

There were statistically significant differences in height among the 10 F1 hybrid lines. The tallest mean height was observed in the 'Red Krang' × 'Khaek Nuan' group, with mean plant height of 128 cm. The 'Yellow Krang' × 'Khaek Nuan' group was the shortest with an average height of 54 cm (Table 1). Papaya plants increase in height every month up until the age of about 1 yr, and then plant height tends to level off or increase very slowly. Plant height increases the fastest when the plant is 4–6 mo old (Janthasri and Chaiyaboon 2014 unpublished). In general, shorter papaya plants are preferred by growers for greater ease of harvest and to reduce the risk of wind damage. Three of the hybrids in this study had a mean height of greater than 1 m, and even the seven hybrids that measured less than 1 m were not as dwarfish as the PRSV-tolerant inbred lines Py-1, Py-2, Py-4, Py-5 and Py-6 developed by the Institute of Plant Breeding, University of the Philippines Los Baños, which were reported to measure 47.50, 49.57, 46.79, 24.00, and 30.00 cm high, respectively, at time of first flowering (Villegas et al. 1996). 'Red Lady' cultivar commonly starts to flower after reaching a height of about 70 cm (Paramount Seeds 2016).

Stem Circumference

Statistically significant differences were also observed in stem circumference (measured 5 cm from ground level) among the different hybrids. The 'Red Krang' × 'Khaek Nuan' group had the largest trunk circumference (56 cm), followed by the 'Florida' × 'Khaek Nuan' group (55 cm), the 'Red Krang' × 'Florida' group (51 cm), the 'Khaek Dam' × 'Florida' group (36 cm), and the 'Red Krang' × 'Khaek Dam' group (34 cm). The 'Yellow Krang' × 'Florida' group had the smallest mean stem circumference of 26 cm (Table 1). The range of stem circumferences of 26–56 cm observed in this study is larger than the average for most papaya cultivars, which is indicative of hybrid vigor. This result is consistent with the findings of Chan (2014), who reported that the 'Frangi' hybrid papaya developed by Malaysian AgriFood Corporation (MAFC) in 2007 was more vigorous in stem and canopy development compared with the parents. Similarly, Prasartsee et al. (2009 unpublished) reported that the 'Phichit' hybrid had morphological characteristics superior to those of the parent plants ('Khaek Dam' and 'Coimbatore No. 2' obtained from Sri Lanka). Trunk circumference increases more slowly than plant height, at the rate of about 1–2 cm a month, with the fastest rate of increase when the tree is 5–7 mo old (Janthasri and Chaiyaboon 2014 unpublished).

Number of Fruits per Tree per Year

There were also statistically significant differences in number of fruits per tree per year among the 10 hybrid lines. The 'Khaek Dam' × 'Khaek Nuan' line and the 'Florida' × 'Khaek Nuan' line gave the highest number of fruits per year (44 and 41, respectively). The 'Yellow Krang' × 'Red Krang'

Table 1. Mean height, circumference at base and number of fruit per year of F₁ hybrid papaya from 10 crosses.

Parents	Height (cm)	Stem Circumference 5 cm from Soil Level (cm)	No. of Fruit/ Tree/Year
'Yellow Krang' × 'Red Krang'	72 ^{b1/}	35 ^{ab}	17 ^b
'Yellow Krang' × 'Khaek Dam'	90 ^{ab}	31 ^{ab}	40 ^a
'Yellow Krang' × 'Florida'	59 ^b	26 ^{ab}	21 ^b
'Yellow Krang' × 'Khaek Nuan'	54 ^b	31 ^{ab}	32 ^{ab}
'Red Krang' × 'Khaek Dam'	109 ^a	34 ^{ab}	35 ^{ab}
'Red Krang' × 'Florida'	98 ^a	51 ^a	38 ^{ab}
'Red Krang' × 'Khaek Nuan'	128 ^a	56 ^a	36 ^{ab}
'Khaek Dam' × 'Florida'	87 ^{ab}	36 ^{ab}	40 ^a
'Khaek Dam' × 'Khaek Nuan'	71 ^b	30 ^{ab}	44 ^a
'Florida' × 'Khaek Nuan'	117 ^a	55 ^a	41 ^a
F-test	**	**	**
C.V. (%)	6.4	2.8	3.2

^a Statistically significant difference at 99% confidence level

^{1/} Mean values followed by different superscripts in the same column signify a statistically significant difference at 95% confidence level using Duncan's Multiple Range Test (DMRT).

group had the lowest number of fruits, at only 17 fruits per tree per year (Table 1). By comparison, 'Red Lady' cultivar typically produces an average of 35 fruits per season (Paramount Seeds 2016) while the 'Sinta F1' hybrid can produce from 35 to 60 fruits per fruiting cycle (Villegas et al. 1996). Chan (2014) has reported very impressive heterosis in hybrid papaya, with yield up to 200% higher than the better parent exhibited by their 'Morib' × 'Solo' cross.

Fruit Weight

Statistically significant differences were observed in fruit weight among the 10 hybrid crosses. The group with the greatest mean fruit weight was 'Yellow Krang' × 'Khaek Dam' (3.48 kg), followed by 'Red Krang' × 'Khaek Nuan' (3.28 kg), 'Khaek Dam' × 'Florida' (2.90 kg), 'Florida' × 'Khaek Nuan' (2.89 kg) and 'Yellow Krang' × 'Red Krang' (2.77 kg). The hybrid lines with the smallest fruit were 'Yellow Krang' × 'Florida' (2.44 kg), 'Red Krang' × 'Khaek Dam' (2.51 kg) and 'Khaek Dam' × 'Khaek Nuan' (2.52 kg) (Table 2). The hybrid lines with the smallest fruit were mostly derived from parent cultivars that were bred to be used as ripe papaya fruit for export, because consumers in overseas markets tend to prefer smaller fruits with yellow-orange flesh. For example, 'Maradol' fruits usually weigh 1.5–2.6 kg (Aloha Seed and Herb 2008) and 'Vega F1' fruits normally weigh 1.0–1.2 kg (Kenya Highland Seed 2012). On the other hand, the 'Khaek Dam' and 'Khaek Nuan' cultivars that are most frequently consumed unripe were selected for their larger fruits. The genetic tendency of 'Red

Krang' and 'Yellow Krang' is to have long fruit, reaching at least 55–60 cm at 7–8 mo, so hybrids with one of these cultivars as parent tended to have larger and heavier fruits (Janthasri and Chaiyaboon 2014 unpublished).

Fruit Width and Length

The fruit dimensions (width × length) differed among the 10 hybrid lines to a statistically significant degree. The three groups with the largest mean fruit size were 'Yellow Krang' × 'Khaek Dam' (19.8 × 34.1 cm), 'Red Krang' × 'Florida' (17.2 × 33.1 cm) and 'Red Krang' × 'Khaek Nuan' (16.9 × 26.7 cm). The two groups with the smallest mean fruit size were 'Yellow Krang' × 'Khaek Nuan' (14.1 × 25.6 cm) and 'Khaek Dam' × 'Khaek Nuan' (11.5 × 22.6 cm), as shown in Table 2.

Total Soluble Solids

Testing for total soluble solids (TSS, a measure of sweetness) showed that fruits from the 'Khaek Dam' × 'Florida' cross and the 'Yellow Krang' × 'Khaek Nuan' cross had the highest TSS at 15.62 °B and 15.60 °B, respectively. Fruits from the 'Red Krang' × 'Khaek Dam' group and those from the 'Yellow Krang' × 'Red Krang' group had the lowest TSS, as shown in Table 2. By comparison, TSS of 'Vega F1' is recorded at 12–14 °B (Kenya Highland Seed 2012) and the TSS of 'Sinta F1' is on average 14 °B, according to East-West Seed (East-West Seed Group 2011). Sweet flavor is not a major consumer requirement for papaya that is normally consumed in the form of unripe fruit for salad making, such as 'Yellow Krang' and 'Red Krang'. Crispiness and

Table 2. Mean fruit weight, fruit width, fruit length, flesh thickness, total soluble solids (TSS), number of seeds and *Papaya ring spot virus* (PRSV) resistance level of F₁ hybrid papaya from 10 crosses.

Parents	Fruit Weight (kg)	Fruit Width (cm)	Fruit Length (cm)	Flesh Thickness (cm)	TSS (°B)	Seeds/Fruit	Observed Level of PRSV (0–4)
'Yellow Krang' × 'Red Krang'	2.77 ^{ab1}	11.4 ^b	31.3 ^a	3.20	9.72 ^{c1}	1,310.8a	3.21 ^a
'Yellow Krang' × 'Khaek Dam'	3.48 ^a	19.8 ^a	34.1 ^a	3.17	12.50 ^b	1,285.3a	3.64 ^a
'Yellow Krang' × 'Florida'	2.44 ^b	14.9 ^b	33.8 ^a	3.00	11.19 ^b	1,069.3 ^b	2.12 ^a
'Yellow Krang' × 'Khaek Nuan'	2.60 ^b	14.1 ^b	25.6 ^b	3.16	15.60 ^a	991.1 ^b	3.39 ^a
'Red Krang' × 'Khaek Dam'	2.51 ^b	16.0 ^a	26.3 ^b	2.96	8.25 ^c	944.6 ^b	2.54 ^b
'Red Krang' × 'Florida'	2.70 ^{ab}	17.2 ^a	33.1 ^a	3.10	11.12 ^b	1,381.4 ^a	2.33 ^b
'Red Krang' × 'Khaek Nuan'	3.28 ^a	16.9 ^a	26.7 ^b	3.11	12.30 ^b	1,246.1 ^a	2.61 ^b
'Khaek Dam' × 'Florida'	2.90 ^a	12.6 ^b	32.7 ^a	2.97	15.62 ^a	1,109.3 ^b	1.45 ^b
'Khaek Dam' × 'Khaek Nuan'	2.52 ^b	11.5 ^b	22.6 ^b	2.94	10.24 ^b	1,159.8 ^b	3.50 ^a
'Florida' × 'Khaek Nuan'	2.89 ^a	14.0 ^b	30.9 ^a	2.98	11.32 ^b	711.3 ^c	1.66 ^b
F-test	**	**	**	ns	**	**	**
C.V. (%)	2.16	7.10	5.12	-	10.52	7.15	4.13

ns: Non-significant difference * Statistically significant difference at 99% confidence level

¹ Mean values followed by different superscripts in the same column signify a statistically significant difference at 95% confidence level using Duncan's Multiple Range Test (DMRT).

lack of bitterness are the main sought-after qualities for papaya consumed in unripe form. This observation is consistent with the findings of the Pak Chong Research Station (2006), which reported on the project to develop the 'Pak Chong 2' papaya cultivar at the Insee Jantarasatid Institute for Plant Science Research and Development in Pak Chong District, Nakhon Ratchasima Province from 1997 to 2006. The researchers there intended to develop a new papaya cultivar that would be superior to the commercial cultivars that were currently available. They selected three lines from the 'Khaek Dam' × 'Pak Chong 1' hybrid cross, and after seven cycles of selection obtained the 'Pak Chong 2(12-21)' line, with medium-sized fruit weighing 1–1.2 kg each, yellow skinned when ripe, with red-orange flesh, 3 cm thick, and total soluble solids of 12–14 °B.

Number of Seeds

Statistically significant differences were also found in number of seeds per fruit. The hybrid groups with the greatest number of seeds per fruit were 'Red Krang' × 'Florida', 'Yellow Krang' × 'Khaek Dam', 'Red Krang' × 'Khaek Nuan', and 'Khaek Dam' × 'Khaek Nuan'. The hybrid group with the least seeds was 'Florida' × 'Khaek Nuan', because the 'Florida' parent is a cultivar with small-sized fruit. When 'Florida' was used as the pollen donor or paternal parent, the trait for few seeds was passed down, but when 'Florida' was the maternal parent, there was no effect (Table 2).

PRSV Tolerance

Data from the field trials of the 10 hybrid lines in Maha Sarakham Province showed that the 'Yellow Krang' × 'Khaek Dam' line, the 'Khaek Dam' × 'Khaek Nuan' line and the 'Yellow Krang' × 'Khaek Nuan' line had less resistance to PRSV than the 'Khaek Dam' × 'Florida' line, the 'Florida' × 'Khaek Nuan' line, the 'Yellow Krang' × 'Florida' line, and the 'Red Krang' × 'Florida' line. The 'Yellow Krang' × 'Khaek Dam' hybrid line was the most susceptible to PRSV with a mean disease incidence rating of 3.64 (Table 2). The leaves of these trees were clearly mottled and there were a large number of ring spots on the fruits as well as severe bruising and streaking on the petioles and trunks. This finding is in agreement with the report of Prasartsee (1997) indicating that 'Khaek Dam' was the cultivar with the least resistance to PRSV. Nevertheless, in the present study, the hybrid line that had the greatest tolerance to PRSV was the 'Khaek Dam' × 'Florida'

line, followed by the 'Florida' × 'Khaek Nuan' line, the 'Red Krang' × 'Florida' line, the 'Red Krang' × 'Khaek Dam' line, and the 'Red Krang' × 'Khaek Nuan' line, in that order. These hybrid lines had a mean PRSV incidence level of 1.45–2.61 (Table 2). Most of the hybrids with 'Florida' cultivar as parent had a good tolerance to PRSV, because 'Florida' has been used as a genetic source of PRSV tolerance in papaya breeding programs in other countries (Prasartsee 1997).

Although we did not achieve a truly outstanding level of PRSV tolerance in any of our hybrids in the present research, our results were basically consistent with the findings of Prasartsee et al. (2009 unpublished), who wrote that the 'Khon Kaen 80' papaya cultivar, which was obtained from crossing 'Florida Tolerant' with 'Khaek Dam', had consistently good overall growth rate and good tolerance against PRSV, showing symptoms of yellow mottling on the leaves but no symptoms on the fruit.

Until transgenic papaya is more widely accepted or a new PRSV-resistant cultivar is introduced as a result of the intergeneric crossing work being undertaken in Australia and the Philippines (Drew et al. 2014), a hybrid papaya combining a reasonable degree of PRSV tolerance with high yield and good eating qualities may be the most feasible alternative for papaya producers in Thailand.

CONCLUSION

This study identified and compared F1 hybrids formed by the crossing of five selected cultivars of papaya with the aim of developing a new cultivar for unripe fruit consumption and industrial use. The results showed that the 'Yellow Krang' × 'Khaek Dam' hybrid line and the 'Yellow Krang' × 'Khaek Nuan' hybrid line were very high yielding (32–40 fruits per year). Normally, 'Yellow Krang', 'Red Krang', 'Khaek Dam' and 'Khaek Nuan' are all cultivars that are used for unripe papaya consumption. When they were used as parental lines for making hybrid crosses, the hybrids thus had good fruit quality for unripe papaya consumption.

In short, three hybrid lines ('Yellow Krang' × 'Red Krang', 'Yellow Krang' × 'Khaek Dam' and 'Yellow Krang' × 'Khaek Nuan') had high yield and good fruit quality for development as cultivars for

unripe papaya consumption. The 'Yellow Krang' × 'Khaek Dam' line was especially promising for good yield and good quality. The 'Yellow Krang' × 'Florida' hybrid line had low yield and low fruit quality. However, most of the hybrid lines that had 'Florida' as a parent showed greater tolerance to PRSV.

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