

# 1 Improving Cultivation of Gac Fruit

Xuan T. Tran<sup>1\*</sup> and Sophie E. Parks<sup>2</sup>

<sup>1</sup>The North Vietnam College of Agriculture and Rural Development,  
Hanoi, Vietnam; <sup>2</sup>Central Coast Primary Industries Centre,  
NSW Department of Primary Industries, Ourimbah, Australia

---

## Abstract

The demand for the Gac fruit is increasing, particularly for the processed food and health industries, but there is a need for improving the cultivation of Gac to meet this demand. Until recently, this crop was underutilized and generally grown in domestic gardens only. Recent research provides us with a greater capacity to propagate and grow the fruit-producing female plants, increase pollen availability with pollen storage, improve fruit set with hand pollination, manage fruit size in plant production and control fruit quality during postharvest. This new knowledge will permit the production of this nutritious fruit at a larger scale and help to conserve this diverse species.

## Introduction

The species *Momordica cochinchinensis* Spreng. has several common names including Gac (Vietnam), Fak kao (Thailand) and Bhat kerala (India) (Kubola and Siriamornpun, 2011) and is endemic to a number of regions in South-East Asia. Gac is a perennial species of the *Cucurbitaceae* family, and it is dioecious with male and female flowers on separate plants. Traditionally, the fruits are collected from the wild or are cultivated from seed or hardwood cuttings in home gardens and are grown over a lattice with the flowers being naturally pollinated by insects. After harvesting the fruit, the main stem of the plant is cut back to about 20 cm above the ground and then regrown, producing fruit again the next year. The plants may produce fruit for up to 15 years.

Several areas of progress have been made through horticultural research on Gac to address

challenges in cultivation and postharvest. For example, one major challenge when growing from seed is not knowing the sex of the plant until the flowers have bloomed. Effective alternatives include vegetative propagation by vine cuttings from plants of known sex, which in one study produced a crop with fruit in less time than for cultivation from seed (Joseph and Bharathi, 2008), and grafting female plants on to seedling rootstocks (Tran *et al.*, 2020). Other areas of progress include research highlighting that pollen can be cool-stored and used in hand pollination, the effects of fruit load on fruit size and the effect of harvest time on fruit maturation and quality during storage (Tran, 2017). This chapter provides an overview of some practices in cultivation and postharvest that can be used as the basis for further developments in the commercialization and conservation of this species.

---

\*Email: [tranxuan77@gmail.com](mailto:tranxuan77@gmail.com)

## Biological Characteristics of the Gac Plant

### Species diversity

*M. cochinchinensis* is a highly variable species with morphological and genetic differences (De Wilde and Duyfjes, 2002; Wimalasiri *et al.*, 2016) that in Vietnam is potentially due to the outcrossing nature of this genus and its adaptability to local conditions (Wimalasiri *et al.*, 2016). This diversity lends itself to selection for cultivation in different climates, with Gac grown in the temperate north and central areas, as well as the tropical south of Vietnam.

Plant breeding is an area of research that can be used for improving the cultivation of Gac. New varieties may be possible with bisexual flowers obtained on a single plant using the technique of female homosexual crosses (Sanwal *et al.*, 2011), which would increase the efficiency of fruit production. Plant breeding is also a promising technique to improve the characteristics of fruit quality since the size of fruit can be increased when *M. cochinchinensis* is used to pollinate *Momordica dioica* (Mohanty *et al.*, 1994) and the effect of genotype on the concentration of carotenoids in the Gac fruit has been demonstrated (Nanta *et al.*, 2020).

### Role of plant parts in crop production

#### Stems and roots

Gac is a perennial climber with high dry matter production and the plant height can reach up to 25 m (Joseph and Bharathi, 2008) (Fig. 1.1a). The stems, as semi-hardwood or hardwood cuttings, play an important role in traditional propagation, particularly in multiplying the female plant for fruit production. The utilization of young stems as softwood cuttings in propagation may be beneficial when the hardwood or semi-hardwood cuttings are limited (Tran *et al.*, 2020). In general, the structure of the stem includes 20 vascular bundles (Shethi *et al.*, 2017) depending on its location (Do and Tran, 2011). The stem is flexible in structure as a result of the wide intercellular spaces between the bundles.

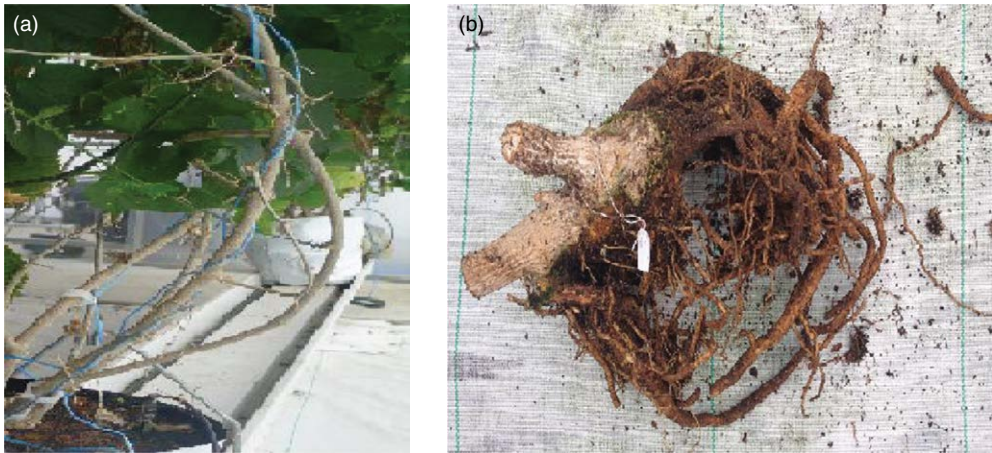
Gac has tuberous roots (Shethi *et al.*, 2017) (Fig. 1.1b). The roots include the bark and pith, with the cork in the bark accounting for 4.5–5.4% of the thickness of the roots. The pith is 80–85% of the root diameter (Do and Tran, 2011), and these are used in some traditional medicines in Vietnam (Do, 2004).

#### Leaves and flowers

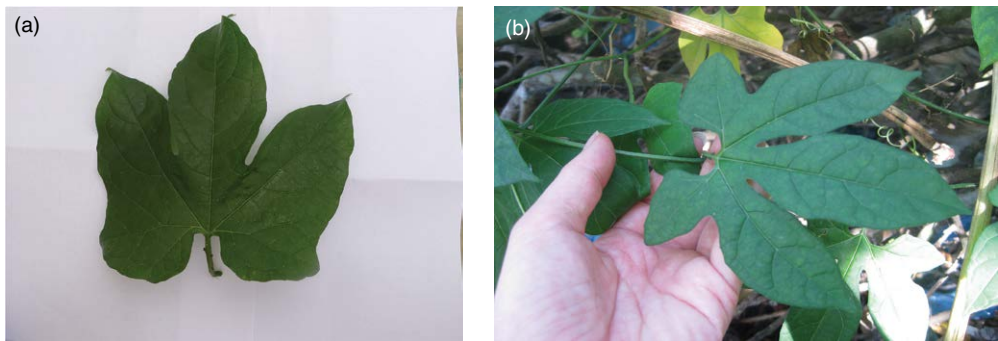
Gac leaves are dark green with three or five lobes (Herklots, 1972; Wimalasiri *et al.*, 2016) (Fig. 1.2a and b) depending on their location (Wimalasiri *et al.*, 2016), and petioles are glandular and robust (Shethi *et al.*, 2017). The leaf is alternifolius with a diameter of 12–20 cm, and the lobes are split into one-third to one-half the area of the blade (Do, 2004). The thickness of the leaf is 143–314  $\mu\text{m}$  (Do and Tran, 2011) and the epidermis has a single layer of barrel-shaped cells with a cuticle (Shethi *et al.*, 2017). The petiole anatomy in the transverse section of the petiole is parabolic.

The number of flowers per plant varies and may be up to 70 flowers. In general, the female flower number is less than the number of male flowers per plant. The first flower is in full bloom 90–100 days after planting and opening (anthesis) usually takes place in the early morning (Bharathi and John, 2013). The flower takes more than 2 h to open and the female flower is receptive for 24 h (Maharana and Sahoo, 1995). The duration of flowering from bud to full bloom can be less for female flowers (19–22 days) than for male flowers (20–24 days) (Vijay *et al.*, 1977). Male flowers tend to appear prior to the main flush of female flowers and pollen can be scarce when required for pollination (Parks *et al.*, 2013a).

The female flower can be detected by a bulge at the base of the flower, which is the unformed fruit (Singh and Vawra, 1988). The bract is small, and sepals are oblong (4–10 mm long). Gac flowers are imperfect flowers which contain either a stamen (male) or a pistil only (female) (Fig. 1.3a and b). The flower is large (7.5 cm across) and cream in colour with five petals and three inner petals (Bharathi and John, 2013). The flower is solitary with a dark bract on the base. The length and width of the calyx are 1.8 and 1.4 cm, respectively.



**Fig. 1.1.** Gac branches (a) and roots (b).



**Fig. 1.2.** Gac leaves: (a) with three lobes; (b) with five lobes. (From Wimalasiri *et al.*, 2016, reprinted with permission from Springer Nature.)



**Fig. 1.3.** Gac flowers: (a) male flower showing three stamens; (b) female flower showing an ovary with three styles.

### *Fruit*

Gac is a large fruit with varied shapes, including globular or oval fruits as observed in the south of

Vietnam and Thailand, and oblong or tapered fruits as in the north of Vietnam (Wimalasiri *et al.*, 2016). The fruit is generally 15–30 cm in length and 8–25 cm in diameter (De Wilde and

Duyfjes, 2002) (Fig. 1.4). The fruit stalk is 5–12 cm long (Bharathi and John, 2013). The components of Gac fruit include the skin, yellow pulp, aril and seed. The fruit generally weighs



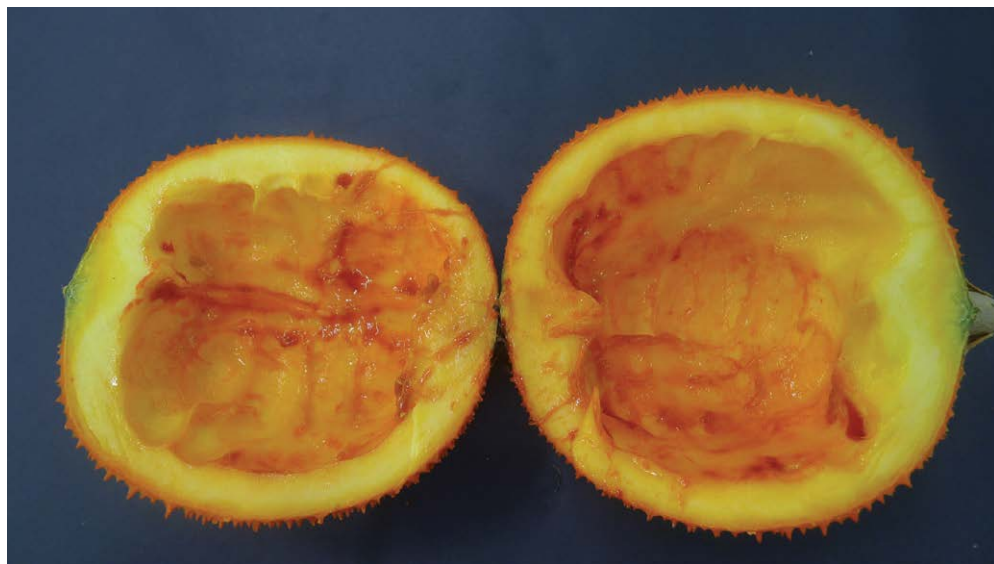
**Fig. 1.4.** Gac fruit.

350–2500 g depending on variety and timing of the season, with smaller fruits towards the end of the season (Tran, 2017).

In general, Gac fruits are harvested at maturity (90–100 days after pollination) (Bharathi and John, 2013; Tran *et al.*, 2016). The skin of Gac fruit is sparsely spiny or densely covered in soft spines, the length of a spine being 10 mm. The skin is dark green when immature and turns orange or red when ripening. The skin contains carotenoids including lutein, with higher concentrations compared with the aril or pulp (Kubola and Siriamornpun, 2011).

The largest component of Gac fruit is the yellow pulp or mesocarp (Fig. 1.5) and accounts for 43% (Tran *et al.*, 2016) to 49% of the total weight (Kha, 2010). It includes some carotenoids but at a lower concentration compared with the skin or the aril (Aoki *et al.*, 2002; Kubola and Siriamornpun, 2011).

The Gac seeds are covered by an aril of deep red colour when mature (Fig. 1.6). The mature red aril has the highest nutritional value of all fruit parts, with lycopene, carotene and other bioactive compounds at high concentrations. The proportion of aril has been recorded previously as 10, 18, 24.6 and 30% of fresh fruit weight (Ishida *et al.*, 2004; Dang *et al.*, 2010; Kha, 2010; Tran *et al.*, 2016). Gac also contains



**Fig. 1.5.** Gac pulp.

bioactive substances such as protein that may inhibit tumour development of some cancers. Furthermore, vitamin E, fatty acids and flavonoid glycosides have been found in Gac fruits (Sarma *et al.*, 2011). The carotenoids in Gac aril are responsible for the orange or red colour of the dish 'Xoi Gac'.

### Seed

The grower must consider the unpredictable ratio of male and female plants when Gac seeds are utilized as a source for propagation, since the ratio of male to female seeds described in one study was 1:10 (Maharana and Sahoo, 1995). The number of seeds per Gac fruit is between about 10 and 50. The seed shape is circular, ovate or elliptic, 2.6–2.8 cm diameter and 5–6 mm thick (Fig. 1.7), and the seedcoat is lumpy and has undulating edges (Handique, 1988; De Wilde and Duyfjes, 2002; Somporn *et al.*, 2009). When fruits are young, the seedcoat is soft and white, and it develops into a brown or black colour when mature. In general, the number of Gac seeds does not change during fruit development (Tran *et al.*, 2016). The seed weight from tested Vietnam varieties was shown to be greater than

that of seeds from Thailand (Wimalasiri *et al.*, 2016).

Gac seeds can be stored for 6 months in the refrigerator (Singh and Vawra, 1988). However, the seed weight declines following prolonged storage and eventually becomes unviable (Tran *et al.*, 2020).

## Cultivation Practices to Optimize Yield and Fruit Quality

### Propagation

Currently, the sex of Gac seedlings can only be identified when flowers develop (Parks *et al.*, 2013a), presenting a challenge when propagating by seed, but more-efficient, large-scale production is a possibility for Gac using the combination of seed production and grafting. To grow a Gac crop from seed, seed needs to be viable and germinated at an optimal temperature (Table 1.1). The use of hormone dips is useful to strike large numbers of female softwood cuttings and the female scion can be grafted on to seedling rootstock of unknown sex to ensure the



**Fig. 1.6.** Gac aril which surrounds the seed.



**Fig. 1.7.** Gac seed.



**Table 1.1.** Key characteristics of Gac propagation using three methods. (From Tran, 2017.)

Method	Requirements	Outcomes
Seed germination	Temperature range: 25–35°C Seed age: <6 months for seed stored under ambient conditions (21°C, 60–70% RH)	Time to >90% germination: 7–8 days Approximate time to planting: 35 days
Cuttings		
Semi-hardwood	No hormone required	Survival rate: > 71% for both types of cuttings
Softwood	IBA hormone concentration: 3–5 g/l	Time to planting: 50 days
Grafting		
Top wedge	Rootstock age: 4 to 8 weeks old	Survival rate: >85% for both grafting methods
Slice	Rootstock age: 4 to 8 weeks old	Time to planting: 45 days

supply of fruiting plants. Further, the grafting techniques of insert, slice and wedge have been successfully used for Gac (Joseph and Bharathi, 2008; Tran *et al.*, 2020).

*Seed germination*

Gac seeds from ripe fruits can be sown directly, and well-developed seedlings can be transplanted. They can be sown on to trays of coir to a depth of 3–5 cm for germination prior to planting out (Tran *et al.*, 2020). Gac seeds germinate at between 25 and 35°C with a maximum germination rate occurring at 30°C (Tran *et al.*, 2020). The seed radicle starts to emerge within 48 h and is visible at the soil surface within 4–5 days after sowing at the optimal temperature.

Seed dormancy is defined as the failure of a viable seed to germinate completely under favourable conditions (Bewley, 1997), and Gac seed has a reputation for being dormant. Traditionally, the steaming of Gac seeds in the dish ‘Xoi Gac’ was used as a method to overcome seed dormancy. Further, removal of the Gac seedcoat increased germination from 0 to 89% (Pandey *et al.*, 2013). However, recent studies have demonstrated that Gac seed can germinate well without treatment (Parks *et al.*, 2013a; Tran *et al.*, 2020). Even Gac seeds stored for up to 18 months (21°C, 60% relative humidity (RH)) have a greater than 50% germination rate and only lose viability after 30 months of storage (Tran *et al.*, 2020).

Ideal conditions have not been determined for Gac seed. Seed age affects germination and one study demonstrated that the youngest seed (6 months) had greater germination proportions

compared with older seed (30 and 18 months) (Tran *et al.*, 2020). The germination proportion of the Gac seed declined by more than 45% from 6 to 18 months and those stored for over 2.5 years (30 months) lost their viability completely. It appears that seed storage during that study (21°C, 60% RH) did not provide ideal conditions. It is not known if Gac seed is desiccant-tolerant or desiccant-sensitive, which will dictate the conditions required. Most cucurbits are desiccant-tolerant and require drying to a moisture content of about 5% for long-term storage (Nelson, 2007).

*Cuttings*

Traditionally, Vietnamese farmers use Gac cuttings from plants that have yielded well for 5–6 years as mother plants. Cuttings called ‘hom’ are prepared from semi-hardwood or hardwood stems that are 0.5–2 cm thick. They are cut into 30–40 cm lengths having four or five nodes and are de-leafed. The cuttings are planted directly into the soil, or a plastic tub containing soil or sand, and the stems root within about 20–30 days. This propagation method is successful for increasing the number of female plants but requires a large biomass of mother rootstock and this may not be as economical for commercial propagation as striking softwood cuttings.

The survival and rooting rate of cuttings of a range of species depend on several factors including selection of the softwood cutting materials, environmental conditions during propagation and the use of rooting hormones (Hartmann *et al.*, 2002). Commercially, auxins are commonly applied to stimulate the rooting of cuttings in

liquid, powder or gel formulations, containing indole-3-butyric acid (IBA), 1-naphthaleneacetic acid (NAA) or a combination of the two (Blythe *et al.*, 2004). The use of rooting hormones for Gac cuttings is promising. In another cucurbit, watermelon, shoot tip and one-node cuttings dipped in IBA solution improved vegetative growth of shoots and produced an early yield compared with the seedling control (El-Eslamboly, 2014). Further, in the same genus *M. dioica* Roxb., the rooting of cuttings increased when they were treated with IBA hormone powder (Ali *et al.*, 1991). For Gac, when dipped in IBA (3–5 g/l), the survival of softwood cuttings increased from 53 to 77% (Tran *et al.*, 2020).

### Grafting

Grafting is a potential technique to salvage unwanted male Gac plants by using them as mature rootstock material. Grafting of the Gac plant has been demonstrated previously using the insertion grafting technique of female scion union with male rootstock with a high rate of success; 25 fruits were harvested per grafted plant compared with 16 fruits for seed-grown and 8 fruits for plants propagated from cuttings (Joseph and Bharathi, 2008). These grafted plants also required less space (4–5 m<sup>2</sup>) and less time for growing compared with plants that were grown from seed or cuttings (Joseph and Bharathi, 2008). Seedlings are used as a rootstock source for grafting of many related species including cucumber, watermelon and squash (Traka-Mavrona *et al.*, 2000; Mohamed *et al.*, 2012; Colla *et al.*, 2013). This method can save time and increase the number of fruiting plants in production, as well as provide other benefits including disease resistance.

Gac rootstock needs more than 20 days from emergence to reach an appropriate stage for grafting (Tran *et al.*, 2020). Generally, cucurbit grafts use rootstock material of a younger seedling stage (10–20 days) (Traka-Mavrona *et al.*, 2000; Amin and Mona, 2014). But the age of the rootstock and the methods of grafting will affect the success of the grafts (Medagoda and Kumari Chandrarathna, 2007; Solomon *et al.*, 2012). In Gac, younger rootstock of 4 to 8 weeks old compared with 12 weeks increased the survival rate of the grafts and the shoot length of grafting combinations (Tran *et al.*, 2020).

### Plant production

Gac can be grown in tropical (south Vietnam and Thailand) and temperate (north and central Vietnam) conditions (Wimalasiri *et al.*, 2016) and can tolerate a range of soil types. Generally, the Gac plant is commonly grown in well-drained soils amended with fertilizer. The optimal fertilizer requirements for Gac have not been established but in several studies, this crop performed well on the standard nutrient regime used for cucumber production and so cucumber requirements can be used as a guide (Parks *et al.*, 2013b; Tran, 2017). The optimal temperature for Gac growth is 25–30°C but in more temperate regions it is deciduous and will senesce during autumn before reshooting in spring.

The planting season of Gac is February to March in north Vietnam or at the beginning of the rainy season (May or June) in central and south Vietnam. The planting distance is 3–4 m between plants and 4–5 m between rows. In home gardens, Gac is often grown next to fences, bamboo shrubs or under large trunks so the Gac plant can climb. Otherwise, it needs a trellis to support the heavy fruit and to keep it off the ground where it would be prone to rotting upon softening and ripening.

Gac can be grown in the greenhouse in temperate areas to avoid dormancy in winter (Parks *et al.*, 2013a). Previously, Gac has been grown hydroponically in a soil-less substrate of coir and using fertigation with a complete nutrient solution used for cucumber with a pH of 6.0–6.5 and electrical conductivity (EC) of 1.2 dS/m up until flowering and an EC of 2.4 dS/m during fruit development. The bags or pots were placed 2 m apart and plants grown up a horizontal trellis with wires placed at 2.8 m above the ground. When the main stem reached the top wire, the growing point was trained to let the plants develop horizontally and cover the truss (Parks *et al.*, 2013a).

### Pollination

*Ctenoplectra* bees have been identified as the insect pollinator of Gac in India (Schafer, 2005). However, in nature, the pollen dispersal is limited by short flight ranges of these bees (Wimalasiri

*et al.*, 2016). Further, bees are less active during overcast conditions so pollination may be reduced, and hand pollination has been recommended to improve fruit set (Maharana and Sahoo, 1995). Moreover, male flowers tend to bloom earlier than female flowers (Parks *et al.*, 2013a) and since their flowering times may not always coincide, pollen availability may be scarce. Therefore, storage of pollen may be useful to provide a pollen source when male flowers are not available. Furthermore, these practices may be used to produce Gac in greenhouses that lack insect pollinators. Ultimately, stored pollen would reduce the need for unproductive male plants within the crop and maximize the number of female plants.

Gac female flowers can be pollinated by hand with fresh or stored pollen (Fig. 1.8). The male flowers are collected, then the petals are removed. The stamen of the male flower is directly dabbed on to the stigma of the female flower, or a paintbrush or swab is used to gently swirl around the stamen and carefully touch pollen on to the stigma. After pollination, a mesh bag can be used to support the fruit weight on the vine. Gac flowers open in the morning. Under natural conditions pollen is viable for only 36 h,

while female flowers are receptive for 24 h (Maharana and Sahoo, 1995); but experience shows the best time to fertilize the flowers is within an hour or two after bloom (Tran, 2017). The average percentage of fruit set using this technique with fresh pollen can be 97% (Tran *et al.*, 2021).

Gac pollen can be stored for use in pollination when male flowers or pollinators are scarce. Pollens are gently collected by using a brush or swab and are placed in vials. When stored in a fridge or freezer for up to 8 weeks, a fruit set of 73% can be achieved without reducing the content of carotenoids in the aril but fruit weight and oil content of the aril can be compromised (Tran *et al.*, 2021). Protocols to dry the pollen to an inactive state, prior to storing, are yet to be developed for Gac and this needs to be addressed in order to minimize damage to pollen in storage (Tran *et al.*, 2021).

**Fruit load**

In several species, increasing crop load has been shown to affect fruit size; for example, a low crop



**Fig. 1.8.** Gac fresh pollen.

load in cherimoya (*Annona cherimola* Mill.) produced heavier fruits (González and Cuevas, 2008) and manual removal of cherries increased fruit size (Sanhueza and Elorriaga, 2010).

Similarly, in Gac, the fruit load relating to the number of leaves per fruit, the fruit position on the plant or harvest date can impact fruit size. One study has indicated that fruit weight at harvest declined as the season progressed (Parks *et al.*, 2013a), which may relate to earlier developing fruits being stronger sinks than later developing ones, as has been shown in melon (Nerson, 2004). In further work, an increasing distribution of dry matter to fruits relative to leaves was associated with smaller fruit size, less aril and fewer seed numbers (Tran, 2017). The largest fruits contained the highest weights of aril, the most seeds and the best-quality aril in terms of high total soluble solids (TSS) values

compared with smaller fruits (Table 1.2). These characteristics, as they are easily assessed, have potential as a benchmark of high quality in the marketplace.

Development of the canopy in balance with fruit development is important to maximize the size of fruit, since allocation of excess biomass to fruit growth may adversely affect the crop (Heuvelink, 1997). Preliminary work has shown that the most marketable Gac fruits (>1.5 kg) are associated with at least 100 leaves per fruit (Tran, 2017) (Fig. 1.9).

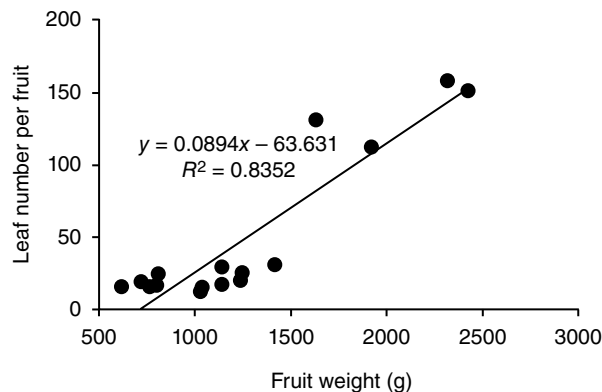
In practice, within a greenhouse setting, the position of these fruits on the same plant was spaced by at least three or four nodes along the stem and this ensures that the fruit size is not below commercial quality (Tran, 2017). However, further research is required to better define sink–source relationships for Gac and to provide a guide for this crop in a range of growing conditions.

**Table 1.2.** Effect of fruit load on some quality characteristics of Gac fruit. (From Tran, 2017.)

Fruit number/ plant	Fruit weight mean (g)	Aril proportion	TSS of aril (°Brix)	Developed seed number	Undeveloped seed number
1	2072.95 ± 82.72 <sup>a</sup>	0.16 ± 0.01 <sup>a</sup>	15.4 ± 0.6 <sup>a</sup>	45.0 ± 5.1 <sup>a</sup>	1.5 ± 0.7 <sup>a</sup>
5	1261.94 ± 57.33 <sup>b</sup>	0.13 ± 0.01 <sup>b</sup>	14.3 ± 0.3 <sup>a,b</sup>	41.2 ± 2.8 <sup>a</sup>	2.6 ± 1.5 <sup>a</sup>
9	937.31 ± 92.16 <sup>b,c</sup>	0.12 ± 0.01 <sup>b</sup>	12.8 ± 1.2 <sup>b</sup>	27.6 ± 3.2 <sup>b</sup>	1.8 ± 0.2 <sup>a</sup>
9–10	794.44 ± 86.57 <sup>c</sup>	0.11 ± 0.01 <sup>b</sup>	12.3 ± 0.6 <sup>b</sup>	25.8 ± 4.9 <sup>b</sup>	1.2 ± 0.4 <sup>a</sup>

Data are presented as mean ± standard error ( $n = 5$ ).

<sup>a,b,c</sup>Values within a column with unlike superscript letters were significantly different by the Least Significant Difference test at  $P < 0.05$ .



**Fig. 1.9.** Relationship between fruit weight and average leaf number per fruit. The four heaviest fruits were from plants with one fruit and the lowest four fruit weights were from plants with nine or ten fruits. (From Tran, 2017.)

## Postharvest practices to improve fruit quality

### *Maturity stages and quality characteristics*

Gac fruit ripening includes colour changes to skin (green to orange and red), pulp (white to yellow), aril (yellow to red) and seed (white to black), as well as reducing firmness of fruit. Traditionally, consumers in Vietnam generally prefer firm Gac fruits, 1.2–2 kg in weight, with a red skin and thick dark-red aril around the seeds (Tran, 2017). Some previous studies report three stages of fruit maturity (green, medium ripe and fully ripe) (Dang *et al.*, 2010; Kubola and Siriamornpun, 2011), but more recent work has explored the relationships between the external measures of fruit quality, such as skin colour and firmness, and the nutritional qualities of the aril inside the fruit at five stages of maturity. This has led to simple and quantifiable indicators of fruit quality and clear definitions of maturity (Tran, 2017) (Table 1.3).

The quality of Gac fruit is strongly affected by its maturity at harvest. In general, ripening commences on the vine in the fruits that are harvested at a mature stage (M3) and following harvest in less-mature fruit (M2). The appearance of yellowing on the fruit skin spines (M2) is a sign that the maturation process has commenced. At the M4 and M5 stages, fruits are ripe and soft, contain the highest concentration of carotenoids in the aril (Dang *et al.*, 2010; Kubola and Siriamornpun, 2011; Tran *et al.*, 2016) and could be considered best for consumption. Preliminary research suggests that Gac fruits can be picked semi-ripe at the M3 stage, which is firm enough for transportation but ripe enough to continue ripening, without compromising quality, following purchase by the consumer.

Simple indices of internal fruit quality may be suitable as commercial tools to assess the marketability of Gac fruit. The skin colour of Gac fruit has a positive correlation with quality indices including TSS and the carotenoid and oil contents. Also, TSS of the aril and fruit firmness correlate with the contents of carotenoids and oil in the aril. TSS may be particularly useful since it can easily be measured in the aril juice using a hand-held refractometer (Tran *et al.*, 2017). The total seed number and titratable

acidity of aril were not shown to be suitable indices of quality (Tran *et al.*, 2016).




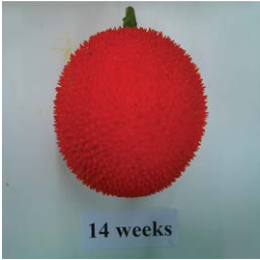

The Gac fruit may be climacteric in nature, shown as ethylene production associated with fruit ripening (Wills *et al.*, 2007). The continued postharvest ripening and peak of ethylene production in fruits harvested at maturity stage M2 provide evidence for this (Tran *et al.*, 2016). However, there is limited information on carbon dioxide production during respiration of Gac fruit which is also a trait of climacteric fruit (Wills *et al.*, 2007). In addition, other measures of ripening need to be investigated, including flesh softening, texture and colour changes and the accumulation of organic compounds (Wills *et al.*, 2007). A better understanding of the ripening characteristics of Gac fruit during postharvest will lead to the development of guidelines for optimal temperature and humidity during storage. Where storage conditions cannot be controlled, predicting the longevity of fruits will also be possible. Ultimately, better information on ripening will allow growers and fruit sellers to better control Gac fruit quality.

### *Fruit quality in storage*

Generally, farmers harvest Gac fruit based on firmness and skin colour. The fruits are placed in a cool place and stored for between 1 and 4 weeks. The time between harvest and the consumption of Gac can be weeks and significant changes in postharvest traits of fruit can occur during storage which are important to quantify given the high nutritional value of the aril. For example, Gac oil extracted from the aril has the potential to be used as a healthy alternative to saturated fatty acids in the diet (Kha *et al.*, 2013) and as an important measure to improve family health and nutrition in poor households in Vietnam (Vuong and King, 2003).

Gac fruit harvested prior to full maturity does not necessarily limit the development of oil, lycopene and  $\beta$ -carotene contents in the aril, postharvest. For example, lycopene increased in aril of semi-ripened fruits after 1 week of storage to levels similar to those in fully ripened fruits, and the oil, lycopene and  $\beta$ -carotene contents reached maximum levels after 12 days of storage at 21°C (Dang *et al.*, 2010). Increase in aril TSS during storage of Gac fruit also highlights

**Table 1.3.** Characteristics of Gac fruit at five stages of maturity. (From Tran, 2017.)

Stage	WAP	Description of maturity stage	External appearance
M1	8	Fully green skin, white pulp, light-yellow aril	
M2	10	Green skin, spines turning yellow at the top of fruit, white pulp, yellow or pink aril	
M3	12	Semi-ripe, skin starting to turn yellow or orange in patches, light-yellow pulp, red aril	
M4	14	Ripened, fully orange or red skin, yellow pulp, red aril	
M5	16	Fully ripe, dark-red skin, dark-yellow pulp, dark-red aril	

WAP, week after pollination.

the potential to promote fruit quality of semi-ripened fruit postharvest (Tran *et al.*, 2017).

Some research has focused on postharvest conditions and treatments to delay ripening of Gac fruit. In one study, the effect of storage temperature of Gac fruit was investigated at three temperatures (4, 13 and 25°C) and showed that storage at 4 and 13°C had the least weight loss, softening and colour change compared with fruit stored at 25°C, but symptoms of external and internal chilling injury occurred at 4°C after 25 days, and fruits could not ripen fully (Win *et al.*, 2015a). In other research, pre-treatment of Gac fruit with 1-methylcyclopropene (1-MCP) at 500 nl/l showed a slight effect of delaying fruit softening during storage at 10°C (Win *et al.*, 2015b). Also, coating yellow Gac fruits with 1.0% sucrose fatty acid esters (SFE) and storing at 10°C and 90–95% RH reduced fruit softening and respiration rates slightly during 16 days of storage (Win *et al.*, 2015c). These studies are a

promising indication that postharvest practices can be developed to extend the storage life of this fruit.

## Conclusion

Our understanding of the responses of the Gac plant to cultivation practices and of its fruit to postharvest practices has advanced greatly in recent years. Evidence-based production practices are sufficiently developed to permit commercial production of this plant on both a small and a large scale. Postharvest research also shows promise in techniques to delay ripening, but further research is required to evaluate the effect of these treatments on fruit quality. As a whole, these practices can be used as a base for further developments in the commercialization and conservation of this species.

## References

- Ali, M. Okubo, H., Fujii, T. and Fujieda, K. (1991) Techniques for propagation and breeding of kakrol (*Momordica dioica* Roxb.). *Scientia Horticulturae* 47, 335–343.
- Amin, A.W. and Mona, A.W. (2014) Protecting cucumber from *Meloidogyne incognita* using graft onto resistant cucurbit rootstocks and antagonistic marigold as an alternative to nematicide. *Pakistan Journal of Nematology* 32, 51–58.
- Aoki, H., Kieu, T.M.N., Kuze, N., Tomisaka, K. and Chuyen, V.N. (2002) Carotenoid pigments in Gac fruit (*Momordica cochinchinensis* Spreng.). *Bioscience, Biotechnology and Biochemistry* 66, 2479–2482.
- Bewley, J.D. (1997) Seed germination and dormancy. *The Plant Cell* 9, 1055–1066.
- Bharathi, L.K. and John, K.J. (2013) *Momordica Genus in Asia – An Overview*. Springer, India.
- Blythe, E.K., Sibley, J.L., Ruter, J.M. and Tilt, K.M. (2004) Cutting propagation of foliage crops using a foliar application of auxin. *Scientia Horticulturae* 103, 31–37.
- Colla, G., Rouphael, Y., Jawad, R., Kumar, P., Rea, E. and Cardarelli, M. (2013) The effectiveness of grafting to improve NaCl and CaCl<sub>2</sub> tolerance in cucumber. *Scientia Horticulturae* 164, 380–391.
- Dang, T.T.N., Pham, N.B., Nguyen, T.H. and Thai, K.P. (2010) Changes in lycopene and beta carotene contents in aril and oil of gac fruit during storage. *Food Chemistry* 121, 326–331.
- De Wilde, W.J.J.O. and Duyfjes, B.E.E. (2002) Synopsis of *Momordica* (Cucurbitaceae) in SE Asia and Malesia. *Botan Zhurnal* 87, 132–148.
- Do, T.L. (2004) *Những Cây Thuốc Và Va Thuốc Việt Nam*. NXB Y Học, Hanoi.
- Do, T.L.H. and Tran, V.B. (2011) Morpho-adaptation anatomy of sweet gourd *Momordica cochinchinensis* (Lour.) Spreng. grown in Sa Pa, Lao Cai and Cuc Phuong, Ninh Binh. *Tạp Chí Sinh Học* 33, 48–53.
- El-Eslamboly, A.A.S.A. (2014) Effect of watermelon on propagation by cuttings on vegetative growth, yield and fruit quality. *Egyptian Journal of Agricultural Research* 92, 553–557.
- González, M. and Cuevas, J. (2008) Optimal crop load and positioning of fruit in cherimoya (*Annona cherimola* Mill.) trees. *Scientia Horticulturae* 115, 129–134.
- Handique, A.K. (1988) Hormonal induction of parthenocarpy in *Momordica cochinchinensis* Spreng. *Current Science* 57, 896–897.
- Hartmann, H.T., Kester, D.E., Davies, F.T. and Geneve, R.L. (2002) *Plant Propagation: Principles and Practices*, 7th edn. Prentice Hall, Upper Saddle River, New Jersey.
- Herklots, G.A.C. (1972) *Vegetables in South-East Asia*. George, Allen & Unwin, London.

- Heuvelink, E. (1997) Effect of fruit load on dry matter partitioning in tomato. *Scientia Horticulturae* 69, 51–59.
- Ishida, B.K., Turner, C., Chapman, M.H. and McKeon, T.A. (2004) Fatty acid and carotenoid composition of gac (*Momordica cochinchinensis* Spreng) fruit. *Journal of Agricultural and Food Chemistry* 52, 274–279.
- Joseph, J.K. and Bharathi, L.K. (2008) Sweet gourd (*Momordica cochinchinensis* (Lour) Spreng.). In: Peter, K.V. (ed.) *Underutilized and Underexploited Horticultural Crops*, Vol. 4. New India Publishing, New Delhi, pp. 185–191.
- Kha, T.C. (2010) Effects of different drying processes on the physicochemical and antioxidant properties of gac fruit powder. M.Phil. thesis, The University of Newcastle, Newcastle, Australia.
- Kha, T.C., Nguyen, M.H., Roach, P.D., Parks, S.E. and Stathopoulos, C. (2013) Gac fruit: nutrient and phytochemical composition, and options for processing. *Food Reviews International* 29, 92–106.
- Kubola, J. and Siriamornpun, S. (2011) Phytochemicals and antioxidant activity of different fruit fractions (peel, pulp, aril and seed) of Thai gac (*Momordica cochinchinensis* Spreng). *Food Chemistry* 127, 1138–1145.
- Maharana, T. and Sahoo, P.C. (1995) Floral biology of *Momordica* species. *Horticulture and Forestry* 4, 143–151.
- Medagoda, I. and Kumari Chandrarathna, W.M.C.J. (2007) Grafting of breadfruit (*Artocarpus altilis*) using breadnut (*Artocarpus camansi*) as root stock. *Acta Horticulturae* 757, 149–152.
- Mohamed, F., El Hamed, K.E.A., Elwan, M. and Hussien, M. (2012) Impact of grafting on watermelon growth, fruit yield and quality. *Vegetable Crops Research Bulletin* 76, 99–118.
- Mohanty, C.R., Maharana, T., Tripathy, P. and Senapati, N. (1994) Interspecific hybridization in *Momordica* species. *Mysore Journal of Agricultural Sciences* 28, 151–156.
- Nanta, N., Songsri, P., Suriharn, B., Lertrat, K., Lomthaisong, K. and Patanothai, A. (2020) Seasonal variation in lycopene and  $\beta$ -carotene content in *Momordica cochinchinensis* (Lour.) Spreng. (Gac fruit) genotypes. *Pakistan Journal of Botany* 52, 235–241.
- Nerson, H. (2004) Fruit-set order affects seed yield and germinability in melon (*Cucumis melo* L.). *The Journal of Horticultural Science and Biotechnology* 79, 985–990.
- Nerson, H. (2007) Seed production and germinability of cucurbit crops. *Seed Science and Biotechnology* 1, 1–10.
- Pandey, S., Devi, C., Kak, A. and Khan, Y.J. (2013) Breaking seed dormancy in sweet gourd (*Momordica cochinchinensis*). *Seed Science and Technology* 41, 133–136.
- Parks, S.E., Murray, C.T., Gale, D.L., Al-Khawaldeh, B. and Spohr, L.J. (2013a) Propagation and production of Gac (*Momordica cochinchinensis* Spreng.), a greenhouse case study. *Experimental Agriculture* 49, 234–243.
- Parks, S.E., Nguyen, M.H., Gale, D.L. and Murray, C.T. (2013b) *Assessing the Potential for a Gac (Cochinchin gourd) Industry in Australia*. Rural Industries Research and Development Corporation, Kingston, Australia.
- Sanhueza, S. and Elorriaga, A. (2010) Effect of different crop load management strategies on fruit production and quality of sweet cherries (*Prunus avium* L.) ‘Lapins’ in central Chile. *Journal of Fruit and Ornamental Plant Research* 18, 51–57.
- Sanwal, S.K., Kozak, M., Kumar, S., Singh, B. and Deka, B.C. (2011) Yield improvement through female homosexual hybrids and sex genetics of sweet gourd (*Momordica cochinchinensis* Spreng.). *Acta Physiologiae Plantarum* 33, 1991–1996.
- Sarma, D.S.K., Babu, A.V.S., Krishna, K.R. and Basha, P.P.N. (2011) Phytochemical studies and biological activities on fruits of *Momordica cochinchinensis*. *Journal of Chemical and Pharmaceutical Research* 3, 875–881.
- Schafer, H. (2005) The biogeography of *Momordica*. *The Cucurbit Network News* 12, 5.
- Shethi, K.J., Begum, M. and Rashid, P. (2017) Comparative anatomy of *Momordica dioica* Roxb. ex Willd. and *M. cochinchinensis* (Lour.) Spreng. *Bangladesh Journal of Botany* 46, 725–732.
- Singh, H.B. and Vawra, L. (1988) Powdery mildew of *Momordica cochinchinensis*. *Current Science* 57, 552–553.
- Solomon, F.K. Jr, Roberts-Nkrumah, L.B. and Rouse-Moller, J.A. (2012) Development of a grafting protocol for the commercial propagation of three West Indian breadfruit cultivars. *Tropical Agriculture* 89, 85–98.
- Somporn, P., Nantachit, K. and Okonogi, S. (2009) Standard pharmacognostic characterisation of fak khaao as pharmaceutical preparation for skin disease treatment. *Natural Science* 8, 189–200.

- Traka-Mavrona, E., Koutsika-Sotiriou, M. and Pritsa, T. (2000) Response of squash (*Cucurbita* spp.) as rootstock for melon (*Cucumis melo* L.). *Scientia Horticulturae* 83, 353–362.
- Tran, X.T. (2017) Improving production and quality of Gac (*Momordica cochinchinensis* Spreng.) fruit. Doctoral thesis, The University of Newcastle, Newcastle, Australia.
- Tran, X.T., Parks, S.E., Roach, P.D., Golding, J.B. and Nguyen, M.H. (2016) Effects of maturity on physicochemical properties of Gac fruit (*Momordica cochinchinensis* Spreng.). *Food Science & Nutrition* 4, 305–314.
- Tran, X.T., Parks, S.E., Roach, P.D., Nguyen, M.H. and Kha, T.C. (2017) Changes in physicochemical properties of Gac fruit (*Momordica cochinchinensis* Spreng.) during storage. *Australian Journal of Crop Science* 11, 447–452.
- Tran, X.T., Parks, S.E., Roach, P.D. and Nguyen, M.H. (2020) Improved propagation methods for GAC (*Momordica cochinchinensis* Spreng.). *Experimental Agriculture* 56, 132–141.
- Tran, X.T., Parks, S.E., Roach, P.D. and Nguyen, M.H. (2021) Reduced pollination efficiency compromises some physicochemical qualities in Gac (*Momordica cochinchinensis* Spreng.) fruit. *Agronomy* 11, 190.
- Vijay, O.P., Jalikop, S.H. and Prem, N. (1977) Studies on floral biology in kakrol (*Momordica cochinchinensis* Spreng.). *Indian Journal of Horticulture* 34, 284–288.
- Vuong, L.T. and King, J.C. (2003) A method of preserving and testing the acceptability of gac fruit oil, a good source of beta-carotene and essential fatty acids. *Food and Nutrition Bulletin* 24, 224–230.
- Wills, R.B.H., McGlasson, W.B., Graham, D. and Joyce, D.C. (2007) *Postharvest: An Introduction to the Physiology and Handling of Fruit, Vegetables and Ornamentals*. University of New South Wales Press and CAB International, New South Wales, Australia and Wallingford, UK.
- Wimalasiri, D., Piva, T., Urban, S. and Tien, H. (2016) Morphological and genetic diversity of *Momordica cochinchinensis* (Cucurbitaceae) in Vietnam and Thailand. *Genetic Resources and Crop Evolution* 63, 19–33.
- Win, S., Kanlayanarat, S., Mejunpet, N., Buanong, M. and Wongs-Aree, C. (2015a) Changes in quality and antioxidant activity of gac fruit (*Momordica cochinchinensis* Spreng) under low temperature storage. *Acta Horticulturae* 1088, 231–236.
- Win, S., Kanlayanarat, S., Mejunpet, N., Buanong, M. and Wongs-Aree, C. (2015b) Response of gac fruit (*Momordica cochinchinensis* Spreng) to postharvest treatments with storage temperature and 1-MCP. *International Food Research Journal* 22, 178–189.
- Win, S., Mejunpet, N., Buanong, M. and Wongs-Aree (2015c) Changes in postharvest quality of gac fruit (*Momordica cochinchinensis* Spreng) coated with sucrose fatty acid esters. *Acta Horticulturae* 1088, 237–242.