From Forest Nursery Notes, Winter 2013

28. Fruits, seeds and germination in five species of globose Cacteae (Cactaceae).
Loza-Cornejo, S., Terrazas, T., and Lopez-Mata, L. Interciencia 37(3):197-203. 2012.

FRUITS, SEEDS AND GERMINATION IN FIVE SPECIES OF GLOBOSE CACTEAE (CACTACEAE)

Sofía Loza-Cornejo, Teresa Terrazas and Lauro López-Mata

SUMMARY

*The morphological characteristics of fruits and seeds, and the germination responses of freshly matured seeds of five species of Cacteae (*Coryphantha bumamma*,* C. clavata*,* C. cornifera*,* Ferocactus histrix *and* Mammillaria uncinata*) were studied at room temperature under laboratory conditions. The aim of the study was to record the macro- and micro-morphology of fruits and seeds of these species and to investigate specific requirements for germination. Variance analysis detected significant differences (p<0.05) for several variables: number of seeds per fruit, weight, and fruit width. Larger fruits with more seeds are observed for* F. histrix*, whereas smaller fruits with less weight and fewer seeds are seen for* C. clavata*. Seed germination is a rapid process and usually starts on the third day. High percentages of germination (>80%) are observed on the sixth day in* F. histrix *and* M. uncinata*. It is concluded that some morphological characteristics of fruits and seeds can be used to support further systematic studies of Cactoideae genera and will contribute new knowledge for their potential use and conservation.*

Introduction

Cacti are a typical component of arid and semiarid environments in the Western Hemisphere, and the second largest plant family restricted to the New World (Anderson, 2001). Mexico is one of the main centers of diversification of the Cactaceae family (Goettsch and Hernández, 2006); around 560 species belonging to 50 genera are distributed in this country (Guzmán *et al*., 2003). Indeed, 73% of the genera and 78% of the species are estimated to be endemic to Mexico (Hernández and Godínez, 1994), and the tribes Cacteae and Echinocereae are almost exclusively distributed in Mexico (Anderson, 2001). Members of Cacteae range from globular or depressed to short columnar cacti, varying in size from dwarf (*Turbinicarpus* and some *Mammillaria* species) to giant (*Ferocactus* and *Echinocactus*) genera. Recently, significant progress has been made in understanding various aspects of the biology, phylogeny, and morpho-anatomy of Cactaceae (Nobel, 2002; Godínez-Álvarez *et al*., 2003; Terrazas and Arias, 2003; Hernández-Hernández *et al*., 2011). The current understanding of cacti, particularly of Cacteae members, is based on scarce analysis of the morphology, anatomy and composition of stems, fruits and seeds. Some species of this tribe produce edible fruits. For example, *Ferocactus histrix* produces a small and acidic fruit called ‘tuna of biznaga’, which is traded in regions of Hidalgo, Querétaro, and San Luis Potosí. The small red fruits of *Mammillaria* species are generally edible and consumed

KEYWORDS / *Coryphantha* / *Ferocactus* / Fruits / Germination / *Mammillaria* / Seeds /
Received: 10/28/2011. Modified: 02/17/2012. Accepted: 02/23/2012.

Sofía Loza-Cornejo. Ph.D. in Botany, Colegio de Postgraduados (COLPOS), México. Professor-Researcher, Centro Universitario de los Lagos, Mexico. e-mail: ofialo@culagos.udg.mx

Teresa Terrazas. Ph.D. in Biology, University of North Carolina at Chapel Hill, USA. Professor, UNAM, Mexico. Address: Instituto de Biología, Universidad Nacional Autónoma de México, Apartado Postal 70-233, México, D.F. 04510. México. e-mail: tterrazas@ibiologia.unam.mx

Lauro López-Mata. Ph.D. in Biology, University of North Carolina at Chapel Hill, USA. Professor, COLPOS, Montecillo, México.

FRUTOS, SEMILLAS Y GERMINACIÓN DE CINCO ESPECIES DE CACTEAE GLOBOSAS (CACTACEAE)
Sofía Loza-Cornejo, Teresa Terrazas y Lauro López-Mata

RESUMEN

*Las características morfológicas de los frutos y semillas, y la respuesta germinativa de semillas maduras y recién cosechadas de cinco especies de Cacteae (*Coryphantha bumamma*,* C. clavata*,* C. cornifera*,* Ferocactus histrix*, and* Mammillaria uncinata*) fueron estudiadas bajo condiciones de laboratorio y temperatura ambiente. Se registraron las características macro y micromorfológicas de los frutos y semillas de estas especies e investigaron los requerimientos específicos de germinación. El análisis de varianza mostró diferencias significativas (p<0.05) para algunas variables tales como número de semillas por fruto, peso y ancho de fruto. Los frutos más grandes y con mayor número de semillas son los de* F. histrix*, mientras que los frutos más pequeños y ligeros con el menor número de semillas son los de* C. clavata*. La germinación es un proceso rápido que inicia al tercer día. El porcentaje de germinación más alto (>80%) se observó al sexto día en* F. histrix *y* M. uncinata*. Se concluye que algunas características morfológicas de los frutos y las semillas pueden apoyar futuros estudios de sistemática en los géneros de Cactoideae y que el conocimiento generado contribuirá a su uso potencial y conservación.*

FRUTOS, SEMENTES E GERMINAÇÃO DE CINCO ESPÉCIES DE CACTEAE GLOBOSAS (CACTACEAE)
Sofía Loza-Cornejo, Teresa Terrazas e Lauro López-Mata

RESUMO

*As características morfológicas dos frutos e sementes, e a resposta germinativa de sementes maduras e recém colhidas de cinco espécies de Cacteae (*Coryphantha bumamma*,* C. clavata*,* C. cornifera*,* Ferocactus histrix*, e* Mammillaria uncinata*) foram estudadas sob condições de laboratório e temperatura ambiente. Registraram-se as características macro e micro morfológicas dos frutos e sementes destas espécies e investigaram-se os requerimentos específicos de germinação. A análise de variação mostrou diferenças significativas (p<0,05) para algumas variáveis, tais como número de sementes por fruto, peso e largura de fruta. As frutas maiores e com maior número de sementes são as de* F. histrix*, enquanto que os frutos menores e leves com o menor número de sementes são as de* C. clavata*. A germinação é um processo rápido que inicia ao terceiro dia. A porcentagem de germinação mais alta (>80%) se observou ao sexto dia em* F. histrix *e* M. uncinata*. Conclui-se que algumas características morfológicas dos frutos e as sementes podem apoiar futuros estudos de sistemática nos gêneros de Cactoideae e que o conhecimento gerado contribuirá a seu uso potencial e conservação.*

locally (Bravo-Hollis and Sánchez-Mejorada, 1991). However, most of these species are threatened because they have been removed from their natural populations or their habitat has been modified by changes in land usage (Hernández-Oria *et al*., 2007). For several genera of Cactaceae, studies on the morphological variability of fruits and seeds are scarce or have focused exclusively on well-known or economically important genera. For example, the composition, phytochemicals, and nutritious elements have been analyzed in *Opuntia* (Joubert, 1993; Domínguez-López, 1996; Sáenz, 1997; Sáenz *et al*., 1998; Butera *et al*., 2002; Duru and Turker, 2005; Stintzing *et al*., 2005), *Hylocereus* (Wybraniec and Mizrahi, 2002), and *Myrtillocactus* (Barrera *et al*., 1998). The study of seed morphology and germination processes is important for supporting systematic studies (Arias and Terrazas, 2004; Arroyo-Cosultchi *et al*., 2006) and may also help explain patterns of population dynamics of Cactaceae species under field conditions. Studies on seed germination in this plant family have focused on the relationship between germination and different attributes of the plant, such as the effect of seed mass and size on regeneration strategies, mechanisms of reproduction, abundance of rare species, and ecophysiological requirements (Rojas-Aréchiga *et al*., 1997; Rojas-Aréchiga and Vázquez-Yanes, 2000; Flores and Briones, 2001; Ayala-Cordero *et al*., 2004; Ramírez-Padilla and Valverde, 2005; Sánchez-Salas *et al*., 2006; Jiménez-Aguilar and Flores, 2010; Flores *et al*., 2011). In the present study, differences in fruit and seed macro- and micro-morphology, and the rates of germination processes were investigated in members of Cacteae that co-exist in the scrub of Jalisco, Mexico.

Materials and Methods

Mature and healthy fruits of *Coryphantha bumamma* (Ehrenb.) Britton et Rose, *C. clavata* (Scheidw.) Backeb, *C. cornifera* (DC.) Lem., *Ferocactus histrix* (DC.) G.E. Linds., and *Mammillaria uncinata* Zucc. ex Pfeiff. were collected from their native populations in Jalisco, Mexico. An analytical scale (Precisa XT 220 A) and a Mitutoyo digital caliper were used to record the size and weight of 30 fruits per species. The fruits were dissected in the laboratory and the seeds were then washed in tap water to eliminate pulp remains and mucilage. The seeds were immediately placed on absorbent paper until they dried and were stored in paper envelopes at room temperature. The number of seeds per fruit for each species was registered. Two hundred seeds per species were used to record quantitative morphological traits (weight, length, width) and qualitative morphological traits (shape, color, structure of the testa) using an analytical balance and a dissecting microscope Leica Zoom 2000 (Z45V) adapted to an image analyzer (Media Cybernetics, 2006). The roundness index (width/length ratio) was calculated from the length and width measurements. For scanning electron microscopy (SEM), three or four seeds per species were washed using ultrasound and 95% ethanol. Dry seeds were fixed to aluminum specimen holders with double-sided adhesive tape and coated with gold in a JEOL-JFC-1100 sputter coater. Morphological observations and micrographs were carried out with a JEOL-JSM-5310LV field-emission scan-

TABLE I
SEED NUMBER, MASS AND SIZE OF FRUITS OF FIVE GLOBOSE SPECIES OF CACTEAE

Species	Seeds/fruit (number)	Weight (g)	Length (cm)	Width (cm)
Coryphantha bumamma	84 ±35 b	2.0 ±0.56 c	2.7 ±0.5 b	0.6 ±0.40 a
Coryphantha clavata	56 ±8 a	0.5 ±0.18 a	1.4 ±0.3 a	0.6 ±0.15 a
Coryphantha cornifera	99 ±2 b	1.4 ±0.22 b	2.7 ±0.9 b	1.2 ±0.80 ab
Ferocactus histrix	2100 ±90 c	8.0 ±2.80 d	3.2 ±0.6 b	2.2 ±0.40 b
Mammillaria uncinata	70 ±13 b	0.5 ±0.20 a	1.5 ±0.3 a	0.5 ±0.01 a

Means ±SD. n= 30 fruits. Different letters in columns mean significant differences (p<0.05).

Figure 1 Fruits of globose Cacteae. a:. *Coryphantha cornifera*, b: *Ferocactus histrix*, c: *Mammillaria uncinata*.

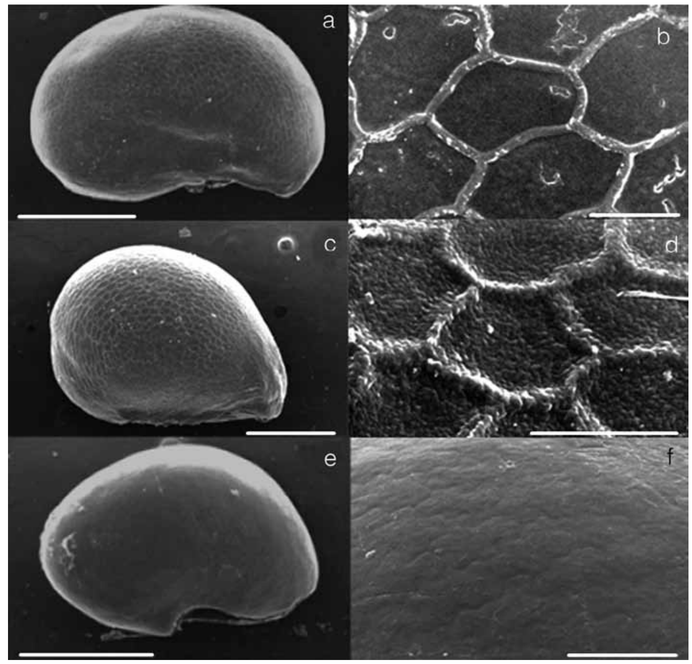

Figure 2 SEM of *Coryphantha* species seeds, whole seeds and seed surface view. a,b: *Coryphantha bumamma*; c,d: *C. clavata*; e,f: *C. cornifera*. Bar= 1mm in a; 500µm in c,e; 50µm in b, d and f.

ning electron microscope. The morphological descriptions of the seeds followed the terminology proposed by Barthlott and Hunt (2000).

The germination experiments were carried out under laboratory conditions using three replicates of 50 seeds per species. Seeds were disinfected by immersion in a solution of 10% commercial bleach during 5min (Vega-Villasante *et al.*, 1996), washed several times with distilled water, and sown on Whatman Nº 2 filter paper saturated with 10ml of distilled water in 9cm diameter sterile Petri dishes. The mean temperature in the laboratory was measured using a Datalogger Dickson SP125/175 Pro series thermometer. The mean temperature was 25°C ±2°C during the day, which has been mentioned to be optimal for seed germination of cacti (Nobel, 1988; Rojas-Aréchiga and Vázquez-Yanes, 2000), and 12°C ±3°C during the night. Germination was recorded at three day intervals for 30 days, when germination ceased. A seed was considered to be germinated when the radicle protruded. Interspecific differences in morphological characters of fruits and seeds were evaluated through variance analyses followed by Tukey's pair-wise means comparison analyses (p<0.05). Differences in the number of seeds per fruit were evaluated through covariance analyses. All analyses were performed with SAS software V 9.1.3 (SAS, 2000).

TABLE II
MASS, SIZE AND ROUNDNESS INDEX OF FEEDS OF FIVE GLOBOSE SPECIES OF CACTEAE

Species	Weight (mg)	Length (mm)	Width (mm)	Roundness index
Coryphantha bumamma	1.9 ±0.10 d	2.3 ±0.12 d	0.7 ±0.50 ab	0.3
Coryphantha clavata	1.8 ±0.28 d	1.4 ±0.12 c	0.9 ±0.13 b	0.6
Coryphantha cornifera	0.2 ±0.07 a	0.9 ±0.04 a	0.6 ±0.10 a	0.7
Ferocactus histrix	0.6 ±0.20 b	1.4 ±0.10 c	0.9 ±0.10 b	0.6
Mammillaria uncinata	1.1 ±0.15 c	1.0 ±0.02 b	0.7 ±0.14 a	0.7

Means ±SD. n= 200 seeds. Different letters in columns mean significant differences (p<0.05).

Results

Morphology of fruits and seeds

Fruits varied in shape, size and color (Table I, Figure 1). Most were juicy berries, varying in color from pale green with light red at the apex in *Coryphantha* species to red berries in *M. uncinata* and yellow-green in *F. histrix*. The fruits exhibited ovoid to claviform shapes, and only *F. histrix* showed thick walls and was dehiscent at the base. The smallest fruit (1.4cm length) with the lowest number of seeds (56 seeds/fruit) occurred in *C. clavata* and the largest fruit (3.2cm length) with the most seeds (>2000) was observed in *F. histrix*, the species that also had the heaviest fruits (8 ±3g, Table I). The seeds were oval to reniform, small to medium-sized (Table II, Figures 2-4), glossy or matte, and light-brown to brown. The anticlinal boundaries were inconspicuous or raised. The boundaries were straight except in *M. uncinata*, and the microrelief verrucose.

Interspecific comparison of fruit and seed morphology

The analysis of variance detected significant differences for the number of seeds per fruit (F= 17419, df= 4, p<0.0001), weight (F= 3295.67, df= 4, p<0.0001),

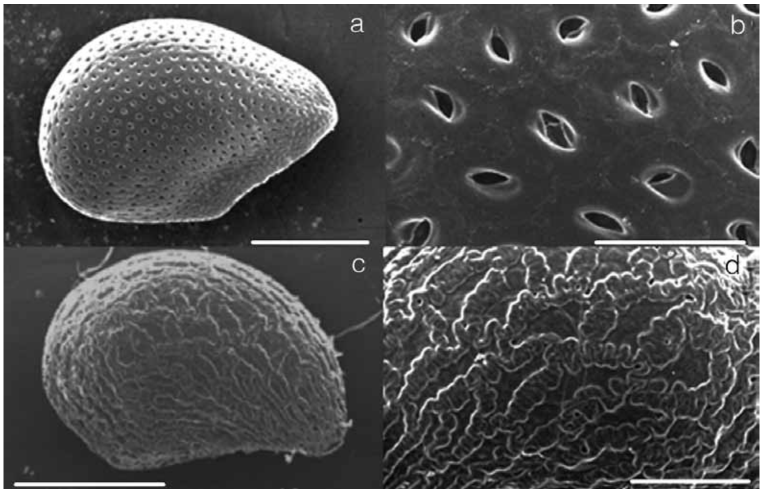

Figure 3. SEM of *Ferocactus histrix* and *Mammillaria uncinata* seeds. Complete seed and details of testa *Ferocactus histrix* (a, b). *Mammillaria uncinata* (c, d). Bar= 500μm in a, c; 100μm in b; 200μm in d.

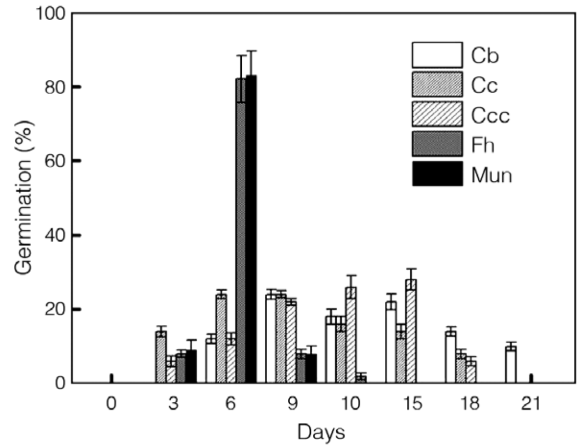

Figure 5 Percentage of germination of seeds of five species of globose Cactoideae. Bars represent mean ±standard deviation of three replicates of 50 seeds each. Cb: *Coryphantha bumamma*, Cc: *C. clavata*, Cco: C. *cornifera*, Fh: *Ferocactus histrix*, Mun: *Mammillaria uncinata*.

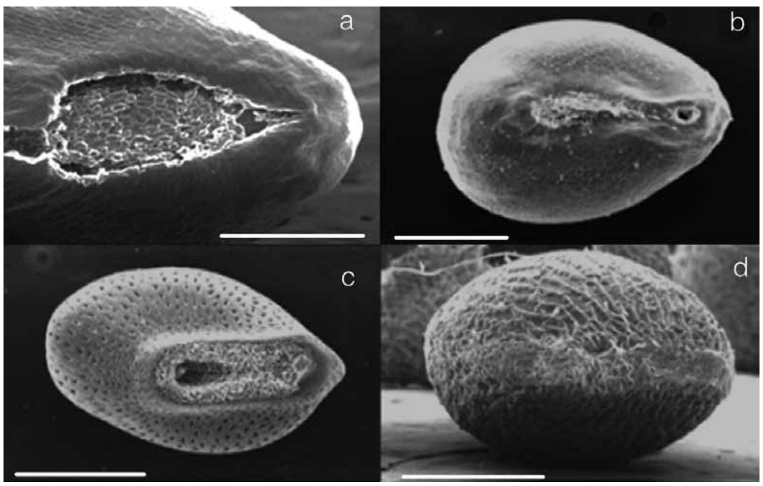

Figure 4. SEM of the hilum-micropylar region, HMR. a: *Coryphantha bumamma*, b: *C. clavata*, c: *Ferocactus histrix*, d: *Mammillaria uncinata*. Bar= 400μm in a; 500μm in b-d.

length (F= 2191.58, df= 4, p<0.0001) and fruit width (F= 1917.22, df= 4, p<0.0001). *F. histrix* was characterized by larger and heavier fruits, and more seeds. By contrast, *C. clavata* and *M. uncinata* had fruits with fewer seeds and were smaller and lighter in weight than the other species (Table I). Significant differences in seeds among species were observed for weight (F= 3797.76, df= 4, p<0.0001), length (F= 9416.14, df= 4, p<0.0001) and seed width (F= 429.19, df= 4, p<0.0001). *C. bumamma* seeds presented higher weights and lengths than the lighter and smaller seeds of *C. cornifera* (Table II).

Seed germination response

All species reached 100% germination in the three repetitions per species. Seed germination was a rapid process that started 3-6 days after sowing (DAS). In *C. cornifera* and *C. clavata*, germination started on the third day, reaching the highest percentages (24-28%) at 6 and 15 das (Figure 5). Seed germination of *C. bumamma* began on the sixth DAS, also reaching the highest percentage (24%) 9 DAS (Figure 5). *F. histrix* and *M. uncinata* were characterized by higher rates of seed germination (>80%) on the sixth DAS. These two species concluded their germination 12 and 8 DAS respectively. By contrast, *C. bumamma* concluded its germination 21 DAS with 10% of its seeds germinated in that time (Figure 5).

Discussion

Morphology of fruits and seeds

The studied species showed considerable variation in fruit and seed morphology. The *Coryphantha* species had similarities in fruit morphology with other species of the genus (*C. echinoidea* Britton & Rose, *C. greenwoodii* Bravo, *C. scheeri* (Muehlenpf.) L.D. Benson, *C. sulcata* (Engelm.) Britton & Rose, and *C. werdermannii* Boed.) (Bravo-Hollis, 1978; Bravo-Hollis and Sánchez-Mejorada, 1991). Characteristics, such as red and claviform fruits of 1.5×0.5cm size, in *M. uncinata* were similar to other *Mammillaria* species like *M. standleyi* (Britton & Rose) Orcutt, *M. johnstonii* (Britton & Rose) Orcutt, *M. heyderi* Muehlenpf., *M. miegiana* W.H. Earle, *M. ortegae* (Britton & Rose) Orcutt, *M. pachycylindrica* Backeb., *M. scrippsiana* (Britton & Rose) Orcutt and *M. magnimamma* Haw. (see Bravo-Hollis and Sánchez-Mejorada, 1991). Other *Mammillaria* species (*M. gigantea* Hildm. ex K. Schum. and *M. melanocentra* Poselg) can be distinguished by their claviform fruits, which are pink or purple in color. Noticeable differences were observed in the fruit size (length) of *M. uncinata* and other species such as *M. gigantea*. In the latter, the fruits were 2.5-3.0cm long (Bravo-Hollis and Sánchez-Mejorada, 1991), whereas the fruits of *M. uncinata* were smaller (1.5 ±0.3cm).

Cactoideae seeds show considerable variation in their shape, size, structure and testa color (Barthlott and Hunt, 2000). Indeed, the studied species exhibited morphological variability. The seeds of *C. bumamma* and *C. cornifera* were curved or reniform, and similar to those of *C. durangensis* (Runge ex K. Schum) Britton & Rose. *C. clavata* and *M. uncinata* had oval seeds, similar to other species of *Mammillaria* like *M. gigantea*, *M. petterssonii* Hildm. and *Coryphantha* like *C. gracilis* L. Bremer & A. B. Lau, *C. pseudoechinus* Boed., *C. recurvata* (Engelm.) Britton & Rose, *C. robustispina* (Ant. Schott ex Engelm.) Brittion & Rose (Bravo-Hollis, 1978; Bravo-Hollis and Sánchez-Mejorada, 1991; Barthlott and Hunt, 2000;

Dicht and Lüthy, 2005). Great variability occurs in the color of the seed testa in Cactaceae. A black or brown color is characteristic in most species, whereas a red or brown color is common in other species, such as *C. bumamma* and *M. uncinata*. *C. clavata* and *C. cornifera* exhibited dark brown or brown seed testas, which is characteristic of *C. duranguensis* (Runge ex K. Schum) Britton & Rose, *C. pseudonickelsiae* Backeb., *C. pallida* Britton & Rose, *C. macromeris* (Engelm.) Lem., and *C. sulcata* (Engelm.) Britton & Rose, according to Bravo-Hollis and Sánchez-Mejorada (1991). Glossy seeds were only observed in *C. bumamma*, in agreement with seeds of some columnar species (Arias and Terrazas, 2004; Arroyo-Cosultchi *et al*., 2007). In Cactaceae, studies on the macro- and micro-morphology of the seeds have been successfully applied to different taxonomic levels (Friedrich and Glaetzle, 1983; Glaetzle and Prestlé, 1986; Arias and Terrazas, 2004; Arroyo-Cosultchi *et al*., 2006, 2007). Buxbaum (1958) recognized four subtribes, particularly in the Cacteae tribe, based on seed morphology: Echinocactinae exhibits a perisperm and hard, black seed testas; Thelocactinae has black seed testas and a mostly warty surface; Ferocactinae exhibits dotted or reticulated seed testas; and Coryphanthinae has soft, smooth, and brown testas, similar to the *Coryphantha* and *Mammillaria* species studied herein. More recently, Taylor and Clark (1983) recognized that the *Ferocactus* section includes species with a larger hilum-micropylar region (HMR), dried fruit dehiscing by a basal pole and glossy seed testas. By contrast, the Bisnaga section includes species with seeds whose HMR is narrow with bright seed testas (Taylor and Clark, 1983). Cota and Wallace (1997) used chloroplast DNA evidence to determine that the members of one lineage (Sect. Bisnaga) are related to *F. flavovirens* (Scheidw.) Britton & Rose and include species distributed mainly in Central Mexico and areas in the putative center of the origin of the genus (Tehuacan Valley). The morphological characteristics of the fruit, seed characteristics and distribution of *F. histrix* support its inclusion in the Bisnaga section along with other species like *F. glaucescens (*DC.) Britton & Rose, *F. lindsayi* Bravo, *F. macrodiscus* (Mart.) Britton & Rose, *F. recurvus* (Mill.) Y. Ito ex G. E. Linds., *F. latispinus* (Haw.) Britton & Rose and *F. flavovirens*, as suggested by Cota and Wallace (1997).

Potential importance of Cacteae fruits

Most cactus fruits are edible; however, information on their morphology and nutritional value is scarce (Kiesling, 2001; Pardo, 2002). According to Esquivel (2004), most studies have focused on the fruit of prickly pears (*Opuntia* spp.). Little has been investigated on the composition and aspects of fruit cultivation of other species of cacti, despite the high potential of these fruits for industrial use (Ortega-Nieblas *et al*., 2001). For example, the presence of red-purple pigments in the fruit epidermis of *M. uncinata* is an important source of natural dyes in foods and in various applications (Stintzing *et al.,* 2001; Wybraniec and Mizrhi, 2002; Stintzing and Carle, 2005; Emaldi *et al*., 2006). Antihyperglycemic and antihyperlipidemic effects found in the fruits of *F. latispinus* and *F. histrix* have been demonstrated, suggesting their application in the prevention of diabetes (Pérez-Gutiérrez and Mota-Flores, 2010). Further studies involving analyses of the nutritional composition of fruits of Cacteae species as well as their morphological characterization may contribute significantly in the search for alternative medicinal products.

Ecological aspects of seed germination response

Differences in the number of seeds per fruit were found between the species studied. A high variability was observed in this trait even within the same genus. For example, *C. bumamma* and *C. cornifera* had 84-99 seeds, whereas *C. clavata* contained 56 seeds per fruit on average. *F. histrix* was distinguished by larger fruits and more seeds than the other Cacteae species studied. Mcintosh (2005) found 1727-3064 seeds per fruit in *F. cylindraceus* (Engelm.) Orcutt and *F. wislizeni* (Engelm.) Britton & Rose, so *F. histrix* is near the average for the genus. According to Rojas-Aréchiga and Vázquez-Yanes (2000), the number of seeds per fruit in Cactaceae species is highly variable; these differences may serve as strategies for reproductive efforts as mentioned by Harper *et al.* (1970). The number of seeds per fruit may also depend on the age and size of the plant, the number of flowers produced, and the origin (wild or cultivated species), as demonstrated for Cactoideae (Parker, 1987; León de la Luz and Domínguez-Cadena, 1991; Rojas-Aréchiga *et al*., 2001; Guillen *et al*., 2011), or may reflect environmental heterogeneity (Harper *et al*., 1970). However, more detailed studies are needed on intra-and interspecific variability for this characteristic.

With the exception of Opuntioideae seeds, cacti seeds germinate quickly (Bregman and Bouman, 1983; Potter *et al*., 1984; Del Castillo, 1986; Rojas-Aréchiga and Vázquez-Yanes, 2000; Mandujano *et al*., 2005). The species analyzed in this study began the germination process between 3 and 6 DAS. Two studied species, *F. histrix* and *M. uncinata*, showed the highest percentages of germination at 6 DAS (>80%), suggesting that this process is synchronized with available water. In contrast, the species of *Coryphantha* showed a wider period of germination with their higher values at 9 DAS or even 15 DAS (22 or 28% respectively). Although there was a differential time of germination all species reached 100% germination after 22 DAS. The germination in the species studied is greater than those reported by Sánchez-Soto *et al.* (2010), Jiménez and Flores (2010), and Flores *et al*. (2011) for other species of *Ferocactus* (62-91%), *Mammillaria* (42-99%) and *Coryphantha* (72-98%) However, the high germination percentages did not include any pre-germination treatment, in contrast with other studies in which specific requirements were needed as for light, water availability, and mechanical scarification (Nolasco *et al*., 1996, 1997; Godínez-Álvarez and Valiente-Banuet, 1998; De la Barrera and Nobel, 2003; Martínez-Mendoza *et al*., 2004; Larrea-Alcázar and López, 2008). The pre-germination treatments include light-dark treatment, different temperatures, addition of growth regulators (Cancino *et al*., 1993; Flores *et al*., 2006; Ortega-Baes and Rojas-Aréchiga, 2007; Ortega-Baes *et al*., 2010; Sánchez-Soto *et al*., 2010), chemical scarification (Rosas-López and Collazo-Ortega, 2004), and various stress conditions and water potentials (Guillén *et al*., 2009). In the present study, seeds recently collected were included. Moreover, laboratory conditions during the experiment (20-25°C) were sufficient to promote seed germination. Temperature is an important factor that can significantly affect the germination percentage. Trujillo (1982) mentioned that cactus seeds germinate at temperatures between 24 and 27°C. There are species of cacti that require temperatures ranging from 15 to 35°C for germination, such as *T. terscheckii* (J. Parm. ex Pfeiff.) Britton & Rose (Ortega-Baes and Rojas-Aréchiga, 2007), *Echinocactus platyacanthus*

Link & Otto (Quintana, 1994) and *Epiphyllum phyllanthus* (L.) Haw. (Simão *et al*., 2010). Other authors suggest that alternating temperatures increase germination rates of globose species such as *Echinocactus platyacanthus*, *F. flavovirens*, *F. robustus* (Pfeiff.) Britton & Rose, and *M. mazatlanensis* (Rojas-Aréchiga *et al*., 1998; Sánchez-Soto *et al*., 2010). In addition to temperature, germination also depends on the species and seed characteristics (thickness of the seed coat, dormancy, etc.). In some species, characteristics of the testa, in particular cuticular secretions, contribute to improve the collection and distribution of water during imbibition and increase germination (Bregman and Graven, 1997). Specific features of the seed (thin seed testa, absence of dormancy and others) in the species studied herein probably influenced significantly the higher germination rate, as has been observed in germinating seeds of columnar cacti (Loza-Cornejo *et al*., 2008). Further work on the mechanisms of germination is needed, particularly on the requirements for the germination of seeds of other Cactoideae, with the aim of contributing to their use, management and conservation. Some species, such as *F. histrix*, are subject to special protection in regions of Jalisco and other Mexican states, and other species, such as *C. clavata*, are considered to be rare species in Jalisco (Chávez-Martínez *et al*., 2007; Harker *et al*., 2008).

Significant differences were observed for the number of seeds per fruit, weight, and fruit width in the cacti studied. Seed germination was a rapid process, usually starting on the 3 DAS, and high percentages of germination were seen. Some morphological characteristics of fruits and seeds can be used to support further systematic studies of Cactoideae genera and will contribute to knowledge for the potential use and conservation of these plants.

REFERENCES

Anderson EF (2001) *The Cactus Family*. Timber Press. Portland, OR, USA. 768 pp.

Arias S, Terrazas T (2004) Seed morphology and variation in the genus *Pachycereus* (Cactaceae). *J. Plant Res. 117*: 277-289.

Arroyo-Cosultchi G, Terrazas T, Arias S, Arreola-Nava H (2006) The systematic significance of seed morphology in *Stenocereus* (Cactaceae). *Taxon 55*: 983-992.

Arroyo-Cosultchi G, Terrazas T, Arias S, López-Mata L (2007) Morfología de la semilla de *Neobuxbaumia* (Cactaceae). *Bol. Soc. Bot. Mex. 81*: 17-25.

Ayala-Cordero G, Terrazas T, López-Mata L, Trejo-López C (2004) Variación en el tamaño y peso de la semilla y su relación con la germinación de una población de *Stenocereus beneckei*. *Interciencia 29*: 692-697.

Barrera F, Reynoso C, Mejía E (1998) Estabilidad de betalaínas extraídas del garambullo (*Myrtillocactus geometrizans*). *Food Sci. Technol. Int. 4*: 115-120.

Barthlott W, Hunt D (2000) *Seed Diversity in the Subfamily Cactoideae*. Remous. Richmond, UK. 173 pp.

Bravo-Hollis H (1978) *Las Cactáceas de México* Vol I. UNAM. Mexico. 755 pp.

Bravo-Hollis H, Sánchez-Mejorada H (1991) *Las Cactáceas de México.* Vol. III 2ª ed. UNAM. Mexico. 599 pp.

Bregman R, Bouman F (1983) Seed germination in Cactaceae. *Bot. J. Linn. Soc. 86*: 357-374.

Bregman R, Graven P (1997) Subcuticular secretion by cactus seeds improves germination by means of rapid uptake and distribution of water. *Ann. Bot. 80*: 525-535.

Butera D, Tesoriere L, Di Gaudio F, Bongiorno AM, Pintaudi AM, Kohen R, Livrea MA (2002) Antioxidants activities of Sicilian prickly pear (*Opuntia ficus-indica*) fruits extracts and reducing properties of its betalains: betanin and indicaxanthin. *J. Agric. Food Chem. 50*: 6895-6901.

Buxbaum F (1958) The phylogenetic division of the subfamily Cereoideae, Cactaceae. *Madroño 14*: 177-216.

Cancino J, León de la Luz JL, Coria R, Romero H (1993) Effect of heat treatment on germination of seeds of cardón *Pachycereus pringlei* (S. Wats.) Britt. & Rose, Cactaceae. *J. Ariz.-Nev. Acad. Sci. 27*: 49-54.

Chávez-Martínez RJ, Hernández-Oria JG, Sánchez-Martínez E (2007) Documentación de factores de amenaza para la flora cactológica del semidesierto Queretano. *Bol. Nakari 18*: 89-95.

Cota JH, Wallace SR (1997) Chloroplast DNA evidence for divergence in *Ferocactus* and its relationships to North American columnar cacti (Cactaceae: Cactoideae). *Syst. Bot. 22*: 529-542.

De la Barrera E, Nobel PS (2003) Physiological ecology of seed germination for the columnar cactus *Stenocereus queretaroensis*. *J. Arid Env. 53*: 297-306.

Del Castillo RF (1986) Semillas, germinación y establecimiento de *Ferocactus histrix*. *Cact. Suc. Mex. 31*: 5-11.

Dicht RE, Lüthy AD (2005) *Coryphantha* Cacti *of Mexico and Southern USA*. Springer. New York, USA. 210 pp.

Domínguez-López A (1996) Empleo de frutos y de los cladodios de la chumbera (*Opuntia ficus*) en la alimentación humana. *Food Sci. Technol. Int. 1*: 65-74.

Duru B, Turker N (2005) Changes in physical properties and chemical composition of cactus pear (*Opuntia ficus-indica*) during maturation. *JPACD 7*: 22-33.

Emaldi UJ, Nassar M, Semprum C (2006) Pulpa del fruto del cardón dato (*Stenocereus griseus*, Cactaceae) como materia prima para la elaboración de mermelada. *Arch. Latinoam. Nutr. 56*: 1-16.

Esquivel P (2004) Los frutos de las cactáceas y su potencial como materia prima. *Agr. Mesoam. 15*: 215-219.

Flores J, Briones O (2001) Plant life-form and germination in a Mexican intertropical desert: effects of soil water potential and temperature. *J. Arid Env. 47*: 485-497.

Flores J, Jurado E, Arredondo A (2006) Effect of light on germination of seeds of Cactaceae from the Chihuahuan Desert, Mexico. *Seed Sci. Res. 16*: 149-155.

Flores J, Jurado E, Chapa-Vargas L, Ceroni-Stuva A, Dávila-Aranda P, Galíndez G, Gurvich D, León-Lobos P, Ordóñez C, Ortega-Baes P, Ramírez-Bullón N, Sandoval A, Seal CE, Ulian T, Pritchard HW (2011) Seeds photoblastism and its relationship with some plant traits in 136 cacti species. *Env. Exp. Bot. 71*: 79-88

Friedrich H, Glaetzle W (1983) Seed morphology as an aid to classifying the genus *Echinopsis* Zucc. *Bradleya 1*: 91-104.

Glaetzle W, Prestlé H (1986) Seed morphology of the genus *Notocactus*. *Bradleya 4*: 79-96.

Godínez-Álvarez H, Valiente-Banuet A (1998) Germination and early growth of Tehuacan Valley cacti species: the role of soils and seed ingestion by disperser on seedling growth. *J. Arid Env. 39*: 21-31.

Godínez-Álvarez H, Valverde T, Ortega-Baes P (2003) Demographic trends in the Cactaceae. *Bot. Rev. 69*: 173-203.

Goettsch B, Hernández HM (2006) Beta diversity and similarity among cactus assemblages in the Chihuahuan Desert. *J. Arid Env. 65*: 513-528.

Guillén S, Benítez J, Martínez-Ramos M, Casas A (2009) Seed germination of wild, *in situ*-managed, and cultivated populations of columnar cacti in the Tehuacan-Cuicatlan Valley, Mexico. *J. Arid Env. 73*: 407-413.

Guillén S, Terrazas T, De la Barrera E, Casas A (2011) Germination differentiation patterns of wild and domesticated columnar cacti in a gradient of artificial selection intensity. *Gen. Res. Crop Evol. 58*: 409-413.

Guzmán U, Arias S, Dávila P (2003) *Catálogo de Cactáceas Mexicanas*. UNAM-CONABIO. Mexico. 315 pp.

Harker M, García-Rubio LA, Riojas-López ME (2008) Composición florística de cuatrohábitats en el Rancho Las Papas de Arriba, municipio de Ojuelos, Jalisco, Mexico. *Acta Bot. Mex. 85*: 1-29.

Harper JL, Lovel PH, Moore KG (1970) The shapes and sizes of seeds. *Ann. Rev. Ecol. System. 1*: 327-356.

Hernández MH, Godínez H (1994) Contribución al conocimiento de las cactáceas mexicanas amenazadas. *Acta Bot. Mex. 26*: 33-52.

Hernández-Hernández T, Hernández MH, De-Nova JA, Puente R, Eguiarte LE, Magallón S (2011) Phylogenetic relationships and evolution of growth form in Cactaceae (Caryophyllales, Eudicotyledonae). *Am. J. Bot. 98*: 44-61.

Hernández-Oria JG, Chávez-Martínez R, Sánchez-Martínez E (2007) Factores de riesgo en las Cactaceae amenazadas de una región semiárida en el sur del Desierto Chihuahuense, Mexico. *Interciencia 32*: 727-733.

Jiménez-Aguilar A, Flores J (2010) Effect of light on seed germination of succulent species from the southern Chihuahuan Desert: comparing germinability and relative light germination. *JPACD 12*: 12-19.

Joubert E (1993) Processing of the fruit of five prickly pear cultivars grown in South Africa. *Food Sci. Technol. Int. 28*: 377-387.

Kiesling R (2001) Cactáceas de la Argentina promisorias agronómicamente. *JPACD 4*: 11-14.

Larrea-Alcázar DM, López RP (2008) Seed germination of *Corryocactus melanotrichus* (K. Schum.) Britton & Rose (Cactaceae): and endemic columnar cactus of the Bolivian Andes. *Ecol. Bol. 43*: 135-140.

León de la Luz JL, Domínguez-Cadena R (1991) Evaluación de la reproducción por semillas de la pitaya agria (*Stenocereus gummosus*) en Baja California Sur, México. *Acta Bot. Mex. 14*: 75-87.

Loza-Cornejo S, López-Mata L, Terrazas T (2008) Morphological seed traits and germination of six species of Pachycereae (Cactaceae). *JPACD 10*: 71-84.

Mandujano MC, Montaña C, Rojas-Aréchiga M (2005) Breaking seed dormancy in *Opuntia rastrera* from the Chihuahuan Desert. *J. Arid Env. 62*: 15-21.

Martínez-Mendoza D, López-Rodríguez B, Flores-Martínez A, Manzanero-Medina G (2004) Evaluación de técnicas de propagación de *Mammillaria oteroi* Glass & R. Foster. *Nat. Des. 2: 5-7.*

Mcintosh ME (2005) Pollination of two species of *Ferocactus*: interactions between cactus-specialist bees and their host plants. *Func. Ecol. 19*: 727-734.

Media Cybernetics (2006) *Image Pro-Plus. Version 6.1.* Springfield, MD, USA. 534 pp.

Nobel PS (1988) *Environmental Biology of Agaves and Cacti.* Cambridge University Press. New York, USA. 280 pp.

Nobel PS (2002) *Cacti-Biology and Uses.* University of California Press. Berkeley, CA, USA. 290 pp.

Nolasco HF, Vega-Villasante F, Díaz-Rondero A (1996) Seed germination of *Stenocereus thurberi* (Cactaceae) under different solar irradiation levels. *J. Arid Env. 36*: 123-132.

Nolasco H, Vega-Villasante F, Romero-Schmidt HL, Díaz-Rondero A (1997) The effects of salinity, acidity, light and temperature on the germination of seeds of cardón (*Pachycereus pringlei* (S. Wats.) Britton & Rose Cactaceae). *J. Arid Env. 33*: 87-94.

Ortega-Baes P, Rojas-Aréchiga M (2007) Seed germination of *Trichocereus terscheckii* (Cactaceae): light, temperature and gibberellic acid effects. *J. Arid Env. 69*: 169-176.

Ortega-Baes P, Aparicio-González M, Galíndez G, Del Fueyo P, Sühring S, Rojas-Aréchiga M (2010) Are cactus growth forms related to germination responses to light? A test using *Echinopsis* species. *Acta Oecol. 36*: 339-342.

Ortega-Nieblas M, Molina-Freaner F, Robles-Burgueño MR, Vázquez-Moreno L (2001) Proximate composition, protein quality and oil composition in seeds of columnar cacti from the Sonoran Desert. *J. Food Comp. Anal. 14*: 575-584.

Parker KC (1987) Seed crop characteristics and minimum reproductive size of organ pipe cactus (*Stenocereus thurberi*) in southern Arizona. *Madroño 34*: 294-303.

Pardo O (2002) Etnobotánica de algunas cactáceas y suculentas del Perú. *Chloris Chil. 5* (1) www.chlorischile.cl

Pérez-Gutiérrez RM, Mota-Flores JM (2010) Attenuation of hyperglycemia and hyperlipidemia in streptozotocin-induced diabetic rats by chloroform extract of fruits of *Ferocactus latispinus* and *Ferocactus histrix. Bol. Latinoam. Car. Plant. Med. Aromat. 9*: 475-484.

Potter RL, Petersen JL, Ueckert DN (1984) Germination responses of *Opuntia* spp. to temperature, scarification and other treatments. *Weed Sci. 32*: 106-110.

Quintana SME (1994) Contribución al conocimiento de algunos factores que disparan la germinación de *Echinocactus platyacanthus* LK & O. Thesis. UNAM. Mexico 85 pp.

Ramírez-Padilla CA, Valverde T (2005) Germination responses of three congeneric cactus species (*Neobuxbaumia*) with differing degrees of rarity. *J. Arid Env. 61*: 331-343.

Rojas-Aréchiga M, Vázquez-Yanes C (2000) Cactus seed germination: a review. *J. Arid Env. 44*: 85-104.

Rojas-Aréchiga M, Orozco-Segovia A, Vázquez-Yanes C (1997) Effect of light on germination of seven species of cacti from the Zapotitlan Valley in Puebla, Mexico. *J. Arid Env. 44*: 85-104.

Rojas-Aréchiga MA, Orozco-Segovia A, Vázquez-Yanes C (1998) Seed response to temperature of Mexican cacti species from two life forms: an ecophysiological interpretation. *Plant Ecol. 135*: 207-214.

Rojas-Aréchiga M, Casas A, Vázquez-Yanes C (2001) Seed germination of wild and cultivated *Stenocereus stellatus* (Cactaceae) from the Tehuacán-Cuicatlán Valley, Central Mexico. *J. Arid Env. 49*: 279-287.

Rosas-López U, Collazo-Ortega M (2004) Conditions for the germination and the early growth of seedlings of *Polaskia chichipe* (Goss.) Backeberg and *Echinocactus platyacanthus* Link and Otto (Rose) Bravo-Hollis (Cactaceae). *Phyton 73*: 213-220.

Sáenz C (1997) Usi potenziali del frutto e dei claddi di ficondidia nell industria alimentare. *Riv. Frutticult. 12*: 47-52.

Sáenz C, Estévez AM, Sepúlveda E, Mecklenburg P (1998) Cactus pear fruit: a new source for natural sweetener. *Plant Foods Hum. Nutr. 52*: 141-149.

Sánchez-Salas J, Flores J, Martínez-García E (2006) Efecto del tamaño de semilla en la germinación de *Astrophytum myriostigma* Lemaire. (Cactaceae), especie amenazada de extinción. *Interciencia 31*: 371-375.

Sánchez-Soto BH, Reyes-Olivas A, García-Moya E, Terrazas T (2010) Germinación de tres cactáceas que habitan la región costera del noroeste de México. *Interciencia 35*: 299-305.

SAS (2000) *User's Guide. Statistics.* SAS Institute Inc. Cary, NC, USA 128 pp.

Simão E, Nakamura AT, Takaki M (2010) The germination of seeds of *Epiphyllum phyllanthus* (L.) Haw. (Cactaceae) is controlled by phytochrome and by nonphytochrome related process. *Biota Neotrop. 10*: 114-119.

Stintzing FC, Carle R (2005) Cactus stems (*Opuntia* spp.): A review on their chemistry, technology, and uses. *Mol. Nutr. Food Res. 49*: 175-194.

Stintzing FC, Schieber A, Carle R (2001) Phytochemical and nutritional significance of cactus pear. *Eur. Food Res. Technol. 212*: 396-407.

Stintzing FC, Herbarch KM, Mosshammer MR, Carle R, Yi W, Sellappan S, Akoh C, Bunch R, Felker P (2005) Color, betalain pattern, and antioxidant properties of cactus pear (*Opuntia* spp.) clones. *J. Agric. Food Chem. 53*: 442-451.

Taylor NP, Clark JY (1983) Seed morphology and classification in *Ferocactus* subg. *Ferocactus. Bradleya 1*: 3-16.

Terrazas T, Arias S (2003) Comparative stem anatomy in the subfamily Cactoideae. *Bot. Rev. 68*: 444-473.

Trujillo AS (1982) Estudio de algunos aspectos ecológicos de *Echinocactus platycanthus* LK. & O. en el estado de San Luis Potosí. Thesis. ENEP Iztacala, UNAM. Mexico.

Vega-Villasante FH, Nolasco C, Montaño Hl, Romero-Schmidt A, Vega-Villasante E (1996) Efecto de la temperatura, acidez, iluminación, salinidad, irradiación solar y humedad sobre la germinación de semillas de *Pachycereus pectenaboriginum* "cardón barbón" (Cactaceae). *Cact. Suc. Mex. 41*: 51-61.

Wybraniec S, Mizrahi Y (2002) Fruit flesh betacyanin pigments in *Hylocereus* cacti. *J. Agric. Food Chem. 50*: 6086-6089.