

## The economic potentialities of cactus pear as food and forage crop for sustainable agriculture in the arid and semi-arid regions: A review

Mohamed Arba \*

*Plant Ecophysiology and Cultures of Arid zones laboratory, Department of Horticulture, Hassan II Institute of Agronomy and Veterinary Medicine Horticultural Complex of Agadir B.P. 121, Ait Melloul 5615, Morocco.*

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### Abstract

The adaptation of cactus pear to arid environments and its importance in animal and human feed make the species largely used in the arid and semi-arid regions. The economic potentialities of cactus pear as food and forage crop and its production in animal and human feed are higher. Cactus pear products and by-products and the production sustainability of cactus pear in the arid and semi-arid areas open a great number of opportunities and hopes to rural populations of these regions. These products and by-products constitute a source of income for low income of rural populations. The nutritional value of cactus pear products and their content in minerals and vitamins make cactus pear fruits and cladodes important in the animal and human feed in the arid and semi-arid areas. Medicinal and cosmetic by-products are also obtained from cactus pear products. They increase the economic income of the farmers and rural populations. Cactus pear is also an important forage for livestock in the arid and semi-arid regions thanks to its high biomass production and palatability. Cactus pear pads are consumed by all the types of livestock. They are rich in water and carbohydrates and their digestibility is high, but their content in crude proteins is low. Cactus pear could be a supplement for low quality fodder such as straw, and the combination of the two elements could be an alternative fodder for the animals of the arid and semi-arid regions.

**Keywords:** Morocco; Arid regions; Sustainable agriculture; Food and forage crop; Cactus pear products; Cactus pear by-products

### 1. Introduction

The land area of the world is occupied by the third of the arid and semi-arid areas and host more than two billion people [1]. These areas are a challenge to conventional cropping systems due to elevated temperatures, poor soils, and low rainfall. There is an increase of the pressure on the natural resources in the arid and semi-arid regions and the future of these regions depend on the cultivation of appropriate crops and the development of sustainable agricultural systems [2]. Low rainfall and its fluctuation in arid and semi-arid areas reduces the yield of annual crops such as cereals and beans, and the irrigation in these areas is restricted by the shortage of water. Therefore, the cultivation of naturalized species as cactus pear in these areas is a suitable alternative to produce food for humans and feed for livestock [3]. The low input demand in its cultivation for production make the cactus pear a sustainable crop, and both its cladodes and fruits can be used as food for humans and animals [4].

The crassulacene acid metabolism (CAM) of cactus pear which is a unique photosynthetic pathway characterized by stomata closing during the day and stomata opening during the night, with nocturnal CO<sub>2</sub> uptake, is the main agricultural

\* Corresponding author: Mohamed Arba

Plant Ecophysiology and Cultures of Arid zones laboratory, Department of Horticulture, Hassan II Institute of Agronomy and Veterinary Medicine Horticultural Complex of Agadir B.P. 121, Ait Melloul 5615, Morocco.

success of cactus pear. High water use efficiency and annual biomass productivity is provided in cactus pear than in C<sub>3</sub> and C<sub>4</sub> plants [5]. Its pads and fruits which provide feed for cattle and food for humans make the cactus pear to be the 'bridge of life' in the arid and semi-arid areas. Cactus pear is reducing malnutrition and contributing to the survival of humans and animals and the improvement of the quality of life in the arid and semi-arid regions [6].

The adaptability of cactus pear to arid and semi-arid climates is due to its interesting morphological and physiological characteristics. The capacity of the cladodes in storing a great amount of water in their aquifer parenchyma enables cactus pear to survive long periods of drought. Low number of stomata per cladode and their closing during the day helps cactus pear to reduce its transpiration. In extreme conditions of water deficiency, the stomata remain closed during both day and night, preventing transpiration and the entry of CO<sub>2</sub> [6].

In the 300 species of the genus *Opuntia*, about 15 species are largely cultivated in the arid and semi-arid regions for their edible fruits, their young cladodes as vegetables, and their pads as forage [6]. In the Mediterranean basin the species *Opuntia ficus-indica* (L.) Mill. is the most cultivated [7]. Cactus pear provides multiple benefits for the society; it provides food for human (e.g. fruit, vegetable) and feed for livestock, and protects soil against erosion and desertification [3]. Cactus pear also contributes to sustainable food and feed production in the arid and semi-arid areas [8].

Cactus pear can be developed and grown in areas where rainfall is weak (less than 250 mm). An average temperature of 23 to 26 °C and full sunning are the favorable conditions for its growth and development. The prickly pear cactus can tolerate high (up to 45 °C or more) and low (up to -5 or -10 °C) temperatures, but for a short period of time (few days). It can adapt to a wide range of soil, but prefers light and draining grounds [9]. Cactus pear has taken a large importance in the arid and semi-arid regions and new plantations are established in the Mediterranean region [6, 10].

The main objectives of cactus pear in the arid and semi-arid regions is the socio-economic development of these regions and the generation of incomes for rural populations. Professional organizations (OP) (co-operatives and economic interest groups) are operational in the production and the marketing of cactus pear products and by-products in the arid and semi-arid regions. The cultivation of cereals in the arid areas is not profitable anymore because of the scarcity of rain, and cactus pear became the principal culture due to its drought resistance and the economic importance of its products in the development of these regions. Cactus pear by-products are manufactured by the OP and small companies. They are sold in the national market or abroad by order in the Web sites of the OP and companies for the cosmetic and medicinal by-products (seed and flower oils, dermal creams, nopal powder).

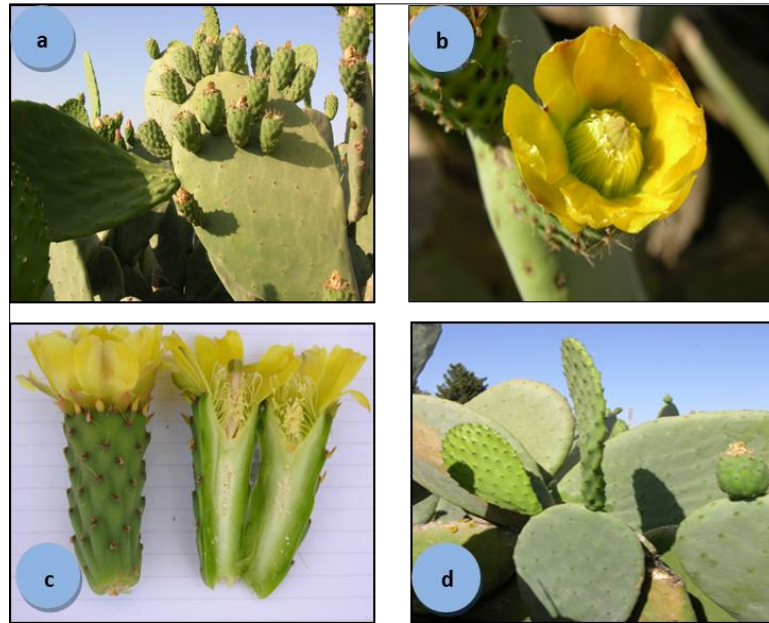
The agricultural systems of the arid and semi-arid regions are based on species that is little demanding for water, as cactus pear. The benefits offered by cactus pear make the species of first choice for the agricultural systems of the arid and semi-arid regions. Its cultivation requires less investment and its yield may be higher than other practiced cultures in these areas, including cereals.

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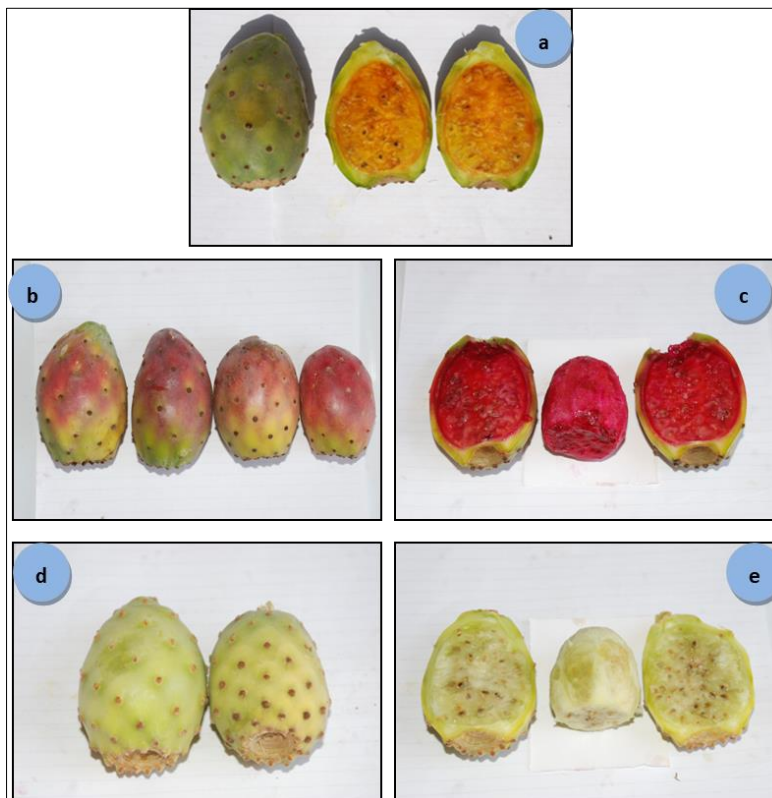
## 2. Geographical distribution and physiological features of cactus pear

Cactus pear is originated from South America [5]. It was introduced in Spain in the beginning of the 16<sup>th</sup> century. It has spread to the Mediterranean basin, Africa, Asia and Australia one century later. The prickly pear cactus can be found, wild or cultivated, in a wide range of agro climatic conditions across the world [4]. It's economically the most important in cactus family as it produce edible fruits. It's a xerophytic plant with flattened stems or cladodes that act as leaves for the photosynthesis. These stems are covered with areoles which are the axillary buds that can develop flowers, new cladodes or roots. The flowers are large, sessile, solitary, yellow color and hermaphrodite (Anon., 2006). Flowers and their futures and young cladodes are shown in figure 1. *Opuntia ficus-indica* is the most cultivated cactus species in the world and in the Mediterranean basin thanks to its sweet and juicy fruits with different colors such as yellow, orange, green, and red [6] (figure 2). It has also various medicinal and cosmetic uses [3].

Cactus pear often flowers once a year, but the plant can flower a second time and give a late fruit ripening in autumn under certain climatic conditions and agronomic practices like as fertilization and irrigation during the dry period of summer [11]. The fruit is fleshy and ovoid, and the pulp contains many seeds which are eaten with the pulp (figure 2). The peel of the fruits includes areoles with abundant yellow glochids [12].



**Figure 1** Flowers and fruits of cactus pear in the upper part of the cladode (a), (b) and (c) flowers and their parts (petals, stamens, ovules), and (d) young cladodes



**Figure 2** Cactus pear fruits of 3 different varieties of *O. ficus-indica* in southern Morocco: (a) variety 'Aissa', (b) and (c) cv 'El Akria', and (d) and (e) variety 'El Bayda'

The total area occupied by cactus pear in Mexico is around 3 million hectares (ha), including more than 70,000 cultivated hectares. Brazil is a major producer of cactus pear with about 500,000 hectares [13]. Around 3,000 ha for commercial production in Italy, 25,000 ha in Tunisia and more than 1,000 ha in each in Chile, Argentina and South Africa are reported by Inglese [14] in these countries. In Morocco, the area occupied by cactus pear has evolved remarkably during the last two decades, reaching around 150,000 ha. Therefore, recently (since the 2017 year), many plantations

of cactus pear 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. Several cooperatives and small firms of rural womens 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).

### 3. The potentialities of cactus pear as food crop

In addition to the use of its fruits and cladodes as food and forage crop, cactus pear also provide additional income to rural populations in the arid and semi-arid regions. Its young cladodes are used as vegetable; they are tender to consumption. Young cladodes are called ‘nopalitos’ in Mexico where they are very popular. Adult pads are used in animal feed, powder making and other products like as mucilage, pharmaceutical and cosmetic by-products. Flowers are edible and fruits are also used in juice, syrup or jams production [6, 7, 15]. Other alternatives for processing and valorizing cactus pear fruits and cladodes are recently developed (food additives, alcoholic drinks). Cactus pear products and by-products can be considered as a source of income for low income populations of the arid and semi-arid regions, and many possibilities of making by-products from cactus pear fruits, cladodes and flowers open a great number of opportunities to arid and semi-arid regions [6].

Intensive orchards of cactus pear are growing in several countries to produce flowers, cladodes and fruits for human consumption and animal feed, and many industries in certain of these countries use cactus pear products for the production of agri-foods, cosmetics and pharmaceuticals. General agronomic practices mainly irrigation, fertilization and pruning are used in these orchards. Intensive orchards for fruit production are grown in Italy, South Africa, Chile and Argentina [16]. Orchards for fruit production and feed for livestock are grown in Tunisia and Morocco where medicinal and cosmetic products on cactus pear are emerging. In south of Morocco, several co-operatives are currently involved in the production of cactus pear by-products: agri-food products (jam, juice, young cladodes cans), cosmetics (natural seed oil, dermal creams, soaps, shampoos, etc...) and pharmaceuticals (dried pads powder or nopal powder, dried flowers, ...), and a considerable number of these co-operatives have benefited from a financial support from the PMV (Moroccan Green Plan) or the INDH (National Initiative for Human Development) (figure 3). Mexico grow cactus pear for fruit and young cladodes production, and medicinal and cosmetic industries. Peru has an intensive cochineal cultivation for red dye production and Brazil is growing cactus pear for feeding livestock [3] (Dubeux, 2016).



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**Figure 3** By-products of cactus pear (jam, juice, cans of young cladodes, nopal powder, dried flowers, natural seed oil, soap from a Moroccan co-operative which has received a financial support from the INDH (National Initiative for Human Development)

Cactus pear fruit quality is based on fruit and pulp weight, sugar content, peel and pulp color, and seed content [17] (Kader, 2002). Pulp yield is a crucial factor for food production and the quantity of pulp in cactus fruit varies according to the zone of cultivation and agricultural practices [18]. Cactus pear fruits are appreciated for their characteristic taste and aroma as well as their dietetic properties [15]. The nutritional value of cactus pear fruits is similar to the other fruits including apple, apricot, cherry, melon and peach. Their content in soluble solids is high, and this makes them suitable for processing, as their high sugar contents are good for preservation. Cactus pear fruits are an important source of nutrients as proteins (0,21-1,6%), fat (0,09-0,7%), fiber (0,02-3.15%) and ash (0,4-1,0%). Cactus pear fruits have a high level of ascorbic acid (40 mg 100 g<sup>-1</sup>) and their calorific value varies between 31 and 50 kcal 100 g<sup>-1</sup>. They are a good source of minerals such as potassium (217 mg 100 g<sup>-1</sup>), calcium (15,4-32,8 mg 100 g<sup>-1</sup>) and phosphorus (12,8-27,6 mg 100 g<sup>-1</sup>). Their contents in amino acids is 257,24 mg 100 g<sup>-1</sup> [6]. The physio-chemical characters of the fruits of some varieties in Morocco are presented in table 1. Cactus pear fruits are classified according to their shape (round, elliptic, ovoid, or oblong) and varieties with ovoid or oval shape and large fruit size have more commercial value than the others [15]. Glochids on cactus pear fruits are easy to remove by mechanical brushing [18].

**Table 1** Physicochemical features of the fruits of cactus pear cultivars in Morocco

Physicochemical Characters of the fruits at ripening stage	Cultivars			
	'Moussa' cv. in Sidi Ifni area	'Moussa' cv. in Agadir area	'Mles' cv. in khouribga area	'Aissa' cv. in Agadir area
Fruit length (cm)	6.49± 0.16	7.14±0.1	6.67±0.2	7.24±0.1
Fruit diameter (cm)	4.92± 0.16	5.02±0.1	4.52±0.1	5.27±0.04
Fruit weight (g)	81.37± 2.22	122±3	66.31±3.84	135±2
Pulp weight (g)	48.65± 0.87	67.2±1.3	39.14±3.47	72.6±1.5
Peel thickness (cm)	0.41± 0.07	0.18	0.35±0.03	-
Dry weight of 100 g pulp	21.8± 0.36	-	-	-
Content of juice	18.82± 0.40 (ml/ 100 g pulp)	71.14%	49.9±2.8%	70.44%
Content of sugars	14.43± 0.28 (g/l juice)	56.78%	12.5±0.5 °Brix	52.47%
Titrateable acidity (TA)	-	52.47 g/l	0.069%±0.005	0.61 g/l
pH	-	6.10		6.12
Vitamin C (mg/ 100 g pulp)	-	-	17.3±1.1	-
Fertile seeds	3.65± 0.05 (/g fresh pulp)	-	70.22±5.94%	-
Aborted seeds	1.46± 0.13 (/g fresh pulp)	-	29.78±5.94%	-

Young cladodes of cactus pear or 'nopalitos' are eaten as vegetable, and like many other vegetables, they are rich in water and contain 3,5% fiber. They are an excellent source of proteins, vitamins, and amino acids (proline, taurine and serine) [19, 20]. Nopalitos are rich in minerals, mainly calcium (93 mg 100 g<sup>-1</sup>) and potassium (166 mg 100 g<sup>-1</sup>). They contain moderate amounts of carotenoids (30 µg 100 g<sup>-1</sup>) and vitamin C (11 mg 100 g<sup>-1</sup>), and low amounts of fats (0.3%), carbohydrates (5.6%) and sodium (2 mg 100 g<sup>-1</sup>) [21]. Their nutritional value is comparable to lettuce and spinach, while their dietary fiber is similar to other vegetables, such as spinach, artichoke, broccoli and radish [6]. Young cladodes of cactus pear are popular vegetable in Mexico and the southern United States where a great number of Mexican are living [22].

Fruits, flowers and cladodes of cactus pear contain a variety of nutrients and bioactive properties that are beneficial for human health [23]. These functional traits or components can help to treat or to prevent different diseases (high cholesterol in the blood, obesity) and enhance health for their contribution to a healthy diet [22]. The nutrients and bioactive properties of cactus pear products are fiber, mucilage, pigments (betalains and carotenoids), minerals (calcium and potassium) and vitamins, mainly vitamin C. Among these functional characteristics, fiber is the most

studied trait because it's the important element in the nutritional value of cactus pear fruits and cladodes [6]. The fiber helps in controlling cholesterol and the treatment of diseases like diabetes and obesity, and the use of cactus pear for the diabetes treatment has been cited by many authors [6, 23, 24, 25]. The demand for natural ingredients and health promoting foods is currently increased. Cactus pear medicinal properties are known since a long time and the products of this species open new hopes for the arid and semi-arid regions due to the sustainability in terms of production of cactus pear in these regions. The powder of cactus pear pads or nopal powder is an excellent element in the nutritional food for human body because it includes fibre (more than 50%), vitamins and minerals. These vitamins and minerals help our body to detoxify and to reduce level of blood sugar and cholesterol [6].

#### 4. The potentialities of cactus pear as forage crop

The degradation of rangeland in different areas of the world is due to the sharp increase in the population of livestock in these areas. The shortage of water is the major factor which limits livestock production and agriculture in the arid and semi-arid regions [26]. The resources of forage for livestock are limited, the green fodder is scarce and the productivity of rangelands in these regions is usually low ( $< 5 \text{ t DM (dry matter) ha}^{-1} \text{ yr}^{-1}$ ), with lower potential of forage ( $< 1 \text{ t DM ha}^{-1} \text{ yr}^{-1}$  of consumable forage) leading to less feeding capacity (12-15 ha to sustain an adult cow) [26, 27]. Fodder species resistant to drought are needed for a sustainable animal production in the arid and semi-arid areas. The prickly pear cactus could be an important forage crop for livestock in these regions due to its drought tolerance and its high biomass production and palatability. All types of livestock (cattle, sheep, goats, camels and horses) are reported to consume cactus pear pads [27]. They provide energy, water and minerals to animals [28]. Cactus pear pads provide water, vitamins, carbohydrates, and calcium that are required in the animal diet [29]. They are easily consumed by animals which preferred them to straw [15]. Cactus pear pads could be a supplement for low quality fodder such as straw, and the combination of the two could be an alternative feed for the nutrition of small ruminants in the arid and semi-arid areas [30]. Food intakes on the basis of cactus pear pads and other fodder elements are developed for sheep in North Africa (table 2). The fiber content in cactus pear pads is lower than in the basic feed, and forages with high fiber contents have poor dry matter intake (DMI) due to their low digestibility [30]. Cactus pear pads have high contents of carbohydrates, water and ash, but less amounts of dry matter (DM), crude proteins (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent leaf (ADL). Whereas, the straw contains high contents of NDF, ADF, ADL and CP [27]. The DMI of cactus pear pads is increased when fresh cladodes are dried before feeding, and animals consume more DM in dried forage than in wet fodder [15]. A low CP content in the pads could be improved by an application of N fertilizer or by adding another source of fodder. The chemical composition of cactus pear pads and other fodder including straw, hay and atriplex are presented in table 2.

The biomass production of cactus pear is very higher than the rangeland productivity (at least 60 times higher) and its potential production is for more than  $200 \text{ t fresh biomass ha}^{-1} \text{ yr}^{-1}$  and this biomass provides good quality water stored in the pads for livestock. This forage production of cactus pear is enough to sustain five adult cows per year. Therefore, the potential of cactus pear is still underexploited; the estimated surface occupied by cactus pear is less than 0.1% of the dry land area used as grasslands. [3, 26]. Brazil is the greater country in the production of cactus pear for livestock, and animal production is one of the main factors that ensure food security, creation of jobs, and income for rural families in the Brazilian arid regions [31]. The preferences in palatability of cactus pads is different between animals. Studies in Ethiopia have shown that the pads of certain varieties are more palatable for the animals than the pads of other varieties. DM of cactus pear pads of different varieties varied between 11,04 and 14,04%, their content in ash varied between 20,15 and 22,80%, while their content in CP varied between 5,38 and 6,02%. An average value of 5,4% CP for the pads of one year and 4,2% for the 2-year-old pads has been reported for different varieties in Mexico [16]. In southern Morocco, the minerals contents in cactus pear pads were also different between varieties and localities (table 2) due to variations in soil and climatic conditions among regions and locations [32]. The CP content in the pads of *O. ficus-indica* cv 'Moussa' in Sidi ifni area (9.37%) met the CP requirement of dairy cows (9.2%) [33] and the CP content of the same variety in Agadir area (6.43%) met the requirement of dry cows (5.9%). The cv 'Aissa' of the same species met the requirement of cows in Sidi Ifni area (8.31%) and both cultivars met those of sheep (0.21- 0.99%) [34] and goats (0.05-0.46%) [35] in both areas (5.37-9.37%).



**Table 2** Food intakes based on cactus pear pads and other fodder elements developed for sheep in North Africa, chemical composition of cactus pear pads in comparison with other fodders, and minerals contents in pads of cactus pear *Opuntia ficu-indica* (L.) Mill cvs. 'Aissa' and 'Moussa' in Sidi Ifni area and Agadir area

Food intakes based on cactus pear pads								
Fodder element	Food intakes developed in Morocco (Chriyâa 1998)				Food intakes developed in Tunisia (Nefzaoui & Ben Salem. 2000)			
	R1	R2	R3	R4	g DM/day	R1	R2	R3
Cactus pear (kg FM/day)	2,5	3,5	5,5	4,5		197	353	550
Atriplex (kg FM/day)	1,5	1,0	0,6			554	391	236
Straw (g/day)	200	200	200	600		160	159	167
CMV (g/day)	30	30	30	30				
Chemical composition of cactus pear pads in comparison with other fodders (Chriyâa, 1998)								
Fodder element	Crude proteins		ADF	NDF	Digestibility <i>in vitro</i>			
	% dry matter							
Cactus pear pads	4,8		27,5	15,8	78,7			
Wheat straw	5,2		69,6	42,4	45,5			
Alfalfa hay	13,8		47,1	31,3	59,4			
Atriplex	13,4		34,2	14,4	63,1			
Minerals contents in pads of cactus pear <i>Opuntia ficu-indica</i> (L.) Mill cvs. 'Aissa' and 'Moussa' in Sidi Ifni area and Agadir area in Southern Morocco								
Mineral elements	cv 'Moussa'		cv 'Aissa'		Level of significance			
	Locality Zluguim in Sidi Ifni area	Locality IAV Hassan II in Agadir area	Locality Ahl Haymad in Sidi Ifni area	Locality IAV Hassan II in Agadir area				
N (%)	1.50±0.08	1.03±0.12	1.33±0.10	0.86±0.04	*			
CP (%) (%N x 6,25)	9.37	6.43	8.31	5.37				
P (%)	0.20±0.02	0.092±0.00	0.090±0.00	0.084±0.01	**			
Ca (%)	5.12±0.35	4.78±0.33	3.99±0.79	4.26±0.54	ns			
Na (ppm)	11±0.10	11±0.20	12±0.30	15±0.30	*			
Mg (%)	0.24±0.05	0.30±0.08	0.22±0.04	0.22±0.03	**			
K (%)	0.65±0.03	0.52±0.08	0.45±0.10	0.56±0.05	ns			

FM: Fresh matter; DM: Dry matter; CMV: Vitaminized mineral supplement; (ns) no significant difference; (\*) significant difference at  $p < 0.05$ ; (\*\*) significant difference at  $p < 0.01$

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## 5. Conclusion

The arid and semi-arid areas represent a challenge to conventional cropping systems due to low rainfall, elevated temperatures and poor soils in these regions. The future of these regions depend on the development of sustainable agricultural systems and the cultivation of appropriate species as cactus pear which is little demanding for water. Cactus pear has taken a large economic and sociologic importance in the arid and semi-arid regions. It serves as a source of food for humans and animals and a means of additional income to rural populations in these regions. Cactus pear fruits are appreciated for their characteristic taste and aroma and their dietetic properties and young cladodes are an excellent vegetable rich in proteins and vitamins. The recent demand of consumers is the natural ingredients and health promoting foods, and cactus pear medicinal properties are known since a long time. Professional associations and small companies are operational in the production and the marketing of cactus pear products and by-products. Food production and animal production are among the main factors that ensure food security, job opportunities and economic income for rural populations in the arid and semi-arid areas. The production of forage in the rangelands of these regions is usually low and the resources of forage are limited in the arid and semi-arid areas. Cactus pear could be an important food and forage crop for human and livestock in these regions due to its drought resistance and its high biomass yield. Water shortage is the major factor that limits the agriculture and livestock production in the arid and semi-arid areas and the search for food and fodder species resistant to drought is needed for a better sustainable agriculture and animal production in the arid and semi-arid regions.

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## Compliance with ethical standards

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