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ADAPTATION OF FIVE COLUMNAR CACTUS SPECIES TO VARIOUS CONDITIONS IN THE NEGEV DESERT OF ISRAEL

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Nerd, Avinoam, Eran Raveh and Yosef Mizrahi (*The Institutes for Applied Research, Ben-Gurion University of the Negev, P.O. Box 1025, Beer-Sheva 84110, Israel*). Adaptation of Five Columnar Cactus Species to Various Conditions in the Negev Desert of Israel. *Five species of columnar cacti were examined with the aim of introducing new orchard crops to the Negev desert of Israel The species were comprised of Stenocereus gummosus, S. griseus, S. thurberi and Pachycereus pringlei , all native to dry regions of Mexico and Cereus peruvianus which is found in subtropical regions in South America. Young seedlings were planted at four sites in the Negev all differing in climatic conditions and water quality. Growth data, expressed as total stem length and stem biomass obtained after five to six years in the orchards, showed that C. peruvianus grew best in the site with moderate temperatures and good-quality water, whereas the other species also did well under more extreme conditions of high temperatures and brackish water. Growth of all species was significantly retarded at the site having the most saline (NaCl) water. In the sixth year a severe frost at one of the sites caused extensive injury to C. peruvianus and S. griseus plants, making the potential of that site is questionable. At this stage C. peruvianus is the most promising candidate for domestication. Its growth rate was much higher than that of the other species, and it had precocious yielding with good-quality fruits. Measurements of ion concentrations (dry weight basis) in the stems showed that accumulation of K^+ was similar at all four sites and that Na^+ and Cl^- were significantly higher (probably in excessive toxic concentrations) at the*

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site with the highest concentrations of Na^+ and Cl^- ions in the water. At all sites Cl^- concentration in C. peruvianus was much lower than that in the other species indicating that the exclusion of Cl^- from the stems was not correlated to salt tolerance.

Key Words: Domestication, experimental sites, growth, fruiting, frost, brackish water, ions

The cactus family consists of about 1600 species, many of which produce edible fruits, but only a few, such as the prickly pear *Opuntia ficus-indica* and recently some epiphyte species of the genus *Hylocereus* (Arcadio L. 1986) are recognized as agricultural fruit crops. Potential candidates for domestication are columnar cacti bearing medium to large edible fruits, consumed by local inhabitants in their indigenous locations (Felger and Moser 1974; Sanchez M. 1984). Of this group, *Stenocereus stellatus* and *S. griseus* are undergoing a process of domestication in Mexico. Plantations of selected clones have been established, and agrotechniques, and fruit physiology are being studied (Castillo H. 1984; C H. 1984; Cruz H. 1985; Liamas L. 1984; Martinez G. 1992).

Our program for the introduction of new orchard crops to the Negev desert of Israel, included the introduction of fruit trees and cacti from warm and dry world regions (Nerd et al. 1990).

In the present study the performance of five species of columnar cacti planted at four different sites in the Negev were examined. In addition, ion concentration was determined in stems in order to obtain further information about their salt tolerance.

MATERIALS AND METHODS

Seeds of *Cereus peruvianus* were obtained from private gardens in California, and those of *Stenocereus gummosus, S. griseus, S. thurberi* and *Pachycereus pringlei* were obtained from natural habitats in Mexico (Table 1). The seeds were germinated in vermiculite in our greenhouse with a day/night ambient temperature fluctuation of 16 to 36°C. Germination occurred within 4-6 weeks for all the species. Young seedlings were transplanted to 1 L pots containing a sand mix (1 sand: 1 peat: 1 vermiculite

v/v/v) and replaced in the greenhouse. After two years the plants (20-30 cm) were ready for planting.

In the summer of 1986 the five species were planted in four experimental sites in the Negev desert, Qetura, Neot Hakikar, Ramat Negev and Besor. Climatological data supplied by local meteorological stations, and properties of the irrigation water determined by standard methods by Extension Service Laboratories are presented for each site in Tables 2 and 3. The soil at Ramat Negev is loamy, while that at the other sites is sandy-loamy. At each site the cacti were planted in three blocks of 5-10 plants per block at a spacing of 1.5 x 5 m. Throughout the year irrigation was supplied to each plant via a 4-L/h dripper every 1-3 days in the summer and every 4-7 days in the winter, in amounts that maintained the soil moisture close to field capacity in a radius of 0.5 m around the plant and to a depth of 1 m. Fertilizer was applied through the irrigation system at concentrations of 40-60 ppm N and K and 18-26 ppm P.

Total stem length was measured in all the plants in the fifth year. as well as for C. *peruvianus* at Besor in the sixth year. In the fifth year, stem biomass was determined as follows: A 30 cm long segment was cut from the middle of a stem of each of five plants of each species at each site. The segments were oven dried (70°C), and the dry weight was used to calculate the stem biomass from the following formula:

$$\text{Biomass (kg)} = \frac{\text{Stem length (cm) x Segment dw (kg)}}{30}$$

Flushes of flowers and yields were recorded in fruiting plants. Cores sampled across the stems in the autumn of the fifth year were used for ion analysis. Chloride was measured with a Buchler-Cotlore chloridometer and Na^+ and K^+ were determined in an atomic absorption spectrometer .

RESULTS AND DISCUSSION

GROWTH AND PERFORMANCE

Total stem length measured in the fifth year was used as a measure of plant growth (Fig. 1). For all species stem length was much lower at Neot Hakikar than at the other sites. Stem length of *C. peruvianus* was greatest at Besor while that of the other species was similar at Qetura, Ramat Negev and Besor or slightly greater at Qetura. Stem biomass, estimated as described above, was also used as a measure of growth (Fig. 2). Variations in the biomass of each species at the different sites generally paralled changes in the total stem length except for Neot Hakikar, where the increase in biomass for most of the species was relatively much smaller than the increase in total stem length. This was a result of the fact that the thickness of stems at Neot Hakikar was 20-30% of those measured at the other sites (data not shown).

At Ramat Negev, which usually experiences frost in winter, plants suffered from extensive cold injury in the sixth year when temperatures dropped to -7°C. The most sensitive species were *C. peruvianus* and *S. griseus*. The percent of necrotic stem surface area out of a total stem surface area was 55 ± 9% in *C. peruvianus*, 51 ± 8% for *S. griseus* and <5% in *S. gummosus* and *S. thurberi*. In *P. pringlei* no cold injury was detected.

Growth data from the various sites in the fifth year indicated that of the five species *C. peruvianus* was the one that grew best under more moderate conditions, i.e., the moderate temperatures and good-quality water at Besor. The other species did well, or even better than at Besor, in the sites characterized by stress conditions—Qetura with hot summer temperatures and brackish water and Ramat Negev with low winter temperatures. At Ramat Negev the picture will change in the future for *C. peruvianus* and *S.*

griseus, since large parts of their stems were injured by a winter frost in the sixth year. Ramat Negev is thus not a promising site for these two species, since they are under constant danger of frost damage. It will, however, be interesting to examine their ability to recover from the frost damage.

The inferior growth of all the species at Neot Hakikar is possibly the result of the high concentration of Na^+ and Cl^- in the brackish water. This is probably the correct explanation for the retarded growth, since Neot Hakikar is similar to Qetura in soil properties and in EC and osmotic pressure of the irrigation water, although concentrations of Na^+ and Cl^- at Neot Hakikar are as much as 2-3 times greater than those of Qetura (Table 3).

Many species of cactus grow slowly, having low annual above-ground productivity (stem and fruits). However, some cacti, such as the cultivated prickly pear species, are highly productive, with their productivity being comparable to common agricultural crops such as maize (Nobel 1991). A comparison of stem biomass of the five species of cactus in in the fifth year, showed that *C. peruvianus* was significantly more productive than the other species. It produced 8 kg of dry matter per plant, which was three times greater than that produced by *S. gummosus* and 6-10 times greater than that produced by the other species. Measurement of stem elongation in the sixth year in five *C. peruvianus* plants at Besor, showed that the average increase in total stem length was 3.9 ± 0.3 m, which corresponded to about 2 kg dry matter per m^2 ground area. This figure is similar to the annual production of stem biomass reported for *O. ficus-indica* (Nobel 1988).

FRUITING

The duration of the juvenile phase is much shorter in *C. peruvianus* than in the other species. At all sites, flowering started in most of the

C. peruvianus plants in the third year and was abundant from the fourth year onward. Flowering in *C. peruvianus* occurred in the warm season (May-September), with more than 90% of the flowers setting fruits (data not shown). Among the other species, only a few plants of *S. gummosus*, *S. griseus* and *P pringlei* produced individual flowers from the fifth year onward.

Yields are shown in Fig. 3 for the four sites. Yields at Neot Hakikar were very small, less than 2 kg/plant for the fifth and sixth years. The highest yields were obtained at Besor, 16 and 22 kg/tree in the fifth and sixth years, respectively. The total yield at Besor was 2.2 times higher than that at Qetura and 6 times that at Ramat Negev. Since flowers are born along the nodes of the previous year's growth, it was expected that yields would correlate with total stem length, and in general, this trend was indeed confirmed. However, at Ramat Negev, yields were lower than those predicted from plant size, probably as a result of low winter temperatures that damaged stem tissue.

MINERALS IN STEMS

Comparisons between plants at the Qetura and Neot Hakikar sites, where brackish water was used for irrigation, showed that stem concentrations of Na^+ and Cl^- were usually 1.5- to twofold higher at Neot Hakikar. K^+ concentrations were generally similar at the two sites or slightly higher at Neot Hakikar. Ion concentrations in plants grown at the sites with good quality water, Ramat Negev and Besor, were generally similar to those at Qetura, except for Na^+ in *S. gummosus*, which was much higher at Qetura.

There is evidence that in nonhalophytes salt damage is due to excess Na^+ and Cl^- in shoots and that the exclusion of salt ions from shoots is a mechanism for salt tolerance (Greenway and Munns 1980; Mass 1986). For

some cactus species, it has been demonstrated that concentrations of salt ions in stems remained very low even when salinity in the culture medium increased up to 400-500 mM NaCl (Nobel et al. 1984; Silverman et al. 1988; Nerd et al. 1991). The present study shows that the five columnar species were efficient in excluding salt ions from stems at Qetura, but not at Neot Hakikar, where their accumulation may account for the retarded growth. The accumulation of Na^+ and Cl^- at Neot Hakikar can be related to the higher concentrations of Na^+ and Cl^- and the higher ratio of Na^+/Ca^{2+} in the water of Neot Hakikar. For many plants, it has been documented that an increase in Na^+/Ca^{2+} ratio in the growth medium increases salt sensitivity, most likely by interfering with the integrity of the cell membrane (LaHaye and Epstein 1971; Greenways and Munns, 1980; Kent and Läuchli 1985).

It must be noted that Cl^- concentrations in *C. peruvianus* were 23-39 times lower at the sites with fresh water and at Qetura, and 2-3.8 times lower at Neot Hakikar than those in the other four species at the corresponding sites. These results indicate that those species that exhibited higher tolerance to salinity are able to function under higher stem concentrations of Cl^- as opposed to *C. peruvianus*, which was the species most sensitive to salinity. A similar phenomenon related to Na^+ was shown for *O. humifosa*, in which an ecotype of a marine strand tended to accumulate more Na^+ and had higher tolerance to salinity than an ecotype of an inland site (Silverman et al. 1988).

GENERAL DISCUSSION

Usually, an initial test of introduced wild or primitive plant material is carried out in a location with favorable environment comparable to that of its natural habitat (Hayland 1970). In the present study, the introduced plants were examined at four different locations, one with moderate conditions and

the other three with known specific stresses. This study design allowed us to obtain more information about the environmental adaptability of the five species than would have been possible in the usual way. It appears that species adaptability was associated with environmental background. In general, the Mexican species, *S. gummosus*, *S. griseus* , *S. thurberi* and *P. pringlei*, all native to dry regions, were more tolerant to temperature and salt stresses than *C. peruvianus*, which is a native to the subtropical rainy regions of the southeastern coast of South America (Backeberg 1984).

Since the plants were well irrigated and fertilized, it is possible to evaluate their potential productivity under the various Negev environments. Among the five species, *C. peruvianus* exhibited an outstanding growth rate and precocious yielding, features which are important for modern horticultural crops. The plants bore juicy, sweet, medium-sized fruits, with a good flavor (Weiss et al. 1993). We are therefore promoting the cultivation of this species. Productive clones bearing high-quality fruits have been vegetatively propagated and will be planted in semi-commercial plantations.

More time is needed to evaluate the productivity and fruit quality of the other species. Although they are not precocious yielders when raised from seed, it is possible that productivity in the early years will be increased in vegetatively propagated plants. The commercial cultivation of these species can be considered, if the fruit proves to be of a high quality.

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Figures legends

Fig. 1. Total stem length in the fifth year of five coloumnar cacti grown in four sites in the Negev. Values are means ± SE for 15 plants at each site.

Fig. 2. Stem biomass in the fifth year of five coloumnar cacti grown in four sites in the Negev. Total stem length and weight of stem segments were used for calculation of biomass. Values are means ± SE for 15 plants at each site.

Fig. 3. Fruit yield of *C. peruvianus* in the fifth and sixth years in four sites in the Negev. Values are means of ±SE for 15 plant at each site.

TABLE 1. LIST OF INTRODUCED CACTI AND COLLECTION SITES.

Botanical name	Common name	Collection site
Cereus peruvianus	Apple cactus	Gardens in California
Stenocereus gummosus	Pitaya agria	Hermosillo, Sonora, Mexico (29°13'N, 11°05'W, 60 m)
Stenocereus griseus	Pitaya de mayo	Haajupan, Oaxaca, Mexico (17°06'N, 98°20' W, 1500 m)
Stenocereus thurberi	Pitaya dulce, organ pipe	Desemboque, Sonora, Mexico (20° 32'N 4°30'W, 60 m)
Pachycereus pringlei	Cardon pelon	Desemboque, Sonora, Mexico (30°32'N, 11°30' W, 60 m)

TABLE 2. CLIMATIC DATA FOR THE FOUR SITES.

	Qetura	Neot Hakikar	Ramat Negev	Besor
Max/min mean daily temperature (°C)				
August (hottest month)	37/23	38/28	33/15	30/18
January (coldest month)	18/7	20/12	15/5	17/8
Annual pan evaporation rate (mm)	3000	3600	2200	1800
Annual rainfall (mm)	<50	<50	200	90

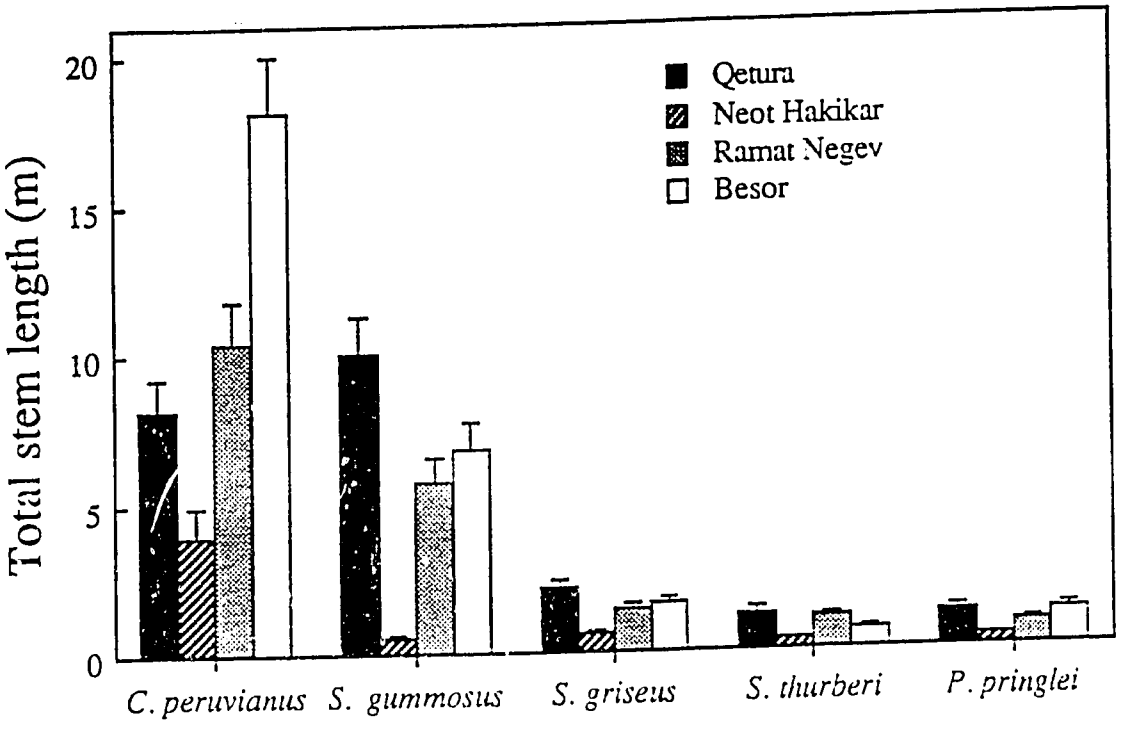
TABLE 3. IRRIGATION WATER QUALITY FOR THE FOUR SITES.

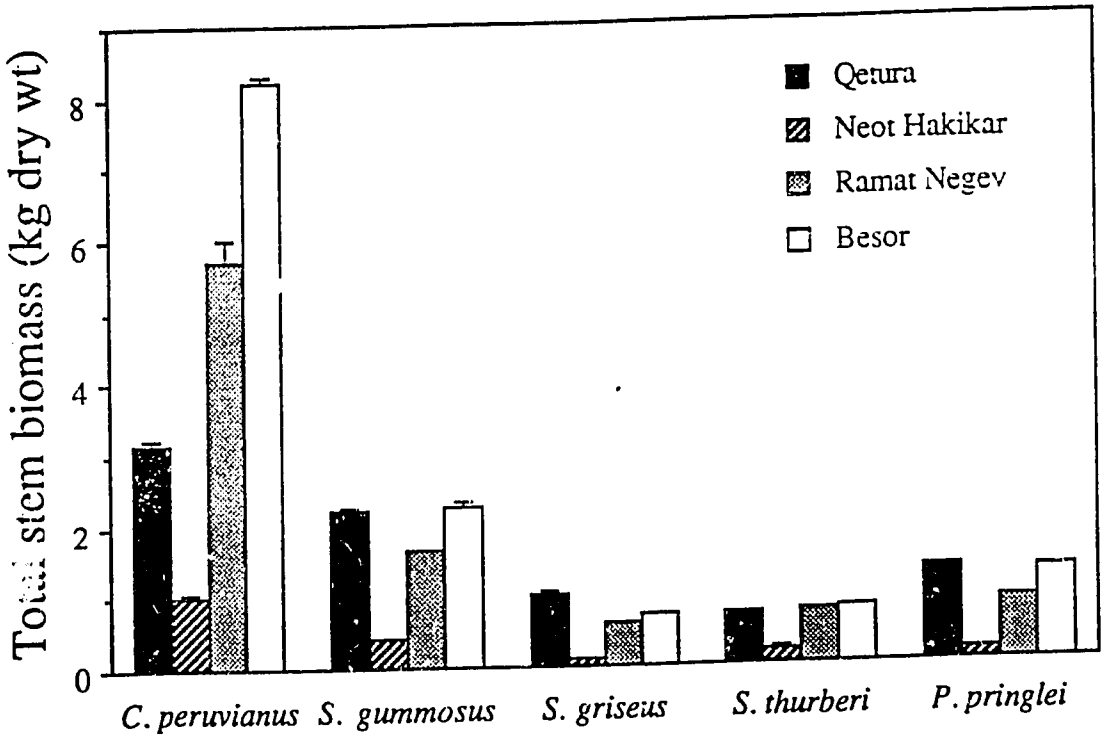
DATA ARE RANGES OF VALUES OBTAINED BETWEEN 1987 AND 1991.

	Qetura	Neot Hakikar	Ramat Negev and Besor
EC (dS/m)	3.5-4.5	3.7-4.5	0.9-1.1
Osmotic pressure (MPa)	1.3-1.7	1.4-1.7	0.3-0.4
pH	7.7	7.6	7.5
Ion content (mg/L)			
Na^+	240-304	520-1080	100-130
Ca^{2+}	260-272	200-265	48-111
Mg^{2+}	100-138	131-148	26-52
Cl^-	520-650	865-1003	265-278
SO_4^{2-}	818-840	360-630	50-102

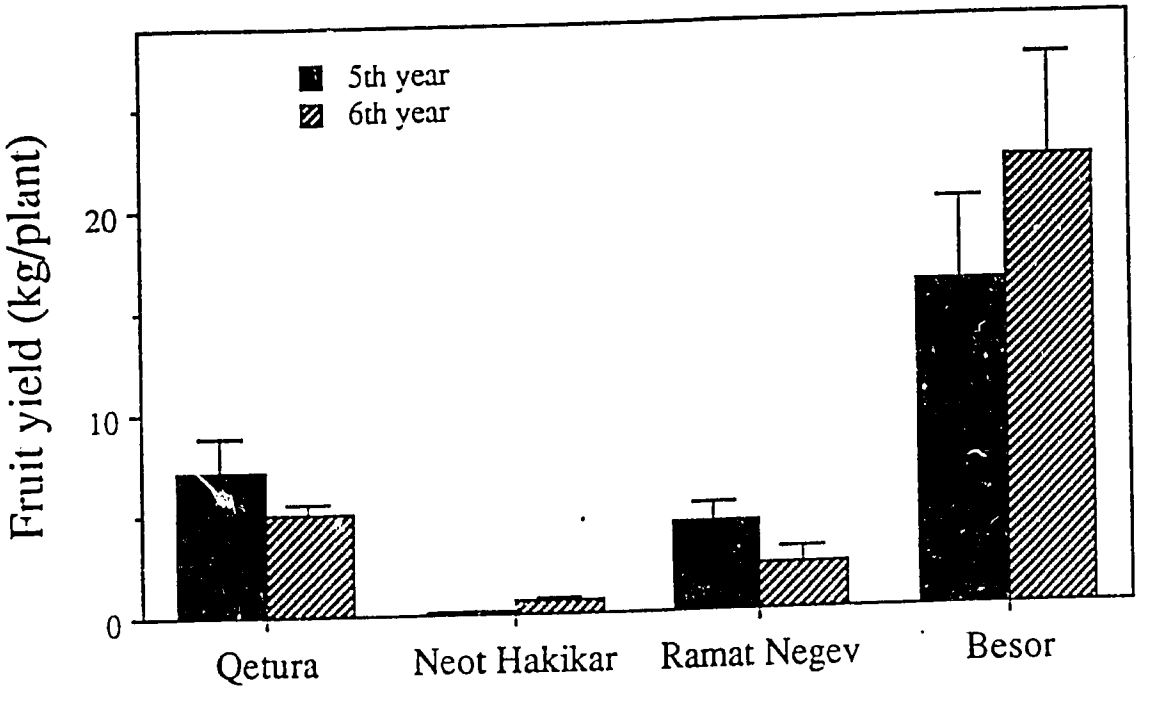
TABLE 4. ION CONCENTRATION IN STEM TISSUE OF VARIOUS COLUMNAR CACTI GROWN IN THE NEGEV. VALUES ARE MEANS FOR 5 PLANTS ± SE

	Ion concentration (mol/kg dw)			
	Qetura	Neot Hakikar	Ramat Negev	Besor
		Na^+		
C. peruvianus	0.032±0.005	0.054±0.008	0.018±0.003	0.008±0.002
S. gummosus	0.062±0.006	0.086±0.024	0.020±-0.008	0.017±0.006
S. griseus	0.015±0.003	0.022±0.004	0.014±0.033	0.016±0.003
S. thurberi	0.013±0.001	0.072±0.025	0.018±0.006	0.015±0.003
P. pringlei	0.023±0.004	0.054±0.015	0.011±0.001	0.015±0.004
		K^+		
C. peruvianus	0.010±0.005	0.018±0.003	0.018±0.002	0.017±0.003
S. gummosus	0.015±0.003	0.007±0.004	0.014±0.001	0.017±0.001
S. griseus	0.016±0.001	0.016±0.002	0.016±0.002	0.016±0.001
S. thurberi	0.018±0.001	0.025±0.008	0.015±0.001	0.014±0.002
P. pringlei	0.016±0.002	0.022±0.002	0.011±0.002	0.015±0.003
		Cl^-		
C. peruvianus	0.009±0.02	0.158±0.071	0.008±0.007	0.006±0.001
S. gummosus	0.186±0.004	0.314±0.090	0.193±0.022	0.189±0.036
S. grieseus	0.261±0.014	0.516±0.090	0.161±0.019	0.103±0.017
S. thurberi	0.249±0.049	0.453±0.110	0.182±0.042	0.292±0.043
P. pringlei	0.349±0.051	0.606±0.047	0.125±0.016	0.297±0.030


Total stem length (m)
20
15
10
5
0
Qetura
Neot Hakikar
Ramat Negev
Besor
C. peruvianus
S. gummosus
S. griseus
S. thurberi
P. pringlei


Total stem biomass (kg dry wt)
0
2
4
6
8
Qetura
Neot Hakikar
Ramat Negev
Besor
C. peruvianus
S. gummosus
S. griseus
S. thurberi
P. pringlei

3


5th year
6th year
Fruit yield (kg/plant)
0
10
20
Qetura
Neot Hakikar
Ramat Negev
Besor