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CHAPTER 5

# CARAMBOLA

## (*Averrhoa carambola* L.)

**H. Rymbai, N.A. Deshmukh, K. Wanshnong, C.R. Patel , T.R. Ahlawat**

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### 1. INTRODUCTION

Carambola (*Averrhoa carambola*) is an important member of the family *Oxalidaceae,* and it is reported to contain high amount of oxalic acid. It is a good source of potassium, copper, as well as folate and panthothenic acid. The fruit is gaining importance for its therapeutic potentials, and are being utilized in various traditional folklore medicines. Fruits are also consumed as an addition to fruit salads, as they are crisp and juicy. Further, they are also used in preparation of processed products like wines, jellies and canned, or preserved as dried fruit (Anonymous, 2013a).

This species is found growing in kitchen gardens, small and scattered orchard and also occurring wild in various part of the country. In South India, its fruits have high popularity and it is being used as a substitute of a tamarind in cooking. Similarly, it is also have a widely used in West Bengal for preparing chutney (Mazumder, 2004). While, carambola in North Eastern part of the country, is being consumed as fresh fruit. Although, it is growing in most parts of the country, however, there is no reliable data available on area and production under carambola in India. With the increasing in human population and shrinking of land, there is a need to popularize this crop for it better utilization and conservation. Therefore, it is necessary to comprehensively review and documentation of several germplasm existing in the country.

This will generates knowledge for proper utilization, genetic resources conservation and possible utilization the existing variability breeding programmes.

## 2. DOMESTICATION

Carambola was domesticated throughout India and southeast Asia including the Philippines, Malaysia, Bangladesh and other Southeast Asian in prehistoric times (Morton, 1987; Anonymous, 2013b). There is even a name in Snakrit 'karmara' for this species in India (Popenoe, 1974), which indicates it existing since ancient times. In the American tropics, this fruits has been known in since 150 years ago (Anonymous, 2013b). At present, carambola is commercially cultivating in India, Southeast Asia, southern China, Taiwan, Hawaii, Florida and throughout tropical regions of the world (Anonymous, 2013b). They are also grown in Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, Brazil, Jamaica, Haiti, the Dominican Republic, Puerto Rico, Trinidad, Guyana and parts of Africa (Morton, 1987). In Australia, carambola was not known until the end of the 19$^{th}$ century (Stephens, 1936; Watson *et al*, 1988).

## 3. TAXONOMY

Earlier carambola was included in a new family, the *Averrhoaceae* (Hutchinson, 1959). However, majority of the botanists, prominently Cronquist (1981) and Takhtajan (1981), do not agreed with this new family to have a separate identity within the Order *Geraniales*. Since studies on the distribution of phenoloic and free amino acids among *A. bilimbi, A. carambola, Biophytum sensitivum, Oxalis barrelieri, O. corniculata* did not support the separation of Averrhoa into an independent family Averrhoaceae (Devi and Narayana, 1990). Therefore, they grouped carambola in the *Oxalidaceae.*

This family has 7-8 classes, which consisting up to 900 species which are distributed throughout the tropics and subtropics, occasionally at high altitude, with relatively few representatives in the temperate zones (Sauco and Menini, 1993). The family is predominantly consists of herbaceous plants, tubers or bulbs, shrubs, however with only two woody genera, *viz*., *Averrhoa* and *Sarcotheca*. The most important genus is *Oxalis* consisting up to 800 species, many of which can be found as garden weeds in some temperate zones of the northern hemisphere; some species are grown as ornamental plants in garden and houses (Cronquist, 1981). The most important species of the family is undoubtedly the oca (*Oxalis tuberose* Mel.) which is cultivated at high elevations in the Andes, from Columbia to Bolivia, where its importance as a tuber is surpassed only by that of the potato (Chandler, 1958). Among the woody plants of the family, besides carambola, only *Averrhoa bilimbi* L, also originating in South-east Asia which is of interest as a fruit. However, it is very acidity and is therefore unsuitable for fresh consumption although it is often used in the tropics for preparing curries, chutneys, pickles and candied fruits.

**Classification of *Averrhoa carambola* (Manda *et al*., 2012)**

| | |
|---|---|
| Scientific Name: | *Averrhoa carambola* |
| Kingdom | *Plantae* – Plants |
| Subkingdom | *Tracheobionta* – Vascular plants |
| Superdivision | *Spermatophyta* – Seed plants |
| Division | *Magnoliophyta* – Flowering plants |
| Class | *Magnoliopsida* – Dicotyledons |
| Subclass | *Rosidae* |
| Order | *Geraniales* |
| Family | *Oxalidaceae* – Wood-Sorrel family |
| Genus | *Averrhoa* Adans. – averrhoa |
| Species | *Averrhoa carambola* L. – carambola |

## 4. CENTER OF ORIGIN/CENTERS OF DIVERSITY

Carambola may have originated in India-China (Ranjit Singh, 1969) and/or India or Sri Lanka (Pijpers *et al*., 1986). However, some authors are of opinion that the species is of Moluccas and Indonesia origins (Zewen and De Wet, 1982).

It has been cultivated in the Philippines, Malaysia, India, Bangladesh and other Southeast Asian for many centuries (Morton, 1987). The fruits are cultivated commercially in India, Southeast Asia, southern China, Taiwan, and Florida. They are also grown in Nicaragua, Costa Rica, Panama, Colombia, Ecuador, Peru, Brazil, Jamaica, Haiti, the Dominican Republic, Puerto Rico, Trinidad, Guyana and parts of Africa (Morton, 1987). In other areas they are usually grown as ornamentals, rather than for consumption (Morton, 1987).

## 5. OBJECTIVE OF CROP IMPROVEMENT

### Ideal Cultivars

Although there is no single cultivar possesses all the desirable features, as some traits is not due to genotypic influence but also due to environmental as well their interactions. For instance, many organoleptic traits, *viz.,* sweetness, acidity and flavor as well as fruit size can be considerably influenced by environmental conditions. Traits like fruit shape, colour, texture, oxalic acid and tannin content and number of seeds appear to be determined primarily by genetic factors. Therefore, selection and/or transferred with a specific desirable traits is more important in carambola. Considering the opinion made by Sauco and Menini (1993) and Lim (2013) regarding ideal cultivars of carambola, the improvement of this crop should be focused on:

i. Development of high yielding cultivars of fruits of acceptable weight (100-300 g fruit).

ii. Development of cultivars having fruits of attractive shape and colour. Fruit with five-angled shape confers special attractiveness and in cross-section must appear as five-pointed star. The length and width ratio must be 2:1; Attractive colour with intense (golden) yellow colour which further enhanced by the presence of wax on peel is probably the ideal. However, a bright orange colour is also acceptable.

iii. Development of cultivars having long shelf-life. The retention of high quality during post-harvest life of fruits is very essential.

iv. Development of cultivars having maturity period coinciding with high market demand. Appropriate ripening period is essential from marketing point of view, and it is a very complex criterion for a species like carambola, since it has several or even continuous flowering, fruiting and harvesting periods. However, for better marketing it must be available for an intended marketing period. For instance, in Europe like Christmas and Easter are the best ripening periods during which many exotic fruits are consumed, while summer is the worst time of the year due to the competition from other seasonal fruits.

v. Development of cultivars with fruits of low number of seeds and having acceptable peel thickness. Peel must neither be very thin for essential protection during post-harvest phase nor very thick since fruits are consumed with peel remain intact. However, a balance must be given so that the peel thickness does not affect the edibility, fruit also must be strong, broad ribs to withstand bruising.

vi. Development of cultivars having acceptable acid: sugar ratio with adequate texture and flavor. As it is a market targeted feature. For instance, Asian prefers sweeter fruits than Europeans. In general, fruits must have a sugar content of more than $11^0$ Brix and lower than 0.5 % of acidity. Similarly, the ripe fruit must contain less than 0.25% oxalic acid of fruit weight. Yellow fruits normally possess higher sugar content than green fruits (Baker and Kuppelweiser,1988), therefore the general preferences is higher for the yellow coloured fruits. Fruits with crispy texture is preferable. Flavour is partially governed by the sugar and acid content, but slight differences due to the presence of esters and other volatile components may play a role in cultivar selection. The tannic or earthy flavor that is mainly located on the edges of the wings, the reason for these often being removed before consumption, is particularly important and is probably related to a relatively high oxalic acid concentration.

vii. Development cultivars having processing quality traits. Fruit of this crop have several processing adaptability like juice and hot-air dried slices, although fresh fruit is still the widely used. Therefore, this wide utility of the fruit must be taken in to advantages while develop a cultivar.

viii. Development cultivars having resistance to pests, diseases and physiological disorders. Pests, diseases and disorders affect both yield and quality of the crop. The ideal cultivar must also be resistant to anthracnose and fruit fly.

ix. Fruits with higher fleshy, firmness and thick ribs with wide angles between the ribs are preferred for better post-harvest management and transportation. So development of cultivars at this angle may be another breeding objective.

x. Development of early bearer, high yielding and regular bearer will be one of the objectives of carambola improvement. The important characteristics of ideal tree are early bearing habit which is relatively easy to identify, since carambola is characterized by its ability to bearing as early as during the second year after planting; regular bearer and high yielding of more than 40-60 mt/ha/year.

xi. Development of cultivars having well adaptability in adverse agro-climatic condition. The cultivars having resistance to salinity both at rootstock and scion level, especially to low quality irrigation water; tolerant to drought, adverse soil conditions like waterlogged soils, alkaline and limestone soils; and tolerant to climate change include dry winds, cold and heat, hail etc is very important in order to allow for a rapid initiation of growth coincident with the onset of favourable climatic conditions.

## 6. CYTOGENETIC

Carambola possesses a diploid number of chromosomes; 2n = 22 or 28 (Ramsammy, 1989). Cytogenetic studies in carambola are still unknown and appear to contain little information. Although, several works have been done in the evolving of cultivars through selection, however there is a scarcity of information and publications related to genetic studies of carambola. Schnell and Knight (1989) have recently initiated the studies of enzymes and separating systems which may provide basis information for the future genetic analysis in this crop.

## 7. INHERITANCE PATTERN/LINKAGE OF CHARACTERS

A very little study has been carried out in carambola. Approach through proteomics has been carried out for studying the heterostyly in *Averrhoa carambola* L. (Wong *et al.*, 1994). Cohen (2010) observed different proteins between the stamens and styles of the long style (LS) and short style (SS) morphs, both in immature and mature flowers. However, a greater number of protein differences was found between the organs of the two morphs at anthesis than earlier in development. The morph-specifi c proteins in *Averrhoa* is involved in either the incompatibility reactions and/or the development of the SS style. The SS morph is the derived condition; therefore, suppression of the growth of the SS style would be necessary in order for two different floral morphs with different style lengths to develop. Style length of the LS morph would not require any additional proteins for elongation, as this is the ancestral condition (Wong *et al*., 1994; Cohen, 2010).

## 8. PROBLEM IN BREEDING

The breeding in carambola is one of the most important areas of horticultural science, however it is yet to be explore and the progress in breeding of carambola has been far

from spectacular. The major breeding problems encounters for carrying breeding program in carambola are;

i. **Heterostyly and incompatibility**: Heterostyly is one of the reason for some pollination failure in carambola, sometimes may also be due to the problems of self-incompatibility (Knight, 1965). Almost complete failure of pollination is observed where short style x short style crosses is involved. This situation arises for flowers belong to the same tree, or as well of different trees (Sauco and Menini, 1993). Similarly, the fruit set (%) may also be poor in long style x short style crosses and vice versa.

ii. **Dioecious**: Carambola is normally dioecious which required pollenizer for proper cross pollination, fruit setting for fruit production. The breeding system in carambola combines distyly with self-incompatibility, and in addition that most cultivars require cross-pollination with a clone of the complementary floral type to set fruit and mature normal seed (Knight, 1965).

iii. **Temperature:** Temperature has great influenced on pollen viability and germination in carambola. It is reported that temperature above 30-35 $^0$C reduced pollen germination as well tube growth (Pupers *et al*., 1986 and Salapetch, 1987). Hence, during the hottest summer months in subtropical climates, fruit set are highly affected.

## 9. FLORAL BIOLOGY

### 9.1. Flower Structure

In carambola, flowers are arranged in loose panicles or cymes and are borne on basally branched, slender twigs which are 1-8 cm long, with a reddish and pubescent axis. Flowers form in the leaf axils, but they may also develop, in small clusters (double or triple), on leafless branches or terminal shoots or on large and thick branches and even on trunks. The carambola flowers and fruits developed well both on exposed (periphery of the canopy) as well as on unexposed portions of trees and can be clearly distinguished by their reddish-pink colour. Fruits are borne in cluster (Nand, 1970). The flowers are perfect, 5-12 mm long and are somewhat bell-shaped; they are attached to short, articulated, round, smooth, dark-red pedicels which are approximately 1 mm long. Heterostyly or distyly is a characteristic of the species, with some trees bearing flowers with long styles and short stamens and others producing only flowers with short styles and long stamens.

The five dark red sepals, which are almost twice as long (3-4 mm) as they are wide, are erect, ovate and smooth or almost smooth. The five petals are obovate-oblong, smooth on their upper side and pubescent below. There are 10 stamens of which the five adjacent to the petals are reduced to staminoids with no anthers or, at the most, with only abortive anthers which have no pollen. The stamens nearest to the sepals are smooth and yellowish-white in colour; their length varies according to the structure of the flower from about 3-4 mm for the long-styled forms to 5-6 mm for the short styled types.

Four to five styles develop from the ovary and eventually fuse. Styles in the long-styled type of flower are about 2 mm long and between 0.5 and 0.1 mm long in the short-

style forms. The stigmatic surface has numerous papillae. The ovary is furrowed, greenish-white and about 15-25 mm long. It has four or five loculi, each containing 2-4 superimposed ovules.

## 9.2. Flowering Time

Flowering occur periodically which depending on the varieties and agro-climatic conditions. There is a greater tendency for flowering to occur continuously in tropical climate. It is reported that carambola blossoms in rainy season and fruit ripens in December-January (Watts, 1889). Similarly, Hayes (1957) mentioned that flowers are borne profusely in rainy season and spring. In India, flowering was observed in three flushes, *viz*., spring flush (April - May), rainy flush (July - August) and autumn flush (September-October) and harvesting periods of fruits from these flushes are July-September, November-December and February-March respectively (Nand, 1970). In Southern Queensland, there are two major flowering periods, i.e., December-February and April-May. Fruit development of summer flowering it may take 10 to 12 weeks from anthesis, while it may take 12 to 16 weeks with autumn flowering. In North Queensland, there are two main flowering occurring during September-November and February-April although the peaks may vary by up to 5 weeks from year to year (Watson *et al*, 1988). Under greenhouse, carambola plants start flowering in late spring and produces up to 4 flushes of flowers throughout the year (Sauco and Menini, 1993).

## 9.3. Stages in Reproductive Development

Sauco and Menini (1993) found that different section of the tree following apparently random and different reproductive programmes. There is a less information regarding reproductive process of carambola in India. However, some of the research work conducted by Chin and Phoon (1982) in Malaysia; Darshana (1970) in India; Knight (1965) and Knight (1982) in Florida; Watson *et al*. (1988) and Wong (1970) in Australia formed the basis for information on the series of reproductive process in carambola. Sauco and Menini, (1993) reported a series of stages occurs during reproductive developments in carambola in the sequences of i. Floral bud initiation, ii. ii. Panicle development, iii. Flowering (anthesis, anther dehiscence and pollination) and iv. Fruit production (fruit set to maturity)

### 9.3.1. *Floral Bud Initiation*

In carambola, the productivity is not a problem which one of its distinct features. This is mainly due to the readiness with which floral initiation occurs in the buds, provided ecological conditions are favourable. Carambola bears flowers in the leaf axils, with maximum appearance towards the periphery of the plant. The potential flower-producing buds are normally initiated from the wood of the entire tree (Sauco and Menini, 1993).

The juvenile period of this crop is considered to be shorter than that of many other fruit trees. In tropical conditions, the grafted plants can produce flowers with in 9 months (Watson *et al*., 1988), although seedlings normally initiated flowering at 4-6 years old (Coronel, 1983).

The floral initiation is apparently neither a direct response to changes in the day/night temperature in the ranges (30/25, 25/20, 20/15, 30/15 and 34/20 $^0$C respectively). However, it is known that water stress is the most important external factor that influence flowering in carambola (Green, 1987; Salakpetch *et al*., 1989; Salakpetch *et al*., 1990). While according to Watson *et al*. (1988) reported that in Australia, temperatures may have some affects on flower initiation, otherwise it would be difficult to understand the occurrence of different flowering periods under different ecological conditions under irrigated conditions.

Similarly, there may be genotypic influence on floral initiation, as there is existing variation among genotypes or varieties. Further, the various factors discussed above and several others (fertilizer applications, girdling, phytohormone sprays) do not function separately but interact to control the pattern of vegetative development as well as floral initiation.

Flowering occur approximately two and a half weeks after initiation, with flowers developing on each inflorescence over a period of 2-4 weeks, during which more than 50 flowers of the total number present in each panicle may open. High temperatures, within the non-damaging range, accelerate not only the stage of inflorescence development but also the whole reproductive process. Temperatures below 0$^0$C, as well as dry winds, will destroy inflorescences (Sauco and Menini, 1993).

## 9.4. Anthesis

Floral anthesis takes place during day time. Flowers are opening between 8:00 am and 10:00 am and closing between 2:00 to 6:00 pm (Salakpetch *et al*., 1990). Following anthesis in the morning, there is falling of petals and exposing of the white-greenish ovaries. Post flowers opening, the flowers may remain on the tree for about 16 days, although no longer receptive (Salakpetch *et al.,* 1989). According to Sauco and Menini (1993) that the development sequence of the flowers within the inflorescence is basi-petal, the terminal flower of the main axis of the inflorescence opening first, followed by the terminal flowers of the secondary axes; these are then followed by the flowers on the tertiary axes. After anthesis the petals fold inward and the flower closes.

## 9.5. Pollination

Carambola are normally self-incompatible and dioecious, needing of male tree for proper cross pollination for fruit production. Type of pollination varies with cultivars and their feature of style in carambola. All flowers have either long or short styles; this condition is called heterostyly. A cultivar with short styles is normally having improved fruit set and

high yields by cross-pollination with long styles cultivars or vice versa. However, some cultivars like in 'Arkin', 'Fwang Tung' and 'Golden Star' produced abundant crops when planted in large solid blocks away from other clones of carambola, indicating that the need for cross-pollination by opposing stylar types is not always compulsory, similarly this demonstrated that that a partial loss of self-incompatibility (Knight, 1982). Other varieties such as 'B-10' and 'B-17' produce more fruit when cross pollinated with another variety (Anonymous, 2013; Crane, 2013). Fruit deformity in carambola is due to improper pollination, and is more related to incomplete pollination or incompatibility problems than the lack of calcium, zinc or boron (Lim, 2013).

### 9.5.1. *Pollinators*

The main pollination agents are insects, prominently by honey bees and sting-less bees (Manda *et al*., 2012). Wind can also be partially act as pollinating agent since some pollen are also bursting outward during anther dehiscence. However, the pollen having viscosity feature means that insects are a necessary agent for good pollination. The attractive bright colour of the flowers, the nectar and pollen also attract insects, especially *Apis* spp. and *Trigona* spp. In Malaysia, *Apis mellifera* is thought to be an efficient pollinator hence it is recommended that one beehive per 0.4 ha of carambola trees to be placed in orchards (Wahab Ngah *et al*., 1989). Natural pollination by insects gives higher percentage of fruit set than various controlled pollination methods (Nand, 1971). Application of any harmful pesticides to bees must be avoided especially during blooming period.

### 9.5.2. *Pollen Viability and Germination*

Pollen of carambola has no viability problems. However, certain factor which reduced pollen germination as well as the growth of the pollen tube leading to poor fruit-set are:

i) **Temperature:** Temperature above 30-35 $^0$C reduced pollen germination as well tube growth (Pupers *et al*., 1986 and Salapetch, 1987). Therefore, fruit set are also affected during the hottest summer months in subtropical climates.

ii) **Heterostyly and incompatibility:** Heterostyly is one of the reason for some pollination failure in carambola, sometimes may also be due to the problems of self-incompatibility (Knight, 1965). Knight (1982) studied pollen germination under a fluorescent microscope using aniline blue staining had found that germination of pollen in variably occurs, however, not the case in non-compatible crosses including short x short and long x long styled flowers as the pollen tubes usually remain on the style but germination is inhibited. However, in some long-styled cultivars, such as 'Golden Star', 'Newcomb', 'Thayer' and 'Arkin' set fruit well. In 'Golden Star' some pollen tubes do penetrate the ovary, which lead to normal fruit set. While 'Newcomb', 'Thayer', 'Arkin' and even 'Golden Star' grown in isolation in the Canary Islands, also fruit well (Galan Sauco *et al*., 1989). Similarly in Australia, long-styled cultivars are reported to be self-fertile; as well some short-styled cultivars are

also described to be self-compatible (Watson *et al*., 1988). In these cases, although the number of seeds is generally lesser, but the fruit size is not reduced, which is a significant commercial advantage (Sauco and Menini, 1993).

## 9.6. Fruit Set

Fruit set normally begins about 7 or 10 days after pollination as indicates by the swelling of the ovary, or otherwise the flowers fall, indicates that fertilization does not occur (Knight, 1965). Fruit set in carambola is coincided with the stage where petals have fallen, ovary expansion has begun and a colour has change from almost white to bright green (Campbell, 1987). The growth of the fruit until 12-15 mm long of it size occur through cellular division, further increase in size is due to cell enlargement and elongation, mainly in the mesocarp region (Dave *et al*., 1975 and Kumar, 1975). Although, the main factors which affect fruit set in carambola are high temperature, heterostyly and incompatibility as discussed above. However, the main problem of carambola fruit production does not appear to be lack of fertilized fruits but excessive production of fruit which may lead to the breaking of branches, combined with reduced fruit size and, possibly the rubbing together of adjacent fruits. This may be a serious problem which can only be solved by thinning and by selecting appropriate cultivars.

## 10. GENUS AND SPECIES

Earlier carambola was included in a new family, the *Averrhoaceae* (Hutchinson, 1959). However, majority of the botanists, prominently Cronquist (1981) and Takhtajan (1981), do not agreed with this new family and to have a separate identity within the Order *Geraniales*. Since studies on the distribution of phenoloic and free amino acids among *A. bilimbi, A. carambola, Biophytum sensitivum, Oxalis barrelieri, O. corniculata* did not support the separation of Averrhoa into an independent family Averrhoaceae (Devi and Narayana, 1990). Therefore, they grouped carambola in the *Oxalidaceae.*

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interest as a fruit. However, it is very acidity and is therefore unsuitable for fresh consumption although it is often used in the tropics for preparing curries, chutneys, pickles and candied fruits.

The only related species of carambola is Bilimbi (*Averrhoa bilimbi* L.).

## 11. CROP IMPROVEMENT METHODS

### 11.1. Selection

So far no systematic programme for genetic improvement of carambola has been undertaken, however several number of selections based on desirable characteristics has been identified, particularly in South-east Asia. Popenoe (1974) stated that although some sweet and acid types of carambola could be distinguished but no "horticultural varieties' had yet been established. A similar statement was made by Stephens (1936) in Queensland. Coronel (1983) also stated that no commercial varieties of carambola had been identified in the Philippines, a country close to the area of carambola origin. Therefore, it seems that Campbell (1965) was the first to report on selection of varieties, which had selected a variety 'Golden Star' in Florida. Following which other countries have also selected several varieties as represented in Table 1, and in particular Malaysia and the Department of Agriculture has already selected more than 17 varieties. These varieties are of commercially important which are maintained and multiplied through grafting in the MARDI (Malaysian Agricultural Research and Development Institute) collections.

**Table 1. Development of cultivars by selection in different part of the world.**

| Country | Cultivars |
|---|---|
| Australia | 'Arkin' ('Star King Sweetie'), 'B-1', 'B-6', 'B-10', '11-1', '9-4', 'Jungle Gold', 'Giant Siam', 'BCP-1', 'Hosie', 'Chujuba' |
| Brazil | 'Hart', 'Malaysia', 'Nota 10' |
| China | 'Hong Hug', 'Far Dee', 'Xiangmi Yantao' |
| Columbia | 'Icambola' |
| Indonesia | 'Kaput', 'Ting Go Demak' |
| Malaysia | 'B-2', 'B-10', 'B-16', 'B-17', 'Hew-1', 'Maha', 'Sri', 'Sri Kembangan' |
| Singapore | 'Leng Bak', 'Juron' |
| Taiwan | 'Cheng-Tsey' ('Chun Choi'), 'Cheng Chui', 'Dah Pon', 'Tean Ma', 'Mih Tao', 'Meeshi', 'Er-lin', 'Soft Sih', 'Miss', 'Pasi', 'Wai Wei', 'Wubentou' |
| Thailand | 'Fwang Tung', 'Thai Knight' |
| United State | 'Arkin' ('Star King Sweetie'), 'Golden Star', 'Thayer', 'Newcomb', 'Mih Tao', 'Dah Pon', 'Demak' and 'Tean Ma', 'Kajang', 'Kary', 'Lara', 'Thai Knight', 'Kona Beauty', 'Hart', 'Kajang', 'Seemban' |

Source: Pareek and Sharma (1993); Sauco and Menini (1993); Ping Sheng (1999)

## 11.2. Hybridization

So far there is no cultivar of carambola developed for large scale commercial cultivation through hybridization, especially in India. However, in view of recent development, the prospect for evolving promising hybrids through systematic genetic improvement programme is practical. The carambola's breeding system combines distally with self-incompatibility, and most cultivars require cross-pollination with a clone of the complementary floral type to set fruit and mature normal seed (Knight, 1965). However, 'Golden Star' is an exception, as its dependable production (Campbell, 1965), and which sets a significant amount of fruit when self-pollinated (Knight, 1982). There has been reported by Knight (1965) that the level of fruit set can be obtained through hand pollination in long style x short style crosses and vice versa is almost 3%. Similarly almost 0.5% set can be achieved from long style x short style crossings. Thus, there is a possibility of produced higher seed number with known pedigree.

### 11.2.1. *Hybridization Technique*

The technique of pollination for hybridization is relatively simple in carambola. The emasculation process is relatively easy in short-styled flowers, a forceps or a similar instrument can be employed to remove the anthers, in which the stamens project above the style, without damaging the flowers. However in long-styled flowers, this procedure is complex and becomes more difficult if long-styled flowers are used as maternal parents because they are self-fertile.

Furthermore, the juvenile phase in this crop is very short, which is an importance features in relation to genetic improvement and which facilitates early selection. Its early bearing ability nature enabled even a seedling to produce fruit within two years. High dense planting, therefore, allows for a rapid rate of selection to be carried out within a limited space.

## 11.3. Mutation Breeding

The conventional breeding programme in carambola is slow and costly attributes to long juvenile phases. Mutation breeding is one of the options to overcome this problem and produce material which can be used in the screening of advantageous genes in subsequent breeding programmes (Vos *et al*., 2009). Vos et al. (2009) treated graft wood from carambola with 0, 25.0, 37.5, 50.0, 62.5 and 75 Gy of acute gamma radiation derived from a cobalt 60 (Co60) source. The treated scions were whip grafted, however, the result was poor due to problems with top working. In the subsequent season, top working method was refined which gave 80% of graft-take.

## 12. CULTIVARS

Mainly there are two distinct types of carambola cultivars, *i.e*. sweet type and tart type. Sweet type- fruit is larger, thicker and larger ribs, sweet, mild-flavored, rather bland, with

less oxalic acid and are recommended for fresh fruit, processing as well for home recipes; tart type is smaller, very sour, richly flavored, with more oxalic acid and are more useful for processing (Manda *et al*., 2012). Few tart cultivars, like 'Golden Star' attain a sweet flavor if they are allowed to ripen to golden yellow colour stage on the tree. Some of the Chinese strain claim to be very sweet, for instance 'Xiangmi Yantao' a high quality variety of carambola which is a sport of a sweet variety (Ping Shen, 1999). The sweet or sour taste of the fruit is determined by the content of ascorbic acid (Manda *et al*., 2012). In sweet fruit, the amount of ascorbic acid in fruit juice is around 10.40 mg/100ml, while about 15.4 mg/100ml in sour fruit (Manda *et al*., 2012).

In Australia, cultivars are grouped into long and short styled cultivars (Table 2). Short styled cultivars are self-incompatible and require pollination from long styled cultivars but long styled cultivars can be self-fertile (Lim, 2013). In the recent past due to advance in crop improvement through selection and introduction there has been improving in fruit quality especially sweetness and flavor in Florida and other part of the world. In India there is existence of only Local genotypes.

**Table 2. Classification of carambola cultivars based on style length.**

| Short style | Long style |
|---|---|
| 'B-2', 'B-4' ('Sg. Besi 1'), 'B-8' ('Sg. Besi 5'), 'B-10', 'B-17', 'Fwang Tung', 'Lu Tho', 'Wheeler', 'Sri Kembangan', 'Pat Chun', '9-4', '8-1-Kara' | 'B-1' ('Yong Toh Yin'), 'B-6' ('Sg. Besi 3'), 'B-11' ('Chan Yong 1'), 'B-16' ('R. Hamilton'), 'Real B-2' ('Maha-66'), 'Star King', 'Maha', 'Arkin', '11-1 Kary' |

**Source:** Watt *et al*. (1988); Lim (2013)

## Cultivars Developed

Description of some of the major cultivars are given in the following paragraphs (Anonymous, 1982; Bender and Arpaia, 1988; Campbell, 1965; Campbell *et al*., 1985; Green, 1987; Knight, 1989; Sedgley, 1983; Wahab Ngah *et al*., 1989; Wahab Noah *et al*., 1988; Watson *et al*., 1988).

### 12.1. Arkin

Arkin synonym is 'Star King Sweetie', the leading commercial cultivar and occupied at least 98% of the current hectarage in South Florida (Crane 1993). It is developed through selection in Florida from a seeds imported from Thailand in 1973. The flowers have long styles. Fruit is medium-sized, similar to 'B-2', weighing between 90 - 200 g. Fruit colour is golden yellow at early maturity stage and becoming yellow-orange at ripening. Ribs are thick, somewhat more compact than those of 'B-10', with a relative large angle; the edges of the wings are also slightly rounded. The texture is excellent and sweet flavor, juicy and relatively less acidity, although its malic acid content is higher than that of 'Golden Star'.

Fruits are suitable for fresh as well as processed fruits. The cultivar is a relatively high resistance to mechanical damage and to insects of the *Othreis* genus which includes drilling or fruit sucker moths. Fruits are also relatively insensitive to chilling injury during storage.

## 12.2. B-2

This cultivar originated from Malaysia. Trees are slow growing and flowers have long styles. Fruits size is 8-12 cm x 8 cm in width, weight ranged between 100-200 g and somewhat elongated. Colour of the fruit is greenish-yellow and becoming completely yellow at maturity. The ribs have large angles with deep furrows. The fruits are sweet, as high 17% in Malaysia, similar to 'Arkin' although less than 'B-10' or 'B-17'. The pulp is having a fine texture and very juicy, thus makes it suitable for fresh fruits as well for processing. Fruits are relatively resistant to transport but the storage period is not very long. 'B-2' is a good pollinator for 'B-10'. 'B-2' is quite sensitive to damage by fruit flies.

## 12.3. B-10

It is developed in Malaysia, and it is the most widely accepted cultivar worldwide. The trees grow vigorously and flowers have short styles. Fruit size are large (14 cm x 7-8 cm), weight ranges between 100 - 200g, although fruits can weigh up to 315 g after appropriate thinning. Fruit colour varies from yellow to golden reddish or orange. The ribs are more compact than B-2, the edges of the wings are slightly rounded and the texture is good, with a TSS content varying between 8-12%. Fruits are slightly acid and high juice content, are useful both as fresh fruits and processing. are moderately resistant to fruit flies.

## 12.4. B-17

.This cultivar is originated in Malaysia, and is also known as 'Cristal Honey' or 'Honey carambola'. Fruits are cylindrical, large and uniform, with elongated, large wings, which make them very suitable for packing in boxes. The fruit is usually elongated with whitish sugar spots and ripens to a golden yellow colour. It is crispy, juicy, and extremely sweet with a brix of as high as 15-18% in Malaysia.

## 12.5. Cheng-Tsey

This cultivar is also known 'Chun Choi', originated in Taiwan. Fruits are large and may weigh up to 315 g after thinning. They have very deep and firm furrows. Their TSS content is high, acidity is low and the texture is good; fruits are orange in colour at maturity.

## 12.6. Fwang Tung

It origin is from Thailand. Fruit size is large with 5-8 inches long. Fruit have pale yellow peel and flesh. Pulp is very sweet, juicy, and firm flesh with few seeds. Thin ribs are easily damaged during handling. When cut in slices, given beautiful star shape (Crane, 1993).

## 12.7. Golden Star

It is seedling selection in Florida, from seeds collected from Hawaii in 1935. The tree is quite small and adapted to training habit. Flowers have long styles with high degree of self-compatibility. The fruit is large (10-12.5 cm long), deeply winged, ovoid or ellipsoid and weigh (100-200 g). The fruit is decorative, undoubtedly the most attractive fruits from a visual point of view, with a bright golden-yellow colour and a thick waxy cuticle. The ribs are thick, with relatively large angles and are similarly to those of 'Arkin' and 'B-10'. The pulp is very juicy and crisp. In Florida, fruits are less sweet and more acid than those of 'Arkin', however, in the Canary Islands; 'Golden Star' had a better TSS/total acidity ratio than 'Arkin' and also a better flavor (Campbell and Koch, 1989). The fruits are highly resistant to mechanical damage and chilling injury. This cultivar shows the least minor-element deficiency in alkaline soil, and even isolated trees bear well and regularly without cross-pollination (Manda *et al*., 2012). 'Golden Star' is the primary tart cultivar (Crane, 1993).

## 12.8. Kajang

This cultivar originated in Hawaii. Fruit size is 4-5 inches long. Colour is bright yellow peel and pulp. Pulp is sweet, juicy, firm flesh with few seeds.

## 12.9. Kary

It is also originated in Hawaii. Fruit size is medium to large, yellow to orange skin and flesh. Fruit is a sweet, firm-fleshed, very good quality and flavor with good shelf life. 'Kary' is an improved cultivar for commercial planting (Hamilton and Ito, 1992).

## 12.10. Lara

This cultivar originated in Florida. Fruit is medium to large size, with yellow to orange skin and flesh. Pulp is good in quality and flavor.

## 12.11. Sri Kembangan

Originated from Malaysia. Fruit size is 5-6 inches long and elongated pointed fruit. Colour is bright yellow-orange skin and flesh. Pulp is juicy, firm flesh, few seeds, flavor rich and sweet, makes it an excellent dessert quality.

**Table 3. Description of other cultivars of carambola in different countries**

| Variety | Origin | Size | Sweetness | Comments |
|---|---|---|---|---|
| 'Dah Pon' | Taiwan | Medium to large | Insipid | Poor quality and flavour |
| 'Demak' | Indonesia | Medium to large | Sweet | Poor quality and bitter aftertaste |
| 'Erlin' | Taiwan | Small to medium | Insipid | Poor quality and flavour |
| 'Hew-1' | Malaysia | Medium to large | Sweet | Whitish spots on fruit, good flavour |
| 'Kajang' | Hawaii | Medium to large | Sweet | Good quality and flavour |
| 'Kary' | Hawaii | Medium to large | Sweet | Very good quality and flavor. |
| 'Lara' | Florida | Medium to large | Sweet | Good quality and flavor. |
| 'Maha' | Malaysia | Medium to large | Insipid | Poor quality and flavour |
| 'Miss' | Taiwan | Small to medium | Insipid | Poor quality and flavour |
| 'Newcomb' | Florida | Medium to large | Tart | Tart |
| 'Pasi' | Taiwan | Small to medium | Insipid | Poor quality and flavour |
| 'Star King' | Florida | Medium to large | Tart | Tart |
| 'Tean Ma' | Taiwan | Medium to large | Insipid | Poor quality and flavor. |
| 'Thayer' | Florida | Medium to large | Tart | Poor quality and flavor. |
| 'Wai Wei' | Taiwan | Small to medium | Insipid | Poor quality and flavor. |
| 'Wubentou' | Taiwan | Small to medium | Insipid | Poor quality and flavor. |

**Source:** Crane (2007).

## 13. FUTURE PROSPECTS

Carambola is a hardy crop which has an immense potential for adapting in variably agro-climatic conditions. Although several researches have been carried out abroad in carambola, however in India, no systematic work has been taken yet. Few works had been fragmentary carried out at various centre in the country, which needs a proper networking and correlating each other to achieve a fruitful outcome. The systematic research planning and implementation will help in popularization and increased productivity of carambola in India. Some progress has recently been made in understanding the mechanisms that determine the flowering of carambola however; research is still needed to determine precisely the influence of the combination of physiological processes and the environment on floral initiation. Augmentation of available variability and breed for a quality sweet varieties with high fruit size and sugar with low oxalic acid content, high coloured and self fertile varieties. Emphasized may be given to identify a varieties with specific harvesting period, during which no other fruit available in the market. Development of standardization of vegetative propagation technique for maintaining true-to-type of improved genotypes. High attention must also be given to its conservation and utilization in near future. There is also a need to enhance shelf-life and improvement in packaging of the fruits.

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## CARAMBOLA (*Averrhoa carambola* L.)

**Arkin**

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**Sri Kembangan**