CHAPTER 4

DRAGON FRUIT
Hylocereus undatus (Haw.) Britton and Rose

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INTRODUCTION

Dragon fruit (*Hylocereus undatus* (Haw.) Britton and Rose) is a climbing vine cactus species which has received worldwide recognition, first, as an ornamental plant and then as a fruit crop (Plate 4.1). Its fruit is the most beautiful in the family Cactaceae with a bright red skin studded with green scales and white or red flesh with tiny black seeds. The flower is so beautiful that it is nicknamed as "Noble Woman" or "Queen of the Night". The juicy flesh of the fruit is delicious in taste. It is well established as a new crop in Australia, China, Israel, Malaysia, Nicaragua, Taiwan and Vietnam. In Vietnam, it has become a major export, which fetches a higher price than even Durian, the "King of Fruits" in southeast Asia. The main constraint is that the establishment cost is high due to the use of trellises for climbing. However, the cost of establishment will depend on the type of trellises used, and experience shows that a relatively cheap trellising is sufficient. The other agronomic practices are easy and less expensive; maintenance cost is low and aftercare is minimal due to fewer pest and disease attacks. The biggest advantage of this crop is that once planted, it will grow for about 20 years, and one hectare could accommodate about 800 Dragon fruit plants. More importantly, it is a fast return perennial fruit crop with production in the second year after planting and full production within five years. The crop could be grown organically using locally available organic manures and composts, as the demand for nitrogen is comparatively less compared to most other fruit crops. Thus, although underutilized, Dragon fruit is considered a fruit crop for the future (Gunasena and Pushpakumara, 2006; Gunasena *et al.*, 2006).

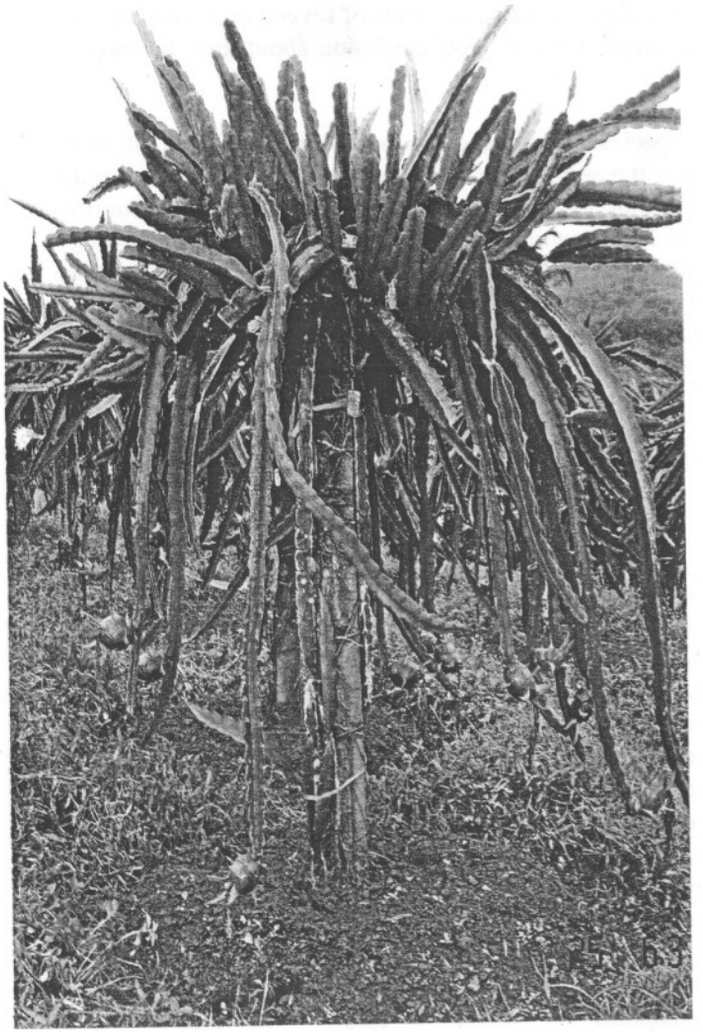


Plate 4.1: Dragon Fruit Plant with Flowers and Fruits Trained to a Concrete Trellis.

TAXONOMY

The genus *Hylocereus* (A. Berger) Britton & Rose is a small genus that contains about 18 tropical American species (Barthlott and Hunt, 1993; Mabberley, 1993). The members of the genus are vine (climbing with aerial roots or epiphytic in nature) cacti with three angled stems and mostly with very fragrant nocturnal white flowers. Dragon fruit is a common name for fruits of several cacti species. As these are new crops, there is great confusion about their taxonomic identity.

Edible cacti species classification is based on the nature of stem habit, colour of the skin of the fruit and the colour of the fruit pulp (Table 4.1). Edible cacti are divided into two groups based on the nature of stem habit, namely vine (epiphytic, climbing or crawling) cacti and columnar cacti. Edible vine (climbing) cacti species belongs to two different genera *Hylocereus* and *Selenicereus* whilst the columnar cacti species belongs to three genera, namely *Cereus*, *Pachycereus* and *Stenocereus* (Crane and Balerdi, 2004).

Table 4.1: Classification of Different Edible Cacti Species Based on Nature of Stem Habit, Skin and Pulp Colour.

	Colour of	
Species	**Fruit skin**	**Fruit pulp**
Vine cacti		
Hylocereus undatus	Red	White
Hylocereus undatus	Red	Red
Hylocereus triangularis	Yellow	White
Hylocereus costaricensis	Red	Red
Hylocereus polyrhizus (syn. *H. monacanthus*)	Red	Red
Hylocecreus ocamponis	Yellow	Red
Selenicereus megalanthus (syn. *H. megalanthus*)	Yellow	White
Columnar cacti		
Cereus triangularis	Yellow	White
Acanthocereus pitajaya	Yellow	White
Cereus ocamponis	Red	Red

Sources: Crane and Balerdi (2004); Mizrahi and Nerd (1999); Tel-Zur *et al.* (2004a/b).

The nomenclature of Dragon fruit is as follows:

Kingdom	Plantae (Plants)
Sub kingdom	Tracheobionta (vascular plants)
Super division	Spermatophyta (seed plants)
Division	Magnoliophyta (flowering plants)
Class	Magnoliopsida (dicotyledons)
Order	Caryophyllales
Family	Cactaceae (cactus family)
Subfamily	Cactoideae
Tribe	Hylocereae
Genus	*Hylocereus* (Berger) Britt & Rose.
Species	*Hylocereus undatus* (Haw.) Britt & Rose.

Sources: Britton and Rose (1963); ISB (2002); NPDC (2000).

Synonyms

Dragon fruit is known by several synonyms (Table 4.2).

Table 4.2: Synonyms of *Hylocereus undatus*.

Synonyms	Full citation
Cactus triangularis L. var. aphylla Jacq.	*Cactus triangularis* Linnaeus, var. aphylla Jacquin, Select. Stirp. Amer. Hist. 152. 1763.
Cereus guatemalensis (Eichlam) A. Berger	*Cereus guatemalensis* (Eichlam) A. Berger, Kakteen 121. 1929, non Vaupel 1913.
Cereus triangularis (L.) Haw. Var. Major DC.	*Cereus triangularis* (Linnaeus) Haworth, var. major de Candolle, Prodr. 3: 468. 1828.
Cereus tricostatus Gosselin	*Cereus tricostatus* Gosselin, Bull. Soc. Bot. France 54: 664. 1907.
Cereus trigonus Haw. var. guatemalensis Eichlam	*Cereus trigonus* Haworth, var. guatemalensis Eichlam, Monatsschr. Kakteenk. 21: 68. 1911.
Cereus undatus Haw.	*Cereus undatus* Haworth, Philos. Mag. Ann. Chem. 7: 110. 1830.
Hylocereus guatemalensis (Eichlam) Britton & Rose	*Hylocereus guatemalensis* (Eichlam) Britton & Rose, Cact. 2: 184. 1920.
Hylocereus tricostatus (Gosselin) Britton & Rose	*Hylocereus tricostatus* (Gosselin) Britton & Rose, Contr. U.S. Natl. Herb. 12: 429. 1909.

Common/Vernacular names

Dragon fruit is known by a variety of common/vernacular names that vary both within and from country to country. This is mainly due to its importance, distribution and popularity among different countries (Table 4.3).

Table 4.3: Common/Vernacular Names of Dragon fruit.

Country/ Language	Common / Vernacular Name
Chinese	Zunlongguo
Colombian	Pitahaya roja/blanca, Flor de Calis, Pitajaya
English	Strawberry Pear, Dragon fruit, Red pitaya, Red Pitahaya, Night Blooming Cereus, Belle of the Night, Conderella Plant, Queen of the night
French	Belle de nuit, Cierge-lezard, Pithaya rouge, Pitaya, Poire de chardon
German	Distelbrin, Echte stachelbrin
Hawaii	Paniniokapunahou, Papipi pua, Panani o ka
Indonesian	Buah naga
Israel	Pitaya
Mexico	Junco, Flor de calis, Pitajava, Pithaya roja, Tasajo
Portuguese	Cato-barse, Cardo-ananas
Puerto Rico	Flor de caliz, Pitajava, Junco, Junco Tapatio, Orijona, Reina de la Noche
Venezuela	Flor de calis, Pitajava, Pithaya roja
Vietnam	Dragon fruit, Thanh long
Spanish	Chaca, Chak-wob, Flor de caliz, Junco tapatio, Pitahaya, Pithaya orejona, Tuna, Nopal, Pitjaya, Reina de la noche, Zacamb
Sri Lanka	Dragon fruit
Swedish	Distelbirn, Echtestachelbrin, Dachenfr skogskatus, Rud pitahaya

Sources: IPGRI (2006); ISB (2002); USDA (2005); Zee *et al.* (2004); www.toptropicals.com (2006).

BOTANICAL DESCRIPTION

Plant: It is a perennial, fast growing, climber, with triangular or rarely, four or five sided stems. The stems are fleshy, vine like, with many branched segments (Plate 4.1). Each segment has three wavy wings or ribs with corneous margins and 1-3 spines, or are sometimes spineless. These form aerial roots that adhere and climb and keep erect. These roots enable the vine to climb over rocks, trees or cling to walls and form dense masses. There are 2-5 short sharp spines in each areole. The stems may reach 6 m or more depending on the growing conditions. In *H. undatus*, the stomata are sunken in the epidermis and the stem tissues contain a considerable volume of parenchyma. However, they do not have a wax layer. Therefore, drought tolerance is lower compared to *H. polyrhizus* (Mizrahi and Nerd, 1999).

Floral morphology and flowering phenology: At the onset of flowering, 3-5 spherical buttons emerge from the stem margins and 2-3 of these may develop into flower buds in about 13 days (Plate 4.2 (1)). The light green cylindrical flower buds reach about 28 cm after 17 days when anthesis occurs (Plate 4.2 (2)). The flowers are large, hermaphrodite, and extremely showy. They are white-pink in some types-very fragrant, nocturnal, and bell shaped (Plate 4.2 (3)). The flower opens rapidly, starting between 6.30-7.00 pm and opening of the flower is completed by about 10.00 pm (Plate 4.2 (3)). At about 2.00 pm the flower closes after pollination and thereafter the flower begins to wilt. The petals close completely by daybreak.

It is reported that temperature and light intensity may affect the blooming. On warm cloudy days the flower may open at about 4.00 pm while in cool temperatures the wilting may be delayed till about 1.00 am. If flowers are not pollinated during the night, they remain open until the next morning. The development of a floral bud to a fully opened flower takes 25-35 days (Pushpakumara *et al.*, 2005; Zee *et al.*, 2004).

Flower production in Sri Lanka is usually from April to November, sometimes extending till December and occurs in four to six flushes (Pushpakumara *et al.*, 2005). Flowering is induced by long days; hence it is a photoperiod-responsive species. However, the effect of photoperiod is dependant on temperature, and that the time from photoperiodic induction to flower appearance increases when the

temperature rises beyond the optimal point (Feng-Ru and Chung-Ruey, 1997a; 1997b; Luders, 2004; Yan and Wallace, 1995).

Pollination and self-incompatibility: Pollination is essential in fruit production of the Dragon fruit. As the flowers open in the night, bats and hawk moths in the natural range pollinate the flowers. In many countries where the crop is grown as a new crop, pollination is poor due to the lack of natural pollinators. Hence, hand pollination has been suggested to increase fruit set. Under Sri Lankan conditions, Honey bee (*Apis cerana*), little honey bee (*Apis florae*) and Rock bee (*Apis dorsata*) effectively pollinate the Dragon fruit during the early hours of morning (Pushpakumara *et al.*, 2005).

H. undatus possesses a weakened self-incompatibile mechanism. Therefore, efficient pollination could be achieved by cross pollination of compatible clones (Lichtenzveig *et al.*, 2000; Nerd and Mizrahi, 1997; Weiss *et al.*, 1994). Hence, to avoid low fruit set, mixed plantings with several genotypes is recommended. Although information is limited, experiments conducted by Tel-Zur *et al.* (2004b) Lichtenzveig *et al.* (2000) and Weiss *et al.* (1994) showed that some *Hylocereus* spp. cross readily with each other (cross compatible). The crossability among different taxa of different species may provide information about their close genetic relationships despite their classification as independent botanical taxons. This indicates that different species may be considered members of the same genepool.

Fruit morphology and fruiting: The fruit is a medium to large, oblong shaped epigenous berry. The berry is distinguished with red skin with large scales. The fruit pulp may be white, red or yellow and juicy depending on the varieties/species (Plate 4.2 (4)). Fruits develop from both ovary (pulp) and the receptacle that surrounds the ovary (peel). The fruit change its peel colour from green to red about 25 days after anthesis. The peel turns fully red in the next 4-5 days after the first colour change. About 25-41 days after anthesis, the dry weight of fruit pulp increases significantly whilst peel dry weight and the percentage water in the peel decreases. Fruit firmness also decreases during this period. Dragon fruit is a non climacteric fruit. At peak ripeness the fruits become pink-red although the scales remain green. Ripened fruits can be harvested between 30-50 days after fruit set (pollination) (Nerd *et al.*, 1999; Pushpakumara *et al.*, 2005).

ORIGIN AND GEOGRAPHICAL DISTRIBUTION

The origin of *Hylocereus* spp. is in the tropical and sub tropical forest regions of Mexico and Central and South America (including Southern Mexico, the Pacific side of Guatemala, Costa Rica, El Salvador, Venezuela, Colombia, Ecuador, Curacao, Nicaragua, Panama, Brazil and Uruguay (Britton and Rose, 1963; Backeberg, 1966; Barthlott and Hunt, 1993; Mizrahi *et al.*, 1997). From the centers of origin, Dragon fruit has spread to tropical and sub tropical America, Asia, Australia and the Middle East. Currently, it is being cultivated in at least 22 countries of the tropics, Australia, Cambodia, China, Colombia, Ecuador, Gautemala, Hawaii, Indonesia, Israel, Japan, Laos, Malaysia, Mexico, New Zealand, Nicaragua, Peru, the Philippines, Spain, Sri Lanka, Taiwan, Thailand, the south western USA and Vietnam (Mizrahi and Nerd, 1999; Nerd *et al.*, 2002b; Nobel and Barerra, 2002). Historical evidence indicates that the French introduced the crop to Vietnam about 100 years ago and it was grown for the King. Later, it became popular among the wealthy families of the entire country. Vietnam has favourable climatic conditions for growing tropical fruits, mainly in the southern part in the Mekong Delta and in the southeast, and Dragon fruit thrives in these areas. Dragon fruit was introduced to Sri Lanka in 1997.

PROPERTIES OF SPECIES, USES AND PRODUCTS

Dragon fruit is a nutritious fruit with a variety of uses, although the composition of this species has not been extensively studied, particularly with reference to the components of the fruit. The most valuable and commonly used edible part of Dragon fruit is the fruit pulp which constitutes 70-80% of the ripe fruit. The composition of fruit pulp is given in Table 4.4.

The most valuable and commonly used edible part of Dragon fruit is the fruit pulp which is eaten raw as a fresh fruit. The pulp constitutes 70-80% of the ripe fruit. The flavour of fruit pulp is sometimes similar to that of the Kiwi fruit. Dragon fruit pulp could be chilled and cut into half to show the attractive flesh, either sliced or scooped with a spoon. It is widely used in fruit salads at restaurants (Luders, 2004).

Table 4.4: Average Composition of Dragon Fruit and Related Species.

Composition	Amount per 100 g of Pulp		
	Hylocereus undatus	*Hylocereus polyrhizus*	*Selenicereus megalanthus*
Water (g)	89.4	82.5-83	85.4
Protein (g)	0.5	0.159-0.229	0.4
Fat (g)	0.1	0.21-0.61	0.1
Crude fibre (g)	0.3	0.7-0.9	0.5
Ash (g)	0.5	0.28	0.4
Calcium (mg)	6	6.3-8.8	10
Phosphorus (mg)	19	30.2-36.1	16
Iron (Fe) (mg)	0.4	0.55-0.65	0.3
Carotene (mg)	-	0.005-0.012	-
Thiamine (mg)	-	0.028-0.043	-
Riboflavin (mg)	-	0.043-0.045	-
Niacin (mg)	0.2	1.297-1.3	0.2
Ascobic acid (mg)	25	8-9	4
Brix value	11-19	-	-
pH value	4.7-5.1		

Sources: ICBF (1992); Morton (1987); www.ilovepitaya.com. (2006)

Dragon fruit can be processed into a range of industrial products such as juice, sherbets, jam, syrup, ice cream, yogurt, jelly, preserve, candy and pastries. Sometimes the pulp is mixed in pizzas. Wine making, using Dragon fruit is a popular industry in Malaysia. Processed products can be produced from fresh fruit pulp or frozen pulp. The red and pink pulp of Dragon fruit can be used as a food colouring agent, and as a raw material for the food colouring industry (Gao-Xi and Wan, 2004). The flower buds of Dragon fruit are used to make soups or mixed in salads, and could also be eaten as a vegetable. Sometimes, tea is also made using the flowers.

Dragon fruit possess medicinal properties. The red-fleshed varieties of Dragon fruit are rich in antioxidants. It is known to prevent colon cancer and diabetes, neutralizes toxic substances such as heavy metals, reduce cholesterol and high blood pressure. It is also reported to control high sugar levels, prevent cancer and bleeding, and promote dental health. It is rich with vitamin C, phosphorus and

calcium (Table 4.4), helps to develop strong bones, teeth and skin. The fruit is considered as a "health fruit".

Dragon fruit could be an asset to smallholders as well as entrepreneurs of medium and large scale plantations. It is a fast return perennial fruit crop with production in the second year after planting, and full production within five years. The yields are also high, and regular bearing brings early incomes to the growers. In large scale plantations, although initial investment is comparatively high, profit is substantial and within 4-5 years about Rs. 5.5 million/ha could be earned.

Dragon fruit is an ideal new crop for the dry areas. As it is salt-tolerant to some extent, it could be grown as an income generating crop in the coastal belt of Sri Lanka. It is also a good candidate plant for the development of sustainable agroforestry systems. In this aspect, rather than replacing one crop with others, it is important to integrate the species into existing farming systems, particularly into tropical agroforestry systems.

ECOLOGICAL REQUIREMENTS

Climate: Unlike other cacti, which are from desert origin, Dragon fruit has its origin from areas with sufficient rainfall ranging from 1,730-2,540 mm/year. An average yearly rainfall of 500-1,500 mm is required for healthy plant growth. Excessive rain may cause the flowers to drop and sometimes the fruit rots. Suitable growth conditions for Dragon fruit is shown in Table 4.5.

Table 4.5: Suitable Growing Conditions for Dragon fruit.

Climatic factor	Optimum condition
Altitude (m)	up to 1,700
Temperature (^{0}C)	20-30
Rainfall (mm/year)	500-2,000 (with alternative dry and wet period)
Soil	Well drained red yellow podzolic, lateritic soil and reddish brown earth
pH	5.5-6.5

Soil: Dragon fruit could be grown in a wide range of soils. The most important factor is that the soil should be well drained as it does not tolerate water logging. Dragon fruit prefers slightly acidic soil. The best soils are loams with plenty of organic matter. It can tolerate some salt in the soil, although the extent of tolerance will depend on the cultivars.

AGRONOMY

Propagation

There are two methods of propagating Dragon fruit plants: (i) seed propagation and (ii) vegetative propagation.

Seed propagation: Seed propagation involves the collection of seeds from selected fruits of mother plants, washing them with water and germinating them on wet blotting papers or a sand clay mixture. Seeds start germination in 3-4 days and seedlings can be potted 4-5 weeks after germination. They are ready for field planting by 9-10 months. This method is very simple, however the quality of the new offspring cannot be guaranteed due to cross pollination (not true to type). Further, seedlings also grow slowly and the time taken to reach bearing age is usually (3-4 years) longer than for plants propagated using cuttings.

Vegetative propagation: The easiest and cheapest method of propagating Dragon fruit vegetatively is by cutting. Dragon fruit plants established from cuttings start flowering after one to two years of planting. Cuttings can be obtained throughout the year, however, it is preferable to collect the cuttings after fruiting season of mother plants. Cuttings displaying colours other than normal plant colour should be avoided. All cutting should be collected early in the morning. In propagation by cuttings, the entire stem segment or 15-60 cm cuttings could be used (Zee *et al.*, 2004). The longer the cutting, faster is the regeneration rate of new shoots - probably associated with the amount of stored food. In removing the cuttings, a slanting cut is made at the stem base. Mature cuttings are better as they are resistant to insect and snail damages. To prevent the occurrence of diseases, the cuttings are treated with fungicide. Treated cuttings should be cured in a cool, dry area for 5-7 days before planting.

The cuttings can be directly planted in the field, but the most common practice is to pot them in a suitable potting media for rooting. Use of a rooting hormone before planting will encourage the quick formation of roots. The number of adventitious roots increased when dipped in IBA at 10,000 mg/l (Vargas-Santiago *et al.*, 2003). If rooting hormone is available it should be applied to the cuttings as it can improve rooting success and induce the time taken for root development (10-15 days instead of 40-50 days). The cut end of the cutting should be moistened and dipped for 10 seconds in the powder, before inserting into a normal nursery soil mixture. These cuttings grow fast, about 3 cm per day and develop a strong root system in 4-6 months. If the cuttings have to be transported long distances they should be wrapped in moist cloth or paper to prevent loss of moisture. The cuttings should be watered regularly but not excessively, and once well established, they can be transplanted into the field. Dragon fruit usually produces a shallow adventitious root system which, when plastic bags and natural pots are used, may penetrate into the soil. Moving the pots with the plants for field establishment is therefore a delicate operation. Placing the pots on a raised bench (perforated or latticed) reduces this problem, as the roots can be air-pruned with no damage to the growing plants.

Dragon fruit can also be propagated vegetatively by grafting. Grafting is however not very common as cuttings are easy and convenient method of propagation. However, the grafting method is beneficial when using selected rootstocks and scions.

Preparation of nursery: The nurseries are preferred as they give much more and easier control of soil, water, light and nutrient factors. The nursery can be started 3 months before the onset of the rains and located close to the planting site to avoid transport costs and damage to plants. Shade is used for cuttings establishment. Selections can be made for uniformity, vigour and health of planting material. In general, 1,100 plants could be accommodated in 10x10 m of nursery space. Therefore, the size of the nursery is dependent on the number of plants required. Not all cuttings will root, so it is better to prepare a slightly larger area than for the exact number of plants required.

Field Establishment

Dragon fruit plants prefer full sunlight, hence open areas are most suitable for planting. They should not be planted under heavy shade

or in boggy patches. The land should be free draining and not subject to flooding.

Land preparation: Weeding is required on all Dragon fruit planting sites, up to 1 m in diameter around the planting hole. If planted on a grassland, the grass needs to be removed to 1 m in diameter around the planting site. If a site is over-run with woody growth and shrubs, some clearance will be necessary.

Spacing: The spacing for field planting varies depending on the size and slope of the plantation. In small-scale plantings no proper spacing is required. Wider spacing will provide adequate air circulation and fewer chances for occurrence of diseases. The spacing will also depend on the type of posts used for trellising. The common spacing used is given in Table 4.6.

Table 4.6: Common Spacing of Dragon Fruit Plants

Spacing (m)		No of plants/ha
Between rows	Within rows	
3.0	3.0	1,100
4.0	3.0	833
4.9	3.0	680
3.7	3.7	730

Trellising: As the Dragon fruit is a climbing cacti, the vines have to be train to climb concrete or wooden posts, fences, walls, and trees for support. There should be a post for each vine and a structure to support it at the top. The life of a Dragon fruit vine is as long as 20 years; hence the durability of the post is of considerable importance. The post has to be very strong as a 3-4 year old vine may weigh about 100 kg; hence only concrete or hard timber posts will be able to bear the weight. The wooden posts are cheap, but their durability is low compared to concrete posts. It is also not possible to change the posts half way through the growth of the crop as the vine entangles with the post to secure itself for climbing. Hence, the best would be to use concrete posts although the initial cost is high. The suggested post size is 100-150 mm diameter and 2 m high and should be buried 40 cm in the ground.

In Sri Lanka concrete posts are commonly used. A used rubber tyre cut cross-wise and placed on the top of the posts has been used

successfully to train the vines in local Dragon fruit plantations. Steel wires or frames made of wire mesh should not be used as it could cut and damage the vines; they also corrode and are not long lasting (Figure 4.1; Plates 4.1 and 4.2 (4)).

If there are only a few vines, even a garden wall or tree trunk such as Arecanut could be used as a post. Any type of trellis that can support the weight of the vines and allow easy access to flowers for artificial pollination and fruits for harvesting will be satisfactory in commercial plantations.

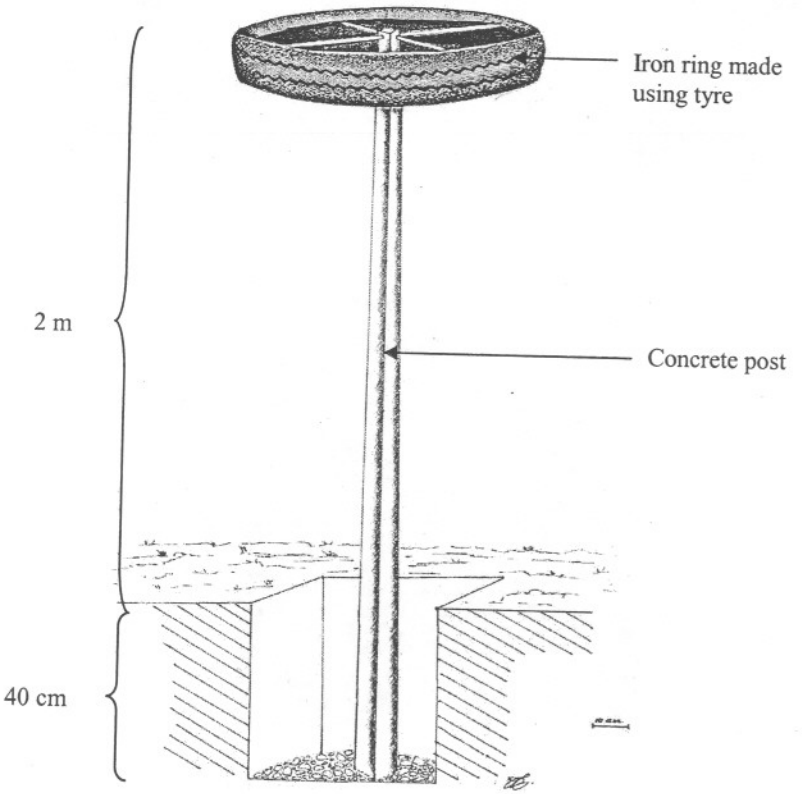
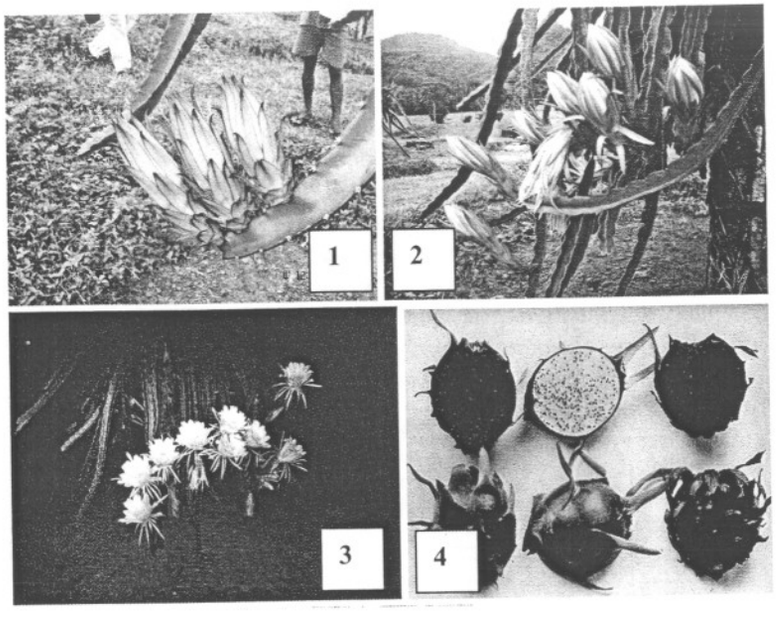


Figure 4.1: Trellises Made of Concrete Post and Rubber Tyre Used at Bulathsinhala Dragon fruit Plantation in Sri Lanka.



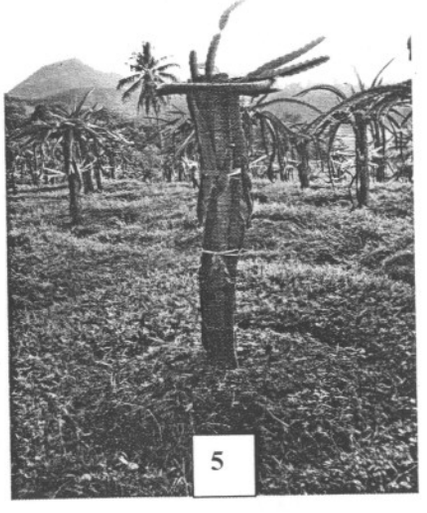


Plate 4.2: Floral Buds, Flowers, Fruits and Plantation of Dragon Fruit.

Note: 1= floral buds, 2= flowers at anthesis, 3= opened flowers during the night, 4=fruits of different varieties, and 5=plantation with ring weeding and mulching.

Planting: The planting of seedlings or cuttings in a well-prepared hole is the commonest method for establishing a Dragon fruit plantation. The hole should be about 30 cm deep and 20 cm wide. The soil should be loosened on the sides of the hole-walls and base as this will help the development of root systems. The supporting post is planted at the centre of the planting hole, well in advance by embedding it on concrete to make it firm to enable the vine to climb. The hole should be filled to ground level with the soil that was removed. If there is insufficient soil after digging the pit, the topsoil should be used to fill the pit. It is important to flatten the soil around the base of the plant to ground level. The plant should be watered daily if rains do not occur.

Dragon fruit plants are placed near the post to enable them to climb. The number of plants for each post may vary from 1-4 plants. Under Sri Lankan conditions, 2-3 plants per post may be adequate. If water is constantly available, planting may be done throughout the year. However, the best time for planting is at the beginning of the rainy season, particularly in seasonally dry regions. The best time of day is late afternoon to early evening.

Managing Dragon Fruit Plants

Training to trellises and pruning: The plants grow fast and reach the trellis in a short period. As the vines grow they may fall to the ground and severe damage could occur. Tying the vines loosely to the trellis could prevent this. The lateral branches should be pruned when the vines grow towards the trellis and only the outer leader vines should be allowed to grow. Once the vines reach the trellis free branching is allowed (see Figure 4.2 for details). Removal of the tip of the main stem will induce lateral branching. This pruning is referred to as **structural pruning** or making a structure on the trellis. Dragon fruit grows very fast and forms a thick dense mass of vines on the top of the trellis. A well-grown plant in the first year should produce about 30 branches increasing to 130 branches in the fourth year. This condition may increase pest and disease problems. It will also interfere with the cultural operations and harvesting.

This is the stage for **production training** and in this process the excess stems and those that are dead and diseased are removed. This will maintain healthy and vigorous stems. After harvest there should be about 50 main branches with one or two secondary branches on a

main branch. The tertiary and quarterly branches should be removed. Once pruned, the pruning cuts should be treated with fungicide. The pruning cuts produce flowers and new stems. The cut portions of the vines should be removed out of the field to prevent contamination. They could be used as propagules or composted. Training operations are easier at midday when the vines become soft.

Irrigation

Dragon fruit, although a member of the family Cactaceae requires plenty of water for their growth because they have originated from tropical rainforests. Their root system is distributed in the top 15-30 cm of the soil; hence irrigation is required to ensure the needed soil moisture content particularly during the dry spells. The rainfall requirement is 1,145-2,540 mm per year. If the rainfall is well distributed irrigation may not be required, but in some months of the year when rain is less, irrigation is essential to maintain good growth. Excessive irrigation is not desirable as it may promote bacterial and fungal diseases. If there are frequent dry periods without irrigation, fruit production will be less and the vines will produce small fruits.

In general, the crop should be subjected to a dry period in the pre-bloom period to produce more flowers. Then the soil should have adequate moisture for flower and fruit development. Fruit splitting may result when exposed to wet and dry periods during fruit development. In order to avoid this, soil moisture-maintenance is very necessary. Micro-irrigation systems will be very useful to control soil moisture. Mulching is necessary to reduce moisture loss and maintain moisture status in the soil.

Fertilizer Application

Dragon fruit requires judicious application of fertilizer for higher yields. The recommendations of fertilizer rates vary widely. Available reports indicate that the crop has to be fertilized frequently in the early phase of growth. The recommended fertilizer application in Taiwan is 4 kg of organic manure/plant every 4 months, supplemented with 100 g/plant of a commercial 13-13-13 fertilizer. In Hawaiian plantations, a 16-16-16 NPK mixture is applied at 4-6 monthly intervals at 180-230 g/plant. Calcium and micronutrients are also applied to enhance fruit growth and firmness.

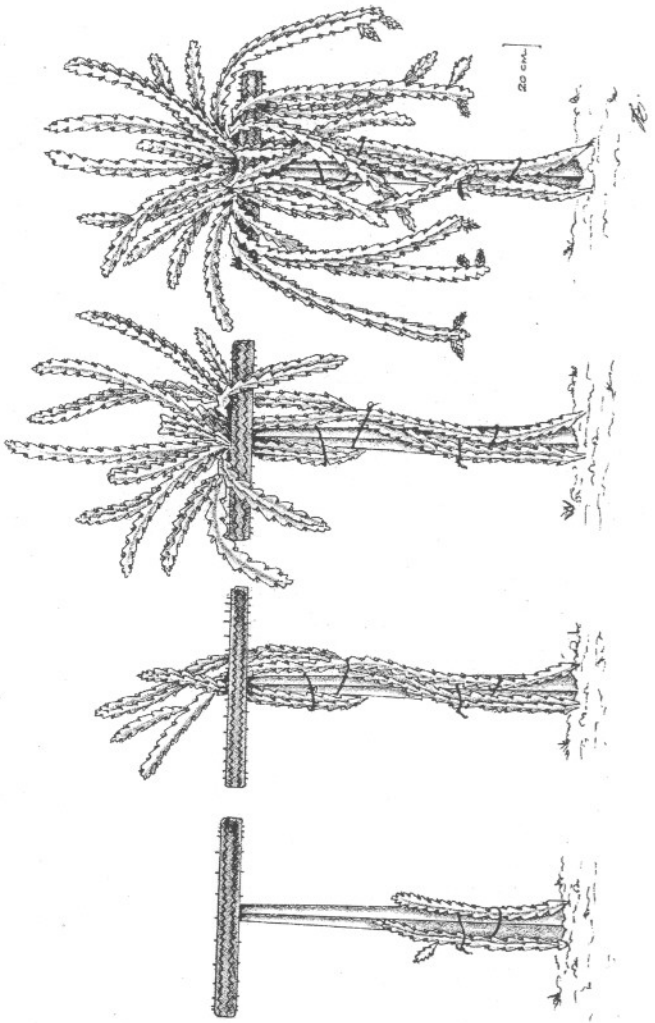


Figure 4.2: Training of a Dragon fruit Plant from Establishment to Production.
Note: The branches which hang down are the main producers of flowers and fruits in Dragon fruit. Once fruit bearing is completed, branch margins develop a silver lining. These branches should be removed and branches at the top should be trained to hang downwards for the next fruiting season.

Super Bloom fertilizer which has a composition of 0-10-10 or 2-10-10 has been- recommended for Dragon fruit. These are low nitrogen fertilizer mixtures.

In Vietnam, young (less than 3 years old) plants are fertilized with 10-15 kg of farmyard manure and 100 g of super phosphate/plant at the time of planting. During the first two years, 300 g of urea and 200 g of NPK (16-16-8) is applied to each plant every year. The fertilizer is applied in three lots, at one month, six months and twelve months after planting, respectively (Ke, 1997). Mature plants (at least three years old) should be given 540 g N, 720 P_2O_5, 300 g K_2O and 20 kg of farmyard manure/plant/year. The quantity is divided into four lots. The first is applied immediately after harvest, and includes 40% N, 30% of the P_2O_5 and all the farmyard manures. The second is applied two months later (30% N, 20% P_2O_5, 15% K_2O) and the third just before flowering (10% N, 40% P_2O_5, 40% K_2O). The fourth contains the remaining fertilizer, and is applied when the young fruits are developing (Tri *et al.*, 2000).

There are no fertilizer recommendations for Dragon fruit in Sri Lanka. The Agricultural Research Station at Makandura has suggested a mixture of NPK 1:1:2 at 30-40 g/vine applied 3 times per year (Alwis, 2006). The plantation at Bulathsinhala uses organic manures at different rates with a special fertilizer mixture (15N-5P-15K-8S-1.6Mg-TE) imported from Thailand at 100 g/plant/year. The nutrient requirement for Dragon fruit in various areas of Sri Lanka has to be studied.

Dragon fruit can be grown organically without applying inorganic fertilizers, or pesticides; hence it has market potential as a healthy organic fruit. Organic manures such as cattle or poultry manure or well decomposed compost could be used. The current trend in many countries is to use organic manures without any chemical fertilizers due to the high international demand for organically produced fruits.

Floral induction for Off Season Flowering

Although limited information is available, experiments conducted in Taiwan revealed that off season crops can be obtained by inducing flowering by breaking the dark period with artificial light between 10.00 and 2.00 pm. This utilizes incandescent light bulbs (100 watts) at about 1.2-1.5 m spacing suspended above 1.8 m above the ground

(Feng-Ru and Chung-Ruey, 1997a; 1997b; Zee *et al.*, 2004). The off-season fruits are larger and sweeter and they fetch better prices in the market. The very long fruiting period will benefit the growers as the fruits could be sold in the markets during the off-seasons. Khaimov and Mizrahi (2006) in Israel showed that growth regulators [N-(2-chloro-4-pyridinyl)-N-phenylurea (CPPU) and gibberellic acid (GA_3)] and flower thinning can be used to either promote or delay flowering in Dragon fruit, and suggested that CPPU can be used to obtain early flowering and GA_3 or flower thinning to delay cropping. Flower thinning can be done by the removal of floral buds or by not pollinating the flowers.

Weed Management

Weed management is important as they could compete with the crop for water and nutrients, and provide shelter for other pests such as birds and ants that may eat the stems. Weeds could also grow easily as the crop is widely spaced. Special care should be taken to control creeping weeds, as they will entangle with the vines making removal very difficult. Intercropping with suitable crops will be the best as additional income could be generated. Further, soil and moisture conservation could be achieved by the use of intercrops which would cover the soil. In Sri Lanka, ring weeding and mulching is practiced for weed management and moisture conservation (Plate 4.2 (5)).

Pests

Dragon fruit is comparatively free of pests. The common pests reported are ants, scale insects, mealy bugs, beetles, slugs, snails, borers, caterpillars, termites, nematodes, fruit flies, bats, rats and birds. These pests should be monitored regularly and controlled when observed. Insect infestations of a severe scale have been reported in Florida (Crane and Balerdi, 2004).

Diseases

A few diseases have been reported in Dragon fruit. A soft watery stem rot caused by *Xanthomonas compestris* common due to over-watering or in wet weather has been reported in Central America and Australia. Brown spots caused by *Dothiorella* and anthracnose has also been reported in plantations in Florida and Nicaragua. A stem disease has been observed in wild and commercial plantings in

Mexico, probably by fusococcum-like anamorph of *Botryosphaeria dothidea*. The pathogen produces lesions of various sizes, these lesions sometimes expand and affect the entire stem Valencia *et al.*, 2001; 2004). Anthracnose also attacks the fruits. *Fusarium oxysporum* attacks the vines. In Colombia most of the plantations of *S. megalanthus* have been uprooted due to heavy infestations with fungi (Bibliowicz and Hernandez, 1998). The practice of wider spacing is suggested to improve air circulation and light penetration which in turn could reduce disease problems.

YIELD AND HARVESTING

Yield: Dragon fruit bears within six to nine months and yields could be obtained from the second year onwards. The average yield is about 10-12,000 kg/ha at the end of the third year. However, commercial plantations in Israel, Malaysia and Taiwan produce between 16,000-27,000 kg/ha (Mizrahi and Nerd, 1996; 1999). The proper management of the vines and fruit thinning improves the size of the fruits and yield. The average fruit weight is about 350 g. The flowers and fruits can be thinned to improve and maintain fruit size and quality, which is important when producing for export markets. Under Sri Lanka conditions at Bulathsinhala, a yield of about 18,000-22,000 kg/ha of fruits can be obtained per year with fruit-weight ranging from 350-850 g/fruit (Pushpakumara *et al.*, 2005).

Harvesting: The harvesting time varies depending on the country where the crop is cultivated. The ripening time is usually from June-December. In most of the countries including Sri Lanka, Dragon fruit ripen during this time. The fruits have to be selectively harvested as they ripen at different times. Most often harvesting is done twice a week. The harvesting is done carefully using pruning knives without damaging the fruits. After harvesting, the fruits should be kept in a cool shady place before transferring them for storing.

As stated, the Dragon fruit is a non climacteric fruit (Nerd *et al.*, 1999). Therefore, the fruits have to be picked at maximum sugar levels and acidity. At peak ripeness, the fruits become pink-red, although the scales remain green. Peak ripening reaches at 40-50 days after flowering. If fruits are left longer up to 50 days, the fruit becomes sweeter and heavier (Chang and Yen, 1997). Since overripe

fruits have less shelf life and a tendency to split. Thus, it is important to harvest fruit at the correct time.

PROCESSING AND MARKETING

Processing and Storage: It is necessary to store Dragon fruits after harvesting for varying periods of time. Evidence indicates that after harvesting the respiratory rate decreases and the weight loss increases showing visible shrivelling after about the eighth day (Arevalo-Galarza and Ortiuz-Hernandes, 2004). If they are sold in the local markets, the storage period will be less but when grown for overseas markets proper storage is necessary. It is reported that the fruits could be stored in perforated bags for 25-30 days at 8 ^{0}C (Zee *et al.*, 2004). Storage temperature for the fresh fruit market should be 15-20 ^{0}C at 85-90% RH (Crane and Balerdi, 2004). Dragon fruits could be stored up to 45 days at 7-10 ^{0}C at a relative humidity of 90-98% (Luders, 2004). It is reported that fruits harvested close to full peel colour development keep their visual acceptance and marketing quality for at least 3 weeks at 6 ^{0}C, 2 weeks at 14 ^{0}C or 1 week at 20 ^{0}C. Yellow Dragon fruit could be stored for four weeks at 10 ^{0}C. If the temperature is 20 ^{0}C the storage period is less (Nerd *et al.*, 1999).

If the fruits are moved in and out of cold storage, shelflife is drastically reduced. This happens often when the fruits are brought from storage for sale and moved into stores again if they are unsold. The skins of stored fruits become thinner as water moves into the flesh from the skin, but they have higher sugar levels although the taste will be less. The frozen pulp is also sold in some markets. The marketing of frozen pulp is an alternate method, which is becoming popular, as the product is not subjected to quarantine for fruit fly.

Marketing: In the countries of production there is a local market for Dragon fruit. Some reports indicate that the fruits sold in the European markets are bought mainly for their beauty and used for decoration. The European market has accepted Dragon fruits well but the super market chain requires over 300 mt/year (Mizrahi *et al.*, 2002). The total Dragon fruit production has to be increased to meet this and the expanding demand. The production in 2001 was about 70 mt. Vietnam's most important export fruit is Dragon fruit. In Thailand and Vietnam the fruit is used locally in fresh form, for decorations, and widely mixed in fresh fruit salads. Vietnam has

expanded its markets in China, Hong Kong and Japan, which prefer large high quality fruits. Dragon fruit has a niche market in Australia. The fruit industry in Northern Australia is well developed for the introduction of the new fruit. They have a bland taste, but the hybrids produced in Israel have much better taste than the original clones. A breeding program focusing on the taste of these fruits may be able to overcome this problem in the future.

According to local information in Sri Lanka there is a growing local and export demand for Dragon fruit. In the local super markets the cost of a fruit is about Rs. 250-300/kg whilst the export market price is about Rs. 350-450/kg. There appears to be a great future for these fruits due to early and precocious yields, beautiful appearance, delicate taste, comparatively long shelflife and above all the easy nature of cultivation and the minimum demand for irrigation water in dry areas and stress tolerance.

COST OF PRODUCTION AND PROFITABILITY

Accurate information on the cost of cultivation of the Dragon fruit is not available due to the recent origin of this crop. Even in the countries where Dragon fruit is grown as a commercial crop, the cost and profit is not documented; hence there is a dearth of information on the cost of production and profit. The estimated cost of cultivation, in respect of recurrent and capital costs and profit of Dragon fruit cultivation in Bulathsinhala, Sri Lanka, provides some guidelines in the estimation of recurrent costs and profits. The total cost has been categorized into two major components namely labour and material costs. According to the above estimations, the profit of Dragon fruit cultivation is Rs. 5.5 million at fifth years after planting (Gunasena and Pushpakumara, 2006; Gunasena *et al.*, 2006).

In general, material cost in Dragon fruit cultivation is comparatively high in comparison to other fruit crops due to the requirement of strong trellises (concrete posts) and relatively expensive planting materials. Cultural practices of Dragon fruit cultivation include land preparation, digging of holes to establish posts and plants, field establishment, support and training of Dragon fruit vines, weeding, fertilizing, and harvesting. Sometimes artificial pollination is also required. If the land is steep, terraces should be constructed for easy establishment and soil conservation. Holes should be deep enough to

establish posts. The crop duration is about 20 years. Hence regular incomes could be obtained over a long period provided that good agricultural practices are followed in crop management.

GENETIC RESOURCES AND IMPROVEMENT

Several cultivars of Dragon fruit are used in different countries. Most common are the selections of the *Hylocereus* species. Hybrids developed by crossing *Hylocereus* and *Selenecereus* species are also available in some countries such as Israel. Malaysia has developed a number of cultivars of Dragon fruit, which are commercially available for growers. The research on breeding and selection in Taiwan and Vietnam has produced self-fertile and high-productive Dragon fruit varieties. Outstanding selections have also been made in Vietnam. Many selections are also made from the red fleshed varieties belonging to the closely related species *H. polyrhizus* and *H. costaricens* and their hybrids with *H. undatus*. These varieties could be imported from commercial nurseries. It is essential to select mother plants with desirable qualities, to collect either seeds or vegetative material. When selecting good mother plants the following points should be considered:

- good vigour and well developed crown;
- disease-free and undamaged without signs of pest attacks;
- good yielders of quality fruits (over 30 fruits per year with average weight of over 450 g);
- regular fruit yielders (every year with 5-7 flushes per season).
- self compatibility and uniformity of fruits.

This research is needed to understand the botanical classification for breeding and crop improvement. Molecular and cytological studies are currently underway in Israel to identify the taxonomic relationships between species.

RESEARCH NEEDS

Usually hybrids developed from different species have shown better quality and taste compared to varieties of a species. Therefore, a germplasm enhancement and a breeding program focusing on the taste and other characteristics of the fruits will be essential to develop new varieties and hybrids to promote cultivation. Breeding programs should also identify and develop self-compatible cultivars/varieties since poor pollination and low fruit set has been reported due to selfing. Further, an understanding of the mode of inheritance of important agronomic traits such as fruit taste and quality are also necessary for further development of this species.

The available information also clearly indicates that the taxonomy of Dragon fruit is still is a state of confusion. Thus, understanding of reproductive biology and taxonomy should be investigated. A combination of classical and molecular breeding tools should be used to better understand the genetic composition, to breed desirable varieties of Dragon fruit.

Dragon fruit is usually pollinated by bats and moths in their natural environment. Further, self incompatibility has been reported in many countries reducing the potential yield of fruits. Therefore, research on pollination and compatibility with different clones and even different species will be useful for the expansion of Dragon fruit cultivation in countries where it has been recently introduced.

Dragon fruit requires less nitrogen and more phosphorus and potassium for enhanced growth. However, no information is available in Sri Lanka on the fertilizer requirement of this crop. As the correct use of fertilizer is necessary to promote growth and fruiting, studies should be undertaken to make appropriate recommendations for different areas of the country. Furthermore, there appears to be a demand for organically produced Dragon fruits, particularly in the European markets. Presently, local growers use poultry and cattle manures in various proportions without any basis for their application. If Dragon fruit is to be promoted among growers, as an export crop, basic information on its nutrient requirements will be crucial; hence, a comprehensive research program should be initiated.

Another main constraint in cultivation of Dragon fruit is the high establishment cost due to the use of concrete posts as trellises for climbing. Thus, research on durable; low cost, locally available trellises should be conducted on a priority basis. The other agronomic practices such as training of vines and pruning of reproductive vines should be studied to improve yields of Dragon fruit.

The composition of Dragon fruit has not been extensively studied, particularly with reference to the components and properties of the fruit. There is no local information on processing and postharvest management of this fruit. The information available in foreign countries is also scanty; hence this is another area that deserves study. In particular, postharvest management, storage and product diversification deserves research attention.

Marketing is not a problem at present as the local production is small. However, as cultivation expands, marketing problems are likely to occur similar to other crops. The creation of markets will be necessary for new crops, hence advertising should be undertaken. Market intelligence will be necessary to identify niche markets around the world, especially for organically produced Dragon fruit.

CONCLUSION AND FUTURE IMPACT

There is considerable potential for the expansion of Dragon fruit cultivation in most of the countries where it is presently grown. Many countries, due to insufficient attention given to this new crop, have not identified the areas favourable for growing and the potential markets for Dragon fruit. Except for the high initial establishment cost due to the use of trellises, the other agronomic practices are easy and less expensive, hence the low maintenance cost. In addition, once planted, it will grow for about 20 years with a density of around 800 plants/ha. The yields are also high and its regular bearing and precocious early yielding ability brings early incomes to the growers. In many countries, including Sri Lanka and South and Southeast Asia the soil and climatic conditions for growing Dragon fruit are highly favourable. More importantly, there is a growing export demand in the developed countries. Further, it is also possible to grow Dragon fruit organically, which is particularly demanded by the European markets.

Thus, this crop could be an asset to smallholders as well as for the establishment of large scale plantations. In addition, it is a good candidate for the development of sustainable agroforestry systems which would avoid risks and therefore increase farmers' income particularly in the dry and arid zone areas (which would avoid risks and improve farmers' income). Therefore, the government and policy makers should be encouraged to promote Dragon fruit production in the dry, arid and semi arid areas to take advantage of its economic and nutritional benefits.

Dragon fruit is suitable for growing in regions that have spells of dry weather with supplementary irrigation. The farmers in these areas will benefit immensely if the species is improved and cultural practices studied for its incorporation into the existing farming systems.

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