Opuntia ficus-indica (L.) Mill Species

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Opuntia ficus-indica (L.) Mill. (OFI) belongs to the *Cactaceae* family, which contains about 130 genera and nearly 1600 species. This plant is originally from South America, namely Mexico, and can be found in the Middle East, South Africa, India, Australia, and some Mediterranean countries.

Keywords: prickly pear ; food composition ; Opuntia ficus-indica

1. Botanical Aspects

Cactus refers to the botanical family *Cactaceae*, which encompasses about 1600 species divided into 130 genera, divided into the three subfamilies *Pereskioideae*, *Opuntioideae* and *Cactoideae* [1][2]. In the order *Caryophyllales*, the botanical genus *Opuntia* is the most common, grouping more than 300 species, namely the *Opuntia ficus-indica* (L.) Mill. (OFI) species [3]. The scientific name of this species was attributed in 1700 by the French botanist Joseph Pitton de Tournefort, due to the similarity to thorny plants that grew in the ancient Greek city of Opus. The OFI has various designations, depending on the country and the region where it is located. In Portugal, the common names of this species are prickly pear, agave, devil's fig tree, and tabaio or tabaibo (Madeira Archipelago) [4].

As a result of the long domestication to which it has been subjected, the OFI is characterised due to its genetic variability. Its taxonomy is complex, and its phenotypes vary according to the environmental conditions it is subjected to, increasing the diversity of adaptive responses. This plant has polyploidy, reproduction occurs sexually and asexually, and several hybrids are interspecific [5]. Thus, the taxonomic classification of this plant becomes difficult, and a detailed study is needed to recognise and identify each species, the varieties, and the adaptations reflected in its phenotype [6]. **Table 1** describes the taxonomic classification of the OFI, according to Britton et al. (1919) and Bravo-Hollis et al. (1978) [7][8][9].

Table 1. Taxonomic classification of *Opuntia ficus-indica* (L.) Mill [7][8][9].

OFI Taxonomic	
Domain	*Eukaryota*
Kingdom	*Plantae*
Subkingdom	*Embryophyta*
Phylum	*Spermatophyta*
Division	*Magnoliophyta*
Class	*Magnoliopsida*
Subclass	*Caryophyllidae*
Order	*Caryophyllales*

OFI Taxonomic	
Suborder	*Cactineae*
Family	*Cactaceae*
Subfamily	*Opuntioideae*
Tribe	*Opuntieae*
Genus	*Opuntia*
Subgenus	*Plantyopuntia*
Species	*Opuntia ficus-indica* (L.) Mill

OFI is derived from a diploid Mexican ancestry, but polyploidy is favoured by natural hybridisation [10]. Several studies have reported this species as octoploid, heptaploid, pentaploid, hexaploid, and diploid [11][12][13][14]. There is a variation in the number of chromosomes of this species, depending on the origin of the plant [5].

Cactaceae have a set of adaptive, evolutionary, and ecological strategies, which give them a great capacity for development in different habitats [15]. OFI adapts to extreme weather conditions and grows rapidly in poor soils with little need for water [16]. Thus, this species is the most cultivated in the world and the most economically important within the genus *Opuntia*, being a viable option in tropical and subtropical regions, where other plants cannot survive, mainly in arid areas (annual rainfall of less than 250 mm) and semi-arid regions (annual rainfall of 250 to 450 mm) [17].

2. Morphological Characteristics

OFI presents ecological adaptations due to the photosynthetic metabolism that occurs in cacti, namely, crassulacean acid metabolism (CAM). In these plants, the stomata open at night to fix carbon dioxide (CO_2) and accumulate oxygen (O_2), simultaneously losing water (H_2O), which leads to the gradual acidification of the stem. During the day, they keep the stomata closed and prevent the loss of H_2O through transpiration. The CO_2 is fixed overnight as malic acid ($C_4H_6O_5$), which is stored in vacuoles and used during the day [4]. In conditions of extreme water deficiency, stomata remain closed day and night, preventing transpiration and the entry of CO_2 [6]. In this way, CAM plants increase the efficiency of using H_2O and the ability to survive in arid and semi-arid environments [5].

Anatomically, the OFI consists of roots, cladodes, leaves, flowers, and fruits (**Figure 1**). OFI can reach up to 5 m in height and is very extensive, fleshy, and densely branched, with fine, absorbent surface roots. The root system develops horizontally, reaching laterally up to 10 to 15 m from the base of the plant [18][19]. The length of the roots is related to the environmental conditions, the type of soil, the availability of water, and the cultivation practices, mainly irrigation and fertilisation [6].

Figure 1. *Opuntia ficus-indica* (L.) Mill.

OFI stems, called cladodes, are fleshy and succulent, and are responsible for CAM (**Figure 1**). They have an ovoid or elongated shape, and their weight ranges from 40 to 100 g. The cladode length varies between 30 and 50 cm, the width varies between 20 and 30 cm, and the thickness varies between 2 and 4 cm. The outer part of the cladode is the chlorenchyma (green part), which is essential for its photosynthetic action, and the inner part of the cladode is the parenchyma, which corresponds to about 50 to 70% of the cladode, where H_2O and organic acids are stored [2][18][19]. Depending on environmental conditions, the cladodes have areolas, capable of developing new cladodes, flowers, or roots. Areolas have two types of spines in their cavity, serving as a means of defence against damage from prolonged exposure to sunlight and the attack of animals. Large thorns are modified leaves, and the glochids are sharp and grouped in large numbers [6][19]. As the plant ages, the base cladodes lignify and form a trunk-like structure [18].

The leaves develop on the areolas, only visible on the tender cladodes. The leaves are cylindrical and deciduous, remain on the plant for just over a month, and are widely used as animal feed [4][19].

The flowers are large and showy, develop in the upper margin of leaves, are hermaphroditic, and are pollinated by insects or wind [4]. They have no aroma, but beautiful colours, such as yellow, orange, pink, purple, red, or white. Due to the limited flowering duration (March to June), few studies have been carried out on this plant's flowers [16][19].

The prickly pear (PP) is the OFI fruit that is formed from an inferior ovary located in the stem tissues (**Figure 2**). Its maturation is completed about 110 to 120 days after flowering, and its final weight can vary between 80 and 200 g. PPs are ovoid or cylindrical, 5 to 10 cm long and 4 to 8 cm wide [4][18].

Figure 2. White, orange, and red prickly pear ecotypes and image of the respective cross-sections of the fruits.

The PP can be divided into peel, pulp, and seeds. Of the total weight of PP, 30 to 40% corresponds to the peel, 60 to 70% corresponds to the pulp, and 2 to 10% corresponds to the seeds [5][20].

The PP peel can be divided into pericarp and mesocarp. The pericarp is thin and presents the same morphology as the cladodes, including the glochids, and the mesocarp is edible and has nutritional value. However, the mesocarp is not customarily consumed because it is discarded when the fruit is peeled [1][4]. In the initial phase of fruit development, the peel is green, evolving with its maturation to other colours. Depending on the ecotype and variety of the plant, the peel may be greenish-white, yellow, orange, red, purple, or purplish [1][6]. The pulp is the edible portion of the fruit. It is soft, juicy, translucent, gelatinous, and velvety, with a sweet taste. Its colour corresponds to the colour of the peel and it has numerous tiny seeds with hard integuments [1][15]. The seeds, distributed regularly throughout the fruit, are dark, edible and have been extensively investigated [1][21]. The PP's short shelf life is 3 to 4 weeks, limiting its long-term storage and worldwide distribution [2].

3. Cultivation System

A successful PP crop must follow specific rules and procedures, always respecting good agricultural practices [22]. The main climatic factors affecting any culture's yield and quality are temperature, precipitation, sun exposure and wind. Therefore, before starting an OFI plantation, there are several aspects to consider, namely the climate of the place of cultivation, the physical and chemical characteristics of the soil, the choice of the cultivar, the preparation of the soil, the planting distances, the orientation crop rows, and the irrigation system, among other factors [5].

Regarding planting material, this can be obtained from simple asexual vegetative reproduction from whole cladodes or parts of cladodes or through in vitro micropropagation [6]. This last method provides high propagation rates, requires little space for cultivation, allows the production of healthy plants without the intervention of pathogens, selects specific genotypes, avoids physiological disturbances and morphological anomalies, and obtains plants with the desired characteristics [23]. Khalafalla et al. (2007) demonstrated that OFI micropropagation, through areolas, can combat desertification in arid and semi-arid areas [24].

The PP is a perennial crop with an annual cycle, which can occur naturally with a second flowering and subsequent fruiting when favourable conditions exist [18]. The physiological development of the PP occurs between 70 and 150 days after flowering, depending on the production season, variety/ecotype, climatic conditions, and post-harvest treatments. This development begins with an intense cell multiplication, followed by an increase in volume, which gives rise to the appearance of vacuoles, which accumulate nutrients [15]. There are three phases to fruit growth: dry matter growth of the husk, the development of dry matter of the seeds, and the development of the pulp. During maturation, changes occur in the colour of the peel and the texture of the fruit, the drop of glochids occurs, and the total soluble solids (TSS) content increases [18].

The parameters that help define the best PP harvest time are size, weight, and firmness of the fruit, changes in peel colour, degree of receptacle depth of the flower, the SST content, the minimum of 14 °Brix, the drop of glochids, the thickness of the peel, the ease of skin removal, and the pulp/peel ratio [6].

PPs are difficult to harvest due to glochids and spines, which can pierce the peel and enter the eyes and respiratory system of the person performing the collection. Therefore, this is carried out manually, during the night and until the beginning of the morning, when there is greater ease of cutting, better resistance to damage, and higher maintenance of turgor of the fruit tissues, in which the glochids are more humid and attached to the fruit [5]. There are several harvesting techniques: turning or twisting, which is a procedure that causes damage to the fruit and is used when the product is intended for processing; cutting flush to the insert, through which fruits are obtained with little conservation time, used when the fruit is for immediate consumption or sale; and cutting a small piece of the cladode attached to the fruit, which is the most used technique for the commercialisation of PP, as it allows an increase in the time of conservation [18].

After harvesting, the glochids are removed mechanically without damaging the epidermis of the fruits. Then the fruits are selected according to the purpose for which they are envisioned (or “for the purposed application”). Subsequently, the fruits are washed with drinking water or chlorinated with sodium hypochlorite to reduce the microbial load. Then the fruits are waxed by immersion in, or sprinkling of, wax, to control the loss of water by transpiration, reduce the intensity of the fruits’ gas exchange, improve the visual appearance, and prolong their conservation. The classification of PPs is performed manually or mechanically, according to colour and size [4][15]. Generally, the fruits are packaged on the day of harvest and transported to their destination in refrigerated conditions. If the fruits are handled a few days after harvest, they must be stored under certain conditions. For PP storage, low temperatures are recommended, between 5 °C and 8 °C, with a relative humidity between 85% and 95%, depending on various factors such as storage time, type of packaging, the season of harvest, and the variety of the fruit [15]. Under these conditions, the shelf life of the fruits varies between 3 and 8 weeks [18]. The *Codex Alimentarius* contains standards that describe the quality, presentation, packaging, and hygiene requirements relating to the PP [25].

Like other cultures, OFI can also suffer biotic diseases (fungal, bacterial, and viral infections) and abiotic diseases from frost, hail, herbicides, pesticides, and fruit splitting [5]. In Portugal, the PP species are relatively resistant to pests and diseases. Due to the resistance of this plant and the climatic conditions, which are not unfavourable, there are no stressful situations. Concerning diseases, these are mainly caused by fungi or bacteria and pests. The Mediterranean fly (*Ceratitis capitata*) is the insect that causes the most damage in the culture of PP, but damage can also be caused by ants, slugs, snails, mealybugs, and fruit flies [4][22].

4. Worldwide Distribution

The OFI originates from South America, namely Mexico. This species was introduced in Spain, by Christopher Columbus, in 1493, on one of his trips to America. Subsequently, the OFI was dispersed and naturalised in the Mediterranean area of Europe and northern Africa [10][19].

Due to its genetic variability, OFI has a high adaptability, ecological and, consequently, a wide geographic distribution, can be found in locations with diverse climatic conditions, including North, Central and South America, Northern, Central and Southern Africa, Middle East, Australia, India, and some Mediterranean countries [1][26].

The leading producers and consumers of OFI are Mexico and Italy, and it is in Mexico that this species has the highest degree of genetic diversity. Of the approximately 590,000 ha grown worldwide, Mexico and Italy contain 70% and 3.3%, respectively [17][27]. In Mexico, cladodes are the fifth most consumed vegetable, and PP is the third most consumed fruit [12].

In Europe, the economic and agricultural importance of the PP dates to the 16th century. The OFI began by decorating bourgeois-class gardens and properties, and then served as a hedge to delimit rural properties due to the thorns and, later, its fruits became a food source for the lower classes in times of food scarcity. Currently, PP presents itself in different forms, from fresh to processed, also being sold as a gourmet product [4][19].

In Portugal, mainly in the Alentejo and Algarve, the cultivation of OFI is allowed, being an introduced, naturalised, non-invasive species, which is in the phase of expansion, often being found on the edges of rural roads and paths or even to delimit private land [20][22]. Recently, the private sector has started focusing on this species’ growth for fruit production in

the semi-arid areas of the Alentejo and Algarve. Since 2009, with the help of a programme for unemployed young farmers, more than 200 ha have been planted, and a further 500 ha will be planted in the coming years [5].

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