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VINE-CACTI PITAYAS - THE NEW CROPS OF THE WORLD

YOSEF MIZRAHI[2]

ABSTRACT - Until 1994, only scarce research existed on these plants; however the worldwide interest in this novel fruit crop is evident, as numbers of pitaya-related publications have grown rapidly, especially during the past decade .There is a big confusion about both botanical and commercial names and there is a need to clear this point. Herein, we attempt to review existing knowledge on the taxonomy, breeding and other horticultural characteristics of this unique crop. This paper comments abou taxonomy,breeding,physiology and horticultura e chatera ristics,postsharvest and uses.
Index terms: Pitaya, taxonomy, physiology , postsharvest.

PITAIA - UMA NOVA FRUTA NO MUNDO

RESUMO- Até 1994, só existiam pesquisas escassas destas plantas, no entanto o interesse mundial nesta nova fruta é evidente, pois o número de publicações relacionadas com a pitaya tem crescido rapidamente, especialmente durante a última década. Há uma grande confusão sobre os nomes botânico e comercial e há necessidade de esclarecer este ponto. Aqui, procura-se revisar o conhecimento existente sobre a taxonomia, reprodução, melhoramento, fisiologia, além da cultura, pós-colheita,
usos e outras técnicas da cultura.
Termos para indexação: Pitaia, taxonomia, fisiologia, pós colheita.

INTRODUCTION

The vine-cacti pitaya of the Cactaceae, subfamily Cactoideae, tribe Hylocereeae, is known to have been used for thousands of years by the indigenous people of the Americas (Ortiz- Hernández & Carrillo-Salazar, 2012). In the mid nineteenth century it was introduced by French priests to "Indochina", at that time the name for Vietnam, Laos and Cambodia. It acclimatized so well there, that the local people believed that this plant was native to their region (Mizrahi et al 1997). In 1995 Vietnam was the first country to sell pitayas in world markets, under the name Dragon Pearl Fruit (Thang Loy in their language); however nowadays this crop is grown and marketed in over 20 countries as a new horticultural fruit crop. Vietnam is the leading producer and exporter of this fruit, far ahead of all other countries combined; hundreds of thousands of tons are shipped and sold from Vietnam around the world annually. However, the taste of the Vietnamese fruit is quite bland, which is an obstacle for converting it into a major world fruit crop. Moreover, many countries obtained their clones from Vietnam and unfortunately, these clones currently govern the world pitaya markets. Consumers who have tasted these fruits are reluctant to try new better tasting varieties which exist today. This marketing obstacle should be resolved for the pitaya to become a mainstream fruit crop.

Until 1994, only scarce research existed on these plants; however the worldwide interest in this novel fruit crop is evident, as numbers of pitaya-related publications have grown rapidly, especially during the past decade (Fig 1). There is a big confusion about both botanical and commercial names and there is a need to clear this point. Herein, we attempt to review existing knowledge on the taxonomy, breeding and other horticultural characteristics of this unique crop.

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[2]Department of Life Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel. E-mail: mizrahi@bgu.ac.il

Taxonomy- The vine-cacti belong to three separate genera. The three- ribbed shoots belong to *Hylocereus*, the two-ribbed shoots belong to *Epiphyllum,* while four and more ribbed shoots belong to *Selenicereus* genus (Hunt 2006, Tel-Zur et al 2011a). Over the years, our group has collected many genotypes of this group of plants, and we have produced a large genetic database. This database includes over one hundred genotypes of various genera, species and clones differing in their appearance and many other characteristics (Fig. 2 and http://www.bgu.ac.il/life/Faculty/Mizrahi/index.html)

All tested genotypes were found to be diploids, with the exception of the real yellow pitaya *Selenicereus megalanthus* (synonym *H. megalanthus*) and *S. vagans* which are tetraploid genotypes (Lichtenzveig et al 2000; Tel-Zur et al 2011a & b). In the scientific literature this plant appears under three names, the above two and *Mediocactus coccineuss* (Infante 1992; Tel-Zur et al 2004). Recent taxonomic and molecular data suggest that this species belongs to the *Hylocereus* genus, hence the new recent name *Hylocereus megalanthus* (Hunt 2006; Tel-Zur et al 2004; and Plume et al 2013). Personally, I prefer to use the name *Selenicereus megalanthus* and not *Hylocereus megalanthus* since this pitaya has common morphological characteristics with species of the *Selenicereus* genus, especially the spiny fruit (Fig 3). It also differs in 17 characteristics from all other *Hylocereus* genotypes (Table 1).

It is very important to distinguish between the yellow clones of the *Hylocereus undatus,* which we named "Golden" pitayas, and the real yellow pitaya *S. megalanthus* (Fig 3). After visiting Nicaragua I found that they also have yellow clones of *Hylocereus costaricensis* which they name Pitaya amarilla (yellow pitaya in Spanish).

Breeding

When we started to research these species almost nothing was known in scientific literature (Fig 1). The first thing we did was to collect genotypes from cacti collectors, botanical gardens, private gardens, wild types from countries of origins etc. The variation in appearance among these groups of vine-cacti is obvious (Fig 2). However there are also huge differences in many other aspects including taste, pigment profiles both of peel and flesh and many other characteristics. The first genotypes we released to farmers were beautiful but their taste was very bland, similar to the Vietnamese clones. We started to perform crosses between clones of the same species (inter-clonal hybrids), between different species (interspecific hybrids) and between different genera (inter-generic hybrids) [Tel-Zur et al 2004]. Luckily enough, many crosses were successful, and some yielded our first generation of hybrid clones which are grown today as commercial pitayas both in Israel and abroad. The *Hylocereus* sp hybrids, either inter-clonal or interspecific ripen in summer; while the inter-generic hybrids ripen from the autumn to the end of winter; and the real yellow pitaya (*S. megalanthus*) ripen from the end of winter to the late spring. The only month we cannot obtain ripe fresh fruits is June. The crosses between the tetraploid *S. megalanthus* and various *Hylocereus* genotypes yielded diploids, triploids, tetraploids, pentaploids, hexaploids and octaploids hybrids (Tel-Zur et al 2004; 2005; 2011a & b and Cisneros et al 2013). Among all these polyploids the triploids yielded two commercial hybrids which exhibit good taste, long shelf-life and ripening in late autumn to mid-winter, differing from all other *Hylocereus* genotypes. The fruits are spiny, but to a much lesser extent than the *S. megalanthus*. All these crosses enable us to find dominant, co-dominant and recessive characteristics which will help us in future breeding (Tel-Zur 2004). Tel-Zur and her co-workers also developed an *Embryo-Rescue* technology which enables to produce a viable hybrid when normal crossing fails (Cisneros & Tel-Zur, 2010, Cisneros et al 2013).

One of the problems with growing these genotypes is self-incompatibility. Among our *Hylocereus* spp we found around 10% of self-compatible genotypes, while all others need cross pollination. This means that the grower has to grow at least two clones which flower at the same time and are compatible. We developed a technology to preserve viable pollen for long periods of time (over 18 months) by desiccating fresh pollen under vacuum to 5-10% humidity and storing at -20ºC (Metz et al 2000). Doubling the chromosomes also solved this problem by breaking incompatibility (COHEN E TEL-ZUR 2012). Chromosome doubling was achieved by several means; by applying colchicine and/or oryzalin, both to germinating seeds and to areoles (Te-Zur et al 2011b), by crossing between genotypes of various ploidy where some offspring were found to be of different ploidy than the parents (Tel-Zur et al 2004), or alternatively - by gynogenesis (Benega-Garcia et al 2009b). Today, we work on F_2 offspring of self and cross pollination of the existing hybrids (F_1) with their parents as well as with other *Hylocereus* species. On the basis of one single seedling, some hybrids seem to have a much better appearance than the original F_1, lack of spines, good taste and long shelf-life; some of them are tetraploids and self-compatible (Fig 4). Of course one cannot rely on good performance of one seedling; hence, several cuttings were given to good growers around the country to test their performance in comparison with the existing commercial hybrids. We hope that within a few years we will have much better clones than the existing ones. The crosses of *Hylocereus* genotypes with *Epiphyllum* may be of special interest, since some of the *Epiphyllum* fruits are very tasty and aromatic, reminiscent of passion fruits. On the other hand crosses between *Hylocereus* spp and *Selenicereus* spp other than *S. megalanthus* have so-far yielded un-tasty fruits. A very powerful breeding tool was developed by Tel-Zur and coworkers. They were able to produce haploids from both pollen mother cells and ovaries (Benegra-Garcia et al 2009a; Benegra-Garcia et al 2009b). By doubling the chromosomes of these haploids one can obtain homozygous clones which are easy to work with as parents, for further future breeding.

It is important to note that our success in breeding new hybrids is the result of our pioneering efforts to improve this new crop through known genetic techniques used with other crops. Most likely, with time further improvement will be become harder to achieve, as is the situation today with well-established old fruit trees crops that have already undergone many years of breeding.

Physiology and other horticultural characteristics

After establishing plants mainly from seedlings and cuttings of several genotypes, we planted them in various ecozones around Israel. We soon realized that the plants have to be protected from the intense Israeli solar radiation, which caused severe photo inhibition and death. The stems turned yellow then bleached and die. In summer our radiation as PPFD (photosynthetic photon flux density), may reach 2,200 µmol photons/m^2/second, hence, all pitayas in Israel are currently grown under nets. The provided shade is from 20% along the Mediterranean coast to 60% in inland desert areas (Raveh et al 1998). The needed degree of shade may vary among clones; those having layers of wax on stems might need less shade than those without the wax.

Since these genotypes utilize the Crassulacean Acid Metabolism (CAM) pathway, it is expected that their water use efficiency will be much higher than that of other fruit crops. Indeed, according to Mizrahi et al (2007), the vine-cacti pitaya, the columnar pitaya *Cereus peruvianus* and the famous cactus-pear *Opuntia ficus-indica*, use around 10% of the water used by various C_3 fruit crops such as citrus fruits, peach, avocado and pear. The data were taken from farmers who grow both C_3 and CAM cacti fruit trees in the Israeli Negev desert. With the yields and prices which these farmers obtain for these exotic fruits, they claim that it is a negligible expense to pay for the water, even if they need to pay for desalinated water at 1 USD per cubic meter. We found that the root system of these hemi-epiphytic plants is very shallow; the depth is no more than 40 cm (Mizrahi et al 2007). Irrigation is required only during summer (the dry season). In mid-summer we irrigate every day with a small amount of water; otherwise the water will slip below the root system. Farmers apply between 50 – 250 mm of water annually, and those who irrigate with 250 mm/year cannot believe that our recommendation of 120 mm/year is enough (Mizrahi et al 2007).

Pitaya does require mineral fertilization, especially when annual yields are high– between 20 to 45 tons/hectare. However, data on mineral fertilization needs are lacking, thus the exact demand for the various mineral nutrients is unknown. Evidence for the need for fertilization came from the works of Nobel & De la Barrera 2002, and Weiss et al 2009, who tested the effect of mineral application and CO_2 enrichment on these vine-cacti. The common belief that CAM plants do not respond positively to CO_2 enrichment, was proven several times to be a misconception (Nobel & De la Barrera 2004, Raveh et al 1995; Weiss et al 2010). CO_2 enrichment enhanced growth and production of both vegetative and reproductive organs (Weiss et al 2010). Today we recommend to farmers to apply 23/7/23 N/P/K + microelements with any irrigation, containing around 70 ppm pure N.

The optimal temperature for growth of this cactus was found to be between 20 to 30ºC while the range of 30-40 ºC was found to be damaging (Pelah et al 2003, Nobel & De la Barrera 2004; Ben-Asher et al 2006). In these experimentations it was also found that CO_2 enrichment might alleviate water stress damage. We have recently noticed several hybrids which can be productive even in the Israeli Arava valley where the average temperature in summer is around 40ºC. After a spell of subfreezing temperatures in January 2008, we also found big differences in cold tolerance of various clones grown in different ecozones around the country.

The hemi-epiphytic vine-cacti require a trellis system for support. Many countries adapted the Vietnamese system where they plant 3-4 cuttings around a support pole which allows the shoots to bend down (Fig 5). It is not very efficient system to harvest. Also there is no need to plant 3-4 cuttings around the main pole where one can produce 20-45 tons/hectare/year. In Mexico they use live trees for trellising (Ortiz-Hernández & Carrillo-Salazar, 2012). In Israel we use a different support system, where we hang the shoots on wires at a height of no more than 160 cm. This allows two "walls" of fruit production on both sides of the system and also provides easy access to growers, to pollinate flowers and harvest fruits (Fig 6).

Today several Israeli farmers grow the pitayas in soilless systems, in 20 liter buckets (Fig 7). This system may solve many soil- borne problems and enable to more precisely regulate both irrigation and fertilization, by monitoring water efflux collected from the bottom of sampled buckets. It also enables to measure the uptake of minerals delivered by the irrigation system (Fig 8).

One major problem with the pitaya plants is that they tend to flower in waves (Weiss et al 1994). Some clones will flower twice per season which will result in two waves of ripe fruits. Each wave takes about one week from the first flower to the last one, and fruit ripening will occur after ~30 days. One way to solve this problem and provide the market with a steady supply of fruits throughout the season is to use clones with many waves (up to ten throughout the season). Another possible solution is to use different clones which flower and ripe at different times (http://www.bgu.ac.il/life/Faculty/Mizrahi/index.html). If these solutions are adopted, fruit quality will fluctuate throughout the marketing period, since fruits from different clones reach the market. We have also tried several other solutions such as thinning fruit buds and hormone applications (Khaimov & Mizrahi 2006). We tested the *Hylocereus undatus* and *Selenicereus megalanthus* and found that removal of young flower buds delayed the wave of flowering and produced late cropping. In both species, CPPU (horticulture cytokinin) promoted precocious and early flowering and led to early ripening, whereas GA_3 delayed both flowering and ripening. Hence, CPPU can be used to obtain early fruit production, and GA_3 or flower thinning to delay cropping (Khaimov & Mizrahi 2006). Khaimov and Mizrahi (2006) reported that application of long days was not effective in induction of early flowering as was reported by other papers (Yen & Chang, 1997, Jiang et al 2012). Recently, we found that the positive response to long days in the pitaya is temperature dependent. Temperatures ranging between 20 to 30 ºC are the optimal, while either lower and/or higher will decrease or even inhibit induction of flower bud production (Khaimov-Armoza et al 2012). It is important to note that this temperature regime is also optimal for growth and development, as mentioned above.

Analyses of endogenous cytokinins throughout the year supported the assumption that active cytokinins are important inducers of flower bud production in *Hylocereus undatus* (Khaimov –Armoza et al, 2012). The active cytokinins peak just before flower buds appear. Pruning shoots at the proper times can regulate the flowering in both *S. megalanthus* and its triploid hybrids. When pruning the shoots every week between the beginning of August to the beginning of September, these genotypes will burst in flower bud production. Consecutive pruning will result in consecutive flowering and ripening. The periods which elapse between the waves of flowering and ripening become longer with time, due to shorter days and lower temperatures (Figure 9). Hence, ripening will occur from November to April, namely providing winter crop. The first fruits of the season are 50% of the size of the later fruits, probably due to more appropriate temperatures for fruit development and ripening in the late season.

Another approach to stretch the season is by pollinating the flowers with two different sources of pollen. If pollinated with *Hylocereus* spp, the time which elapses from pollination to ripening is shorter by ~5 to 30 days than if pollinated with of *Selenicereus* spp clones. This is a classical metaxenia phenomenon to be used for elongating the ripening season (Mizrahi et al 2004).

Post-harvest

Pitaya fruits are very attractive in appearance when fresh. However, in most end-markets which sell these fruit, the appearance becomes very poor, mainly due to the shriveling of the fruit scales (Fig 10). We found that the pitaya fruit-peels contain active stomata. These stomata follow the CAM photosynthetic pathway like those of the shoots (Fig 11). The fruit stomata density varies throughout the fruit surface. They are more concentrated in the scales than in the other parts of the fruit peel (Fig 12), and are most concentrated on *Hylocereus undatus* fruit peel (Fig 12). Indeed we found that that shriveling occurs more rapidly in *H. undatus* fruit than in the other two tested species (Kaplan-Levy 1999). Covering fruit with plastic sheets can extend the shelf-life by a few days and the most effective film is IP9 (StePac, Tefen Israel). The main reason that pitaya fruits lose their taste after harvest is a sharp decline in acidity, as malic acid concentration (Nerd et al 1999). This problem could probably be solved by crossing with parents which have high acid content or in clones in which the decline in acid is inhibited, or both. We have not materialized this option yet.

We found that the minimum temperature to store pitayas is 10^0C since they are sensitive to chilling injury (Fig 13). Chilling injury is manifested by early shriveling of scales, watery pulp, decline in taste and development of off-flavor (Nerd et al 1999). We found that the best way to achieve long shelf-life fruit is by breeding. We bred several clones which can tolerate sea-freight to Europe, having a 26 day shelf-life, 21 days at 10^0 C followed by 5 days at 20^0 C.

Additional pitaya plant uses

Pitaya plants can also serve other important human needs. The most important of all is to use the beautiful pigments of the red flesh pitayas as food coloring agents (Naderi et al 2010). We found a new glowing-magenta-pigment in *Hylocereus polyrhizus* (*H. monacanthus*). Since it was first found in this genus we named it Hylocerenin (Wybrabiec et al 2001; Wybraniec & Mizrahi 2002). Afterwards a tsunami of new papers was published mainly by German researchers Stintzing, Carle, Herbach, & Moßhammer, and some others. Some of their work was reviewed by Stintzing & Carle (2007) emphasizing the importance of this group of pigments to the food industry. The Betalain pigments, especially those from the vine-cacti are excellent pigments due to their beautiful color, their stability in various ranges of pH and heat treatments and their high nutritional value. They contain antioxidants among other compounds, all summarized in the excellent review by Azeredo (2009).

Flowers of *Hylocereus undatus* are used as a vegetable named ‘‘Bawanghua’’ in Chinese cooking (Chinese Academy of Sciences. (1999). Recently, ‘‘Bawanghua’’ has been commercialized as a healthy beverage in China, on top of many other uses as a health food (Yin et al 2012). Ortiz-Hernández & Carrillo-Salazar, (2012) also mentioned in their review many other medicinal uses of the pitaya species such as hypoglycemic, diuretic, for treatment of heart disease, dysentery, anti-proliferation properties, antimicrobial activity and more. Also the pitaya shoots and seeds are an important source of nutraceuticals.

Pitaya pests

In tropical countries pitayas are infested with many fungi, bacteria, viruses, insects and nematodes. In Israel which is a semi-arid zone, this crop was free from any pests for many years. Only recently we found that two nematode species are causing damage mainly to the *Selenicereus megalanthus* and few other *Hylocereus* genotypes. The nematodes belong to the *Meloidogyne* genus; they are *M. incognita* and *M. javanica,* and cause problems only in sandy soils. Resistant clones of pitayas are available to be used as rootstocks. It is very easy to graft these plants and they become productive one year after grafting.

Recently several fungi were discovered, which might become a problem in pitaya fruits. One is *Bipolaris cactivora* which appears as black patches on the fruits, sometimes penetrating into the fruit flesh - however damaged fruits are discarded. The other fungus is *Scytalidium lignicola,* which penetrates into the fruit via the flower style but has not reached a stage of causing real commercial damage.

TABLE 1- Differences between *Selenicereus megalanthus* (real yellow pitaya) and all other *Hylocereus* clones (red pitayas). These characteristics were documented in Israel. Changes may occur in other locations.

Component	Fresh after harvest		After 2 weeks of storage	
	Clone 7	Clone 13	Clone 7	Clone 13
Fruit mass (g)	194±14	267±23	232±30	187±16
Pulp/peel (fwt ratio)	1.3±0.1	1.7±0.3	1.6±0.2	2.1±0.3
Water (%)	86±1	84±1	86±0	86±1
pH	4.4±0.1	4.4±0	4.8±0.1	4.5±0.2
Fiber (% dwt)	8.7±0.4	6.3±0.4	7.0±1.2	10.7±0.7
Ash (% dw)	2.5±0.1	2.7±0.1	2.1±0.3	--------
Soluble protein (mg/g fwt)	1.2±0.1	1.1±0.1	1.1±0.1	0.9±0.1
Vitamin C (mg/100g fwt)	31±6	53±5	43±4	55±4
TSS (% in juice)	11.3±0.6	13.2±0.2	10.5±0.5	9.7±0.4
Soluble sugars (mg/g fwt)	71±5	82±5	58±4	65±2
Reducing sugars (mg/g fwt)	64±3	59±5	27±2	29±10
Titratable acidity (meq/g fwt)	35±5	38±4	13±2	28±2

Mineral content (mg/g fwt)				
	Clone 7	Clone 13	Clone 7	Clone 13
Zn	0.01	0.01	0.02	0.04
Fe	0.05±0.01	0.03±0.01	0.02±0	0.02±0
Mg	0.99±0.03	0.97±0.05	0.95±0.06	1.04±0.13
Ca	0.37±0.01	0.38±0.04	0.99±0.06	0.82±0.10
K	6.47±0.15	5.76±0.35	4.45±0.45	6.34±0.15
Cl	0.21±017	0	0.10±0.10	0

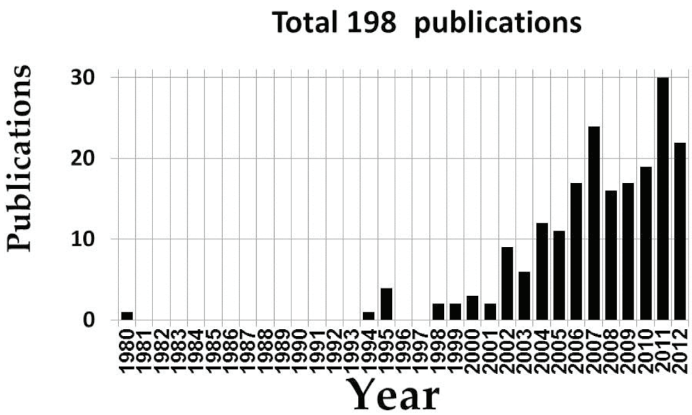


FIGURE 1- Number of published scientific papers on vine-cacti piatya (*Hylocereus* spp) which appeared in the scientific databases.

FIGURE 2- Appearance of various clones of pitaya genotypes (all *Hylocereus* spp), included in our Vine-Cacti genes bank.

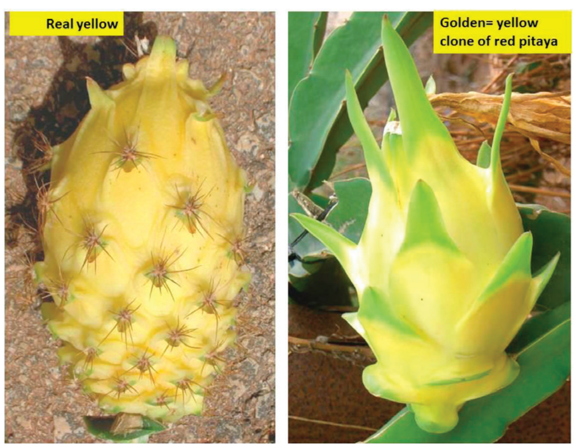


FIGURE 3- Appearance of yellow fruits of *S. megalanthus,* the real yellow pitaya and the yellow clone of *H. undatus* which we named Golden. Both fruits are named by the local people of their country of origin Pitaya Amarallia which means yellow pitaya.

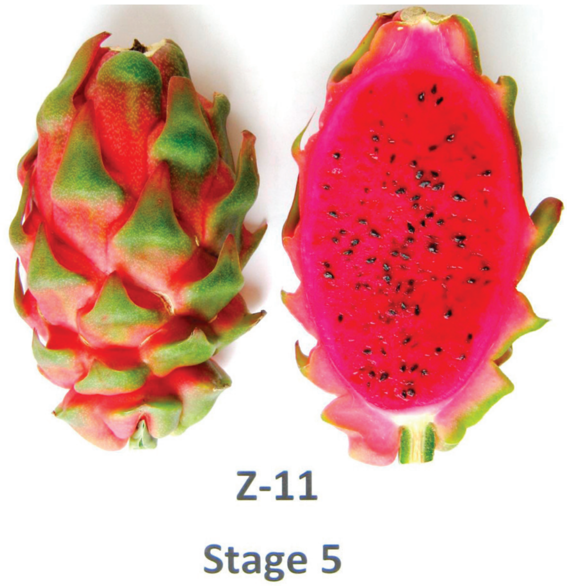


FIGURE 4 - Appearance of one of the new F_2 hybrids under consideration of being a new commercial clone. This genotype has much less spines, better appearance, good taste, is self-compatible and has a long shelf-life.

FIGURE 5 - Typical Vietnamese trellis system. Note four stems, planted around the main pole.

FIGURE 6 - Typical Israeli trellis system. Fruits are produced on the 2 “walls” of the system.

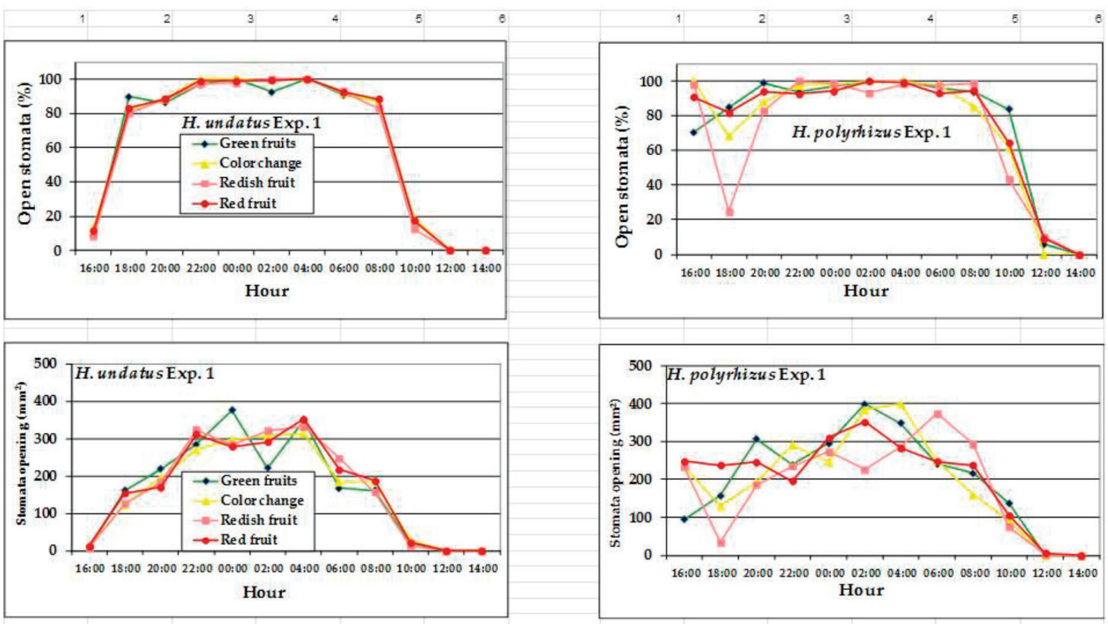
FIGURE 7- Soilless pitaya, trellised and grown in 20 liter buckets, in 30% shade net-house.

FIGURE 8- Pitaya bucket in the orchard with a tray to collect and measure efflux of water and minerals.

FIGURE 9-Appearance of the triploid commercial clones at various stages of flowering, resulting from pruning at different times. The three pictures were taken on the same day of October 10th 2011. The difference in stages of flowering is the result of weekly consecutive pruning from August 3rd (a) to September 3rd (c).

FIUGRE 10 - Poor appearance of pitaya fruits in Sweden and Paris. Similar appearance can be seen all over the world.

Kinetics of fruit stomata opening of *H. polyrhizus* and *H. undatus* at 4 stages of fruit ripening



FIUGRE 11- Daily stomata opening in *Hylocereus undatus* and *Hylocereus polyhrizus* (synonym *H. monacanthus*) at four stages of fruit ripening. Stomata opening is presented both as % of open stomata and average area of open stoma in mm^2.

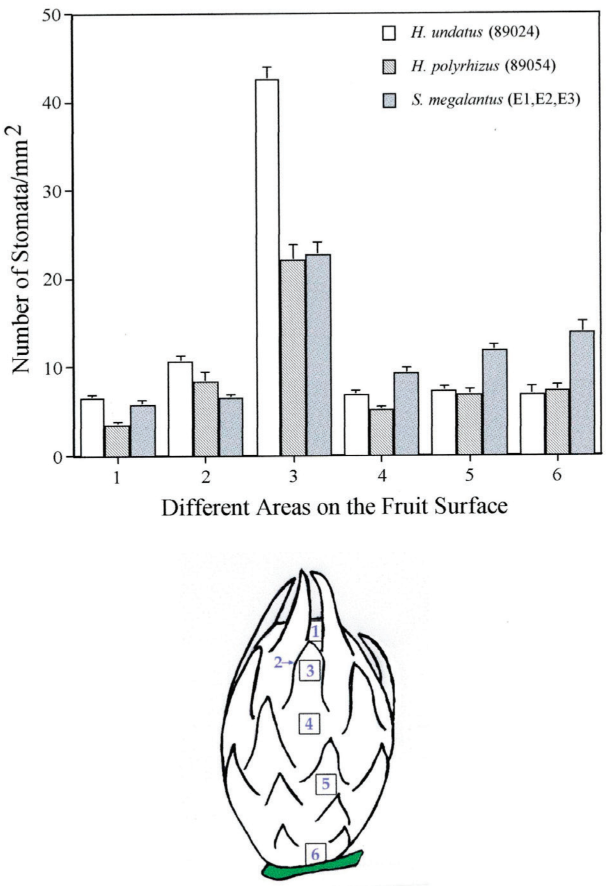


FIGURE 12 - Stomata distribution and density throughout the pitaya fruit surface. A. - Areas from where stomata print were taken and counted per mm^2. B - Density of stomata (number/mm^2) in three species of pitayas.

FIGURE 13- Chilling injury in *H. undatus* fruits in Barcelona market. The first tissue to deteriorate is the fruit scales, followed by the watery pulp shown in this picture.

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CONCLUSIONS

To sum up almost three decades of worldwide research and development on this unique vine-cacti plant; it seems that the pitaya has a bright future due to the following reasons: It is an extremely visually attractive fruit; which also nowadays has a good taste thanks to the new hybrids. The water use efficiency is the highest among all fruit trees. It contains many nutraceuticals which today are highly appreciated by consumers; yields are high; fruits can be produced almost year around which is huge market advantage; and finally - plants have uses other than for fresh market fruits. One obstacle to the success of this fruit is the marketing of the old bland clones, which should be avoided in the emerging new markets. We have already experienced consumers who were reluctant to taste the new hybrids since they experienced the old un-tasty clones.

Many essential areas of research are in need for R&D activities, among them fertilization, irrigation and many other manipulations used in other fruit trees.

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