Greenhouse cultivation of tropical fruits

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Greenhouse Cultivation of Tropical Fruits

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Abstract

Greenhouse cultivation of tropical fruits has evolved enormously since Louis XIV of France exercised his royal privilege by tasting the first pineapple produced in Europe. Modern greenhouse technology has even made it possible to commercially cultivate the banana, with high yields and profits, of interest in subtropical areas such as the Canary Islands and Morocco. Although herbaceous tropical fruits are better adapted to this type of cultivation, woody tropicals may also benefit particularly under certain geographic or economic conditions. The subject is dealt with by crops, rather than by disciplines.

INTRODUCTION

The idea of cultivating tropical fruits in greenhouses is certainly not new. The first European pineapples were produced during the reign of Louis XIVth of France (Py, 1967). Of the tropical fruit crops, pineapple is probably the best adapted to greenhouse cultivation, due to its short height, herbaceous nature, and growth habit, and its popularity as a greenhouse crop in Europe only waned towards the end of the IXth century when competitive fruits from the tropics became more readily available to consumers. Its cultivation under glass does however persist to this day on the Portuguese island of San Miguel, in the Azores Archipelago.

Other tropical fruits, especially woody species, are obviously not as well suited to greenhouse cultivation, although, as will be seen, technological advances allow viable cultivation under particular geographic locations or economic conditions. To best illustrate the greenhouse potential of these crops, they can be divided in the two broad groups established by Verheij (1986): 1) Single-stemmed fruits, and 2) Branched species (including woody and vine crops). Within these two categories a crop to crop approach, will be followed.

SINGLE-STEMMED CROPS

Three commercially important single-stemmed crops - banana, pineapple and papaya - are cultivated under greenhouse in the subtropics. In single-stemmed crops, growth tends to take precedence over flowering and fruiting: vegetative growth precedes flowering in the banana and the pineapple and flowering occurs at the axil of each leaf in the papaya. Conditions that favor vegetative growth will also favor flowering and fruiting and, as a result, these crops respond very favorably to good cultural practices. In general, there is a good knowledge of cultural practices for these species which reach high and predictable yields. Under tropical conditions there appears to be little scope for crop manipulation apart from breeding, but the situation changes in the subtropics - best defined by Samson (1986) as those areas having an isotherm of 10 ºC for the coldest month of the year - where winter temperatures stop the growth of tropical crops. While this could be an advantage for branched species, it is a serious problem for single-stemmed crops, causing among other problems flower and fruit failure, longer crop cycles, and poor fruit quality. Greenhouse cultivation deals effectively with these problems as well as providing other advantages such as protection against wind, higher photosynthetic efficiency (Galán Saúco et al., 1998) and reduced evapotranspiration (Santana Ojeda and Suárez Sánchez, 1998). The high cost of the greenhouse, around 8 US $\$/m^2$ in the Canaries, and the negative aesthetic impact of the structure itself are the chief drawbacks.

Banana

Morocco, with 3000 ha (Ait-Oubahou, personal communication,1999), and Spain, with 2400 ha in the Canary Islands, are the only two countries where greenhouse bananas are being commercially cultivated on a large scale. Small commercial plantings of banana under plastic are found in Crete (72 ha) (S. Lionakis, personal communication, 2000), Cyprus (260 ha) (Papandreou, 1992) and in the Algarve region of Portugal (12 ha) (Louro, 1998). South Africa currently has a few hectares under greenhouse cultivation (Eckstein et al., 1998), as do several other countries like Israel (E. Lahav, personal communication, 1999), Turkey, Korea, Tunisia, Italy (Sicily and Sardinia), and Argentina.

The general advantages of greenhouse cultivation in the subtropics have been studied in depth in the Canary Islands (Galán Saúco et al., 1992) and include: 1) Increase in the number of hours with a temperature above 20 ºC, considered the threshold below which growth and development cannot be improved by any cultural technique (Green and Kuhne, 1970); 2) Protection against wind and other weather conditions (sunburn, hail); 3) Reduction in water consumption, as evapotranspiration is reduced by up to 25%: 4) Increase in the leaf surface leading to higher photosynthetic capacity. An additional advantage of greenhouse cultivation is the theoretical prevention of the dispersal of Sigatoka as the two inoculum types (conidia and ascospores) are spread mostly by wind (Carlier et al., 2000).

All of these points are of economic importance in reducing costs and increasing yields, to the extent where in some areas of the Canary Islands bunch weights have increased up to 61.7 % (Galán Saúco et al., 1992), which translates into average yields of over 80 Tm/ha (exceptionally 100 Tm/ha and year) in comparison with averages of 60 Tm/ha year for well-managed open air plantations (Galán Saúco and Cabrera Cabrera, 2000). Morocco reports similar yields for its greenhouse plantations (Janick and Ait Oubohou, 1989).

Grande Naine is the most widely planted greenhouse cultivar, with 92% of total surface area in Morocco (Ait-Oubahou, personal communication, 1999) and roughly 75% in the Canary Islands. Dwarf Cavendish is the second in importance both in Morocco and the Canary Islands, with token plantings of Williams and Poyo in Morocco (<2%) and Williams alone in the Canaries. Only Grande Naine and Dwarf Cavendish are planted in other countries.

The basic greenhouse used for banana in Morocco is a 5-to-6-m-high structure covering 1.25 ha. It was described in detail by Janick and Ait-Oubahou in 1989 and remains very much the same today, with size dictated by the dimensions of the plastic sheets —3-to-6 m wide by 120 to 140 m long — wherein a single sheet of film is stretched over a wooden (usually eucalyptus) or metal frame, resulting in the basic Moroccan greenhouse measuring 100 m x 125 m, with a flat roof and curved ends. The sheeting usually used is 200 μm in thickness, which needs replacing every three years. Ventilation is usually achieved by opening/closing wall sections although in some areas the cladding is woven around the framework, leaving openings which can cause excessive heat loss problems in the winter. Black netting is frequently added to protect sides over-exposed to the sun.

The typical banana greenhouse in the Canary Islands, as indicated by Galán Saúco (1992a) and Galán Saúco et al. (1998), is a frame of galvanized steel pipes (∅ 2-to-4 inches and 6-to-7 m in length) embedded in concrete bases. Cladding is fine net, polyethylene film or a combination of the two sandwiched between a double-weave wire network. Net cladding is particularly recommended in the warmer areas of the Islands where the main goal is to protected the plants from wind damage. Banana structures last for more than 20 years but plastic covers should be replaced every 2-to-3 years and netting every five years.

Cultural techniques for greenhouse banana cultivation in the Canaries include the use of vitroplants, with variable planting distances, with up to 3 plants/hole (2-2.5 m between groups) but always allowing aisles of 5-to-6 m. The grouping of 3 plants/hole allows easy aerial tying as well as more rational management, facilitating mechanization of different cultural techniques (desuckering, chemical treatments, harvesting). Although 1st cycle densities can be very high, up to 4000 plants/ha, they should be reduced by around half for 2nd and successive cycles. In the warmer, spring-type climate of the Canary Islands, planting is generally done in the spring or at the beginning of the summer. Recent trials also include planting in greenhouse in the spring at 10 x 1 m (2 plants/hole) and again during the summer in the middle of the aisle (also at 2 plants/hole, spaced 1 m within the row), so that the initial spring planting can be automatically replaced during the summer of the following year and the summer planting is replaced in the spring of the second year, with a subsequent replanting by halves (specialized machinery is needed for this type of practice, in order to shred and bury the unwanted plant material); obviously no desuckering is done as the plantation is maintained permanently on a parent-crop cycle.

With drip irrigation, water consumption can be reduced by up to 25%. Daily greenhouse consumption is in the range of 10 L/plant in the winter and 20 L/plant in the summer, which is of capital importance due to the high cost of water in the Islands (around 0.5 US $/m^3).

Cycle length is much easier to control under greenhouse conditions, as a direct consequence of both high temperatures and bigger leaf surface (i.e. higher photosynthetic activity per unit of land) (Galán Saúco et al., 1998): providing appropriate leaf removal is done shortly after bunch emergence (retaining a minimum of eight leaves/plant) each plant will produce a bunch/year in contrast with open-air plantings, where in many locations of the Canary Islands only 80% of the plants bunch in a given year.

Cultural techniques in Morocco are similar to those in the Canaries, although the comparatively cooler climate of Morocco makes it advisable to have two planting periods, February-May or September-October, to avoid flowering in winter. Given the temperature extremes found in the Moroccan greenhouses, they are usually equipped with an overhead mist system to reduce the risks of high summer temperatures and chilling in the winter.

Pineapple

As with the banana, a single meristem produces the aerial parts in orderly succession. As growth and fruiting are separate in time, the incidence of low temperatures also delays the achievement of adequate size for flowering.

Again as for bananas, in subtropical regions the pineapple's cycle is easier to control under greenhouse than in the open air where temperatures are somewhat marginal. The higher temperatures experienced in greenhouses increase leaf emergence rate, in turn producing two and even three crops every 3 years, as occurs in tropical conditions. They also favor a better quality fruit with a higher sugar:acid ratio.

Between 10 and 15 hectares of greenhouse pineapples are currently cultivated in the Canary Islands, Morocco, and Israel, and some experimental work is underway in the Portuguese Algarve. Special mention should made of the Azores (Portugal), where oustanding pineapples have been produced under glass since early in the 19th century and which currently fetch prime market prices. The Azores cultivates around 70 hectares in individual glasshouses, using structures of 9.50 x 50 x 2.80 m. A detailed description of the glasshouse as well as the cultivation system can be found in Orsi & Pagani (1972) and in Tavares & Baptista (1997), but the main features include: the plant is cultivated only as parent crop; the cycle is divided into three phases: propagation (6 months), first transplant (6 months), and second transplant (12 months up to harvesting); use of organic substrates, with local manures mixed with composted local forestry waste (foliage and branches especially of *Pittosporum undulatum*) and wood chips; periodic whitewashing of the roof to avoid excess light; use of smoke to induce flowering; production is completely organic.

Smooth Cayenne is grown both in the Azores and Morocco. A local selection of Red Spanish is the predominant cultivar in the Canary Islands, and Queen types do best in the Algarve (Farinhó, 1993).

The local Red Spanish selection grown in the Canaries exhibits a better sugar:acid ratio than Smooth Cayenne, particularly in winter (Cabrera Cabrera and Galán Saúco, 1988).

Average fruit weight is 1.5 to 2.0 kg, and its red skin is extremely attractive to consumers. It is a small-crowned type, which makes reduction by chemical or mechanical means unnecessary, and it is not very prone to crown fasciation (small crownlets are frequently produced but easy to remove). Sucker emission, unlike Smooth Cayenne, is excellent allowing an easy selection of followers for second and third cycle crop.

Cultural practices in the Canary Islands and Morocco are similar to those used for open-air pineapple cultivation elsewhere. Planting densities are in the rank of 35,000 plants/ha, with a typical layout of twin lines 0.45 m apart (0.4 m within the line) and 1 m of aisle. Black polyethylene mulching is currently used over all the soil surface, obviating herbicides, although pine needle (*Pinus* spp.) mulching is sometimes used in the Canaries. Sprinkler irrigation is generally used and annual water consumption is in the range of 7000 m^3/ha. With good technical management yields may reach 40 Tm/ha and year. The structures do not need to be as tall as those designed for bananas, typically reaching only 2.5 to 3.5 m in height (occasionally, structures of the type usually used for vegetable or flower production are used). Netting is preferred instead of polythelene film in the Canaries although polyethylene film is necessarily used in Morocco.

Papaya

As opposed to banana and pineapple, vegetative growth in the papaya coincides with flower development - in fact, after a short juvenile phase, an inflorescence emerges in the axil of each leaf. When environmental conditions are poor, flowering and fruiting suffer the most: temperatures below 20 ºC have a very negative effect causing, among other problems, carpeloidy, reduced pollen viability, and low sugar content of the fruit (Galán Saúco, 1992b; et passim). Thus, in theory, the papaya will only thrive in stable tropical climates; in practice, however, the grower must maintain a high constant growth rate throughout the entire life of the plant in order to obtain maximum yield. One solution for the mild subtropics is again protected cultivation, as is done in the Canaries where over 150 ha of papaya are already being grown in greenhouses and further plantings are planned for the near future. Commercial greenhouse cultivation of papaya is also done in Japan (N. Utsonomiya, personal communication, 1999), with 40 hectares, and in Israel with 30 hectares (E. Lahav, personal communication, 1999).

Greenhouse papayas grow and fruit better than in the open air as a consequence of both higher temperatures and wind protection, as well as providing protection against papaya ringspot virus (PRV) (Rezende and Costa, 1995). Consumer objections to genetically modified produce have potentiated the need for exclusion measures such as greenhouse cultivation, which is currently the only way to avoid PRV. In fact the incidence of PRV in the Canaries is very small (Espino de Paz et al., 1995) as long as clean planting material is used and Cucurbitaceae or other host plants are not interplanted with the crop. Recent studies done in Brazil corroborate the economic interest of cultivating papayas under greenhouse, recommending this as a commercial practice (Sabagg et al., 2000). A further advantage over open-air plantings is the prolonged harvest period producing good quality fruit, which allows excellent prices for out-of-season produce.

Some disadvantages associated with the use of greenhouses include the shortening of the commercial productive life of the plants as a consequence of greater internode length which in turn means that plants are taller when flowering begins, quickly reaching ceiling height, increased incidence of mites and powdery mildew, and scarce or absent natural pollination of female flowers (Rodríguez Pastor et al., 1990; Rodríguez Pastor and Galán Saúco, 1995). The recent development of Baizinho de Santa Amalia, a dwarf mutant of Sunrise and very similar to it in quality, which flowers very close to ground level, has considerably advanced papaya greenhouse cultivation and is replacing Sunrise as the predominant cultivar in the Canary Islands. Sunrise prevails is Japan, although the cultivars Tainou 1, 2, and 5 are also used. Locally selected female papayas are prevalent in Israel.

Greenhouses for papaya in the Canary Islands are of the same type as those used for bananas. Japan and Israel use similar structures, either of steel pipe or steel frame with a height of 2.5 m or slightly more.

Planting densities in the Canaries are at around 1600 plants/ha, yielding up to 200 Tm/ha over three years, after which replanting is necessary. Some local growers are using the Pelibüey sheep (fed on a basic diet of banana leaves) to provide manure and to graze the plots to control weeds; other agrotechniques are similar to those used elsewhere for open-air cultivation. A practice currently used in Japan (used by some Canary Islands growers prior to the switch to Baizinho de Santa Amalia) is to extend the shoot obliquely, nearly parallel to the ground, in order to reduce plant height (Utsunomiya, personal communication, 1999). Interest in organic greenhouse production is currently high in the Canary Islands, with its incentive of higher market prices.

BRANCHED SPECIES

Greenhouse cultivation of woody tropical fruit trees is more complicated due to the growth habit of the plant, with vegetative growth stimulated by high temperatures, and this continuous growth making for larger and larger trees requiring frequent pruning. The fact that a growth check is necessary for regular and profuse flowering discourages the use of greenhouses since the reduction in winter temperatures in the subtropics may act as a natural trigger for the desired annual flowering. There are, however, some special situations in which greenhouse use can be justified. Greenhouse cultivation of tropical and subtropical vines is easier, as floral development coincides with extension growth, and plant manipulation, using different trellis systems, is the rule.

Mango

Greenhouse mango cultivation is mainly done in Japan, which currently has 200 ha (Yamashita, 2000), but the Canary Islands has a small commercial area (less than 10 ha) and Israel is experimenting with 0.3 ha (E. Lahav, personal communication, 1999).

The reasons for greenhouse cultivation are both economical and climatic. Mangoes in Japan are restricted to the southern-most districts, namely Okinawa and the Kagoshima and Miyazaki prefectures in Southern Kyushu. Greenhouse use evolved from the installation of a plastic roofing film to protect the trees from rains that would in turn increase anthracnose problems. Typhoon risk required a more solid structure be built, using iron frames and rigid acrylic sheets, with later provision for ventilation and irrigation as well as heating system not only to protect the trees against cold snaps in winter but also to help flush development during the autumn. The importation of mangoes is seriously restricted due mainly to fruit fly quarantine requirements and market prices for locally produced fruit can be as high as 5,000-10,000 yen/kg (110 yen = 1 $US), amply offsetting the building cost of 150×10^6 yen/ha for the greenhouse.

Irwin, grafted on Formosa, is the only cultivar planted in Japan. The initial planting density of 2.5 x 2.5 m is changed to 5 x 5 m as the trees age (Utsunomiya, personal communication, 1999). Canopy growth is limited by restricting root development, planting in an 80 x 150 cm hole lined with sackcloth. Early pruning of terminals is done immediately after harvesting, to allow the production of two vegetative flushes before flower differentiation (Yamashita, op. cit.). Depending on when the terminals have flowered and with discretionary heat control of the greenhouse, harvesting can be prolonged from April to August. The relatively weak self-incompatibility of Irwin allows good yields as long as beehives are present inside the greenhouse (in Okinawa, flies are also used). Heating starts in January, providing a night temperature regime above 23 ºC. Ventilation becomes necessary when temperatures during flowering and fruit set exceed 35 ºC, to avoid damaging the young fruit.

The reason behind greenhouse mango cultivation in the Canary Islands is primarily to anticipate the market, obtaining prime prices for fruit produced up to one month earlier. As in the case of Japan, severe phytosanitary restrictions do not allow the Canaries to import mangoes. The main cultivars are Irwin, Tommy Atkins, Lippens, and Torbet, grafted on Gomera-1, and pollination is also guaranteed employing flies and beehives; of note is that fruit set of Tommy Atkins improves in the presence of Irwin (Galán Saúco et al., 1997). In general, yields use can be as high as 37.5 Tm/ha at the sixth year of growth. Planting distance is 3 x 4 m and no root restriction is practiced as greenhouse heights are around 6-to-7 m (the same type of structure as that used for banana). Cultural practices do not differ from those practiced in open-air subtropical plantations, and no heating is needed due to the mild winter climate. Interplanting with pineapple during the first two years has been practiced to obtain early returns (Galán Saúco, 1999).

Loquat

Around 450 ha of loquat (*Eriobotrya japonica* (Thunb.) Lindl.) are cultivated in greenhouses in mainland Spain, with the main surface in the mainland province of Castellón. The economic importance of the crop is such that it has been given an *Appelation Controlée*, "Nísperos Callosa D'En Sarriá" (*níspero* is Spanish for loquat and Callosa D'En Sarriá is the region of cultivation). The main cultivar planted is Algerie. The main reason for greenhouse use is to anticipate harvesting: early loquats are the first fresh fruit produced in Europe after the winter and command very high prices which compensate for the investment. Additional advantages are higher total soluble solids and bigger fruits due to higher diurnal temperatures. The same basic greenhouse structure as described earlier applies, with ceilings at a height of between 4 and 6 m. Cladding is usually translucent polyethylene anti-aphid netting — although film is used in the Cartagena region — using 3-m strips on the roof, with openings of 20 cm left between strips. Pollination is achieved by placing beehives in the greenhouse, either honeybees or bumblebees (*Bombus terrestris)* (E. Soler López, personal communication, 1999).

Other Crops

Carambola (3 ha in Israel and around the same in the Canaries) and cherimoya (6 ha in Japan) are also cultivated under netting greenhouses.

In the case of carambola, a highly productive and early bearing crop (Galán Saúco and Menini, 1993), wind damage to the fruit is the main reason for protected cultivation. As the crop is also susceptible to diverse fruit flies additional advantages may be obtained from greenhouse cultivation. The tree is also easily adaptable to different training systems with appropriate pruning, and several different trellis systems are regularly used.

In the case of the cherimoya, the extremely limited shelf life of this delicate fruit make it an expensive commodity in distant markets such as that of Japan, thus justifying the expense involved in greenhouse production. Also the severe phytosanitary restrictions applied in this country on imports of tropical fruits may contribute towards the same end. The development of highly efficient hand-pollination devices to obtain high yields (Soria et al., 1990) has further stimulated the development of this crop under greenhouse.

Small-scale greenhouse cultivation of guava and litchi may be recommended in some situations. The guava, like many other tropical and subtropical fruits, has a well defined production season which implies surplus and consequent price reduction. Trials to modify the flowering pattern have been undertaken in Mexico (Castelán Estrada and Becerril-Román, 1994; Otero Sánchez, et al., 1997) using ethrel, water stress, and nitrates. As this crop flowers on current-season growth, the potential to obtain two crops per year could be explored under certain tropical conditions. Benefits derived from avoiding fruit fly infestation in this very susceptible crop should also be taken into account, as in the case of carambola.

In the case of the litchi, slow growing cultivars like Wai Chee could merit being tried under greenhouses in subtropical areas. Benefits in the mild subtropics could be manifold including:

1. Possibility of better flower induction, as night temperature during winter are slightly lower under greenhouses than in the open-air (Galan Sauco, 1987) and soil humidity is easier to control as rain is excluded.
2. Early cropping becomes feasible, as day temperatures are higher than in open-air plantings, giving rise to accelerated growth and consequently to a reduction in the initial unproductive years of the tree.

3. Advancing the harvesting season, also due to increased diurnal temperatures, with the consequent increase in market prices.
4. Wind protection and protection against birds, bats and even fruit flies.

Some trials of greenhouse cultivation have been done in the Chinese province of Guangzhou where the author visited — during a field trip organized by the 1st International Symposium on Litchi and Longan (June, 2000) — the Yelai farm, where high density plantings of litchi were maintained through root restriction and severe pruning. Pollination failure ended the trials and the greenhouse structures were removed. Conditions conducive to pollination, probable using beehives inside the greenhouse, is one of the chief goals for successful cultivation.

Finally, small plots of passion fruit under greenhouse have been implemented in the south of France (Plotto and Vaysse, 1989). No technical problems for cultivation of this vine exist since pollination can be achieved, as with the loquat, through the release of *Bombus* spp., natural pollinators of this species (Galán Sauco et al., 1978). However, investment can only be justified in view of the high prices this crop fetches in some European markets.

CONCLUSIONS

Cultivation of single-stemmed, herbaceous tropical fruits is technically feasible as both growth and flowering habit benefit from the climatic modifications achievable in a greenhouse. In the case of the banana, the tremendous increase in yield and the improvement in harvest planning can justify the investment in infrastructure. This has been amply illustrated in both the Canary Islands and Morocco. In the case of the papaya, besides improved yields, both in quantity and quality, there may also be additional benefits derived from virus exclusion which all told may also make this a profitable system of cultivation. Successful greenhouse cultivation of the pineapple is limited to small surfaces of organically produced fruit for niche markets, like the Azores produce, or to situations where import restrictions affect supply and demand, although this would no longer apply once the current recommendation of the World Trade Organization comes into effect.

Branched species are less favored by greenhouse cultivation due to the difference in their growth requirements and flowering habits compared with woody trees and to the continuous increase in tree size. Technically, pruning and adequate cultural practices can solve many of these obstacles, but in the end run greenhouse cultivation is only justified when the solution of a specific marketing problem can compensate the investment, or where wind, insect and bird protection is inherent to successful production. The same may be applied to passion fruit vines, thus explaining the relatively small surfaces of this crop planted all over the world. The only exception is the cultivation of 460 ha of the subtropical loquat in the south of Spain, as early cropping after winter (better prices) cannot be improved upon by open air cultivation.

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