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**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 Echinocereeae 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 (*Turbini-*

carpus 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 /

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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 Cactaceae (*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 semi-

llas 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 Cactaceae (*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 lar-

gura 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 system-

atic 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 investi-

gated in members of Cactaceae 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)
<i>Coryphantha bumamma</i>	84 ±35 b	2.0 ±0.56 c	2.7 ±0.5 b	0.6 ±0.40 a
<i>Coryphantha clavata</i>	56 ±8 a	0.5 ±0.18 a	1.4 ±0.3 a	0.6 ±0.15 a
<i>Coryphantha cornifera</i>	99 ±2 b	1.4 ±0.22 b	2.7 ±0.9 b	1.2 ±0.80 ab
<i>Ferocactus histrix</i>	2100 ±90 c	8.0 ±2.80 d	3.2 ±0.6 b	2.2 ±0.40 b
<i>Mammillaria uncinata</i>	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 Cactaceae. a.: *Coryphantha cornifera*, b: *Ferocactus histrix*, c: *Mammillaria uncinata*.

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 N° 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 Data-logger 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,

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

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

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 fol-

cies 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

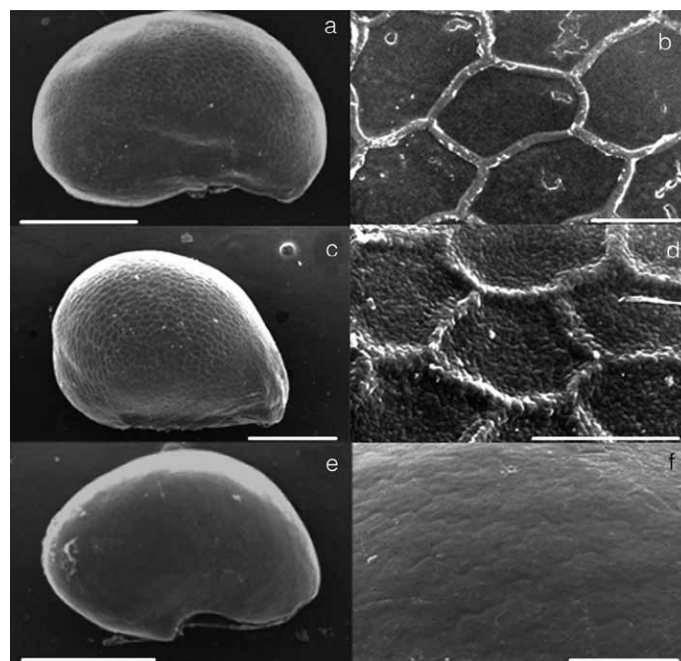


Figure 2 SEM of *Coryphantha* species seeds, whole seeds and seed surface view. a,b: *Coryphantha bumamma*; c,d: *C. clavata*; e,f: *C. cornifera*. Bar= 1mm in a; 500µm in c,e; 50µm in b, d and f.

lowed 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).

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

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),

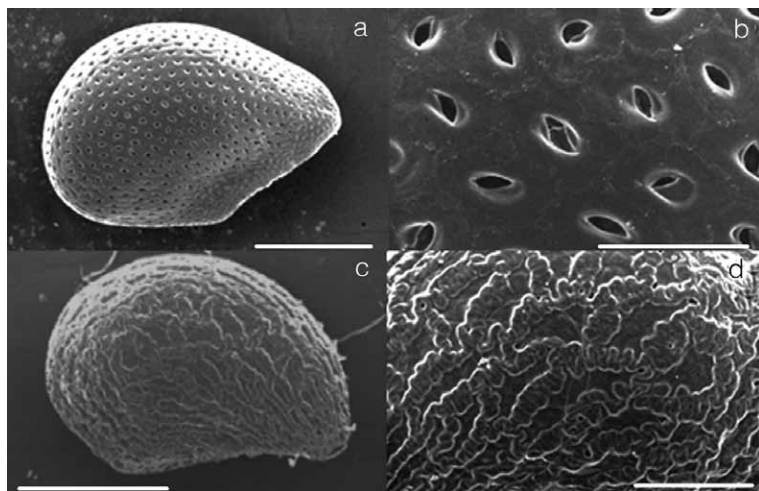


Figure 3. SEM of *Ferocactus histrix* and *Mammillaria uncinata* seeds. Complete seed and details of testa *Ferocactus histrix* (a, b). *Mammillaria uncinata* (c, d). Bar= 500µm in a, c; 100µm in b; 200µm in d.

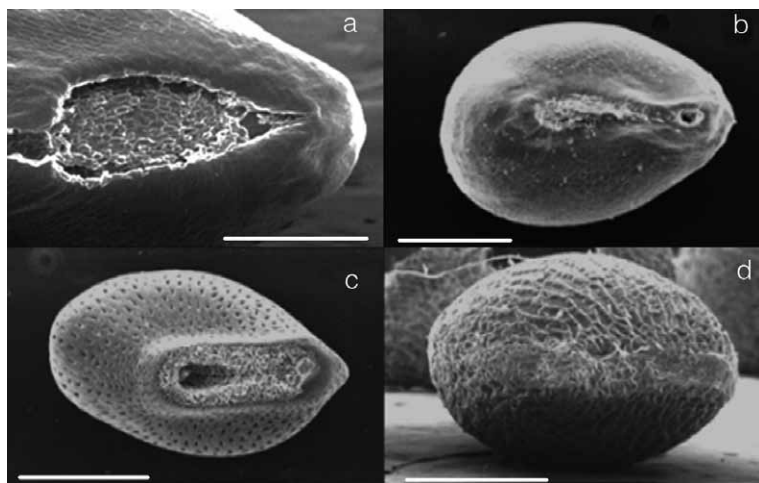


Figure 4. SEM of the hilum-micropylar region, HMR. a: *Coryphantha bumamma*, b: *C. clavata*, c: *Ferocactus histrix*, d: *Mammillaria uncinata*. Bar= 400µm in a; 500µm in b-d.

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

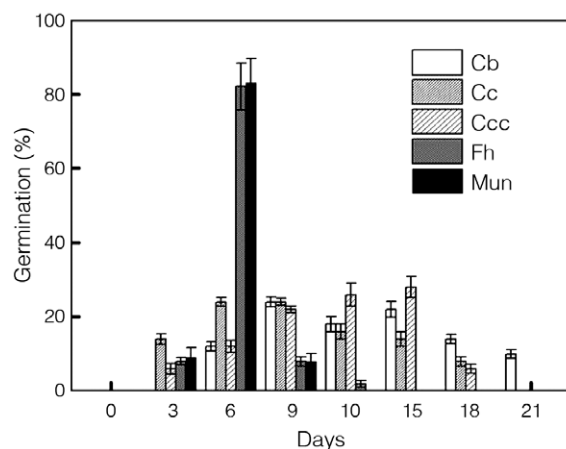


Figure 5 Percentage of germination of seeds of five species of globose Cactoideae. Bars represent mean $\pm$ standard deviation of three replicates of 50 seeds each. Cb: *Coryphantha bumamma*, Cc: *C. clavata*, Cco: *C. cornifera*, Fh: *Ferocactus histrix*, Mun: *Mammillaria uncinata*.

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 $\pm$ 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.) Britton & 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 Cactaceae 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. hystrix* 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 Cactaceae 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. hystrix* 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 Cactaceae 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. hystrix* was distinguished by larger fruits and more seeds than the other Cactaceae species studied. McIntosh (2005) found 1727-3064 seeds per fruit in *F. cylindraceus* (Engelm.) Orcutt and *F. wislizeni* (Engelm.) Britton & Rose, so *F. hystrix* 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; Guillén *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. hystrix* 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 Cactoidae, 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 Cactoidae genera and will contribute to knowledge for the potential use and conservation of these plants.

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