

# **A Review of *Hylocereus* Production in the United States<sup>♦</sup>**

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## **INTRODUCTION**

Pitaya, pitahaya or dragon fruit, grow on a veining epiphytic cactus (*Hylocereus* sp.) native to the tropical forest regions of Mexico and Central and South America (Mizrahi et al., 1997). The plants grow up tree trunks and are anchored by aerial roots. The fruits have red or pink thornless skins, while the juicy flesh can range from white to magenta. The skin is covered with bracts or "scales", hence the name dragon fruit. The seeds are small and are consumed with the fruit. The fruit can weigh up to 900 grams, but the average weight is between 350 and 450 grams. The weight depends on pollination as well as the variety selection. When ripe, the dragon fruit are most often consumed fresh. In some parts of South America, the pulp is used in drinks.

Dragon fruit have been cultivated in Vietnam for over 100 years and much longer in their native locations. Only recently have they received attention from growers in other parts of the world, including Israel, Australia, and, most recently, the United States (U.S.). They are currently being grown commercially in Nicaragua, Columbia, Vietnam, and Israel, with the Australian and U.S. industries just beginning.

Production in the United States is in its infancy, but recent newspaper (Karp, 2002; Smith, 2002) and magazine articles (Seabrook, 2002; Valdivia, 2000) have generated a good deal of consumer interest, especially by chefs, high-end restaurants, and hotels. Presently, the demand far exceeds the supply, although that is bound to change as more and more growers dedicate acreage to dragon fruit.

There are several problems to deal with when adapting these cacti to growing conditions outside of their native environment, but thanks especially to Dr. Mizrahi's group in Israel and Paul Thomson of California, many of the problems have been worked out.

## **U.S. PRODUCTION**

Presently, it is believed that there are only 10 to 15 hectares of dragon fruit planted commercially on the U.S. mainland. They are all located in Southern California. The largest planting is 7 hectares, while most plantings are less than one hectare. There are also some commercial plantings in Hawaii. As more growers learn about dragon fruit, and how productive they can be, the acreage planted is bound to increase significantly. South Florida as well as any frost-free areas of the southern U.S. probably will be suitable for dragon fruit production, but, as yet, there are no known commercial plantings in these areas.

Presently, the majority of the fruit produced are being sold in Asian communities in Orange and Los Angeles counties, with a small amount going to private chefs. In 2002, prices paid to growers ranged from \$13 to \$22 per kg. This price will drop as production increases. To open up new markets the price will

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have to be reduced to encourage consumers unfamiliar with the fruit. Currently, the supply does not come close to meeting the demand from the Asian communities, not to mention the potential new markets throughout the United States. It will be important to implement standards, perhaps through a growers association, in order to ensure that only quality fruit go to market. Fruit that is immature or of poor quality has the potential to turn away consumers and spoil markets.

## POLLINATION

These cacti are night blooming and the hermaphroditic blooms remain open for one night only. They are large, up to 30 cm across, and are adapted to pollination by bats or hawk moths. As is the case in California, one of the main problems with growing these cacti in new regions is that often times these pollinators are absent. Bees are not efficient pollinators of *Hylocereus* sp. flowers (Weiss et al., 1994) due to the large size of the flower and the arrangement of its parts. Bee pollinated fruit were found to be smaller than fruit resulting from hand pollination. The fruit set was also found to be less (Nerd and Mizrahi, 1997).

Many of the varieties are not self-compatible; therefore, the flowers need to be cross pollinated with pollen from a different clone or species in order to set fruit. Hand pollination is required with self-incompatible varieties to ensure proper fruit set and weight. This adds a considerable amount to the labor cost of growing these fruit. Whenever possible it is recommended to plant self-compatible (self-fertile) varieties, although there are problems with these, as well.

Many of the varieties from Asia (predominantly *H. undatus*) are self-compatible, and some of these are autogamous and will set fruit without the involvement of a pollen vector. It has been previously reported (Weiss et al., 1994) that *Selenicereus megalanthus*, the yellow pitaya, is autogamous. The anthers and stigma are at the same height in these flowers and touch as the flower closes. They also found that in their clones of *Hylocereus* species the anthers and stigma were separated by at least 2 cm. This may be the reason why their self-compatible *Hylocereus undatus* clone was not autogamous. Several varieties of *Hylocereus* sp. that have similar flower morphology to the yellow pitaya have been identified in California. If these varieties are self-compatible, they often set fruit without hand pollination. Most of the autogamous varieties in the *Hylocereus* genus are varieties of *H. undatus* from Asia. A few red-fleshed species from Guatemala are self-compatible and possibly autogamous, although that will need to be tested to rule out bee pollination.

The only disadvantage to autogamous varieties is that the fruit is often smaller than if the flowers were cross-pollinated with pollen from a different clone or different species. This is similar to what has been demonstrated in Israel where self-compatible clones when self-pollinated produced smaller fruit than when cross-pollinated (Nerd and Mizrahi, 1997; Lichtenzweig et al., 2000). Fruit weight is positively correlated with the number of viable seeds (Weiss et al., 1994). The more successful the pollination is, the larger the fruit will be. Several of the autogamous *Hylocereus undatus* clones produce 350-gram fruit, on the average, when the flower is not hand pollinated. Although these are large enough to go to market, growers will have to determine if it is economically advantageous to hand-pollinate flowers in order to increase the fruit weight.

Hand pollination is carried out easily by physically removing anthers from one flower and touching them to the stigma of another or collecting the pollen and using a brush to pollinate multiple flowers. Pollen is most viable at the time of flower opening, but hand pollination was found to be successful well into the evening of the following day (Weiss et al., 1994). Another problem that often occurs is that varieties will bloom when there are no other flowers open from which to obtain pollen. This will often happen early in the season (Metz et al., 2000). The plants bloom in waves during the summer. Two or three waves of

flowers per season were reported in Israel, with a similar pattern occurring in California. Often, the first wave of flowers will not set fruit due to a lack of cross-pollination. To circumvent these problems Metz et al. (2000) developed a protocol for the long-term storage of pollen. They found that the pollen must be dried to 5% to 10% moisture content by weight and stored at subfreezing temperatures. Pollen stored in this manner remained viable for at least 9 months. The colder the storage temperature the larger the resulting fruit was after hand pollination. This protocol will enable growers to store pollen over the winter and pollinate the first blooms of the season thus getting an earlier and larger crop.

The flowering season in California is from May through November (Thomson, 2002), which is in line with what is reported in other locations (Raveh et al., 1993, Mizrahi and Nerd, 1999). Dragon fruit are known to be a long-day plant (Lauders, 1999) so controlling bloom initiation with artificial lighting may be a possibility, thus extending the season.

## VARIETIES

There are many named varieties of dragon fruit. More than 60 have been identified in California alone. Some certainly were started from seed, but most were undoubtedly brought in from Asia and South America as cuttings. Importation of cuttings from outside of the country is difficult because the plants are protected under CITIS regulations, even though the majority of the *Hylocereus* species are not endangered.

Quality of the fruit does vary between varieties, but harvest time has a much greater effect on quality than varietal differences. As mentioned previously, there are self-compatible and self-incompatible varieties. The majority of the varieties from Asia are self-compatible and are autogamous, as well. Except for a few varieties from Guatemala, the red-fleshed varieties are self-incompatible. There is considerable variation in fruit size and shape between the varieties. Fruit shape ranges from nearly round to an oblong shape that is typical of the white-fleshed varieties from Vietnam. Much work remains to be done in evaluating existing varieties and in selecting and developing new varieties based on fruit quality, shelf life, and productivity. It would be advantageous to bring in commercial varieties from other countries for evaluation in the US.

## FRUIT RIPENING AND QUALITY

Two groups have looked at the fruit ripening and harvest times of these cactus fruit (To et al., 2002; Nerd et al., 1999). These studies were performed in Vietnam and Israel, respectively. Both groups found that the optimal time to harvest *Hylocereus undatus* fruit was 28 to 30 days after flowering at full color development. These fruit are nonclimactic and were found to maintain their quality for at least two weeks when stored at 14°C (Nerd et al., 1999). They also found that pigment development in red-fleshed varieties paralleled skin color development.

Brix readings of fruit grown in California have been found to fall between 13% and 16%, on average; with the soluble solids percentage increasing the longer the fruit are left on the plant. The highest brix so far recorded was 20% for a red-fleshed variety. Fruit with brix readings at or above 12% or 13% seem to have an acceptable sugar level for most consumers. It will depend somewhat on the variety, but from currently available data; it appears that for fruit grown in California it takes between 40 and 45 days after bloom to reach acceptable sugar levels. If California fruit is picked at 30 days, as recommended in Israel and Vietnam, the fruit will be low in sugar and of poor quality. The temperature and climate of coastal California, as compared to the desert of Israel or the tropics of Vietnam, may be the reason for this

difference. More data must be collected, and the shelf life must be considered, before the optimal time between bloom and harvest can be determined for California.

For the most part, fruit from the plants of the *Hylocereus* genus are picked too early in California. As a result many people who have tried these fruit are not overly impressed with the quality. It has been the author's experience that the main part of the fruit reaches full color development before the sugar content reaches acceptable levels when grown in California. Possibly, as has been suggested by an Asian dragon fruit grower, the bract color can be used as a scale of maturity, but this will have to be worked out in the future.

## **PRODUCTIVITY**

Unlike the majority of fruit crops, plants of the *Hylocereus* genus begin to produce significant crops two to three years after planting and reach full production after five years (Jacobs, 1999). This results in quick returns for farmers who have a high initial setup cost for this type of crop. *Hylocereus polyrhizus* plants gave an estimated 16 tons per hectare in the second year after planting in Israel (Raveh et al., 1997). The plants are very productive with mature Vietnamese orchards producing 30 tons of fruit per hectare (Mizrahi et al., 1997). In Nicaragua plantings yielded 10 tons to 12 tons per hectare in the fifth year (Jacobs, 1999).

## **TEMPERATURE LIMITS**

The plants are sensitive to extremes in temperature. This should be taken into consideration when selecting a site for a commercial planting. Ideally, a frost-free location should be selected. These cacti will show damage at  $-2^{\circ}\text{C}$  and often die at  $-4^{\circ}\text{C}$  (Thomson, 2002). The plants also will be damaged at temperatures above  $45^{\circ}\text{C}$ . It must be remembered that they are an understory cacti originally adapted to a shady environment (Mizrahi and Nerd, 1999) and not a desert species. Therefore, they will be better suited to growing in areas along the coast where temperatures are moderated by the ocean influence. There is considerable variation of sensitivity to cold and heat between varieties as well as between species (Thomson, 2002). Consequently, there is the potential to develop varieties that can endure higher and lower temperatures through breeding.

Slight temperature damage will show as blistering and cracking of the green fleshy parts of the stem. Moderate damage will cause yellowing and "liquefaction" of areas of the stem, while heavy damage will cause the whole plant to "liquefy" and, more than likely, the plant will not recover from such severe damage.

Reduced flowering has been demonstrated in areas where temperatures rise to  $45^{\circ}\text{C}$  ( $39^{\circ}\text{C}$  average) (Mizrahi and Nerd, 1999). Flower production was found to be only 15% to 20% of levels in areas where average summer temperatures were just 7 degrees cooler.

## **PESTS AND DISEASES**

The plants are relatively free from harmful pests and disease. Rarely, aphids will cover a bloom or fruit, but they are easily controlled and not usually a serious problem. Slugs and snails will damage new growth. Rabbits and squirrels will feed on the green parts of the lower stems, leaving only the central core. While this type of damage does not usually kill the plant, it should be prevented. Chicken wire, a piece of pipe or any suitable material can be placed around the base of the plants to protect them from this

sort of damage. Gophers will do extensive damage if they are not kept under control. When gophers are expected to be a problem it is advisable to plant in gopher baskets made of suitable chicken wire or hardware cloth to prevent plant loss. Rats and mice will eat the fruit, causing damage to the crop. Blistering and black spots will sometimes develop on the stems, but in California these have been shown to be a physiological response to stress as opposed to a pathogen or disease (Thomson 2002, author's experience). These symptoms seem to develop in response to temperature extremes, sun exposure, poor soil fertility, improper irrigation practices, or other stresses to the plants.

## LIGHT REQUIREMENTS

Due to the fact that these plants are adapted to growing as an understory plant they need protection from intense sunlight. Near the coast in Southern California they often will thrive in full sun, but the further inland they are planted, the more shade they seem to require. Covering plantings with shade cloth is necessary in many areas. When the plants receive too much light they become bleached, their growth is retarded and the plant can be killed (Raveh et al., 1997; Raveh et al., 1993; Mizrahi et al., 1997; Mizrahi and Nerd, 1999; author's own observations). When these plants are grown under heavy shade, they become etiolated, resulting in narrow stems and elongated growth. The main problem with too much shade is that flowering will be severely reduced and, consequently, production will be drastically reduced. To maximize production it is recommended that a minimum amount of shade be used to prevent bleaching out. There are differences between varieties and species as to their shade requirements. The species with a waxy coating on the stems will tolerate more sunlight than the others (Thomson, 2002; Raveh et al., 1997). If plants are water stressed, their resistance to light intensity and bleaching will be reduced.

## TRELLIS

Plants of the *Hylocereus* genus can reach a very large size. Branches can grow up to 5 m in a year and mature plants can weigh well over 50 kg. Because their growth pattern is similar to a vine, they need some type of support when grown in an orchard. Many trellis designs have been used. In Asia they are most often grown up through a vertical pipe to a height of 1.5 m to 2 m at which point they are allowed to branch and hang down, thus forming a circle of branches all around the pipe. Standard grapevine trellis has been used with center posts and cross arms. In Israel, they have been grown on a similar trellis, but without the cross arms. Three wires are run down the center of each row at three different heights. The plants are grown to the top wire with all the side shoots removed and then allowed to branch and hang down from the top. To prevent wind damage and to form a compact hedge the branches are secured to the lower wires. This compact hedge allows for a closer spacing of the rows than when using a standard trellis with cross arms. Any type of trellis that can support the weight of the plants and allow easy access to flower and fruit will work for commercial production.

Spacing depends on the type of trellis used. Numerous spacings have been listed in the literature: 3 m by 5 meters in Nicaragua (Jacobs, 1999), 2 m by 1.7 m (Thomson, 2002), in Israel 1.5 m by 1.5 m (Weiss et al. 1994), 1.5 m by 2.5 m (Nerd et al., 1999), and 1.5 m by 3 m (Raveh et al., 1997). The closest spacing used in California with the three-wire trellis described above is 2.5 m between the rows. If the spacing is any closer, it is difficult to maintain the plants and harvest the fruit. Spacing between the plants within the row varies. If plants are not in short supply, 1.5 m between plants will give quicker production than a larger spacing. They have been planted 3 m, or more, apart. Higher density plantings will produce returns sooner, but the plants also will begin to crowd each other sooner.

## **WATER REQUIREMENTS**

Although these plants are cacti, they take more water than expected for a typical desert cactus. It must be remembered that they come from areas of high precipitation and humidity. Several papers have mentioned amounts of water given, 150 mm of water per year (Mizrahi and Nerd, 1999), 4 liters per plant per day (Raveh et al., 1997), 5 liters per plant per week in the hot season and 2 liters in the cool season (Lichtenzveig et al., 2000), and 5 liters per week in the summer and 2.5 liters in the winter (Nerd et al., 1999). Raveh et al. (1997) were attempting to keep the topsoil continuously wet. It has been the author's experience (originally suggested in a personal communication with Dr. Avinoam Nerd) that a small amount of water every day is more beneficial to these plants than a larger amount of water less often. They have a very shallow fibrous root system and seem to respond well when the upper portion of the soil is kept continuously moist. The amount of water will depend on the type of soil, but in a sandy soil (decomposed granite) in Southern California young plants responded well to 1 liter per day by drip irrigation. The optimal amount of water still needs to be worked out and it will vary by location, depending on climactic factors as well as soil type. Heavy rains (greater than 1300 mm) will lead to flower drop and fruit rot (Jacobs, 1999), so plantings in heavy summer rainfall areas such as Florida or Hawaii may have reduced yields and crop loss due to rot.

## **FERTILIZER REQUIREMENTS**

These cacti respond well to most fertilizers, although care must be taken not to burn the shallow root system. In Israel small amounts of fertilizer have been applied in the irrigation water with every watering (Raveh et al., 1997; Nerd et al., 1999; Lichtenzveig et al., 2000, Weiss et al., 1994). It was recommended to add 35 ppm N from 23N-7P-23K fertilizer in the irrigation water (Mizrahi and Nerd, 1999). Animal manures and composts have been used in California with much success (Thomson, 2002). Very little has been published on fertilization of these plants, and a proper schedule will need to be worked out to increase flowering and fruit production.

## **PROPAGATION**

Propagation of dragon fruit by cuttings is the most common and simplest method. The plants are very prolific and, if allowed, will produce many side shoots each year that can be removed and used for propagation. It is often possible to increase plant numbers by at least ten fold in one season by this method. Well-hardened cuttings 15 cm or longer are taken by cutting at a constriction in the stem or branch. Cuttings can also be taken in the middle of a stem. When this is done, it is important to let the cuts callous over for a week before planting to prevent rotting. Although it is not required, dipping the ends in a suitable rooting hormone will accelerate rooting. In areas with cool wet winters, such as southern California, it is best to propagate these plants in the spring and summer months or in a greenhouse. When propagated in the winter, rotting is more common and the plants often will not begin to grow until temperatures increase in the spring.

Seed viability is very high and germination is quick when using a fine medium such as peat moss. There are several drawbacks to growing these plants from seed. The first is a longer juvenility period than when grown from cuttings. Cutting propagated plants will take two to three years to begin to fruit in California. Seedlings, however, often take 4 years, or longer, before their first bloom. In more tropical climates this period will be reduced. The other disadvantage is that there will be much seedling variation affecting fruit quality and production.

Drew and Azimi (2002) have developed a protocol for the micropropagation of these cacti. If this can be adapted to a large-scale operation and not induce a long juvenile period in the plants, it will enable the production of large numbers of plants from a relatively small stock. This will be important because very few nurseries in the U.S. carry *Hylocereus* species. The fruit quality of these plants usually is unknown because they are most commonly grown as an ornamental. So, for now, anyone in the U.S. wanting to plant commercial acreage of dragon fruit has to propagate them themselves or must import cuttings, which can be a large expense.

## CONCLUSION

Fruits of the *Hylocereus* genus have the potential to be a profitable new crop for farmers in the US. With a market already established in the Asian communities and a much larger potential market, commercial plantings can be increased without saturating the market in the short term. Imports from Asia and Mexico presently are prohibited, because the fruit is a host for fruit flies. At least one irradiation facility is being built in Asia, which will allow for the importation of some dragon fruit as well as other exotic fruits. If certain areas of Mexico, where the pitaya are grown, can be certified as free of fruit flies, this fruit also may be allowed into the US. This has the potential to flood the U.S. market and cause a significant drop in the price of dragon fruit. It will be difficult for U.S. growers to compete because the labor costs are much higher here. Production levels in the U.S. have not yet been proven, except in Hawaii, to be comparable to other areas. This is still a very speculative crop for the majority of the US.

Much work remains to be done. Standards for fruit quality need to be established. Optimal spacing, water requirements, trellising systems, fertilizer regimes, and pruning requirements all need to be worked out. Harvest time and postharvest storage also need to be examined. There is also a need for breeding new varieties in hopes of obtaining a good quality fruit with a long shelf life that is autogamous and sets a large fruit without the need for hand pollination. Attempts should also be made to extend the season whether through breeding or manipulation of growing conditions. The University of California Extension has recently taken an interest and a small planting is in the planning stages.

Overall, dragon fruit is a promising crop, but growers should be cautious before dedicating significant amounts of resources to large-scale plantings.

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