1

Development of *Cereus peruvianus* (Apple Cactus) as a new crop for the Negev desert of Israel*

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Cereus peruvianus (apple cactus) is a large erect, thorny columnar cactus found in southern America (Fig 1). It is an unexplored, underutilized cactus, grown only as an ornamental plant, even though it produces attractive, edible fruits, which are known as pitaya in Latin America (Morton 1987). The nocturnal flowers remain open for one night. The fruits are thornless and vary in skin color from violet-red to yellow. The flesh, which is the edible part of the fruit, is white and contains small, edible and crunchy seeds. Fruits of a number of other columnar cacti, also belonging to the subfamily Cactoideae, tribe Cereeae, are known to be of economic significance for native use in south America (Felger and Moser 1974).

The aims of this study were to investigate growth and fruiting of *C. peruvianus* under different climatic, soil, and water conditions in the Negev desert of Israel and to study the biology of pollination and fruit maturation.

METHODOLOGY

Seeds were obtained from California (private and public botanical gardens). The seeds germinated easily and after two years in the nursery reached 25 cm height. The plants were then transplanted into four orchards in the Negev desert, varying in climatic, soil and water conditions as described (Nerd et al. 1990). Besor is characterized by moderate temperatures and fresh water irrigation , whereas high temperatures and saline irrigation

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prevail at Qetura and Neot-Hakikar. Ramat Negev is characterized by low winter temperatures and fresh water irrigation. A smaller orchard was also established on the grounds of our institute (Beer-Sheva). The compatibility system was tested by experimental pollinations.

Fruits were picked at weekly intervals from first color change until 29 days after full color change and the fruit quality parameters (totale soluble solids (TSS), reducing sugars, titratable acidity and pH) were analyzed in the pulp. Changes in fruit length and diameter were determined during fruit development for attached fruits.

RESULTS AND DISCUSSION

Plant performance

Annual growth occurred in the warm months, but plants started to grow at Qetura earlier (March) than at the other orchards (April, May). Growth occurred at a relatively constant rate at Qetura and Ramat Negev, but at Besor the onset of the summer was associated with faster growth (Fig.2).

The total shoot length and the biomass were higher at Besor than at Ramat Negev and Qetura, while at Neot Hakikar growth was almost arrested (Table 1). Plants at Ramat Negev showed visible cold injury such as brown spots or yellowing after temperatures dropped to -7° C for several hours. Since the plant material and the agrotechniques used were similar (plants were propagated from the same batch of seeds)) in all the plots, variations in growth can be attributed to the diverse environmental conditions prevailing at the different locations. The fresh water and moderate temperatures favored growth at Besor, while water salinity at Qetura and Neot Hakikar and low temperatures at Ramat Negev inhibited growth. Sensitivity to low salinity was also shown for other cacti species such as *Opuntia ficus-indica* (Nobel 1987; Nerd et al. 1990). The salinity at Neot Hakikar caused greater stress to the plants than that at Qetura, probably because the main salt ions in the water at Neot Hakikar, i.e. sodium and chloride, were more toxic than the ions in the water at Qetura, i.e. calcium, magnesium and sulfates.

Flower production was negligible at Neot-Hakikar and Ramat Negev, but abundant at Besor and Qetura. The low winter temperatures at Ramat Negev and the water salinity at Neot-Hakikar may have inhibited flowering.

The natural fruit set of 15 individual plants at Besor varied in the summer, 1990, between 0 and 95%, and pollination studies were conducted to evaluate the origin of variation.

Pollination

The compatibility system of various individual plants was tested by comparing fruit set with cross, self, and open pollinations in summer 1991 at the Besor orchard and at Beer-Sheva. Flowers that were covered with bags before anthesis and were hand-self-pollinated did not set fruit (Table 2). This suggests that *C. peruvianus* is self-incompatible. Hand-cross-pollination led to 100% fruit set. Open-pollinated flowers set fruit at Besor but not at Beer-Sheva (Table 2). Fruits from hand-cross-pollinations were heavier and had a higher pulp to peel ratio than fruits which derived from open-pollinated flowers. They also had more seeds/g pulp tissue and the seed number was positively correlated to the pulp weight. Open-pollination did not lead to optimal fruit development compared to experimental cross-pollination. These results indicate that it is necessary to plant two or more different clones in close proximity and which flower over the same time period. One reason for the low fruit set of some seedlings in open pollination might be a lack of other flowering plants in the vicinity.

The main insects visiting the flowers were bees, although small flies were also observed. The insects visited the flowers when the flowers are opening before sunset, and after sunrise, when the flowers are closing. The placing of beehives in an plantation would increase fruit set and improve fruit production.

Differences among seedlings of *C. peruvianus*

Seedlings varied in thorn development on the shoots, in onset and duration of the flowering period, and in fruit appearance and quality (Table 3).

The ribbed stems of *C. peruvianus* bear thorns (Morton 1987). Nevertheless, some of our seedlings exhibited a reduction in thorn length with increasing age, leading to thornless upper stem parts. Cuttings taken from such thornless stem parts produced thornless plants, which indicates that this phenomenon is a growth phase phenomenon and is genetically controlled. Thornlessness is obviously an important advantage for cultivating this plant.

Flowering of *C. peruvianus* occurs in two waves. The first wave starts in spring (May) and the second in mid-summer (July). Detailed observations made on the first wave in 1991 showed that there are considerable variations between the various seedlings in both the onset and the duration of flowering period, which may last from two weeks to one month.

The color of the fruits varies from violet-red through orange to yellow and the fruit length ranges from 7 to 10 cm. The taste of the fruits also varies markedly, some fruits are juicy and aromatic, whereas others are mucilagenous and inferior in taste. Furthermore, the fruits differ in their tendency to burst upon ripening. A reduction of irrigation during the crititical stage of fruit development might prevent this phenomenon.

Fruit quality parameters (TSS, reducing sugars and titratable acidity of the pulp), fruit weight, pulp to peel ratio and percentage of peel and pulp dry weight of different individual plants from Besor and Beer-Sheva are shown in Table 2 and 4. Significant differences were found in titratable acidity of the pulp and dry weight of the peel as well as in fruit weight and pulp to peel ratio. Preliminary taste-tests showed, that fruits with a higher content of titratable acids were less tasty than the fruits with a lower acidity. Fruits of the various individual plants were all harvested in the stage of full color change, but since they were not tagged at the beginning of color change, they might have reached different stages of ripeness at harvest and this fact might partially be responsible for the differences in the quality parameters.

Maturation and harvest

CO_2 and ethylene evolution were measured in ripening fruits. No increase in gases evolution was observed indicating that the fruits of *C. peruvianus* are nonclimacteric. Changes in reducing sugars, TSS, pH, and titratable acidity are shown in Figs. 3 and 4. The TSS and reducing sugars increased and the titratable acidity decreased significantly within 10 days after first color change. No distinct changes in the amount of reducing sugars and the titratable acidity occurred until ripeness, whereas the TSS increased significantly upon ripeness. Fruit growth followed a sigmoidal growth pattern (Fig. 5). These results indicate that the time of full color change is the most favorable harvest time in terms of fruit size, but the optimal harvest time in terms of taste and postharvest behavior is still unclear.

CONCLUSION

It seems that the optimal conditions for growth and flower production of *C. peruvianus* are moderate temperatures and fresh water irrigation; low winter temperatures and saline irrigation inhibited growth.

Plants propagated by seeds were self-sterile. Open pollination led to a fruit set of between 0 and 95%, depending on the individual plant, but experimental cross-pollination resulted in 100% fruit set and heavier fruits with more seeds. The pulp weight was positively correlated to the seed number. Bees were the main insects visiting the flowers. The placement in the orchard of beehives may be desirable to maximize fruit yield. Selection for plant appearance, flowering time and fruit appearance and quality is now needed for the commercialization of *C. peruvianus*.

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Figure legends

Fig. 1. *Cereus peruvianus* tree at Besor (5-years-old)(0ctober 1991).

Fig. 2. Growth of *Cereus peruvianus* plants at four sites in the Negev desert of Israel during 1989. Values are means of ten plants.

Fig. 3. Acidity and pH in fruits of *Cereus peruvianus* during color change. Values are means of 4-12 fruits from 15 plants, growing at Besor. Values followed by different letters were significantly different ($p \geq 0.001$)

Fig. 4. TSS and reducing sugars in fruits of *Cereus peruvianus* during color change. Values are means of 4-12 fruits from 15 plants, growing at Besor. Values followed by different letters were significantly different ($p \geq 0.01$)

Fig. 5. Changes in length and diameter of *Cereus peruvianus* fruits. Values are separate readings of 10 fruits of one individual plant growing in Beer-Sheva.

Table 1. Plant biomass, plant size and flowering of 3.5-year-old *Cereus peruvianus* plants at four sites in the Negev desert of Israel.[z]

Site	No. of plants	Biomass (kg dw)	Total stem length (m)	No. of flowers per plant
Besor (Western Negev)	15	7.2	15.8±1[y]	75±5
Ramat Negev (Negev Heights)	12	4.5	8.5±0.6	2
Qetura (Arava Valley)	10	3.2	8.1±0.2	68±7
Neot Hakikar (Arava Valley)	12	1.0	3.9±0.6	1

[z] Segments, 30-40 cm in length, were sampled from three plants at each site. Plants were oven dried at 70°C, and the total stem length used to calculate plant dry weight.

[y] ±SE

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Table 2. Effect of pollination on fruit set, seed development and selected parameters of fruit quality for four individual plants.[z]

Site	Seedling no.	Pollination[y] treatment	fruit set (%)	No. seeds/ fruit	Seeds/g pulp tissue	Fruit weight	Pulp/Peel ratio
Besor	1	cross	100	3222 a	13 a	401 a	1.56 a
		self	0	~	~	~	~
		open	20	399 b	6 b	124 b	1.13 b
Besor	5	cross	100	1993 a	13 a	194 a	3.00 a
		self	0	~	~	~	~
		open	37.5	384 b	7 b	78 b	1.93 b
Beer-Sheva	7	cross	100	1289	16	149	1.79
		self	0	~	~	~	~
		open	0	~	~	~	~
Beer-Sheva	16	cross	100	2879	17	239	2.31
		self	0	~	~	~	~
		open	0	~	~	~	~

z Values are means of 7-10 fruits. Values followed by different letters for each seedling were significantly different at $p \geq 0.05$.

y Flower buds or the stigmata were covered with cloth bags before anthesis to prevent cross- or self-pollination. Flowers were then hand-cross- or self-pollinated at anthesis. Flowers remained unbagged for open-pollination.

Table 3. Variation in thorn development, flowering period and fruit appearance for five exemplary individual plants growing in Beer-Sheva.

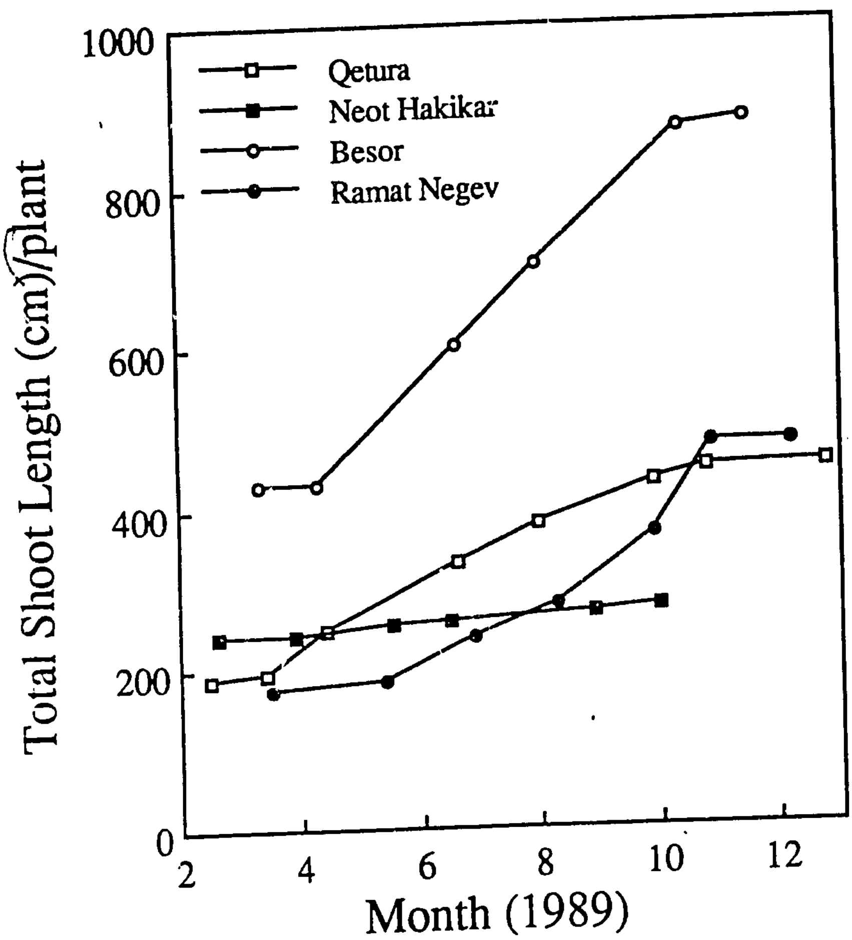
Seedling no.	Thorn development	First flowering period (1991)	Fruit appearance[z]		Comments
			Peel color	Fruit length (cm)	
7	Thorny	May 24-June 12	Orange	8.2	Fruits burst on ripening Ripe fruits are mucilagenous
8	Thornless	June 28-July 1	Dark-red	7.1	Fruits burst upon ripening Ripe fruits are mucilagenous
10	Thorny	June 14-June 29	Violet-red	7.5	Fruits do not burst on ripening Fruits are juicy and aromatic
16	Thorny	May 20-June 21	Violet-red	10.3	Fruits do not burst on ripening Fruits are juicy and aromatic

[z] Descriptions of the fruits refer to fruits at full color change.

Table 4. Fruit quality parameters for five exemplary individual plants growing at Besor.[z]

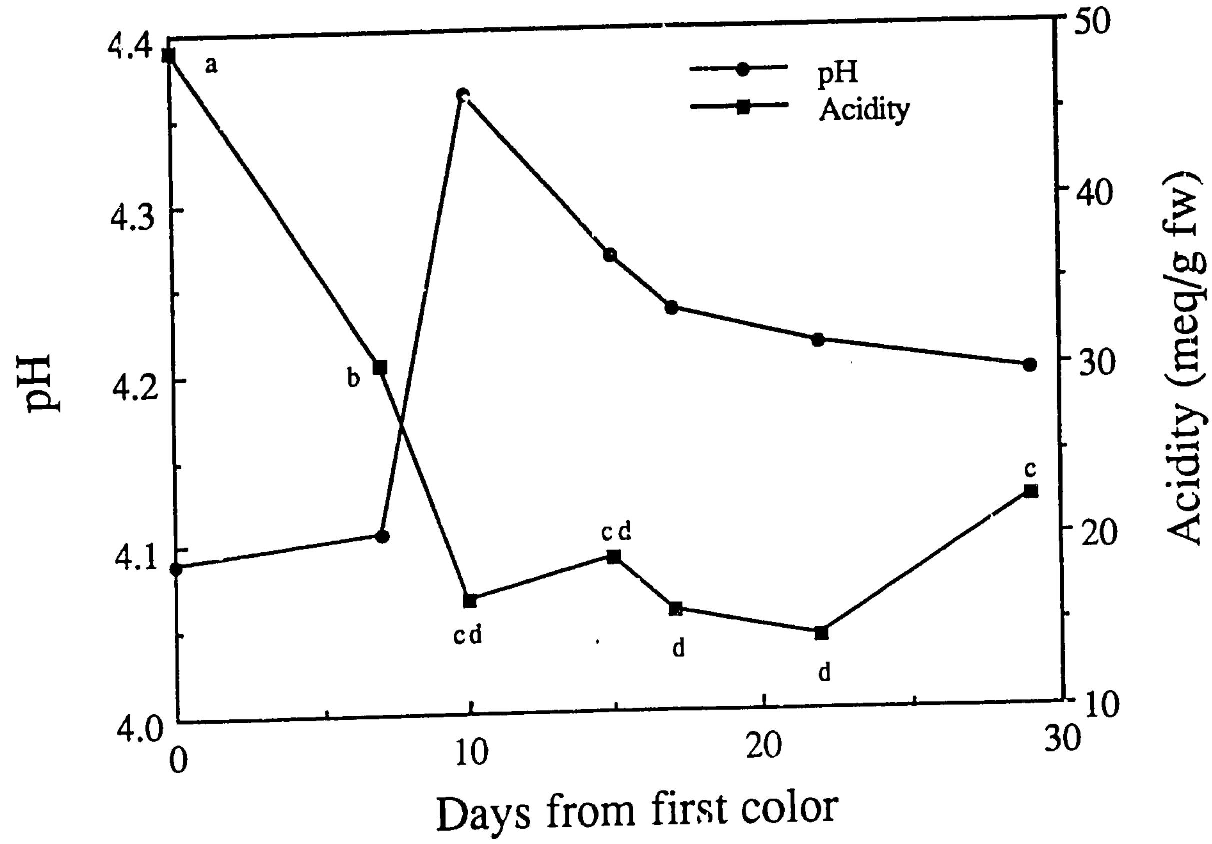
Seedling no.	Pulp (% dry weight)	Peel (% dry weight)	Pulp		
			TSS (%)	Reducing sugars in (mg/g fw)	Titratable acidity in (meq/g fw)
1	14.60±0.74	6.40±0.20	9.3±0.15	101±3	61.7±5.6
5	12.82±0.54	10.90±1.27	8.20±0.64	83±9	17.4±1.9
7	13.68±0.87	13.73±1.14	11.65±0.54	91±10	26.8±1.6
12	15.42±0.86	6.64±0.83	9.31±0.31	106±4	65.4±3.5
16	15.34±1.13	12.39±1.09	10.80±0.23	107±8	17.6±1.6

[z] Values are means of 7-10 fruits ± SE.



Qetura
Neot Hakikar
Besor
Ramat Negev
Total Shoot Length (cm)/plant
1000
800
600
400
200
0
2
4
6
8
10
12
Month (1989)

Fig 2.



4.4
4.3
4.2
4.1
4.0
pH
50
40
30
20
10
Acidity (meq/g fw)
pH
Acidity
a
b
cd
cd
d
d
c
0
10
20
30
Days from first color

Fig3.

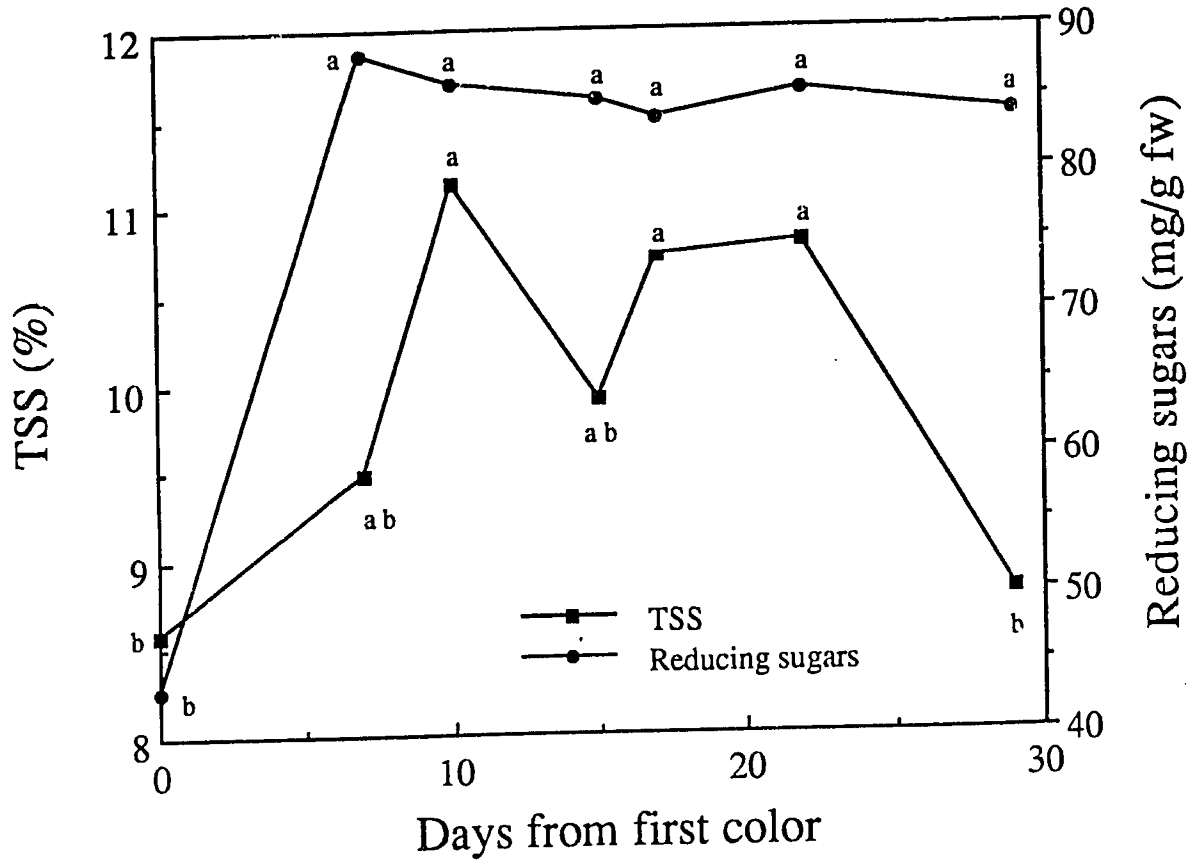

TSS (%)
Reducing sugars (mg/g fw)
Days from first color
TSS
Reducing sugars
12
11
10
9
8
90
80
70
60
50
40
0
10
20
30
a
a
a
a
a
a
a
a
a
a
ab
ab
b
b
b

Fig 4.

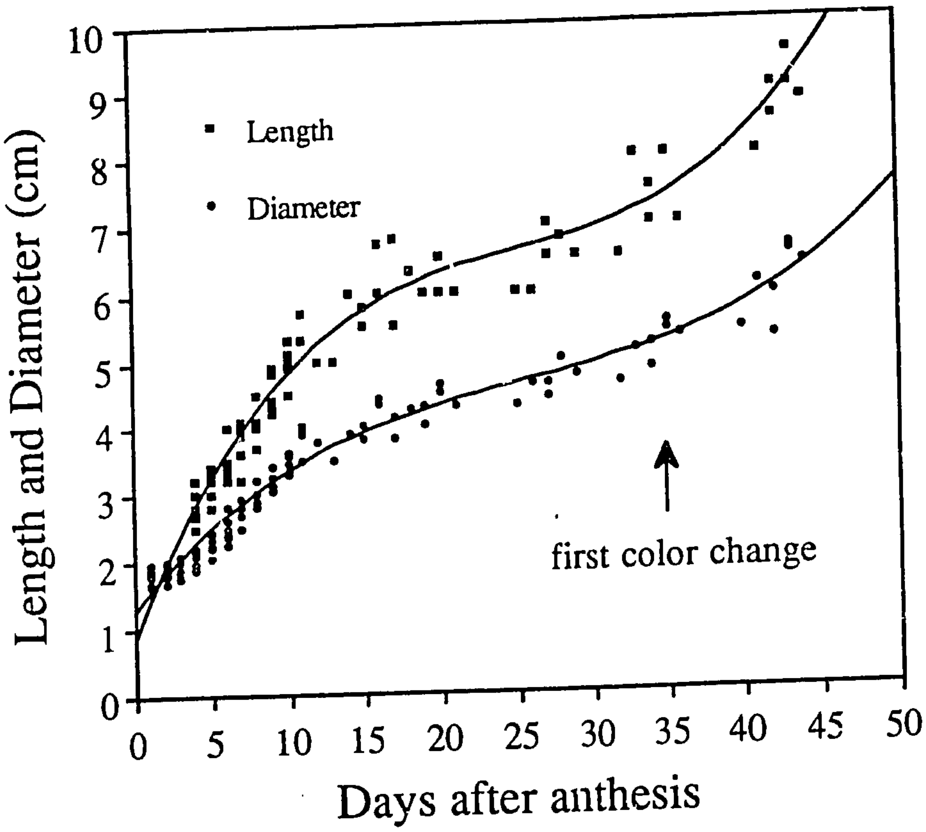

Length
Diameter
first color change
Length and Diameter (cm)
Days after anthesis
0
1
2
3
4
5
6
7
8
9
10
0
5
10
15
20
25
30
35
40
45
50

Fig 5.