Prickly Pear Fruit Development and Quality in Relation to Gibberellic Acid Applications to Intact and Emasculated Flower Buds♦

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ABSTRACT

The fruit of the prickly pear cactus ("Tuna blanca", *Opuntia amyclaea*) has a sweet juicy pulp containing numerous hard-coated seeds, which limit the overall acceptability of the fruit. This study extended previous attempts to develop prickly pear fruits with reduced or smaller seed structures by applying gibberellic acid to floral buds. Solutions of gibberellic acid (GA_3) were applied by spraying (100 and 500 ppm) or by injection (10 and 100 ppm) to intact or emasculated floral buds at three stages of development, and twice subsequently to the developing fruits. The GA treatments did not significantly affect fruit development when applied to intact floral buds, but reduced seed size when applied by injection. None of the treatments to emasculated buds resulted in fruit size or pulp development equal to that of the control fruits from intact floral buds. Spray application of 100 ppm GA to emasculated buds was the only treatment in which there was no hard seed coat development, but fruit size and percentage pulp were low as well. The other GA treatments were more effective in inducing pulp development but also resulted in the development of hardened seed coats (abortive seeds). These results further illustrate the dual role of the funiculus in the development of the pulp and seed coats in prickly pear fruits. The soluble solids contents of fruit pulp from intact and emasculated GA-treated buds were similar, but titratable acidity values were lower in the fruits from emasculated buds. GA treatments also tended to result in reduced peel firmness.

INTRODUCTION

The fruit of the prickly pear cactus is a false berry composed of a juicy sweet pulp containing numerous hard-coated seeds. The fruit is formed from an inferior ovary of an hermaphroditic, protandrous flower whose period of differentiation has been estimated at between 35 to 45 days (Aguilar-Becerril, 1980; Pimiento-Barrios and Engleman, 1985) and 55 days (Alvarado y Sosa, 1978) for *O. amyclaea* and 70 days (Gil et al., 1977; Rivera et al., 1981) for *O. ficus-indica*. Time from anthesis to fruit maturity is about 110 days (Alvarado y Sosa, 1978; Lakshminarayana et al., 1979).

The prickly pear fruit resembles pomegranate fruit development in that the fleshy edible parts are derived from seed tissues and, therefore, increase in conjunction with seed development (Coombe, 1976; Maheshwari and Chopra, 1955). Some of the pulp of prickly pear fruits is enlarged papillary structures arising from the carpel walls, but most is from papillate coverings of the seed coats derived from the funiculi. The funiculus joins an ovule to the placenta, and in the genus *Opuntia*, it also envelopes each ovule to give the appearance of a third integument. During fruit development, the inner cell layers of the funiculus develop into fibers that combine with the lignified integuments to form the hard seed coat of viable and false seeds. The outer cell layers of the funiculus remain parenchymatous and develop the

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papillate structures that form a large part of the fruit pulp (Aguilar-Becerril, 1979; Benson, 1982; Maheshwari and Chopra, 1955; Pimienta-Barrios and Engleman, 1985). Abortive or empty seeds also contribute to pulp development (Pimienta-Barrios and Engleman, 1985; Pimienta-Barrios, 1991; Weiss et al., 1993). The ratio between abortive and normal seeds is a fruit quality attribute since the former may be small and softer (Barbera et al., 1992).

Seed size and number have always been important characteristics used in the selection of prickly pears for fruit production (Colunga Garcia-Marin, 1984). Seeds constituted 4% to 8% of the pulp by weight in 12 commonly cultivated Mexican fruits (Mondragon-Jacobo and Perez-Gonzalez, 1996) and 5% to 9% in 14 cultivated prickly pears (Pimienta-Barrios, 1990). The large number of hard-coated seeds is a major limitation to acceptability of prickly pear fruit in some markets (Inglese, et al., 1993). Seed weight or seed number are highly correlated with fruit size (Barbera et al., 1992; Pimienta-Barrios, 1990).

Attempts have been made to develop prickly pear fruit cultivars with increased pulp or reduced seed size and number (Aguilar-Becerril, 1980) or parthenocarpic fruits (Díaz and Gil, 1978; Gil et al., 1977; Gil and Espinoza, 1979). Parthenocarpy refers to the development of the ovary of a flower into a fruit without fertilization. Fruits that develop parthenocarpically are typically seedless. Although that is not possible in the prickly pear (Pimienta-Barrios, 1991), Weiss et al. (1993) reported vegetative parthenocarpy in an *O. ficus-indica* clone. Aguilar-Becerril (1980) tested the effect of the growth regulators 2,4-D, promalin, IBA, and GA3 on fruit weight, length, development of abortive seeds, and fruit ripening and composition. These treatments and combinations thereof were applied 2 days before anthesis to intact floral buds, and 4 times subsequently at intervals of 10 days. Promalin ($GA_{4/7}$ + benzyladenine) was the most effective in increasing fruit size, whereas GA3 was most effective in augmenting the proportion of abortive or false seeds and reducing total seed weight. Gil and colleagues (Díaz and Gil, 1978; Gil et al., 1977; Gil and Espinoza, 1979) successfully obtained parthenocarpic prickly pear fruits with applications of gibberellic acid to emasculated floral buds. They obtained normal-size fruits with a single application of 500 ppm or 3 applications of 100 ppm GA3 to emasculated floral buds. Although the fruits were parthenocarpic, the treatments also stimulated the development of the ovular integuments and the funiculus, resulting in abortive seeds with hard coats. They also found that GA3 treatments generally induced longer fruits and slightly reduced the soluble solids content of the pulp. Martínez-Rodríguez and Arreola-Avila (1990) reported a large increase in abortive seeds with a single application of 100 ppm GA at flower opening. GA treatments are widely used to stimulate development of parthenocarpic fruits in other plant species (Schwabe and Mills, 1981).

The present study further examines the use of gibberellic acid treatments to induce parthenocarpy and reduce seed size in prickly pear fruits of the commercially important species *O. amyclaea,* commonly called Tuna Blanca in Mexico. The objective was to obtain fruits with an acceptable proportion of pulp coincident with seeds coats of reduced size. This study was conducted in 1985 and was partially summarized as a professional thesis (Mejia-Nuñez, 1986).

MATERIALS AND METHODS

This study was conducted in the prickly pear orchard (*Opuntia amyclaea* Tenore, selections COPENA 1 and 15) of the School of Agriculture, University of Sonora, Hermosillo. The plants had been established for 4 years and were in their second year of production. They were healthy with no visible pest problems, had received annual fertilizations with manure, and were irrigated periodically from April to June. Flowering occurred during the first 2 weeks of April and fruits were harvested during the first 2 weeks of July. Prior to the experiments, flower bud growth was studied and the following three stages of development were subsequently used: Stage 1: buds were 1 cm to 1.5 cm diameter; stage 2: buds were 1.5 cm to 2.0 cm diameter and slightly rounded at the apex; and stage 3: buds were of similar diameter as stage 2, but more rounded at the apex due to internal development of floral parts (Figure 1). The 3 floral

stages averaged 9, 7, and 3 days from anthesis, respectively, and are near stage B described by Rivera et al. (1981).

Gibberellic acid (ProGibb®, Abbott Labs, 10% a.i. GA_3) treatments were applied in 15 replicates (15 cladodes on different plants, each with a minimum of 10 floral buds with some at each of the 3 stages of development). Treatments were applied to the buds by spraying with a household pesticide applicator to the drip point or by injecting 1 ml of the solution into the ovary using a syringe with a no. 22 needle. Treatments were applied between 5:30 a.m. and 8:30 a.m. at the floral bud stages indicated and twice subsequently at intervals of 21 days. The treatments were 1) control, 2) 100 ppm GA sprayed on intact buds, 3) 100 ppm GA injected into intact buds, 4) 100 ppm GA sprayed on emasculated buds, 5) 500 ppm GA sprayed on emasculated floral buds, 6) 10 ppm GA injected into emasculated buds, 7) 100 ppm GA injected into emasculated buds, and 8) emasculated buds with no treatment. Emasculation was carried out 24 hours before GA treatment by cutting out stamens and the upper half of the style with a small knife. Emasculation effectiveness was confirmed by lack of normal development of the untreated emasculated floral buds (see Table 1).

Fruit growth was followed by measuring the diameter of the floral bud and fruits every 15 days with a vernier caliper to the nearest mm. Fruits were harvested over a 2-week period when they had reached 50% to 75% external yellow color (typical commercial maturity). After weighing, the firmness of the thick peel without cuticle was determined with a penetrometer equipped with an 8-mm-diameter probe. The peel was removed and weighed, and the intact pulp was frozen at -10°C. The pulp was subsequently homogenized in a blender at medium speed (to separate but not damage the seeds and seed structures) and filtered though a fine mesh nylon cloth (all normal seeds and visible abortive seed structures were retained). An aliquot of 10 ml was diluted with an equivalent amount of water. Soluble solids were determined on a temperature compensated refractometer. The pH was determined on a potentiometer, and titratable acidity was determined by titration with 0.04 N NaOH to an endpoint of pH 8.1 and calculated as percent malic acid.

The seeds retained in the nylon cloth were washed, weighed, and dried at 30°C. They were separated into 4 weight classes by a laboratory seed air separator: Class A were ovular structures, weighing an average of 0.9 $\pm$0.3 mg each; Class B were partially hardened seed structures weighing 4.5 $\pm$0.7 mg each; Class C were small but normal-shaped seeds with hardened testa, weighing 8.9 $\pm$1.8 mg; and Class D were large well-formed seeds, weighing 16.7 $\pm$0.9 mg. The seeds were further characterized by flotation and tetrazolium tests. For the former, the percentage of seeds that floated on water after 1 min was calculated, and it was found that any seed structures in Classes A and B floated. In the latter test, seeds were cut on the concave side and left to stand in a 1% solution of tetrazolium chloride for 48 hours at 30°C, after which they were observed under a dissecting microscope for embryo staining (Delouche et al., 1971). Enzyme activity in viable embryos results in the conversion of the colorless tetrazolium to the insoluble red formazan (Vankus, 1997).

Two separate experiments were conducted on 2 *Opuntia* selections (COPENA 1 and COPENA 15). Results were similar and only data for COPENA 15 are presented here until otherwise specified. Data are averages of a minimum of 40 fruits per treatment per floral stage and were evaluated statistically by calculation of averages $\pm$ standard deviations or ANOVA and mean separation by Duncan's multiple-range test at the 5% level of significance.

RESULTS AND DISCUSSION

The Prickly pear flower buds used in this study were 9, 7, and 3 days from anthesis for stages 1, 2 and 3, respectively (Figure 1). Characteristics of flower buds at different stages of development for 2 *Opuntia* species have been described in Wang et al. (1996). The growth patterns of the floral buds and fruits are

shown in Figure 2 for intact and emasculated buds. All three bud stages were on each cladode and were measured at the same time. It is apparent that the larger, more advanced buds also resulted in larger fruits at harvest. The pattern of development was similar for emasculated GA-treated floral buds (Figure 2b), but final fruit diameter was much less than for fruits originating from intact floral buds (Figure 2a). Fruit growth was similar among all treatments during the first month (data not shown). Large differences in final size were observed between fruits originating from intact or emasculated, GA-treated buds (Figure 2).

Fruit set was defined as fruit, independent of size, that reached full maturity and showed color change typical of ripening. The percentage fruit set values for the COPENA 1 selection were generally lower than for fruit of COPENA 15 selection (Table 1). Fruit set from floral bud stage 1 tended to be lower than for the other 2 bud stages. The emasculated buds receiving no treatment had extremely low fruit set as expected, although emasculated buds at stage 3 of development resulted in about 13% set. Wang et al. (1996) considered that the flower buds should be emasculated about 4 days before bloom to avoid self-pollination. GA treatment of emasculated floral buds resulted in fruit set values similar to those of intact floral buds (Table 1).

Fruits were harvested when they had 50% to 75% external yellow color (~100 days), typical commercial maturity. Hernández and Grajeda (1979) reported that 4 applications of 60 ppm GA to normally developing fruits delayed the harvest date by up to two weeks. In the present study, the 3 applications of GA did not affect the harvest date of the fruit since fruits from all treatments ripened similarly over the same two-week period. Those developing from intact untreated floral stages 1, 2, and 3 weighed 92 g, 107 g, and 120 g, respectively, at harvest (Table 2). There were no large differences in percentage of pulp (Table 2) or percentage of seeds (Table 3) among fruits arising from the 3 stages of intact floral buds. These results for the untreated fruits suggest that the first buds to differentiate and develop on each cladode will result in larger fruits, but that the proportion of fruit parts remains relatively constant.

Gibberellic acid treatments applied to intact buds did not significantly affect fruit weight at harvest (Table 2). Gil et al. (1977) and Hernández and Grajeda (1979) both reported increased fruit weight with GA treatment of intact buds, but Aguilar-Becerril (1980) did not find a significant increase. GA treatments to intact buds did result, however, in a small decrease in the percentage of edible pulp and this was most evident with applications to less developed floral buds (Table 2). In the study by Hernández and Grajeda (1979) GA treatments did not modify the percentage of edible pulp.

All GA treatments applied to emasculated floral buds resulted in fruits significantly smaller than those from intact buds (Figure 3, Table 2). Again, those originating from stage 3 floral buds were the largest at harvest (Table 2). The 100-ppm treatment applied by injection resulted in much larger fruits than the same treatment applied by spraying. Even the 10-ppm injected treatment resulted in significantly larger fruits than the 100-ppm spray (Table 2). Slightly larger fruits were obtained from the 500-ppm treatment compared to the 100-ppm spray treatment, especially at the early bud stages (Table 2).

For any given floral bud stage, the treatments applied by injection resulted in a greater percentage of edible pulp (Table 2). Díaz and Gil (1978) also reported that injections were more effective than aspersions of GA. The edible portion in GA-treated fruits from emasculated floral buds did not equal that of fruits derived from intact buds. The percentage of edible pulp was generally greater in GA-treated fruits derived from the more developed floral buds (Table 2).

In untreated and GA-treated (spray) fruits developing from intact floral buds, the number and weight of seeds as a percentage of edible pulp did not vary in relation to initial floral bud stage (Table 3). However, GA applied by injection to intact buds significantly reduced the weight proportion but not the number of seeds. The number of seed structures was significantly less in fruits developed from emasculated and

injected floral buds (Table 3). GA treatments to emasculated floral buds also reduced the weight percentage of seed structures in some cases. In other cases, such as 100 ppm GA injected into stage 1 buds, the weight of the seed structures increased over that of untreated fruits.

Seeds from 60 fruits from each of the treatments were separated by a seed blower into 4 classes (Figure 4, Table 4). More than 80% of the seeds of untreated and 100-ppm sprayed intact buds were fully formed and found in Class D (Table 3), whereas for the 100-ppm treatment applied by injection, 60% or less, depending on the floral bud stage, were apparently fully formed. In the latter case, there was a corresponding increase in the percentage of seeds in Class C, which are smaller in size, and presumably have a greater number of incomplete embryos, and embryos which do not stain with tetrazolium (Table 5). The distinctions between Class C and D seeds are based on seed separated from fruits developed from intact floral buds and may not apply for other treatments. All four GA treatments to emasculated floral buds decreased the percentage of well-formed seeds (Classes C and D) (Figure 3, Table 4). However, the 100-ppm spray was the only treatment that caused a substantial increase in the percentage of small seed structures (Class A). Increasing the GA concentration to 500 ppm resulted in a shift to better-formed seed structures. These results extend those of both Gil and Espinoza (1979) and Aguilar-Becerril (1980) by providing additional criteria with which to classify the seeds and seed structures resulting from different GA treatments.

Although parthenocarpic fruits of near normal size were developed with the 100-ppm injected treatment, most of the abortive seeds were large with hard coats (Classes C and D). Therefore, this cannot be considered an effective commercial treatment.

In an analysis of 22 types of prickly pear fruits, Colunga Garcia-Marin (1984) reported a high correlation (R^2=0.75) between fruit weight and number of seeds for uncultivated types, but a low correlation (R^2=0.42) for fruits from cultivated types. In the present study of the COPENA 15 selection of the cultivated *O. amyclaea*, regression analysis showed that, independent of treatment, there was a high positive linear relationship between fruit weight and number of seeds ($y = 27.3 + 0.34x$, $R^2 = 0.82$, $n = 680$), fruit weight and seed weight ($y = 54.3 + 0.016x$, $R^2 = 0.79$, $n = 680$), % edible pulp and number of seeds ($y = 16.8 + 0.16x$, $R^2 = 0.79$, $n = 680$), and percent edible pulp and seed weight ($y = 28.2 + 0.0077x$, $R^2 = 0.85$, $n = 680$). Barbera et al. (1992) also show consistently high correlations between fruit size and seed weight or number, as do the breeding results from Wang et al. (1996). These results are consistent with anatomical studies that show the dual developmental role of the funiculus in forming a large portion of fruit pulp and part of the seed coat (Maheshwari and Chopra, 1955; Pimienta-Barrios and Engleman, 1985).

Because the funiculus develops into both the mucilaginous papillary covering of the seed which forms a substantial part of the fruit pulp and the hardened exterior coat of the seed, another approach to achieving parthenocarpic and well-developed fruits may be to modify the seed-coat hardening rather than reducing seed size. Part of the hardening phenomenon is the deposition of tannin granules and the thickening of the outer integument of the seed coat to which the funiculus adheres and reinforces (Maheshwari and Chopra, 1955). It would be desirable to manipulate the development of the funiculus so as to contribute more to the large parenchyma cells of the pulp and less to the seed coats.

The identification of desirable seed characteristics (small size, small in number) is widely recognized as an important objective in selection and breeding programs for *Opuntia* (Inglese et al., 1993; Mondragon-Jacobo and Perez-Gonzalez, 1996; Pimienta, 1990; Weiss et al., 1993). In addition, a high percentage of abortive seeds are considered desirable because they are presumably smaller and softer than normal seeds (Mondragon-Jacobo and Perez-Gonzalez, 1996). It is also known that different species of *Opuntia* have different external seed characteristics. For example, seeds of *O. humifusa* have a corky margin, whereas those of *O. macrorhiza* and other species have hard margins (Benson, 1982).

It would appear that further experimentation with doses and methods of GA application is merited with the objective of obtaining sufficient fruit pulp development with some reduction in seed size or hardness. The 100-ppm treatment sprayed on emasculated floral buds resulted in small amounts of pulp but no hardened seed coats, whereas 100 ppm injected into emasculated floral buds resulted in good pulp development, coincident with hard seed-coat development, but smaller sized seeds. A treatment resulting in an intermediate condition could be of obvious practical interest. With that objective in mind, Quintero and Báez (1987) tested GA and auxin sprayed on stage 3 emasculated floral buds in the range of 50 to 200 ppm. They were, however, unable to induce pulp development to a greater extent than that reported in the present study.

There were some differences in pulp composition of prickly pear fruit (soluble solids, titratable acidity) and peel firmness in relation to the GA applications. Peel firmness (without cuticle) of harvested fruits was decreased by GA applications to both intact and emasculated floral buds (Table 6). Soluble solids were reduced slightly but not significantly by the GA treatments (Table 6), and titratable acidity in fruits from emasculated floral buds tended to be lower than that of untreated or treated fruits developing from intact buds (Table 5). The results for soluble solids are similar to those reported previously for parthenocarpic prickly pear fruits (Díaz and Gil, 1978). Decreased firmness and acidity have been found with the application of GA to other fruits (Bangerth, 1983).

CONCLUSIONS

It is possible to develop parthenocarpic fruits in the prickly pear cactus, but they are very much reduced in size and pulp development. Because a large portion of the fruit pulp is derived from the funiculus, it is not possible to develop good quality and adequately sized fruits without the coincident development of hardened seed coats. This reduces the practical application of "successful" parthenocarpic fruit development in the prickly pear because the hard seed coats limit fruit acceptability in many markets. Further work could be done, however, to maximize pulp development with partial seed coat development and reduced hardening in large fruited *Opuntia* species. Fruits of acceptable size and portion of edible pulp might result and be of commercial interest.

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Table 1. Percent Fruit Set (Developed to Harvest Maturity) in Two Selections of Prickly Pear Cactus from Intact or Emasculated Buds Treated With Gibberellic Acid.
Data are based on 40 floral buds per stage per treatment for each selection.

Treatment	Flora Bud Stage	Percent Fruit Set		
		COPENA 1	COPENA 15	Treatment Average
Intact floral buds				
Untreated control	1	76.5	93.9	92 ± 8
	2	96.8	94.9	
	3	95.0	94.9	
100 ppm spray	1	81.0	93.1	92 ± 6
	2	94.3	96.9	
	3	90.6	93.5	
100 ppm inject	1	61.1	87.9	85 ± 13
	2	80.6	91.4	
	3	97.0	92.0	
Emasculated floral buds				
Untreated control	1	0	0	8 ± 7
	2	7.1	12.9	
	3	10.9	16.0	
100 ppm spray	1	60.7	85.0	84 ± 14
	2	77.5	96.3	
	3	87.1	100.0	
500 ppm spray	1	91.7	100.0	94 ± 5
	2	87.2	97.1	
	3	97.0	93.5	
10 ppm inject	1	88.2	85.2	88 ± 3
	2	93.5	86.5	
	3	90.9	87.1	
100 ppm inject	1	71.4	86.4	85 ± 11
	2	73.5	98.0	
	3	87.5	96.7	

Table 2. Effect of Gibberellic Acid Treatments on the Weight and Proportion of Pulp of Prickly Pear Fruits at Harvest.
Intact or emasculated floral buds were treated at 3 different stages of development. Data are based on 40 fruit per treatment. Data within a column followed by different letters are significantly different at $p \leq 0.05$.

Treatment	Floral Bud Stage 1		Floral Bud Stage 2		Floral Bud Stage 3	
	Weight (g)	Pulp (%)	Weight (g)	Pulp (%)	Weight (g)	Pulp (%)
Intact floral bud						
Untreated control	92a	59a	107a	58a	120a	60a
100 ppm spray	93a	52b	115a	54a	123a	57a
100 ppm injected	89ab	48b	104a	48b	126a	56a
Emasculated floral bud						
100 ppm spray	53d	32e	59c	29d	84c	35d
500 ppm spray	78bc	36de	81b	38c	92bc	40c
10 ppm injected	69c	38d	76b	40c	95bc	47b
100 ppm injected	75bc	43c	80b	48b	104b	50b

Table 3. Effect of Gibberellic Acid Treatments on the Number and Fresh Weight Percent of Seeds/Seed Structures in Pulp of Prickly Pear Fruits at Harvest.
Intact or emasculated floral buds were treated at 3 different stages of development. Data are based on 40 fruit per treatment. Data within a column followed by different letters are significantly different at $p \leq 0.05$.

Treatment	Floral Stage 1		Floral Stage 2		Floral Stage 3	
	Seed, number	Seed, % pulp wt.	Seed, number	Seed, % pulp wt.	Seed, number	Seed, % pulp wt.
Intact floral bud						
Untreated control	194a	6.6ab	229a	6.9a	306a	7.0a
100 ppm spray	189a	6.9a	227a	6.6ab	274a	6.7a
100 ppm injected	202a	5.7b	197a	5.1c	267a	5.3bc
Emasculated floral bud						
100 ppm spray	126c	5.2b	97c	5.3c	147c	4.7c
500 ppm spray	117c	5.2b	139b	4.8c	155c	4.2c
10 ppm injected	161b	6.6ab	166ab	6.8ab	222b	5.9ab
100 ppm injected	156b	7.6a	164ab	5.7bc	208b	5.2bc

Table 4. Effect of Gibberellic Acid Treatments on Seed/Seed Structure Size Distribution in Prickly Pear Fruits.
Data are averages ± standard deviation from 40 fruit per treatment.

Treatment	Percentage of Seeds/Seed Structures by Dry Weight			
	Class A[1]	Class B	Class C	Class D
Floral bud stage 1				
Intact untreated	1 ± 1	4 ± 4	9 ± 2	87 ± 2
100 ppm spray, intact	1 ± 1	4 ± 4	10 ± 1	84 ± 3
100 ppm injected, intact	1 ± 1	14 ± 4	43 ± 4	41 ± 6
100 ppm spray, emasculated	24 ± 8	14 ± 3	25 ± 6	36 ± 9
500 ppm spray, emasculated	5 ± 2	21 ± 4	45 ± 9	19 ± 8
10 ppm injected, emasculated	3 ± 2	21 ± 8	46 ± 12	29 ± 16
100 ppm injected, emasculated	1 ± 1	23 ± 4	45 ± 12	30 ± 17
Floral bud stage 2				
Intact untreated	1 ± 1	3 ± 2	8 ± 3	88 ± 5
100 ppm spray, intact	1 ± 1	2 ± 1	6 ± 2	90 ± 3
100 ppm injected, intact	1 ± 1	9 ± 3	30 ± 1	60 ± 5
100 ppm spray, emasculated	33 ± 10	25 ± 4	26 ± 6	16 ± 8
500 ppm spray, emasculated	6 ± 3	16 ± 7	42 ± 9	36 ± 19
10 ppm injected, emasculated	3 ± 1	22 ± 10	42 ± 7	33 ± 12
100 ppm injected, emasculated	1 ± 1	10 ± 5	62 ± 10	27 ± 6
Floral bud stage 3				
Intact untreated	1 ± 1	3 ± 1	8 ± 1	89 ± 3
100 ppm spray, intact	1 ± 1	9 ± 7	9 ± 4	87 ± 4
100 ppm injected, intact	1 ± 1	9 ± 7	30 ± 3	61 ± 7
100 ppm spray, emasculated	10 ± 8	24 ± 6	48 ± 13	17 ± 3
500 ppm spray, emasculated	5 ± 2	16 ± 12	30 ± 6	48 ± 18
10 ppm injected, emasculated	3 ± 1	24 ± 7	48 ± 9	26 ± 2
100 ppm injected, emasculated	1 ± 1	11± 5	60 ± 6	28 ± 4

[1]Class A were ovular structures, weighing an average of 0.9 ± 0.3 mg each; Class B were partially hardened seed structures weighing 4.5 ± 0.7 mg each; Class C were small but normal shaped seeds with hardened testa, weighing 8.9 ± 1.8 mg; and Class D were large well-formed seeds, weighing 16.7 ± 0.9 mg. See Table 4 for other characteristics of Class C and D seeds.

Table 5. Differentiation of Seed Classes C and D by Tetrazolium Red Staining. Seeds were obtained from untreated fruits from intact floral buds. Data are based on 50 observations for each seed class. See table 3 for description of classes.

Seed Development	Percentage of Seeds	
	Class C	Class D
No embryo present	10	2
Embryo incomplete, no staining	16	2
Embryo incomplete, stained	24	34
Embryo complete, stained	50	62

Table 6. Effect of Gibberellic Acid Treatments on Peel Firmness, Soluble Solids, and Titratable Acid Contents of Prickly Pear Fruits.
GA treatments were applied to intact or emasculated floral buds at 3 stages of development. Data are based on 30 to 40 fruit per treatment. Data within a column followed by different letters are significantly different at $p \leq 0.05$.

Treatment	Floral Stage 1			Floral Stage 2			Floral Stage 3		
	Firmness (kg-force)	S.S. (%)	T.A. (%)	Firmness (kg-force)	S.S. (%)	T.A. (%)	Firmness (kg-force)	S.S. (%)	T.A. (%)
Intact bud									
Control	2.7a	12.2	.078ab	2.9a	12.5	.078a	2.7a	11.8	.082ab
100 ppm, spray	2.8a	11.0	.081a	2.7ab	11.3	.081a	2.5ab	11.4	.086ab
100 ppm, inject	2.4b	10.4	.078ab	2.4c	11.0	0.84a	2.2b	11.1	.093a
Emasculated bud									
100 ppm, spray	2.6ab	12.0	.058c	2.6bc	10.2	.060b	2.4b	11.1	.066c
500 ppm, spray	2.6ab	10.9	.066bc	2.7ab	10.8	.059b	2.3b	11.1	.066c
10 ppm, inject	2.6ab	10.1	.074ab	2.7ab	10.6	.072ab	2.3b	11.4	.072bc
100 ppm, inject	2.7a	11.2	.057c	2.5bc	10.6	.063b	2.4b	12.0	.077bc

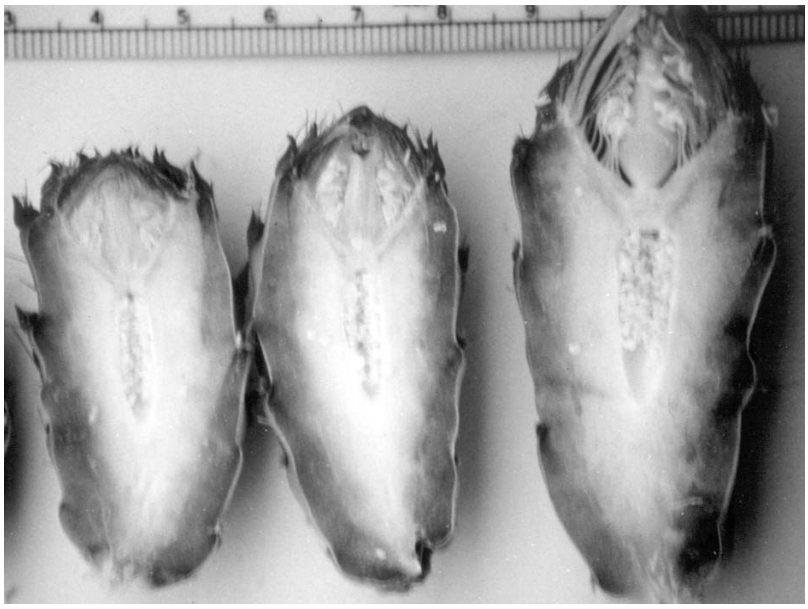

Figure 1. Vertical Cross Sections of *Opuntia* Floral Buds Stages 1, 2, and 3.

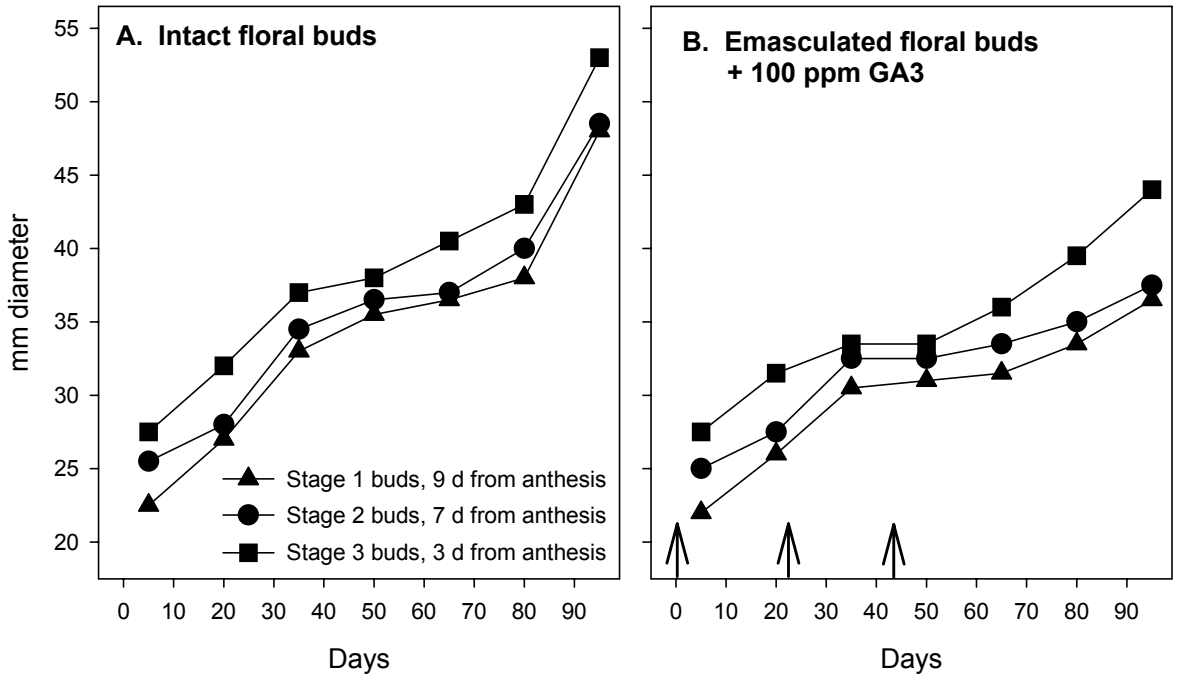

Figure 2. Growth of Prickly Pear Fruits Originating from Intact (A) or Emasculated (B) Floral Buds of 3 Stages of Development. The arrows indicate when emasculated buds were sprayed with 100 ppm GA3. Day 0 is taken as the day of the first GA treatment. Data are averages of 40 fruits per bud stage.

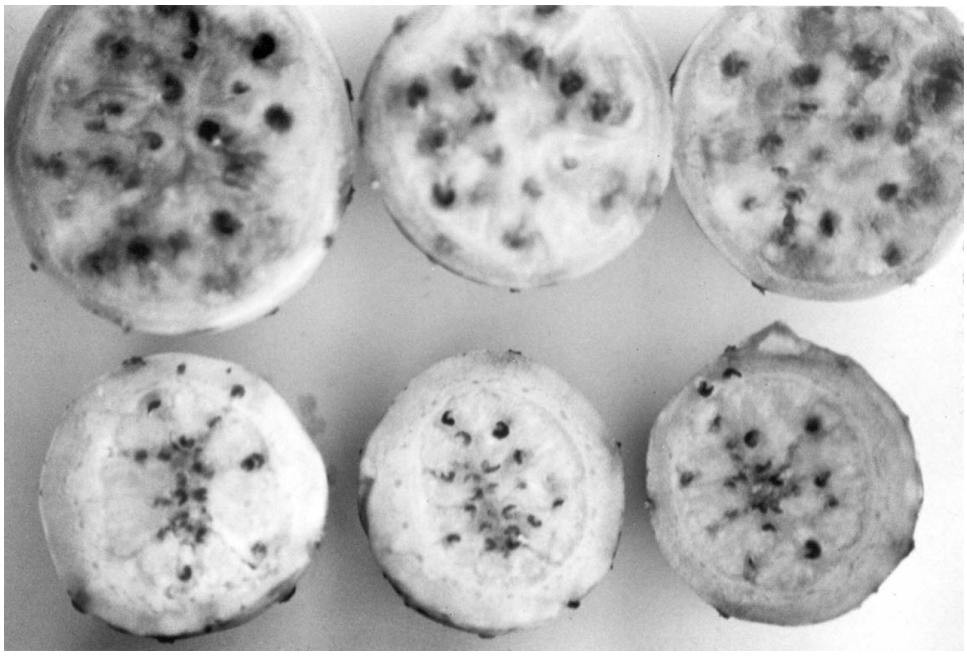

Figure 3. Representative Cross Sections of Ripe Prickly Pear Fruits Developed from Stage 2 Floral Buds That Were Intact (A) or Emasculated (B). The emasculated buds were sprayed 3 times with 100 ppm GA3.

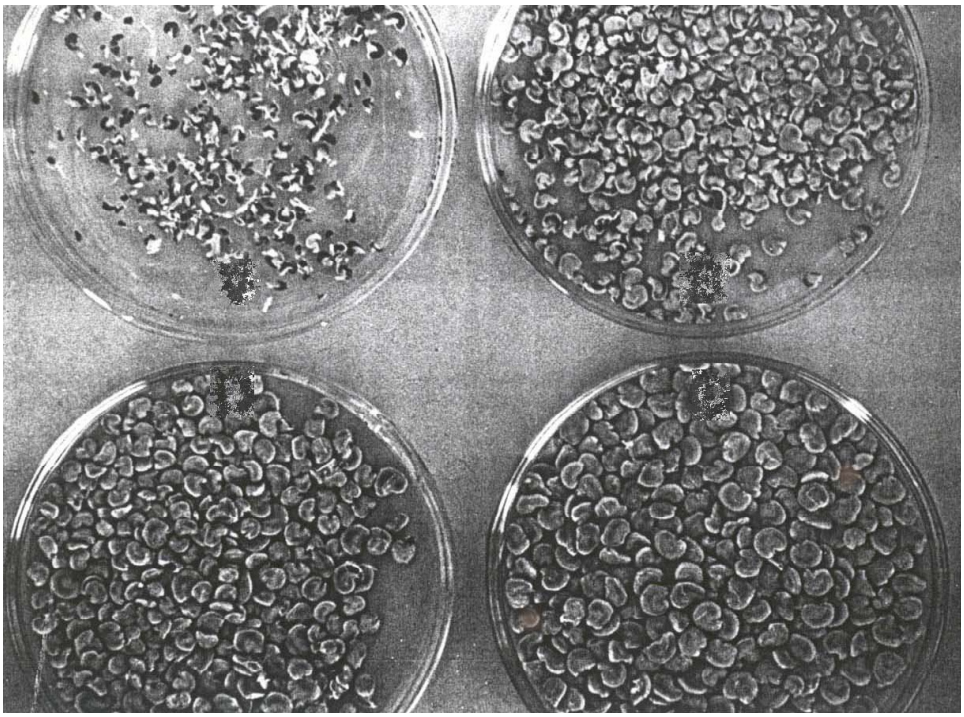

Figure 4. Ovular and Seed Classes Obtained from Prickly Pear Fruits on the Basis of Weight. Average weight per seed structure was 0.9, 4.5, 8.9, and 16.7 mg for Classes A, B, C, and D, respectively. Classes were determined by a seed air separator.