Evaluation of Fifteen Genotypes of *Opuntia* spp for Prickly Pear in Jalpa, Zacatecas, Mexico

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INTRODUCTION

In Mexico, the prickly pear cactus fruit (also called tuna or cactus pear) is cultivated in about 50,000 ha of commercial plantations; 10,000 ha of cactus are cultivated for vegetable production (Flores, 1992a). Most of the prickly pear fruit that reaches the largest cities in Mexico or is exported is produced during one period of 3 to 5 months, which causes serious commercialization problems. This phenomenon is not characteristic of only the prickly pear fruit. For example, the Persia lemon has the same commercialization problem (Contreras et al., 1992; Espinoza and Almaguer, 1992). Beside the seasonal production of the prickly pear fruit, the market supply is determined by the distance of the commercialization center among the different states of the Mexican Republic.

Puebla state has very small areas where the season begins very well in May or before reaching the highest price in the market. After Puebla, production from Mexico state and the closest areas around begins, and, finally, production of the prickly pear comes from Zacatecas, Jalisco, Guanajuato, San Luis Potosi, and Aguascalientes states. Production from the last five states causes the price in the market to go down drastically.

In analyzing prickly pear demand, Flores (1992b) assumed that demand is at a constant level throughout the year and he supported this idea because of the importation of prickly pear from Chile during the cold season. The market expertise suggests two alternatives to avoid importing prickly pear:

- Sell more during the period of maximum supply.
- Increase the fruit production out of the normal season period.

The researchers have presented several proposals for the first suggestion; however, there is not enough research in Mexico to support the second proposal.

Nevertheless, the state of California (U.S.A.) developed different cultivar practices and manipulated the harvest, producing fruits during the months in which the market had the lowest supply. The characteristics observed in California can be found in several valleys close to the seashore of the state of Baja California, Mexico, in several regions of the state of Mexico, and in the Jalpa Canyon in the state of Zacatecas.

In the Jalpa Canyon it is possible to produce fruit during the months that are outside of the normal season. This result requires irrigation, avoidance of low temperatures, and good cultivation practices.

It is important to inform farmers from Jalpa and Juchipila, who are cultivating small areas of prickly pear fruit, that prickly pear fruit is a very good alternative to the guava tree. In the last two decades, the guava tree was considered to be the more productive species, but recently serious commercialization problems have arisen.

Because of the commercialization problems and the direct request from the farmers, the Society of Rural Farmers (called Vergel del Nopal) from the municipality of Jalpa, Zacatecas, decided to dessiminate knowledge and technology in order to give strong support to production of the prickly pear fruit in the Jalpa municipality.

LITERATURE REVIEW

In the Mexican Republic, the prickly pear grows on 30,000,000 hectares distributed among states of the Mexican Territory (CETEMEX, 1981).

Historically, prickly pear has been grown in México in three production systems: wild prickly pear, prickly pear in small orchards, and commercial production of the prickly pear tree.

Mexico ranks first in cultivated area, production, and consumption of prickly pear cactus and the vegetable edible form. Mondragón (1992), Flores and Gallegos (1993), and Pimienta (1994) affirm that the main cultivated area is located within the semiarid region of the national territory. Table 1 shows that the surface area in cultivated prickly pear has increased 400 percent from 1977 to 1992.

Opuntia spp Climatic Requirements

For optimum plant development it is necessary to have sites with an annual mean temperature between 15°C and 16°C; 36°C and 6°C as annual maximum and minimum temperature, respectively; and from 116 to 1800 mm of annual precipitation (Promotora del Maguey y del Nopal, 1987). In regions with more than 1800 mm of annual precipitation, plants of *Opuntia* spp. can grow, but with increasing problems of fungal and bacterial diseases.

Beside the climatic elements that influence the development of *Opuntia* spp plants, factors that determine the thermic regimen, such as latitude and altitude, have to be considered. Borrego (1986) suggests that the range from 1,000 to 2,500 meters above sea level is the best altitude for establishing commercial orchards in Mexico.

MATERIALS AND METHODS

General Description of the Experimental Site
The experimental site is located in a common area limited by 21° 13′ N latitude and 22° 10′ N latitude and 102° 48′ W longitude and 102° 12′ W longitude. The area is integrated by the Tabasco, Huanusco, Jalpa, Apozol, Juchipila, and Moyahua de Estrada municipalities.

However, there are some agricultural valleys where the guava is the major crop. The climate of the valleys is semiarid, characterized by annual mean temperature from 18°C to 22°C, and 600 mm to 700 mm of precipitation annually. A summary of climatic elements is shown in Table 2. There were non-normal years during the experimental period considered here. The years from 1993 to 1995 were drier and warmer than normal.

Table 1. Cultivated area for prickly pear fruit production in Mexico and its behavior

	Area (ha) by Year			
State	**1976[1]**	**1988[2]**	**1992[3]**	**1993[4]**
Zacatecas	3200	13000	16000	13901
San Luis Potosí	2600	9000	9000	3918
Aguascalientes	150	6100	6500	1888
Guanajuato	1000	6080	6500	3059
México	500	5968	7000	8622
Nuevo león	100	5359	6000	
Hidalgo	2000	4000	4000	7000
Durango	400	2068	2000	2000
Coahuila	150	1161	1161	1000
Tamaulipas		1000	2000	
Puebla	550	1000	1000	3000
Querétaro		2000	2000	2000
Jalisco	150	1000	2700	2008
Oaxaca		367	367	620
Sinaloa		268	268	270
Guerrero		300	300	300
Tlaxcala	200	130	52	52
Veracruz				80
Baja California				60
Total	12000	57857	66978	49854

[1]Banco de Comercio Exterior (1977). [2]Pimienta (1990). [3]Flores (1992b).
[4]Flores and Gallegos (1993).

Table 2. Summary of climatic data in Jalpa Canyon during 1993, 1994, and 1995

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)												
1993	16.9	0	0	0	1.2	77.2	180	74.0	111	20.4	0	0
1994	7.0	0	0	0	5.4	138	101	232	122	27	1.8	0
1995	0	3.9	0	0	3.7							
Evaporation (mm)												
1993	70.5	144	205	226	254	232	151	155	119	148	123	115
1994	126	145	213	247	259	188	181	142	126	113	110	113
1995	75.8	70.6	157	237	267							
Mean Temperature (°C)												
1993	17.5	17.4	18.9	21.8	24.8	26.8	23.4	24.0	21.7	21.6	19.0	17.2
1994	16.2	18.9	20.8	22.5	26.5	25.3	23.5	23.3	21.5	21.5	19.5	17.8
1995	16.0											

Germplasm

The 15 genotypes used and the sites where they were collected are listed in Table 3. Mother cladodes were treated with agrochemicals before planting to avoid possible fungal and bacterial diseases and insect damage.

Table 3. *Opuntia* spp. genotypes and sites of origin

No.	Genotype	Site of Origin
1	Ruby Reyna	Banco germoplasma CRUCEN-UACh, Zac., Méx.
2	Torrioja	Rancho Las Papas, Ojuelos, Jal., Méx.
3	Blanco sin Espinas	La Nopalera, Chapingo, Méx.
4	Apastillada	La Nopalera, Chapingo, Méx.
5	C-5	Colegio de Postgraduados, Méx.
6	25-89	La Nopalera, Chapingo, Méx.
7	L-12	Colegio de Postgraduados, Méx.
8	Burrona	Victoria, Pinos, Zac., Méx.
9	Cristalina	Victoria, Pinos, Zac., Méx.
10	Rojo Vigor	La Nopalera, Chapingo, Méx.
11	C-17	Colegio de Postgraduados, Méx.
12	Amarilla sin Espinas	La Nopalera, Chapingo, Méx.
13	Roja	La Nopalera, Chapingo, Méx.
14	Amarilla Montesa	La Montesa, V. García, Zac., Méx.
15	Rojo Pelón	Matehuala, S. L. P., Méx.

Experimental Design

In the field, the 15 genotypes were distributed in a randomized block design with five replications, using one plant per plot as an experimental unit.

Soil Preparation and General Management

Land preparation consisted of common and acceptable practices of the area. Date of planting was July 29, 1993. During the experimental period, practices to control insects were implemented. Water was applied monthly. A dose of 50 g per plant was applied as fertilizer; such quantity was conformed by a ratio of 2:1 of ammonium sulfate and single superphosphate. A sample of cow manure was applied also.

Registered Data

When plant growth for this experiment was registered (October, 1994) the plants were 14 months old. We used some plant attributes as variables for comparisons among 15 genotypes as indexes of potential of adaptation to Jalpa Canyon. The first attribute was length (considered as acumulated length (cm) of new cladodes), but not as changes in plant height. The second attribute was number of levels; each level was integrated by all the new cladodes produced during the same growth season.

During 1995, there were 11 genotypes with prickly pear production; therefore, a comparison among those genotypes is considered here on a fruit-characteristic basis. Such a comparison is important because fruit production is expected only for plants three years old, and in this case, is on plants two years old, which is due to the environmental factors (climatic factors principally).

Ten mature fruits were harvested, based on their color change, in July and August, 1995, from each experimental unit associated with 11 genotypes. Each prickly pear fruit was measured for total fresh weight (TW), peel weight (PW), edible mass (EM), polar length (PL), and equatorial length (EL). The percentage of sugar (soluble solids) was measured as °brix by using a portable refractometer.

RESULTS AND DISCUSSION

Plant Growth

Table 4 shows that genotypes have different responses in terms of plant growth. In this case, growth is considered to be an index of growth easier to measure than dry-weight changes per unit ground area (or per plant) because monospecific stands, knowledge of the ground area explored by the roots, or sacrifice the plants for dry-weight determinations are not needed (Nobel, 1988). Moreover, the genotypes were statistically different for levels of cladodes, log plant height and log number of cladodes per plant. It is important to point out that length and log number of cladodes are better variables than levels and log plant height to compare the *Opuntia* genotypes and as indexes of plant adaptation.

Table 4. Genotype mean square and its statistical significance from the analysis of variance for each growth variable

Variable	Mean Square	F Value	Pr > F
Length (cm)	981266.74	6.68	0.0001
Levels	0.65	2.26	0.016
Log Plant Height	0.19	4.36	0.0001
Log Number of Cladodes	1.45	6.05	0.0001

Table 5 shows the genotypes grouping as a function of variables under study. Three major groups were found. The first group comprises C-17, Apastillada, Roja, Blanca sin Espinas, Rojo Vigor, and Amarilla sin Espinas, which is the most productive group. Unfortunately, we do not have taxonomic classification of those genotypes; because of phenotypic characteristics, such genotypes could be *Opuntia ficus-indica* clones. There is evidence of high productivity in *O. ficus-indica* (García de Cortázar and Nobel, 1992). Clustered in the second group are Burrona, Ruby Reyna, Amarilla Montesa, Torrioja, 25-89, and Cristalina. All of the genotypes, except 25-89, composing the second group are from regional sites (central north part of Mexican territory). In the third group are L-12, C-5, and Rojo Pelón.

Table 5. Mean Tukey's tests (p=0.05) for 15 *Opuntia* genotypes

Genotype	Length (cm)		Levels		Log Plant Height		Log Number Cladodes	
Ruby Reyna	927	abcde	3.0	ab	4.64	ab	3.09	a
C-17	1680	a	3.8	a	4.87	a	3.70	a
Amarilla sin Espinas	1232	abcd	3.0	ab	4.66	ab	3.58	a
A. Montesa	877	abcde	3.0	ab	4.50	ab	3.22	a
Cristalina	707	bcde	3.0	ab	4.47	ab	3.04	a
Roja	1516	ab	3.2	ab	4.70	ab	3.81	a
Apastillada	1522	ab	3.4	ab	4.66	ab	3.81	a
Blanca sin Espinas	1370	abc	3.0	ab	4.59	ab	3.73	a
Rojo Vigor	1355	abc	2.8	ab	4.52	ab	3.66	a
Torrioja	833	abcde	2.8	ab	4.48	ab	3.23	a
Burrona	946	abcde	3.2	ab	4.48	ab	3.40	a
C-5	481	de	2.4	b	4.62	ab	2.77	ab
L-12	526	cde	3.0	ab	4.71	ab	2.79	ab
25-89	746	bcde	2.6	ab	4.38	bc	2.83	ab
Rojo Pelon	144	e	2.4	b				

Five groups were identified for length. The genotype showing highest growth was C-17; Rojo Pelón had the least growth.

Levels do not have a common use as index of plant growth. We are pointing out its use as an indicator of plant response into a non-native climate. In this case, C-17 was able to have four initiations of new cladodes and this phenomena indicates its great potential for adaptation. These results are very similar for the other genotypes, except C-5 and Rojo Pelón.

Because plant height and number of cladodes were not normally distributed, data were log transformed. Log plant height divided genotypes into two groups, but this effect is of little importance because of the variables in the rows of Table 4. Log number of cladodes clustered genotypes into two groups. However, by mixing the result with back-transformed data, it is possible to point out that Roja, Apastillada, Blanca sin Espinas, C-17, and Rojo Vigor produced more than 40 cladodes along three levels or strata within 14 months after planting the mother cladode.

Prickly Pear Characteristics

Pearson coefficients between prickly pear characteristics indicate that of the correlations between all the possible couples, >0.66 are significantly different from zero at p=0.001 (data not shown). All of the fruit characteristics regressed with other ones explained >66 percent of its variations, except sugar content. There was no correlation of any fruit characteristic with sugar content. This means a strong positive dependence between fruit characteristics; therefore, characterization of fresh fruit weight may be done easily by considering one or two characteristics when the major purpose is weight per pear. However, fruit sugar must be measured independently to obtain prickly pear fruit quality.

Remarkably, 11 genotypes seemed to be able to produce prickly pear fruit under Jalpa Canyon conditions. Table 6 shows genotypes have different responses in terms of the magnitude of fruit characteristics.

Table 6. Genotype mean square and its statistical significance from the analysis of variance for each prickly pear fruit characteristic

Characteristic	Mean Square	F Value	Pr > F
Total Fresh Weight (g)	1970.32	8.41	0.0001
Peel Weight (g)	502.13	9.94	0.0001
Edible Mass (g)	562.21	5.40	0.0001
Polar Length (cm)	3.61	13.07	0.0001
Equatorial Length (cm)	0.35	3.46	0.0021
Sugar Content (°brix)	12.29	8.25	0.0001

Data for prickly pear fruit characteristics for 11 genotypes are presented in Table 7. It is evident that Cristalina, Burrona, C-5, and Torrioja genotypes produced the heaviest fruits by considering total weight, peel weight and mass of the edible part. Moreover, the same genotypes have the longest and widest fruits expressed as polar length and equatorial length, respectively. Unfortunately for Cristalina, its sugar content is the least while C-17 is the maximum. In addition to C-17, the Roja, Blanca sin Espinas, and 25-80 genotypes have the highest sugar content. This is an advantage for Roja because of its attractive color for the consumer. It is very interesting that some genotypes with best percent sugar content, except Amarilla sin Espinas, were identified as the group with the best plant growth (Table 5). Particularly, Amarilla sin Espinas had small fruits.

Table 7. Mean Tukey's tests (p=0.05) for 11 *Opuntia* genotypes

Genotype	**TW**		**PW**		**EM**		**PL**		**EL**		**°brix**	
Cristalina	134.7	a	61.5	a	73.2	ab	9.7	a	5.7	a	12.5	d
Burrona	124.9	ab	46.7	ab	78.1	a	9.6	a	5.6	a	14.5	abcd
C-5	111.3	abc	35.5	bc	75.8	a	8.9	a	5.2	ab	14.5	abcd
Torrioja	95.8	bcd	36.7	bc	59.1	abc	9.0	a	5.4	a	12.9	cd
C-17	74.9	cd	25.8	c	49.1	cb	7.0	b	5.1	ab	17.3	a
25-89	72.9	cd	28.4	c	44.5	c	7.2	b	5.0	ab	16.7	ab
Roja	72.5	d	26.1	c	46.3	c	7.2	b	4.9	ab	16.9	ab
Blanca sin Espinas	69.6	d	23.3	c	46.3	c	6.9	b	5.1	ab	16.8	ab
Apastillada	68.6	d	25.6	c	43.1	c	7.0	b	5.0	ab	16.0	abc
Rojo Vigor	67.3	d	24.0	c	43.3	c	6.9	b	4.9	ab	16.1	abc
Amarilla sin Espinas	57.7	d	18.9	c	38.8	c	7.4	b	4.5	b	13.9	bcd

Means with the same letter are not significantly different. Minimum significant differences are 38.75 g for total fresh weight (TW), 17.99 g for peel weight (PW), 25.84 g for edible mass (EM), 1.33 cm for polar length (PL), 0.81 cm for equatorial length (EL), and 3.09 °brix for sugar content.

CONCLUSIONS

The C-17, Apastillada, Roja, Blanca sin Espinas, Rojo Vigor, and Amarilla sin Espinas genotypes of *Opuntia* showed the best initial plant growth under Jalpa Canyon conditions.
The Cristalina, Burrona, C-5, and Torrioja genotypes of *Opuntia* produced the largest and heaviest prickly pear fruits.

The C-17, Roja, Blanca sin Espinas, 25-89, Rojo Vigor, and Apastillada genotypes of *Opuntia* produced fruits with the best quality as measured by percent sugar content.

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