The proportion of aborted (smaller) seeds per fruit is a desirable commercial trait, however, it is strongly influenced by the environment, with a CV of 35%. Other traits with intermediate variability across orchards (CV between 10 and 20%, are fruit weight and total seed weight, which are probably influenced by rain, fruit load per plant and management practices.

Because more than 80% of the national market is dominated by white fleshed fruit and the rest by yellow, orange and red types 'Reyna' will continue to lead in the prickly pear market until new varieties with thicker peel, and higher resistance to frosts and *Alternaria* spp are generated through breeding programs.

Literature Cited

Bravo, H. H. 1978. Las cactáceas de México. Vol 1. Universidad Autónoma de México. Mexico. D. F., México.

Mondragón, J. C. 1992. Variedades comerciales y semicomerciales de nopal tunero en el Norte de Guanajuato. Quinto Congreso Nacional y Tercero Internacional sobre Conocimiento y Aprovechamiento del Nopal. Universidad Autónoma Chapingo, 11 al 15 de Marzo de 1992, Chapingo, Texcoco, México.

Pimienta, B. E. 1990. El nopal tunero. Colección Tiempos de Ciencia. Universidad de Guadalajara, Guadalajara, Jal., México. SARH, 1992, Sistema producto nopal tuna. Datos básicos. Dir. Gral de Politica Agricola. SARH. Documento de Circulación Interna. Mxico, D. F., México.

Fruit Varieties Journal 48(3):136-146 1994

"Tropical Small Fruits": A Workshop Overview with a Summary of Information on Naranjilla and Carambola

JOSEPH C. SCHEERENS[1]

Introductory Remarks

Tropical regions are often areas of tremendous biodiversity, and as such, indigenous species within these regions may include a wealth of fruit crops or potential fruit crops that are relatively under-commercialized. In view of today's "world economy," increased agricultural, exploitation of these species and the expansion of the tropical fruit crop industry seems almost assured due to a myriad of interrelated factors such as: the increase in health-conscious consumer demand for a variety of fruit products; the development of innovative marketing strategies which has fostered greater product recognition by consumers in distant markets; the availability of improved cultivars, cultural practices and postharvest handling/shipping and storage techniques garnered through increased re search efforts; and the focus on increased export trade.

Taking advantage of the Honolulu, Hawaii venue and Pan-Pacific theme of the American Society for Horticultural Science's 89th Annual (1992) Meeting as well as the availability of speakers with specific expertise in tropical fruit crops, the Society's Viticulture and Small Fruit Working Group held a workshop exploring the predominant cultivar characteristics, available germplasm, cultural practices and/or production potential of nine undercommercialized tropical fruit crops. Perhaps the "Tropical Small Fruits" workshop would have been more appropriately titled "Tropical Small and Tree Fruit Crops with Potential" as some species discussed produced rather "large" small fruits and because tree fruits were also included.

[1]Department of Horticulture, The Ohio State University/OARDC, Wooster, OH 44691.

Moreover, although the current economic importance of these species varied substantially, most, if not all are considered to be under-commercialized at present. In the recent past, the Group has organized similar workshops to update commercial trends in cultivar use, characterize newly developed cultivars and to suggest opportunities for germplasm development in "standard" small fruit crops such as strawberries (*Fragaria* X *ananassa*, Duch.) blueberries (*Vaccinium* spp.) and cane fruits (*Rubus* spp.) [e.g., see Fruit Var. J., Vols. 43(1), 44(2) and 46(4), respectively for the most recent workshop proceedings].

During the 1992 workshop, the current cultivar situations and production potentials of naranjilla (*Solanum quitoense* Lam.) and carambola (*Averrhoa carambola* L.) were expertly outlined by Richard A. Hamilton and John D. Mood, respectively (9, 17). A summary of their addresses along with a brief review of published information on their subjects is presented below whereas the remaining species discussed at the workshop are characterized in the three articles which follow.

Naranjilla

Botany, Production and Use: Naranjilla (or lulo) is a tropical small fruit species native to the cool highland regions (800-2000 m) of Central and South America. According to Hamilton (9), the naranjilla plant is a pubescent, herbaceous, perennial shrub commonly reaching a height of 2 m. Its highland adaptation is affirmed by its preference for cooler temperatures; it tolerates temperatures of 8-10°C, thrives best when cultured at 17-27°C and grows optimally at 20°C (6, 9). Because temperatures of 29-30°C or greater are detrimental, naranjillas produce minimally under hot, humid tropical conditions Stamen abnormalities resulting in fruitlessness have also been noted for naranjilla specimens grown outside of their range of adaptation (6). The nutrient requirements for naranjilla culture are yet to be determined, but adequate plant growth does require fertile soil which is well-drained and high in organic matter. Adequate rainfall (2500 mm), which is well-distributed throughout the growing season is also essential. Commercial plantings are commonly established using transplants. Cloud cover or the use of shade is desirable during production as limiting temperature extremes prevents defoliation. Flowering commences approximately 4-6 mo after transplanting and the subsequent fruit development requires an additional 4 mo. Once past its juvenile phase, the naranjilla plant flowers continuously. However, when grown outside of the tropics, naranjilla may exhibit a short day flowering response (6).

Naranjilla produces an abundance of pubescent, bright orange, golfball-sized (diam ≈ 5 cm), tomato-like fruit (berries) with greenish-fleshed, seedy interiors. The fruit are high in Vitamins A and C, and although highly acidic, they can be eaten raw. However, because of their seediness, acidity, and perhaps their pubescence, they are most often produced for their highly aromatic and concentrated juice which is readily extracted, mixed with water (≈ 1:3 or 1:4) and sweetener and then consumed as a cold drink (*refresco*). Harvested fruit retain their fresh quality when held for 1 wk without refrigeration or for 1-2 mo when stored at 7-10°C and 80% R.H. (6).

Naranjilla is currently marketed only in the highlands of Central and South America and even in these regions, the fruit is expensive and scarce in most markets (9, 10). The highly acidic nature of the juice presents some processing and shipping problems (9). The juice is not transportable in steel containers and until recently, its potent flavor was commonly diminished or lost during the canning process which has limited the demand for naranjilla juice as an export product (6). Alternative methods of processing or preservation such as freeze drying are currently being evaluated (10).

Large-scale commercial production was attempted only once in Costa Rica (1960-1965), where several hundred acres were grown for juice production under contract from a Florida firm (9). However, as production was limited, the juice of the naranjilla was adulterated with cocona (*S. sessiliflorum)* juice. Unfortunately, this juice mixture was judged to be inferior in quality to that extracted entirely from naranjilla fruit, so the contract was canceled. Interest in large-scale naranjilla production was briefly rekindled in 1982, while researchers for the Campbell Soup Co. (Camden, NJ, USA) were developing a new product to be called F-8, a mixture naranjilla, cocona and six additional tropical fruit juices. Both production and processing parameters were evaluated, and although a high quality product was developed, the project was abandoned due to production constraints and the high cost of obtaining the fruit under Ecuadorian conditions (6, 9). Nevertheless, naranjilla remains an important cash crop for small farmers in Ecuador and Columbia (6), and garden production now predominates throughout the highlands of Central and South America (9). Moreover, because of the flavor quality of its juice, naranjilla exhibits considerable economic potential as a labor intensive, high value crop (6). Its production potential has recently been evaluated in Florida and several African regions as well (6, 10).

The major factor limiting commercial production of naranjilla is its susceptibility to root knot nematode, (*Meloidogyne* spp.), and because of this susceptibility, commercial plantings are often abandoned after 2 to 3 yrs due to production declines and plant losses (6, 9, 10). Once a site has been abandoned due to nematode infestation, it cannot be replanted to naranjilla. Therefore, as each production site must be virgin (6), the number of suitable sites is declining and the availability of fruit in the market place is decreasing (10). Among possible solutions to this devastating production constraint, interspecific grafting to resistant rootstocks has been most thoroughly explored. If such rootstock can be found, suitable scion wood can be easily wedge grafted for propagation of improved nematode resistant planting stock. Researchers have reported the graft compatibility and nematode response for naranjilla grafted to several related species (6, 9) including the following: the Brazilian potato tree (*S. macronthum* Dun), the mullein-leaf nightshade (*S. verbascifolium* L.), *S. hirsutissimum* Standl., *S. torvum,* the tree tomato (*Cyphomandra betacea* Sendt.), *S. mauritanum, S. lasiocarpum,* and *S. hirtum.* Although limited success has been achieved under test environments, a suitable rootstock for commerciai production has yet to be identified (9). Efficacious nematocides have been developed, but their toxicity restricts or prohibits their use.

Other factors which limit production include naranjilla's exacting climatic requirements, its susceptibility to pathogens and parasites, its apparently high nutrient requirements and its exposure to limited number of markets (6). Heiser theorized that pathogenicity in naranjilla may be exacerbated by and secondary to nematode stress (10).

Germplasm and Cultivar Development: Apparently naranjilla is a relatively new domesticate, first described during the mid Seventeenth Century (10). As archaeological evidence for its use was non-existent and its domestication history somewhat obscure, Heiser (10) attempted to identify the crop's progenitor using both morphological and genetic studies within the section Lasiocarpa — approaches which led to somewhat conflicting results. Based on morphological (numerical taxonomic) studies, the wild, *huevo de gato* plant (*S. candidum,* a lowland species native from Mexico to northern

Peru whose berries are gathered for their juice) was considered to be naranjilla's closest ancestor, even though the two did not readily cross and their hybrids exhibited reduced fertility. In contrast, cross compatibility patterns suggested naranjilla to be closely related to S. *hirtum* (also called *huevo de gato*, an unpleasantly-flavored lowland species ranging from Mexico to Colombia), although the two are morphologically quite distinct. A feral form of S. *quitoense* may yet be found through diligent plant exploration of the highland regions where it is cultivated (10).

To date, naranjilla production relies totally upon the use of unimproved seedlings grown at the species level (9). Although no cultivars have been classically developed to date, two distinct forms (varieties), spiney and spineless, are known to occur (6). Plants of the spiney variety which are common in Colombia whereas the spineless form (S. *quitoense* var. septentrionale) predominates in Ecuador. The spiney trait, which is controlled by single dominant gene, confers the development of spines on both leaves and fruits.

Naranjilla breeding has been limited, but perhaps the most important efforts have focused upon the transfer of root knot nematode resistance from S. *hirtum* to S. *quitoense*. Heiser (10) serendipitously discovered the relative resistance of S. *hirtum* while exploring the taxonomic relationships of various *Solanum* species as described above. Subsequently, he has cooperated with researchers at the Instituto Nacional de Investigaciones Agropecuarias (INIAP) of Ecuador and with additional colleagues in Costa Rica and Columbia and Ecuador by sending seed of S. *hirtum*, its F_1 hybrid with naranjilla and subsequent filial and backcross generations. This material was being evaluated and developed at the time of his last publication on the subject.

Carambola

Botany, Production and Use: Mood (17) asserted that the expanding worldwide marketing potential for carambola fruit has fostered an increase in attention and enthusiasm for this crop species among growers and horticulturists alike. Carambolas are known to be Indomalayan in origin (3, 7, 13, 17, 18) where they are still gathered from the wild and have been cultured for centuries (perhaps millennia) as door yard trees for their attractive, crisp-textured fruit (7). Adapted to hot, lowland tropical climates with medium to high rainfall, they have long been under commercial production throughout Southeast Asia (17). However, through plant exploration and introduction efforts, carambola germplasm and culture has spread pantropically and to some extent, to subtropical regions as well (17, 18), although the potential for frost damage limits its northerly range in subtropics. Very young trees can be killed at temperatures at or slightly below freezing, whereas mature trees subjected to temperatures in the high 20s (°F), mid 20s (°F) and low 20s (°F) can loose terminals and leaves, small branches, and larger branches, respectively. If a severe freeze is prolonged the tree itself will succumb (3).

The history of carambola in the Western hemisphere dates from 1856, when a botanic specimen was planted in Rio de Janeiro (13). Early introductions to North America also occurred over a century ago, but because these carambola seedlings produced small, sour fruit of inferior quality the species remained as a botanic curiosity for many decades (3, 13). Seedlings were introduced to Hawaii over 50 years ago where breeding and selection efforts improved the germplasm. Seedlings from the improved Hawaiian germplasm pool, which were obtained in 1935 by H. S. Wolfe and subsequently evaluated in south Florida, resulted in Florida's first commercial cultivars, 'Golden Star' and 'Newcomb' (3).

Carambola is a member of the Oxalidaceae, forming large, evergreen trees with low branched trunks and irregularly-shaped, dense crowns which normally reach heights of 10 m (range = 5-12 m) and diameters of 3-5 m (17, 18). Carambola leaves are dark green and pinnately compound with 5-7 leaflets that are 2-8 cm long (3). As it is a cross-pollinating species, seedlings do not breed true. Therefore, the propagation of cultivars for commercial production must be accomplished asexually. Fortunately, carambolas are relatively easy to propagate (90-100% success rate) using conventional methods (3, 17). In Hawaii, propagation is accomplished with a standard top wedge graft using semi-hardwood scions and seedlings from superior cultivars as rootstocks. Chip budding or veneer grafting appear to be the most popular methods of propagation in Florida (3). Graftwood for these techniques should be prepared from vigorous shoots. Leaves should be removed 3-4 days prior to use (5-7 in cooler weather) as removal of leaves forces scion buds into active growth. Rootstocks must also be actively growing. The performance of seedlings as rootstocks is variable among cultivars so it is advisable to use seed of cultivars adapted to local conditions. The production of graftable seedling stock (9 mo old, 7 mm in diam) (17) may be hastened substantially by applications of gibberellic acid (500 mg GA/l) during their development (15). In contrast, air layering has not proven to be a successful means of propagation as root formation in air-layered trees is inadequate. Tissue culture methods have been successful experimentally, but as yet they are not being used commercially (3). Grafted stock may be cultured in bags filled with redwood compost mixed with perlite to promote rooting which shortens the period of juvenility (17).

Carambolas grow in a variety of soil types but prefer soils which are well-drained, high in organic matter, salt-free and have a pH range of 5.5-7.0 (3, 17). Carambola trees will survive flooding but do not bear well in poorly drained soils. In tropical regions, orchards may be established during any period free from environmental stress, but in subtropical production areas like Florida, young grafted trees are planted in the late spring to avoid damage from cool dry winds and to provide an adequate establishment period prior to the onset of the next winter (3). Orchard spacings vary tremendously (3, 5, 7, 17) depending upon expected growth rate and intended canopy management schemes. In Hawaii, trees are planted in full sunlight at spacings of 4.6-9.1 m (7.6 m recommended) and are often mulched after planting to limit soil moisture loss (17). A small percentage of Florida growers have established high density plantings which were designed to be hedge-pruned to maintain light penetration in the orchard, but most new Florida plantings have been established at more moderate plant densities (e.g., 375 trees/ha) (3, 5). Since maximum production is not achieved until an orchard is about 10 yrs old, some growers design plantings with temporary trees which provide additional income when trees are small, but are then removed when overcrowding occurs (3). Interplanting young trees with a companion crop such as papaya (*Carica papaya* L.) is an alternate approach used to generate early returns in a newly planted orchard and to provide some wind protection as well (5). Although carambolas are tolerant of winds, the use of wind breaks or other measures are recommended to reduce moisture loss through transpiration and banging, bruising and desiccation of the fruit caused by wind damage. Moreover, in most locations, small trees are pruned to develop a branch framework that promotes fruit bearing in the interior of the canopy which also minimized the possibility of wind damage to fruit (17).

Once an orchard is established, standard maintenance procedures are employed. In Hawaii, soil fertility is maintained by fertilization with a 14-14-14 (N, P, K) formulation and additional amendments are applied as needed prior to flowering. Multiple applications of N, P, K and Mg-containing fertilizers of various formulations are commonly applied to Florida's groves. The high pH level of some limestone-based Florida soils also necessitate supplementation with Fe, Zn and Mn-containing fertilizers as well, either applied to the soil or as a foliar spray (3). Tree growth and fruit production are adversely affected by drought; under drought conditions, Florida growers generally irrigate every 7-10 days. Sprinkler-irrigation is most effective frost control measure in commercial groves (3).

The juvenility period for carambola is relatively short; trees can often bear fruit 2-3 yrs after planting in the field (13, 17). At 5 yrs, 8-10 yrs and 12-13 yrs of age, they may produce as much as 45 kg/tree, 90-135 kg/tree and 135-180 kg/tree, respectively (3). Tree longevity is unknown, but orchards bearing fruit for over 50 years have been documented (17). Flowering in carambola occurs in flushes, each approximately two months in duration (17) so that two crops per year are realized in Hawaii and Florida whereas the harvest of three crops per year is often possible in some tropical areas (3, 13, 17). Normally, for a given cultivar, there is a 4 mo rest period between harvest and the next flower flush, but in tropical areas such as Hawaii, cultivar diversity for flowering response may allow for continuous availability of fruit for up to 5 mo (17). Flower initiation does not appear to be greatly influenced by temperature or photoperiod, but may be retarded by water stress (18).

Flowers are borne in clusters which form laterally on the trunk, on old or young branches and occasionally terminally on "young twigs" (3, 17, 18). Flowers are approximately 5-6 mm in diameter, pink to purplish in color and perfect, usually containing five stamens and five carpels (17). Each flower is receptive for one day, opening in the morning and closing in late afternoon or evening (18); flowers of a single inflorescence will normally reach anthesis during a period of 1-3 days.

Similar to other members of its family, carambola exhibits distyly (i.e., short style and long style flower types exist and pollination must be effected by pollen from the opposite flower type) (3, 12, 13, 18). Hence most carambola cultivars are self-incompatible. When selfed or "illegitimately" crossed (i.e., crosses between clones of similar flower type), the pollen germinates on the stigma, but fails to traverse the style (12). To overcome the problem of self incompatibility, orchards are usually planted with two commercially acceptable cultivars which 'nick' (flower together) but bear different flowering types (e.g., 'Arkin' and B-10). Trees must be planted so that cross compatible pollen is never more than two rows away (3). An alternate solution is practiced Malaysia, where pollinators are grafted to production trees at a frequency of 1 branch/5 trees (7).

Recently, Knight (12) discovered partial self-fruitfulness in 'Golden Star.' Over 400 controlled self-pollinations of 'Golden Star' yielded 2% fruit set and although this level of set was less than one-fifth that of the cross-pollinated control, it was considered to be adequate. Normally, carambola flowers prodigiously so only 0.5% fruit set is required to produce a full crop.

(17). Self-pollinated 'Golden Star' fruit were slightly smaller ($\bar{x}$ = 96 g) than those produced by cross-pollination, but their size was commercially acceptable. Partial self-fruitfulness may be horticulturally advantageous due to the ability to commercially produce carambolas in solid blocks without pollinators and because self-pollinated fruit contain fewer seeds (12).

As in many floriferous tree fruit crops, fruit thinning (accomplished when fruit reach about 3.5 cm) may be necessary to insure marketable fruit size, to increase sweetness and to space fruit approximately 15 cm apart within the canopy to minimize wind-effected bruising of the fruit (17). In Hawaii and many other production areas, fruit are bagged when they reach a diameter of approximately 8 cm (1 mo after flowering) to prevent insect predation and mechanical damage. In Southeast Asian crops, bagging and fruit thinning are accomplished concurrently (7, 17).

In comparison to other tropical fruit crops grown in Hawaii, carambolas are almost pest free with the oriental fruit fly (*Dacus dorsalis* Hende) and birds being the major predators of ripening fruit (17). Florida-grown carambola is also relatively pest-free (14). However, Florida's crop is also susceptible to injury from a preharvest fruit rot syndrome of unknown cause resulting in a darkening of tissues between ribs syndrome as well as from a variety of pests including: anthracnose (*Colletotrichum gloeosporioides*), sooty mold (*Leprothyrium* spp.) three leaf diseases (*Cecospora averrhoae*, *Phomopsis* spp. and *Phyllasticta* spp), leaf minors, philephedra scale (*Philephedra tuberculosa* Nakahara and Gill), ambrosia beetles (*Playtypus teilsoni* Swaine) nematodes (*Rorylenchulus reniformis* Lindford and Oliveira), and green stink bugs (*Acrostermon hilare* Say) (3, 14). Ripening Florida fruit is also subject to damage from the Caribbean fruit fly (*Anastrepha suspensa* Loew) (8) so that fruit shipped from this state to areas free of this pest must be treated postharvest with heat or hot water vapor to kill fruit fly larvae and eggs. In general these quarantine treatments have a deleterious effect on fruit quality.

The fruit of most carambola cultivars matures in 100-120 days after pollination, but consequent to flowering the ripening process occurs over a 2-3 mo period (17). Early fall and spring crops are harvested in Hawaii whereas Florida's crop matures from Aug.-Oct. and then again from Dec.-Jan. (3, 17). Botanically, carambola fruit are five-loculed berries (range = 4-6) with pronounced ribs (18) so that in cross section, the fruit is distinctively star-shaped. The fruit vary in size (5-15 cm long) and weight (up to 300 g; 50 g fruit is marketable), both of which are influence by cultivar and by fruit load (13, 17). Fruit also vary in shape as determine by the "acuteness" of the angles formed by the ribs and "valleys" (13). The epidermis of carambola is smooth, translucent and waxy which results in a highly attractive fruit with a high level of sheen. The color of mature fruit ranges from pale yellow (near white) to deep orange (13). Color is the most reliable indicator of maturity and fruit destined for commercial markets are normally harvested at color break as fruit color changes from dark green to light or yellow green. Fully-colored,tree-ripened fruit may be desirable if produced for local markets (4).

There are two types of cultivars: sweet- and tart-fruited. Each is conditioned by the ratio of sugars (5-11%) to acids (2-13 meq/100 g) in the ripe fruit (3, 4, 13, 17). In the western world, sweet fruit are preferred for fresh consumption while tart fruit are best for processing. During development, oxalic acid is the predominant acid in both types (4, 13, 17). Oxalic acid levels remain relatively constant in maturing fruit of tart cultivars, but in sweet carambolas (e.g., 'Arkin'), levels of this acid drop substantially as fruit begins to develop, leaving a low concentration of malic acid to predominate. Hexoses (glucose and fructose) predominate in both types of fruit whereas sucrose comprises approximately 15-20% of the sugars present. Ripe fruit do not contain starch (17). Fruit which is held on the tree for 1 wk after color break continue to develop color and flavor, accumulate sugars and reduce acid content, but such fruit are too soft for commercial handling and retention of postharvest quality (4). The fruit is a good source of Vitamins A and C (3, 14).

As with most perishable commodities, the commercial acceptability of carambola is limited by damage resulting from postharvest handling of the fragile, thin-skinned and irregularly-shaped fruit and by the fruit's relatively short storage and shelf life (1, 2). Fruit held at room temperature decay rapidly within a 2 wk period whereas those stored at 10°C for 1 wk retain optimal fruit quality (11). Cold storage also reduces the oxalic acid and tannin content of the fruit and therefore, improves their palatability (17). For more prolonged storage, it is common commercial practice in Florida to store fruit at 10°C or higher and at 85-95% R.H. to avoid possible chilling injury (i.e., injury common to many tropical fruits when stored at low but above freezing temperatures). In postharvest studies (1, 2), commercially harvested fruit stored at 10°C for 30 days were more turgid and less affected by pathogens than those stored at higher temperature. No symptoms of chilling injury were apparent but some desiccation in 'Golden Star' fruit was noted. Color development continued during storage, changing from light green to yellow. The lower limits for storage temperature may be very critical and somewhat cultivar specific. In one study, fruit of 'Arkin' and 'Fwang Tung' stored for 4 wks at 7.2°C were of acceptable commercial quality, but a storage temperature of 4.4°C resulted in significant chilling injury (11). Later studies (1, 2) indicated that 'Arkin' fruit harvested at color break stored at 5°C did not exhibit chilling injury and maintained better appearance, lost less weight and maintained sugar/acid levels better than those stored at 10°C. Although color development was retarded at 5°C, these changes as well as others associated with ripening resumed as fruit were held at a shelf temperature (23°C) for six days.

It is also commercial practice by some distributors to cold-store cartons of fruit encased in polyethylene sheeting to retard moisture loss. Kenny and Hull (11) demonstrated the effectiveness of such treatment to be cultivar-specific (i.e., encasing storage cartons in plastic retarded water loss in 'Arkin' but accelerated it in 'Fwang Tung'). Storage at 7.2°C resulted in less water loss than storage at other temperature and under this regime, water loss was highest during the first week of storage. Mood (17) indicated that Hawaiian-grown fruit stored under polyethylene at 5°C for up to 5 wks exhibited a shelf life of 1 wk at 20°C, but he also championed the need for more postharvest studies to improve both postharvest storage and handling techniques.

Carambola is predominantly consumed as a fresh fruit (17). However, because 20-25% of the crop harvested may not meet fresh fruit standards of size, shape and appearance (16), it is also processed into dried fruit, pickles, preserves, jellies, sauces and its juice (60-75% extractable) is also used in the manufacture of beverage products (17). The feasibility of marketing carambola fruit slices held at 4°C in vacuum packaging of low oxygen permeability (300 cc/m^2/24 h or less) was recently demonstrated (16). Slices so processed remained free of microbial damage and retained their color flavor and texture. As the consumer recognition and popularity of carambola continues to increase, it is likely that novel processing techniques will be further explored and developed.

For reasons stated above, the production of tropical fruit is likely to increase with time for the foreseeable future. Carambola production exemplifies this trend, with recently increased market potential in U.S., Canada, Australia, Europe and SE Asia, Israel (13) and Japan (R. L. Knight, pers. comm.). In Florida, commercial production was initiated during the 1950s and 1960s when fruit were harvested from garden plantings and sold to local restaurants (3). By 1971 there were only 4 commercially-planted hectares of carambola in Dade Co. (3). By 1989, the area under produc ion in south Florida had grown to 176 ha, but 89% of these orchards were under 5 yrs old (5). About 94% of the Florida acreage is planted to sweet-fruited cultivars but 'Golden Star,' a tart-fruited cultivar, is still under production and maintains a place in the industry. Current estimated value of the Florida crop exceeds $1.5 million (14), and according to Campbell and coworkers (3) Florida's carambola industry will continue to expand. Acreage in SE Asia has also increased, although the extremely high cost of agricultural land and government policies may limit further expansion of the industry in some areas (7). Malaysia intensively cultures 120 ha and Taiwan almost 2850 ha of carambolas, most of which is under 10 yrs old and all is concentrated on small farms culture without mechanization. Sweet fruited cultivars predominate in Malaysia. Sweet cultivars are preferred in Hawaii, where in the 1991-1992 season, 26,500 kg of carambolas were produced on 16 ha maintaining approximately 3500 bearing trees (R. M. Manshardt, pers. comm.). Tree population and acerage are increasing in Hawaii, but this expanded production is being concentrated on fewer farms.

Germplasm and Cultivar Development: As stated above, carambola's primary center of diversity is located in Malaysia and surrounding locations and selection for desirable traits has been practiced in this region over a long period of time (13, 17). Within this region, the Malaysian Agricultural Research and Development Institute (MARDI) in Selangor acts as the repository for carambola germplasm and currently holds a large collection of selected materials, some of which have been evaluated elsewhere. Importation of germplasm from this region and subsequent selection efforts have ultimately yielded cultivars which are currently grown in both Florida and Hawaii. A secondary center of diversity may exist in northern South America where carambola has been naturalized for about a century. Current exploration of South American germplasm is expected to reveal useful material for cultivar improvement (13). Genetic diversity is also evident among Taiwanese materials, but most cultivars derived from this stock to date have been inferior by western standards (17).

Breeding and evaluation efforts have intensified over the last 30 years in most areas where carambolas are produced, Among cultivars currently grown in the USA, the sweet-fruited 'Kary' and 'Kyra' predominate in Hawaii whereas Florida's industry is dominated by the sweet-fruited 'Arkin,' a general purpose cultivar suitable for fresh fruit markets or processing (3, 13, 17). Cultivars or selections from Malaysia such as B-1, B-6, B-10, B-16, Hew-1 and 'Sri Kembangan' as well as 'Fwang Tung' from Thailand are currently being evaluated for their commercial potential in Hawaii and/or Florida.

Most likely, the optimum cultivars for large-scale production long-distance marketing have yet to be developed.

However, ample genetic diversity among currently-grown cultivars and in germplasm collections is readily available for cultivar improvement (13, 17). Specifically, carambolas show wide variability for some important fruit quality characteristics such as: color, fruit size, fruit form, solids and acid content, volatile flavor constituents, firmness and fiber content (13). Moreover, controlled pollinations are easy to make and large numbers of seed easy to obtain, and the interval of juvenility is relatively short for a tree crop. All these factors suggest that rapid progress in cultivar development can be expected (13).

A "shopping list" of desirable traits in new cultivars might include some of the following items (13, 17): 1) frequent and abundant flowering to produce full crop; 2) self-fruitfulness; 3) an ability to withstand cold, dry, windy weather for subtropically-grown cultivars; 4) disease and insect resistance; and 5) improved fruit quality traits such as a large uniform size, broad (more obtuse) rib angles and stronger ribs to harvest and postharvest handling damage, high sugar/acid ratio, a strong appealing flavor and crisp texture with reduced fiber content, less seediness, attractive appearance (shiny and yellow to orange in color) free of surface blemishes, and resistance to cold injury during storage. Because of the wide variety of uses for carambola fruit, the edaphic and climatic diversity of production regions, and variation in market preferences, it is likely that no one cultivar will emerge that will meet all demands for new cultivar development. Therefore, the search for new cultivars will likely continue to command the attention of breeders for some time to come. In the words of Knight (13): "The popularity newly realized by *Averrhoa carambola* opens up the prospect of a general advance in fruit quality as new cultivars are developed and distributed about the world. This is an interesting time to be involved in carambola cultivation and breeding" (13).

Acknowledgements

I would like to thank the American Pomological Society for their support in publishing the proceedings of this workshop in *Fruit Varieties Journal* and Dr. David C. Ferree, the Journal's editor, for encouraging me to complete this task. Moreover, I express my gratitude to Mr. Charles R. Clement, Mr. John D. Mood, Dr. Richard A. Hamilton, Dr. Robert J. Knight and Dr. Richard M. Manshardt for presenting papers at the workshop and to Dr. Francis T. Zee for suggesting their participation. Finally, I want to thank Dr. Yu (Gary) Gao for his efforts in videotaping the presentations.

Literature Cited

1. Campbell, C. A., D. J. Huber and K. E. Koch. 1988. Postharest response of carambolas to storage at low temperatures. Proc. Ann. Meet. FL State Hortic. Soc. 100:272-275.
2. Campbell, C. A., D. J. Huber and K. E. Koch. 1989. Postharvest changes in sugars, acids and color of carambola fruit at various temperatures. HortSci. 24:472-475.
3. Campbell, C. A., R. J. Knight, Jr. and R. Olszack. 1986. Carambola production in Florida. Proc. Ann. Meet. FL State Hortic. Soc. 98:145-149.
4. Campbell, C. A. and K. E. Koch. 1989. Sugar/acid composition and develpment in sweet and tart carambola fruit. J. Amer. Soc. Hortic. Sci. 114:455-457.
5. Crane, J. H. 1990. Acreage and plant densities of commercial carambola, mamey sapote, lychee, longan, sugar apple, atemoya, and passion fruit plantings in south Florida. Proc. Ann. Meet. FL State Hortic. Soc. 102:239-242.
6. Dennis, F. G., Jr., R. C. Herner and S. Camacho. 1985. Naranjilla: a potential cash crop for the small farmer in Latin America. Acta Hortic. 158:475-481.
7. Green J. G. 1988. Carambola production in Malaysia and Taiwan. Proc. Ann. Meet. FL State Hortic. Soc. 100:275-278.
8. Hallman, G. J. 1991. Quality of carambolas subjected to postharvest hot water immersion and vapor heat treatments. HortSci. 26:286-287.
9. Hamilton, R. 1992. Current status of naranjilla *(Solanum quitoense)* culture. HortSci 27:563 (videotaped oral presentation).

10. Heiser, C. B., Jr. 1985. Ethnobotany of the naranjilla *(Solanum quitoense)* and its relatives. Econ. Bot. 39:4-11.
11. Kenny, P. and L. Hull. 1987. Effects of storage condition on carambola quality. Proc. Ann. Meet. FL State Hortic. Soc. 99:222-224.
12. Knight, R. J., Jr. 1982. Partial loss of self-incompatibility in 'Golden Star' carambola. HortSci. 17:72.
13. Knight, R. J., Jr. 1989. Carambola cultivars and improvement programs. Proc. Interam. Soc. Trop. Hortic. 33:72-78.
14. Lamberts, M. and J. H. Crane. 1990. Tropical fruits. pp. 337-355. *In:* Janick, J. and J. E. Simon (eds.) Advances in new crops: Proceed. 1st Natl. Symp. New Crops Res. Dev. & Econ., Indianapolis, IN, 23-26 Oct. 1988, Timber Press, Portland, OR.
15. Marler, T. E. and M. V. Mickelbart. 1992. Application of $GA_{4,7}$ to stem enhances carambola seedling growth. HortSci. 27:122-123.
16. Matthews, R. F., J. A. Linsay, P. F. West and A. Leinart. 1990. Refrigerated vacuum packaging of carambola slices. Proc. Ann. Meet. FL State Hortic. Soc. 102:166-169.
17. Mood, J. D. 1992. Starfruit (Averrhoa carambola): growth habits, fruiting characteristics, cultivar advantages and propagation techniques. HortSci 27:563 (videotaped oral presentation).
18. Salakpetch S., D. W. Turner and B. Dell. 1990. Flowering in carambola *(Averrhoa carambola)*. Acta Hortic. 275:123-129.

Fruit Varieties Journal 48(3):146-152 1994

Papaya Germplasm and Breeding in Hawaii

RICHARD M. MANSHARDT[1] AND FRANCIS T.-P. ZEE[2]

Abstract

The papaya improvement "program" in Hawaii consists of several projects involving collaboration between researchers at the University of Hawaii, the USDA, and mainland institutions. The program aims to collect and evaluate papaya germplasm from Central and South America, as well as address specific breeding objectives. In addition to conventional techniques, the methodologies of molecular biology are being applied to the germplasm collection to reveal the history of papaya domestication, and to commercial cultivars to increase the speed and effectiveness of breeding efforts.

Germplasm

The UH Department of Horticulture and the USDA/ARS National Clonal Germplasm Repository (Hilo) are collaborating in a joint program to collect, maintain, and evaluate accessions of papaya and other *Carica* species. Our objectives are to use the papaya germplasm for 1) clarifying the genetic relationships among accessions to better understand the history of papaya domestication, and 2) improving papaya cultivars for the local Hawaiian papaya industry. In pursuing these objectives over the last two years, we have collected a total of 166 papaya accessions from Central and South America, as well as 75 accessions encompassing eleven other *Carica* species (Table 1). Part of the collection is currently under evaluation for morphological and fruit quality factors on Oahu.

In addition to the germplasm, our travels have provided us with experience bearing on the origin of the domesticated papaya, about which some controversy exists. Some reports place the center of origin of papaya in the eastern slopes of the Andes Mountains in South America, primarily because that region is the center of diversity of the genus *Carica* (15). Approximately 20 species exist in the genus, and the majority of them have distributions in this area (1). Others suggest the center of origin to be farther north along the Caribbean coast of Central America (2, 17).

Germplasm observed during our travels revealed the geographic range

[1]Dept. of Horticulture, University of Hawaii at Manoa, Honolulu, HI 96822.
[2]USDA/ARS, National Clonal Germplasm Repository, Hilo, HI 96720.
Journal Series No. 3903 of the Hawaii Institute of Tropical Agriculture and Human Resources.