



Cactus pear (*Opuntia spp.*) species and cultivars cultivated in the world: A review

Mohamed Arba *

Hassan II Institute of Agronomy and Veterinary Medicine Horticultural Complex of Agadir Morocco.

Open Access Research Journal of Multidisciplinary Studies, 2022, 03(02), 092–102

Publication history: Received on 12 April 2022; revised on 17 May 2022; accepted on 20 May 2022

Article DOI: <https://doi.org/10.53022/oarjms.2022.3.2.0049>

Abstract

Cactus pears are succulent plants resistant to drought and *Opuntia* Mill. is the typical genus. This genus includes a group of cactus pear plants which are economically the most important in the cactus family. Cactus pears are originated from Mexico. Adapted to harsh and dry conditions, they are cultivated in the arid and semi-arid areas of the world and are now part of the agricultural systems of these areas. *Opuntia ficus-indica* (L.) Mill. is the most important economic species worldwide. It is cultivated in many countries of the world and naturalized in certain regions, as in the Mediterranean basin. The spineless species *O. ficus-indica* resulted from a long selection process in cultivation, and several *Opuntia* species are mentioned to be its ancestors, in particular *O. megacantha* Salm-Dyck and *O. streptacantha* Lem. Several taxa are often confused due to ambiguous descriptions and a lack of types. Molecular studies are a useful tool in plant taxonomy, and most of the taxa in the subfamily *Opuntioideae* are polyploid and *Opuntia* species are tetra, hexa or octoploids taxa. This paper describe the most important anatomical and morphological characters of cactus pears as cladodes, flowers and fruits, and the area of their cultivation and distribution in the world is presented. The taxonomic features of the genus *Opuntia* are highlighted and DNA molecular analysis of its taxa is discussed. Species and cultivars cultivated in the most producing countries are described.

Keywords: *Opuntia*; *Opuntia ficus-indica*; Cactus Pear; Species; Cultivars; Arid Areas

1. Introduction

Opuntias are cultivated in the arid and semi-arid areas since a long time [1]. The names of these plants are often confused due to ambiguous descriptions and a lack of types, and the spineless species *O. ficus-indica* (L.) Mill. known in cultivation today is the result of a long selection process in cultivation [2]. The genus *Opuntia* Mill. is the most widespread of all genera in the cactus family and its species are easily recognized by their flat-shaped stems called pads or cladodes that are growing by segments. The cladodes are covered with areoles which are axillary buds with tiny hairy spines called glochids which are highly irritating. In addition to glochids, many species have large spines and are called spiny or thorny species. Species without large spines are called spineless species as the Indian fig *O. ficus-indica*. New shoots and flowers are borned in the areols [3, 4]. The genus *Opuntia* is also the most important economically as a great number of species are producing edible fruits, like as *O. ficus-indica*, *O. megacantha* Salm-Dyck, *O. stricta* Haw. *O. dillenei* (Ker Gawl.) Haw. *O. schumannii* Weber, *O. robusta* Wend. and *O. albicarpa* Scheinvar. All these species are called by the vernacular name of “prickly pear or cactus pear tree” [3, 4].

Cactus pears are now part of the agricultural systems and natural environment of the arid and semi-arid areas, and *O. ficus-indica* is the most important economic cactus species worldwide [5]. It is cultivated in America, Africa, Asia, Europe and Oceania [1]. The prickly pear cactus can be found from Canada to Patagonia and Argentina and from sea level to 5 100 m elevation as in Peru [6]. It became invasive in areas with a wet season characterized by high temperatures as in South Africa and Australia [7]. In the Mediterranean basin natural invasion is limited by the low humidity and cold winter temperatures and dry conditions of summer [8]. Cactus pears produce edible fruits which are sweet and juicy, and also edible young cladodes which are eaten as vegetable mainly in Mexico where they are called nopales or

* Corresponding author: Mohamed Arba

Hassan II Institute of Agronomy and Veterinary Medicine Horticultural Complex of Agadir Morocco.

nopalitos. The traditional and popular uses of cactus pears and their multiple functions in many countries have caught the imagination of the scientists, farmers and cattlemen [9]. It also seems that many *Opuntia* species hybridize easily in the wild and one population tends to blend into another. The aim of this chapter is to describe the cactus plants family, the genus *Opuntia* Mill. And the species and cultivars of cactus pear cultivated in the world.

2. Systematic and botany

The prickly pears are xerophytic plants which, according to convention-which are currently under review-belong to the new family of Opuntiaceae Desv. (synon. Cactaceae Juss.). This family is composed of 26-160 genera and 1,500-2,000 species native to North and South America, mainly Mexico [10] and the typical genus is *Opuntia* Mill. [11]. The Opuntiaceae Desv. family is an easily recognizable and distinct family of green plants which often possess succulent stems and spines, and are characterized by the crassulacen acid metabolism (CAM) [10]. The prickly-or cactus-pear plants are included in the genus *Opuntia*, and are characterized by the presence of cladodes, which are a kind of jointed stems. Their leaves are often rudimentary and transitory, or absent and replaced by spines and barbed hairs (glochids) carried by areoles (axillary nodes). Flowers are born on the upper half of the cladode until more than 25, and most of them (90-95%) are transformed to fruits. Flowers are generally large and are born individually on the areoles. The perianth is formed by a calice with sepals and a corolla with petals, and stamens are numerous. The ovary is infer and containing 3-20 cyclic carpels [10].

The presence or absence of spines and their size is another variable character in Opuntias. The reversion of the spineless form to spiny form or vice versa is possible and the reversion of a branch of a spineless form to produce spines after a drought stress period is mentioned by several authors [5, 12, 13]. In the other hand, seedlings of the spineless form produce a small part of the spiny forms, or vice versa. Certain authors indicated that the presence of spines is not a valuable character in the taxonomy of Opuntias because the development of spines depends on the environmental factors [14].

The cactus family is assigned to order Caryophyllales, which also includes the families Aizoaceae, Portulacaceae, Caryophyllaceae, Nyctaginaceae, Phytolaccaceae, Amaranthaceae, and Chenopodiaceae [15]. Phylogenetic placement within the Caryophyllales is undisputed, because cacti and other families within the order share derived characters, i.e., synapomorphies that do not occur in any other angiospermous order (a seed contains a strongly curved, peripheral embryo around a central perisperm, not endosperm) [16].

3. Origin and distribution of cactus pear

Cactus pear is originated from central Mexico and has been distributed to other areas of the world with warm climates [17]. Adapted to harsh and dry conditions, Opuntias are naturalized in arid and semi-arid areas of Africa, Asia and Australia. They spread rapidly in many regions of the world, and *O. ficus-indica* is actually naturalized in 26 countries outside its native range [18]. Cactus pears-in particular *O. ficus-indica*, the true prickly pear tree, were introduced to the Mediterranean basin at the end of the 15th century by Christopher Columbus, and then in North Africa one century later [3, 19, 20]. Their distribution in the world was facilitated by the transport of fresh cladodes on European boats at the end of the 15th century [3, 19]. The cultivation of cactus pears extended to the hot arid regions of the world due to their drought resistance. Actually, *O. ficus-indica* is cultivated in more than 30 countries of both hemispheres, and in all the continents except the Antarctic [3, 21].

The total area occupied by the cactus pear in Mexico is around 3 million hectares (ha), including more than 70,000 ha cultivated for fruit and vegetable production (young cladodes as vegetable) [22, 23]. Today, cactus pear is the sixth fruit crop production in Mexico and is more important than peach or table grapes [24]. The area of the prickly pear cactus in Brazil, also a great producer, is 900,000 ha with 600,000 cultivated ha [22] and the major production is destined for forage. Inglese [25] reported around 3,000 ha for commercial production in Italy. The cultivation area of cactus pear in Argentina is for 1 650 ha [26]. The production area in Chile is about 1000 ha [25, 27] and the cultivation area in Peru is about 17 000 ha where 60% is destined for cochineal production under intensive and semi-wild plantations and 40% for fruit production [9]. In the USA, cactus pear is cultivated in small areas in California and Texas [9]. In South Africa, an estimated area of 1 500 ha is actually cultivated for fruit production and another area of 1 500 ha for fodder production. An extensive area of about 150 000 ha of wild plantations of the original invasions are also used for fruit production [9]. In Tunisia, about 70 000 ha of cactus pear were planted as fodder livestock [28], and 142 000 ha were added in 1990 [29]. Most plantations are destined for fodder and fruit production. In Algeria, the cultivation area of cactus pear is about 30 000 ha [30]. In Morocco, the area occupied by cactus pear has evolved remarkably during the last two decades, reaching around 150,000 ha. Several cooperatives and small firms of rural women were created for

the valorization of cactus pear products to by-products with high income for growers and rural populations, such as pharmaceutical and cosmetic products (nopal powder, seed oil, dried flowers, dermal cream, shampoo, and soap), and agri-food products (jam, honey, juice, vinegar, sirop). Therefore, recently (since the 2017 year), many plantations of cactus pear in Morocco are infested by the carmin cochineal insect *Dactylopius opuntiae*. The origin of the infestation is not known, but the insect was signaled in Spain where it was found in Murcia in 2006 and in Almeria in 2013.

4. Anatomy and morphology of Opuntias

4.1. The root system and the pads

The root system of cactus pear is a shallow fasciculate system which spreads horizontally and emits fine roots called rainy roots during the raining season for the absorption of the maximum water. The great mass of absorbing roots is located at the upper part of soil at 30 cm depth and spreading 4 to 8 m outwards [31, 32]. The Opuntias are succulent plants by their pads which are making the storage of water in their acquiescent parenchyma [33]. The pads are bearing areoles which are axillary buds, and covered with a thick and impermeable cuticle which protect them from water evaporation. Areoles are bearing sometimes spines, short hair spines called glochids, flowers and shoots. The presence or absence of spines in the pads is an important morphological character in the taxonomy of the Opuntias. The thorny or spiny varieties are bearing spines and the spineless varieties are without spines, but all the Opuntias are bearing glochids. The number, size and color of spines are also important in the taxonomy of Opuntias [3, 4].

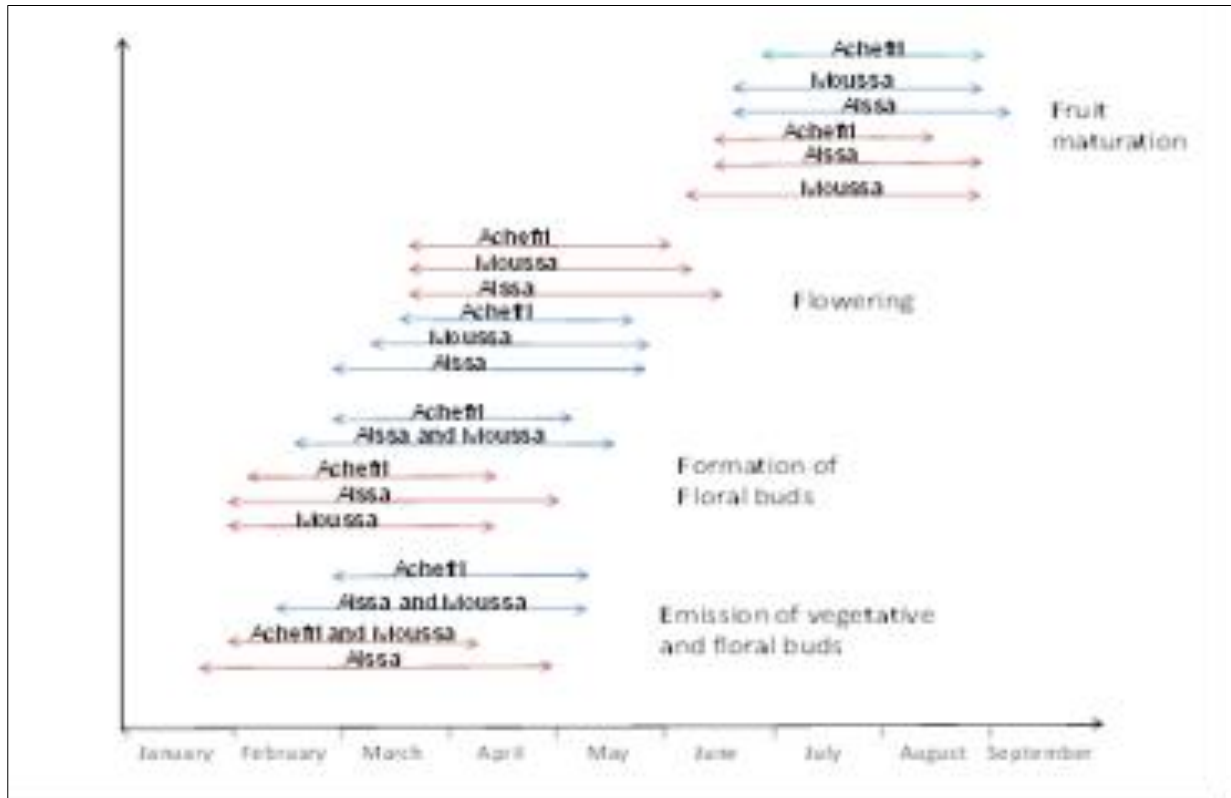
4.2. Flowering



Figure 1 The Overlapping and recovery of vegetative and reproductive phases at cactus pear: (a) and (b) the recovery of the phases of buds and shoots emission, flowering and fruit growth; (c) and (d) the recovery of the phases floral buds development, fruit growth and development and fruit ripening

In cactus pear floral buds are often emitted on one year old cladodes and vegetative buds are mainly emitted on two years or more than two years old cladodes [34, 35, 36]. In Morocco, in Agadir area in south of Morocco, the duration of the phase of the emission of vegetative and floral buds for two consecutive years (2011 and 2012) was 76 days for the thorny variety Achefri of *O. megacantha* Salm-Dyck and varied between 76 and 98 days for the spineless varieties Aissa and Moussa of *O. ficus-indica* [4]. The duration of this phase exceeded what was reported by other authors for 21-60 days [34, 37, 38], but was shorter than the period indicated for *O. joconostle* Weber [37]. The period of time between the end of the emission of floral buds and the beginning of flowering for the three varieties Achefri, Aissa and Moussa in Agadir area, varied from 15 to 23 days in 2011 and 55 to 66 days in 2012 [4]. Several authors reported that the duration of this period for many varieties vary from 7 weeks [34, 36] to two months and half [2]. In Agadir area, the period of flowering of the variety Achefri in 2012 was 65 days long, 81 days for Moussa, and 89 days long for 'Aissa' [4]. Similar periods-ranging from two months to 100 days-are reported by other authors in some countries (Brazil, Italy, Mexico, South Africa) [34, 36, 38, 39, 40]. Several authors indicated that flowering in cactus pear is not synchronous: in parallel with the floral buds emission and formation, flowers are at the first stage of differentiation, others are in flowering and fruit growth is simultaneously occurring [4, 35, 38] (figure 1). The overlay of the phenological phases of flowering and fruiting of cactus pear in the Agadir area in Morocco was reported by Arba et al. [4] on the varieties

'Achefri', 'Aissa' and 'Moussa' (figure 2). The consequence of the superposition of these phenological phases is that the phases of flowering and ripening are spread out over a period of several months [4]. Several authors reported that the phase of flowering is the period which extends from the beginning of flowering (5% of open flowers) until the end of flowering [35, 41]. Therefore, Barbara [42] determined the duration of a phenological phase of flowering or fruiting as the period which extends from the week when the characters of this phase are visible on a variety until the last week when these characters are visible on this variety. Thus, the period of flowering for example extends from the week when open flowers are visible on a variety until the last week when the open flowers are visible on this variety.



Legend: ←→ 2011 season
←→ 2012 season

Figure 2 Phenologic phases of flowering and fruiting of the varieties 'Achefri', 'Aissa' and 'Moussa' during 2011 and 2012 in the Agadir area, Morocco [4]

Cactus pear is able to flower a second time during the same year if the environmental conditions are favorable (i.e. frequent fogs or high hygrometry of the air) or through the use of advanced agriculture techniques such as irrigation during the dry summer period [3, 4]. This phenomenon is called “reflowering” and it presents a non-negligible interest to the farmers by improving their income [4]. Cactus pear flowers are typically yellow, sometimes pink, and rarely white. Flowers are cup-shaped without floral tube. They are sessile, large, often solitary and regular. They are composed of several sepals, yellow petals, stamens, and a single pistil with a lobbed stigma at the apex (figure 3). Stamens and pistil are yellow or green. In *O. ficus-indica*, the average number of petals is 11 and that of stamens is for 240 [4, 34, 35]. The ovary is located under the floral parts; it's composed of several fused carpels and numerous ovules with parietal placentation [3, 4, 34]. The number of ovules per ovary varies from 150 to 400 and that of pollen grains per flower is about 160,000 [34, 35]. In the Mediterranean basin, flowers begin to open in the spring; it is followed by the development of fruits which reach maturity during the summer period [4, 34, 35]. Flowers of the prickly pears are commonly diurnal and anthesis begins early in the morning after sunrise. They typically remain open between 8-11 a.m., but some flowers can remain open until the next day [4, 34, 35]. Full flowering occurs around midday, after which the perianth starts to close gradually until it is completely closed by the end of the day [4, 35, 38]

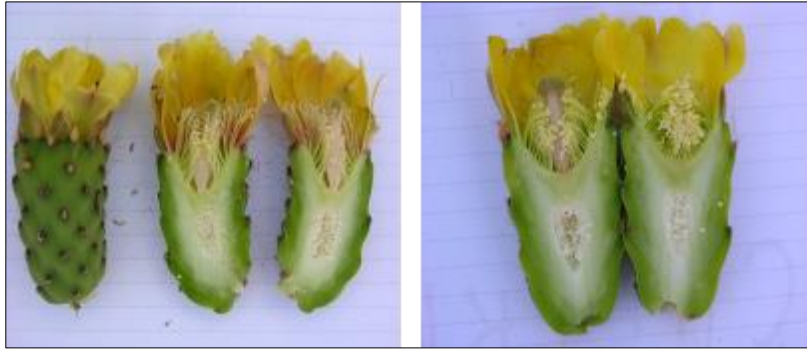


Figure 3 Longitudinal section of cactus pear flower that shows the flower structure and the floral parts

Flowers are often hermaphrodite in cactus pears, but cross-pollination occurs also [4, 34, 35]. Bees are the major pollinators of the prickly pears, and factors favoring the pollination of these plants are the auto-incompatibility and the unisexuality, the dichogamy (male and female organs do not mature at a same time), and the herchogamy (space between anthers and stigma). About 30% of received pollen grains germinate on the style, and the germination of these pollen grains and the development of pollen tubes in the style are made within 24-48 hours [4, 34]. About 95% of formed flowers can yield fruits, whereas in fruit-bearing species like apple, avocado, and orange trees, less than 10% of flowers are transforming into fruits [4, 34].

4.3. The fruit development period (FDP) and fruit maturation

The FDP is the period of time between the formation of floral buds and the ripening phase (50% of fruit maturation) [4, 42]. Floral buds are formed when they reach a length of 4-5 mm; at this stage they become spherical and easy to distinguish from vegetative buds, which are punt-shaped [4, 42]. The FDP varies between varieties and regions, as it depends on the climatic conditions of the cultivation medium [4, 38, 42]. It's for 120-130 days for the majority of varieties in South Africa, and can reach up to 148 days in plants with earlier emission of floral buds [42]. The FDP of *O. ficus-indica* is for 96 days in Brazil [38] and about 122 days in Italy [36]. In Morocco, the FDP of the varieties Achefri, Aissa and Moussa in the Agadir area was 145-165 days long in 2011, and 172-188 days long in 2012 [4, 43]. Arba et al. [4] reported that the fruit maturation period of the varieties Achefri, Aissa and Moussa during 2011 in the Agadir area extended from the end of June to mid-September. It was 63 days long for 'Achefri' (it extend from July 7th to September 8th); 72 days for 'Moussa' (it's located between June 28th and September 8th) and 79 days for 'Aissa' (from June 28th to September 15th). In 2012, the period of maturation was 61 days long for 'Achefri' (from July 7th to September 8th), 84 days for 'Moussa' (from June 14th to September 6th), and 76 days for 'Aissa' (from June 22nd to September 6th). The end of the fruit maturation period for all the three varieties occurred between the 6th and the 15th of September for both years. The fruit maturation period of the varieties varies also between regions and even within a variety between environmental conditions [4, 44].

4.4. Species and cultivars cultivated in the world

Opuntia ficus-indica is the most cultivated species in the world due to its delicious and juicy fruits and its cladodes which are used in human and animal consumption [1, 5]. Several varieties are cultivated in many countries, mainly in Mexico which is the origin country of cactus pear, with high degree of genetic diversity. It's also the greatest country of consumption of cactus pear in the world [2]. The main species cultivated in Mexico are: *O. ficus-indica*, *O. joconoxtle* Weber, *O. megacantha* and *O. streptocantha* Lem. [9]. The main wild species are: *O. robusta* Wend., *O. streptocantha*, *O. leucotricha* DC., *O. hyptiacantha* Weber and *O. chavena* Griffiths; they are harvested on 3 million ha in the arid and semi-arid areas of Mexico (Chihuahua, Zacatecas, San Luis Potosí, ...) [9]. Gallegos-Vasquez et al. [45] reported that 18 varieties of cactus pear distributed between 12 species are producing fruits in Mexico: *O. albicarpa* with 7 varieties (Reyna, Cristalina, Esmeralda, Chapeada Falayuca, Labaria), *O. megacantha* with 4 varieties (Picochulo, Amarilla noutesa, Copena), one variety in each of the species *O. ficus-indica* (Roja San Martin), *O. amyoclea* Tenore and *O. undulata* Griffiths (Bolanera), and 4 other *Opuntia* sp (Blanca San José, Amarilla platano). In the USA, the species *O. lindheimeri* Engelm. is the most used as forage crop [9]. The main cultivated cultivar in Argentina is 'Amarilla sin espinas', a spineless cultivar which yellow fruits [46]. In this late decade, producers have introduced *O. ficus-indica* as forage crop [9]. *O. ficus-indica* is also the most species cultivated in Chile where it gives two crops per year without any cultural practice: the first in February-April and the second in July-September [47]. In Peru, *O. ficus-indiaca* with different fruit color (yellow, greenish and red) is cultivated for fruit production. The main cultivated species in Tunisia is *O. ficus-indica form inermis* and the Sicilian varieties 'Rosa', 'Gialla' and 'Bianca' are used for fruit production. As in Morocco, the agro-industry of cactus pear transformation has also expanded in Tunisia, and several enterprises are specialized in the production of

cactus pear fruits and cosmetic (seed oil, soap and shampoo) and pharmaceutical products (nopal powder). In South Africa germoplasm collections of 42 types or varieties of *O. ficus-indica* are established in Eastern and Western Cape provinces for research purposes [9, 48]. Oelofse et al. [49] have described the plant and fruit characteristics of 10 varieties of different species in South Africa and Ledwaba et al. [50] have compared fruit quality characteristics of 25 varieties with different pulp color among different species of cactus pear in this country.

In Morocco, cactus pear is composed of an important genetic diversity; it includes thorny varieties with spines of different sizes and colors and spineless varieties (without spines). Many spiny varieties are cultivated in the country: (i) the species *O. megacantha* with green-glaucous pads having the similar shape of those of *O. ficus-indica* and white thorns with black tip. It is a common species in Morocco where it's cultivated in different varieties. The variety 'Achefri' (figure 4) is very cultivated in the south part of Morocco, in the areas of Souss, Sidi Ifni and Guelmim and the variety 'Draibina' is cultivated in the indoor central area of Khouribga-Oued Zem. The varieties 'El Harcha' and 'Beldiya' are cultivated in the area of Rhamana and Sraghna (in the north part of Marrakech) [51] and 'Shoul' and 'Mejdoubia' varieties are grown in the coastal part of Rabat-Mohammedia [52]. All these varieties are producing fruits with yellow-orange pulp when ripe. A red pulp fruit variety of *O. megacantha* is also cultivated in Khouribga area where it is called 'Draibina Lhamra' (Red Draibina). The variety 'Dellahia' (*Opuntia robusta* var *guerrana*) (figure 5) is another thorny species which is cultivated in the mediterranean coast of Morocco, in El Hoceima area; its pads are also glaucous green, but smaller than those of *O. megacantha*, and its whitish-green pulp fruit when ripe is with a watermelon appearance to the touch. Another thorny species with oval and long pads (*Nopalea cochenilifera*) produces edible fruits in the north part of Morocco, in Chefchaouen area where it's very cultivated. The variety 'Chyadmya' (*O. Shumannii* Web.) is cultivated in Essaouira area where it produces small fruits like local pears with purple red pulp and acidic task. Its pads are light green, smaller than those of 'Dellahia' variety and are bearing strong yellow spines and abundant yellow glochids. Three other spiny species which produce edible fruits in Morocco are reported by Mabrouk et al. [51]: *O. dillenii* in the Chaouia-Ouardigha area, *O. robusta* Wend. In the oriental area and *O. leuchotricha* DC. In the Middle Atlas area.



Figure 4 Variety 'Achefri' of *Opuntia megacantha* Salm-Dyck cultivated in south-west Morocco (photo credit [4])



Figure 5 Variety 'Dellahia' (*Opuntia robusta* Wend. var *guerrana*) cultivated in the Mediterranean coast of Morocco, in El Hoceima area

The spineless species *O. ficus-indica* (figure 6) is the most cultivated in Morocco among the Mediterranean and Atlantic coast where it is cultivated in different varieties: the varieties 'Aissa' and 'Moussa' cultivated in the south part of Morocco, in Sidi Ifni area (located in south of Agadir); they are well known in Morocco for their delicious task fruits. The first is an early variety and the second is late. Their pulp fruits are orange-yellow when ripe (figure 7). Two other seasonal varieties are also cultivated in Sidi Ifni area, but they are little known: the variety 'El Akria' with carmine red pulp fruit and the variety 'El Bayda' with whitish green pulp fruit (figure 7). The variety 'Rhamnia' and *O. ficus-indica* form inermis are cultivated in the Rhamana area; their pulp fruit is yellow-orange when ripe [51]. The varieties 'Doukkali' with yellow-orange pulp and 'Laâkri' with red pulp fruit are cultivated in Doukkala area (the Atlantic littoral area of El Jadida) and the variety 'El Haddaouia' is cultivated in Ouled Haddou area, in Casablanca.



Figure 6 Tree and fruits of *Opuntia ficus-indica* (L.) Mill. cultivated in Morocco



Figure 7 Cultivars of cactus pear *Opuntia ficus-indica* cultivated in Morocco: (a, b) variety 'Moussa'; (c, d) variety 'El Akria'; (e, f) variety 'El Bayda'

Many vernacular names are given to Opuntias in Mexico and other countries [2]. The vernacular names 'tuna', 'Nopal' and 'Tenochti' are given for several species and varieties of *Opuntia* in Mexico. Several other names are given to Opuntias in other countries: "Indian fig" in English countries, "Fico d'India" in Italy, "Palma forrageira" in Brazil, "Assabar" in Arabic countries, and "Figuier de Barbarie" in French countries.

4.5. Molecular studies on *Opuntia* species and cultivars

Several taxa, in particular *O. megacantha* and *O. streptacantha* Lemaire, are mentioned to be the ancestors of *O. ficus-indica* [1], and Scheinvar [53] has considered *O. ficus-indica* a cultivated form of *O. streptacantha*. Griffith [17] has considered *O. megacantha* a wild spiny form of the spineless *O. ficus-indica*. However, several authors indicated that *O. megacantha* and *O. ficus-indica* have a common ancestor and both resulted from natural hybridization [9]. Other authors have considered *Opuntia megacantha* a synonym of the spiny form of *O. ficus-indica* or a reversed spiny form from the spineless form *O. ficus-indica* [5, 54].

Chromosome number and ploidy level are useful tools in the taxonomy of *Opuntias*. The number of chromosomes in somatic cells of the cactus family is often $2n = 22$. In the genus *Opuntia*, taxa are often polyploid and some others are tetraploid, hexaploid or octoploid [9]. Polyploidy is favoured by natural hybridization [55] and hybridization in cultivation is also common in cactus pears, and higher levels of ploidy are found in cultivated plantations than in wild populations [56]. *O. amyntea*, *O. ficus-indica*, *O. megacantha*, and *O. streptacantha* are octoploids ($2n = 88$) [57], and other octoploids are also reported for other taxa in the genus *Opuntia* [58, 59]. However, the species *O. ficus-indica* could be also heptaploid, pentaploid, hexaploid or diploid, depending on the provenance of the plants of the species [59, 60].

Since taxonomic studies based on the morphological characters are not always evident in the determination of the *Opuntia* species, the importance is given by several authors to molecular studies on the genetic diversity of *Opuntias* [14, 61, 62, 63]. Labra et al. [14] reported a high genetic similarity between *O. ficus-indica* and *O. megacantha*. The only difference between the two species is the presence or absence of spines. These last authors have concluded that *O. ficus-indica* could be a domesticated form of *O. megacantha*. DNA analysis on five spiny and spineless cactus pear fruit varieties from Mexico and Chile, two ornamental varieties from Texas, and one vegetable variety from Mexico, revealed significant differences between ornamental and vegetable varieties, but very small differences between the fruit varieties [64]. Molecular studies carried out by Griffith [17] and Barthlott et al. [65] on *O. ficus-indica* have shown a supported clade including *O. ficus-indica*, *O. streptacantha*, *O. tomentosa*, *O. leucotricha* and *O. hyptiacantha*, all from central and southern Mexico. Majure et al. [66, 67] have concluded that the origin of *O. ficus-indica* and several other species is the polyploidy caused by the hybridization of different species. Some other authors reported that a group of species: *O. ficus-indica*, *O. albicarpa* and *O. megacantha* [68] or *O. ficus-indica*, *O. albicarpa*, *O. megacantha*, *O. streptacantha* Lem, *O. lasiacantha* Pfeiff. and *O. hyptiacantha* Weber [69] are not separated to different clades.

5. Conclusion

A great number of cactus pear species and cultivars are cultivated worldwide for fruit production, young cladodes as vegetable and adult pads as feed for animals. Cactus pears are grown in more than 30 countries and the most cultivated species for fruit production are *O. ficus-indica* (the dominant species), *O. amyntea*, *O. xocnostle*, *O. megacantha* and *O. streptacantha*, and the wild species used for fruit production are *O. hyptiacantha*, *O. leucotricha* and *O. robusta*.

Cactus pears have been used since centuries as food resources for Human and animals. They have a great economic potential due to their drought resistance in the arid and semi-arid climates and the beneficial income of their products (fruits, pads, young cladodes, and flowers) and by products (cosmetics and pharmaceuticals). The prickly pears are among the most diverse and widely distributed species in the worldwide arid and semi-arid regions and the highest richness of edible fruits and vegetable species is in Mexico, the origin country of cactus pear. In the Mediterranean basin, cactus pear is also present with an important degree of genetic diversity. Several varieties are cultivated in this basin for fruit production and animal feed, and cactus pears are now part of the agricultural systems and natural environment of the worldwide arid and semi-arid areas.

Compliance with ethical standards

Acknowledgments

Many thanks for my establishment, Hassan II Institute of Agronomy and Veterinary Medicine and Gembloux Agro Bio-Tech for their support.

References

- [1] Casas A, Barbera G. Mesoamerican domestication and diffusion. In: Nobel PS, ed. *Cacti: Biology and uses*. USA: University of California Press; 2002. p. 143-162.

- [2] Reyes Aguero JA, Aguirre JR, Hernandez HM. Systematic notes and a detailed description of *Opuntia ficus-indica* (L.) Mill. (Cactaceae). *Agrociencia*. 2005; 39: 395-408.
- [3] FAO. Agro-industrial utilization of cactus pear. Rural Infrastructure and Agro Industrial Division. Rome: FAO; 2013
- [4] Arba M, Falisse A, Choukr-Allah R, Sindic M. Biology, Flowering and fruiting of the cactus *Opuntia spp.*: A review and some observations on three varieties in Morocco. *Brazilian Archives of Biology and Technology*. 2017; 60: 1-11.
- [5] Kiesling R. Origen, domesticacion and distribucion of *Opuntia ficus-indica*. *Journal of the Professional Association for Cactus Development*. 1999; 3: 50-59.
- [6] Bravo Hollis H, Scheinvar L. El interesante mundo de las cactáceas. Mexico: National Council of Science and Technology; 1995.
- [7] Zimmermann HG, Moran VC, Hoffmann JH. Invasive cactus species (Cactaceae). In: Muniappan R, Reddy GVP, Raman A, eds. *Biological control of tropical weeds using arthropods*. USA: Cambridge University Press; 2009. p. 108-129.
- [8] Barbera G. History, economic and agro-ecological importance. In: Barbera G, Inglese P, Pimienta Barrios E, eds. *Agro-ecology, cultivation and uses of cactus pear*. Rome: FAO Plant Production and Protection Paper No. 132; 1995. p. 1-11.
- [9] Inglese P, Mondragon Jacobo C, Nefzaoui A, Carmen S. *Crop ecology, cultivation and uses of cactus pear*. Rome: FAO & ICARDA edition; 2017.
- [10] [10] Anonymus. *Field botany at Williams College*. USA: edition Williams College; 2006.
- [11] GRIN. *Opuntiaceae information from NPGS (National plant germplasm system) of GRIN (Germplasm resources information network)*. Taxonomic information on cultivated plants in the USA. Maryland, USA: National genetic resources program, Department of Agriculture, Agricultural research service; 2007.
- [12] Zimmermann HG. History of invasive succulent plants in the region. *Abc Taxa*. 2011; 11: 13-19.
- [13] Leuenberger BE, Arroyo Leuenberger S. Northern hemisphere *Opuntia* and *Cylindropuntia* species (Cactaceae) naturalized in Argentina, and the riddle of *Opuntia penicilligera*. *Succulent Plant Resource*. 2014; 8 : 95-112.
- [14] Labra M, Grassi F, Bardini M, Imazio S, Guiggi A, Citerio S, Banfi E, Sgorbati S. Genetic relationships in *Opuntia* Mill. genus (Cactaceae) detected by molecular marker. *Plant Science*. 2003; 165: 1129-1136.
- [15] Cronquist A, Thorne RF. Nomenclatural and taxonomic history. In: Behnke, HD, Mabry TJ, eds. *Caryophyllales*. Berlin, Heidelberg: Springer; 1994. p. 5-25.
- [16] Clement JS, Mubry TJ, Wyler H, Dreiding AS. Chemical review and evolutionary significance of the betalains. In: Behnke, HD, Mabry TJ, eds. *Caryophyllales*. Berlin, Heideleberg: Springer; 1994. p. 247-261.
- [17] Griffith MP. The origins of an important cactus crop, *Opuntia ficus-indica* (Cactaceae): New molecular evidence. *American Journal of Boany*. 2004; 91(11): 1915-1921.
- [18] Novoa A, Le Roux JJ, Robertson MP, Wilson JRU, Richardson DM. Introduced and invasive cactus species: a global review. *AoB Plants*. 2014; 6: 1-14
- [19] Anderson EF. *The cactus Family*. Oregon, USA: Timber Press. 2001.
- [20] Mottram R. Linnaean cactus legacy. *Cactician*. 2013; 3: 1-83.
- [21] Inglese P, Basile F, Schirra M. Cactus pear fruit production. In: Nobel PS, ed. *Cacti: Biology and uses*. USA: University of California Press; 2002. p. 163-183.
- [22] Santo-Ares T, Venusa de Silva M, Alves de Almeida CM, Oliveira D. Genetic diversity in cactus clones using ISSR Markers. *Acta Horticulturae*. 2009; 81: 55-65.
- [23] Gallegos Vazquez C, Mendez Gallegos S de J, Mondragón Jacobo C. *Produccion sustentable de la tuna en San Luis Potosí*. San Luis Potosí, Mexico: Fundacion San Luis Potosí Produce, Colegio de Postgraduados; 2013.
- [24] Ciriminna R, Chavarría-Hernández N, Rodríguez-Hernández AI, Pagliaro M. *The unfolding bioeconomy of nopal (Opuntia spp.)*. Mexico: Frenksiv Papers; 2018.
- [25] Inglese P. Cactus pear *Opuntia ficus-indica* (L.) Mill. for fruit production: An overview. Rome: FAO Cactusnet Newsletter special issue; 2010.
- [26] Targa MG, Leguizamon G, Coronel de Renolfi M, Ochoa MJ. Economic feasibility of scozzolatura in traditional and improved orchards of cactus pear in Santiago del Estero, Argentina. *Acta Horticulturae*. 2013; 995: 189-200.

- [27] Ian H, Varnero MT, Bedregal C. Nopal (*Opuntia ficu-indica*) energetic potential cultivated in arid and semi-arid zones of Chile: An assessment. *Idesia*. 2020; 38(2): 119-127.
- [28] Le Houerou HN. Cacti (*Opuntia* spp.) as a fodder crop for marginal lands in the Mediterranean Basin. *Acta Horticulturae*. 2002; 581: 21-46.
- [29] OEP (Office of Livestock and Pasture). *Stratégie nationale d'amélioration pastorale*. Tunisia: Ministry of Agriculture; 2016.
- [30] Belkacem S, Hammiche H. Une ressource territoriale à valoriser: cas du figuier de barbarie. Master en sciences économiques. Tizi-Ouzou, Algérie: Université Miloud Mammeri, Faculté des sciences économiques, commerciales et des sciences de gestion; 2015.
- [31] Snyman HA. Effect of various water applications on root development of *Opuntia ficus-indica* and *O. robusta* under greenhouse growth conditions. *Journal of the Professional Association for Cactus Development*. 2004; 6: 35-61.
- [32] Snyman HA. A case study on *in situ* rooting profiles and water-use efficiency of cactus pears, *Opuntia ficus-indica* and *O. robusta*. *Journal of the Professional Association for Cactus Development*. 2005; 7: 1-21.
- [33] Nobel PS. Environmental biology. In: Barbera G, Inglese P, Pimienta Barrios E, eds. *Agro-ecology, cultivation and uses of cactus pear*. Rome: FAO Plant Production and Protection Paper No. 132; 1995. p. 36-48.
- [34] Pimienta-Barrios E, Del Castillo RF, Reproductive Biology. In: Nobel PS, ed. *Cacti: Biology and uses*. USA: University of California Press; 2002. p. 75-90.
- [35] Reyes-Aguero JA, Aguirre JR, Valiente-Banuet A. Reproductive biology of *Opuntia*: A review. *Journal of Arid Environments*. 2006; 64: 549-585.
- [36] Nerd A, Mizrahi Y. Reproductive biology of cactus fruit crops. *Horticultural Review*. 2010; 18: 321-346.
- [37] Reyes-Aguero JA, Aguirre JR, Rodriguez-Flores JL. Variación morfológica de *Opuntia* (Cactaceae) en relación con su domesticación en la altiplanicie meridional de México. *Interciencia*. 2005; 30(8): 476-484.
- [38] Segantini DM, Torres LA, Boliani AC, Leonel S. Phenology of cactus pear in Selviria-MS State, Brazil. *Revista Brasileira de Fruticultura*. 2010; 32(2) : 630-636.
- [39] Mulas M. Blossoming and fructification cycle of *Opuntia ficus-indica* Mill. in the Mediterranean environment. Santiago, Chile: Acts of the 2nd International Congress on cactus pear and cochineal; 1992. p. 53-60.
- [40] Lenz M, Orth AI. Mixed reproduction systems in *Opuntia monacantha* (Cactaceae) in Southern Brazil. *Brazilian Journal of Botany*. 2012; 35(2): 49-58.
- [41] Chessa I, Nieddu G. Descriptors for cactus pear (*Opuntia* spp.). FAO Cactusnet Newsletter special issue. Sassari, Italy: Tipografia moderna; 1997.
- [42] Barbara KM. Characterization of cactus pear germplasm in South Africa. A thesis of Philosophiae Doctor. South Africa: University of the Free State, Faculty of Natural and Agricultural Sciences; 2007.
- [43] Arba M, Falisse A, Choukr-Allah R, Paul R. Phenology of flowering and fruiting of cactus pear and effect of NP fertilizing. *Acta Horticulturae*. 2015; 1067: 31-38.
- [44] Valdez-Cepeda RD, Blanco-Macias F, Magallanes-Quintanar R, Vasquez-Alvarado R, Mendez-Gallegos de Jesus S. Fruit weight and number of fruits per cladode depend on fruiting cladode fresh and dry weight in *Opuntia ficus-indica* (L.) Mill. variety. *Scientia Horticulturae*. 2013; 161: 165-169.
- [45] Gallegos-Vasquez C, Cevantez Herera J, Reyes-Aguero JA, Torrejoja Fernandez MR, Mondragon Jacobo C, Luna Vasquez J, Martinez Gonzalez JC, Rodriguez EI. Inventory of the main commercial cactus pear (*Opuntia* sp) cultivars in Mexico. *Acta Horticulturae*. 2006; 728: 17-28.
- [46] Ochoa MJ. Cactus pear (*Opuntia* spp.) varieties: main characteristics in Republic Argentina. Rome: FAO Cactusnet Newsletter special issue; 2003.
- [47] Saenz C, Berger H, Corrales Garcia J, Galletti L, Garcia del Cortazar V, Higuera I, Mondragon Jacobo C, Rodriguez Feliz A, Sepulveda E, Varnero MT. Utilización agroindustrial del nopal. Rome: FAO Plant Production and Protection Paper 162; 2006.
- [48] Menezes CMD, Schwalbach LMJ, Combrinck WJ, Fair MD, De Waal HO. Effects of sun-dried *Opuntia ficus-indica* on feed and water intake and excretion of urine and faeces by Dorper sheep. *South African Journal of Animal Science*. 2010; 40: 491-494.
- [49] Oelofse RM, Labushange MT, Potgieter JP. Plant and fruit characteristics of cactus pear (*Opuntia* spp.) cultivars in South Africa. *Journal of the Science of Food and Agriculture*. 2006; 86: 1921-1925.

- [50] Ledwaba CR, Nmbi NE, Maphohla VV, Ngwepe MR, Dikgwalthe SB. Comparison of fruit quality characteristics of 24 cactus pear cultivars with different pulp colours at Mara ADC, Limpopo. Limpopo provincial government, South Africa: Departement of agriculture; 2012.
- [51] Mabrouk A, Abbas Y, Fakiri M, Benchekroun M, El Kharrassi Y, El Antry-Tazi S, El Mzouri E. Phenological characterization among Moroccan ecotypes of cactus (*Opuntia spp.*) under soil and climatic conditions of the Chaouia-Ouardigha region. *Journal of Materials and Environmental Science*. 2016; 7(4): 1396-1405.
- [52] Oumato J. Etude des caractères physico-chimiques et organoleptiques de quelques variétés de figuier de Barbarie et valorisation du cactus en produits confits. Thèse de doctorat d'état en sciences agronomiques. Rabat, Maroc: Institut Agronomique et Vétérinaire Hassan II; 2018.
- [53] Scheinvar L. Taxonomy of utilized *Opuntias*. In: Barbera G, Inglese P, Pimienta-Barrios E, eds. *Agro-ecology, cultivation and uses of cactus pear*. Rome: FAO Plant Production and Protection Paper No. 132; 1995. p. 20-27.
- [54] Brutsch MO, Zimmermann HG. The prickly pear (*Opuntia ficus-indica*, Cactaceae) in South Africa: Utilization of the naturalized weed, and of the cultivated plants. *Economic Botany*. 1993; 47(2): 154-156.
- [55] Griffith MP. Using molecular data to elucidate reticulate evolution in *Opuntia* (Cactaceae). *Madrono*. 2003; 50: 162-169.
- [56] Mondragon Jacobo C, Bordelon BB. Cactus pear (*Opuntia spp.* Cactaceae) breeding for fruit production. *Journal of the Professional Association for Cactus Development*. 1996; 1: 19-35.
- [57] Palomino G, Heras HM. Karyotypic studies in *Opuntia cochineria*, *O. hyptiacantha*, and *O. streptacantha* (Cactaceae). *Caryologia*. 2001; 54: 147-154.
- [58] Segura S, Scheinvar L, Olalde G, Leblanc O, Filardo S, Muratalla A, Gallegos C, Flores C. Genome sizes and ploidy levels in Mexican cactus pear species *Opuntia* (Tourn.) Mill. series *Streptacanthae* Britton & Rose, *Leucotrichae* DC., *Heliabravoanae* Scheinvar and *Robustae* Britton & Rose. *Genetic Resources and Crop Evolution*. 2007; 54: 1033-1041.
- [59] Majure LC, Puente R, Pinkava DJ. Miscellaneous chromosome numbers in *Opuntieae* DC. (Cactaceae) with a compilation of counts for the group. *Haseltonia*. 2012; 18: 67-78.
- [60] Pinkava DJ. Chromosome numbers of the continental North American *Opuntioideae* (Cactaceae). *Succulent Plant Research*. 2002; 6: 78-98.
- [61] Bendhifi M, Baraket G, Zourgui L, Souid S, Salhi Hannachi A. Assessment of genetic diversity of Tunisian Barbary fig (*Opuntia ficus indica*) cultivars by RAPD markers and morphological traits. *Scientia Horticulturae*. 2013; 158: 1-7.
- [62] El Finti A, El Boullani R, Rallah M, Msanda F, Elmousadik A. Assessment of some agro-technological parameters of cactus pear fruit (*Opuntia ficus indica* Mill.) in Morocco cultivars. *Journal of Medicinal Plant Research*. 2013; 7(35): 2574-2583.
- [63] Ganopoulos I, Kalivas A, Kavroulakis N, Xanthopoulou A, Mastrogianni A, Koubouris G, Madesis P. Genetic diversity of Barbary fig (*Opuntia ficus-indica*) collection in Greece with ISSR molecular markers. *Plant Gene*. 2015; 2: 29-33.
- [64] Wang X, Felker P, Burrow MD, Paterson AH. Comparison of RAPD marker patterns to morphological and physiological data in the classification of *Opuntia* accessions. *Journal of the Professional Association for Cactus Development*. 1999; 3: 3-15.
- [65] Barthlott W, Burstedde K, Geffert JL, Ibisch PL, Korotkova N, Miebach A, Rafiqpoor M D, Stein A, Mutke J. Biogeography and biodiversity of cacti. *Schumannia*. 2015; 7: 1-205.
- [66] Majure LC, Puente R, Griffith MP, Judd WS, Soltis PS, Soltis DE. Phylogeny of *Opuntias* (Cactaceae): Clade delineation, geographic origins, and reticulate evolution. *American Journal of Botany*. 2012; 99(5): 847-864.
- [67] Chenna Kesava RS, Sucharitha KV, Venkata Ramana DK, Raveendra RM, Syamala B. Medicated prickly pear (*Opuntia ficus-indica*)-the new emerging agricultural crop in arid and semi-arid regions of India. *International Journal of Applied Biology and Pharmaceutical Technology*. 2014; 5(4): 264-270.
- [68] Valadez Moctezuma E, Samah S, Luna Paez A. Genetic diversity of *Opuntia spp.* varieties assessed by classical marker tools (RAPD and ISSR). *Plant Systematic Evolution*. 2015; 301: 737-747.
- [69] Samah S, De Teodoro Pardo CV, Serrato Cruz MA, Valadez Moctezuma E. Genetic diversity, genotype discrimination, and population structure of Mexican *Opuntia sp.*, determined by SSR markers. *Plant Molecular Biology Reporter*. 2015; 34: 146-159.