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Cactus: A Crop to Meet the Challenges of Climate Change in Dry Areas

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Abstract: The future of the arid and semi-arid zones of the world largely depends on the development of sustainable agricultural systems based on the choice of appropriate crops. The suitable ones are those that successfully cope with water shortage, high temperature and poor soils, and easy management to provide food and forage for the subsistence agriculture, in addition to valuable product and by-products. Opuntias, particularly *Opuntia ficus indica* (cactus pear) fit most of the requirements described above. They play an important ecological role in combating desertification as well as producing fruits and vegetables for human consumption, feed for livestock, biomass for energy purposes, cochineal for carmine production, and numerous by-products (beverages, vegetarian cheese, drugs, and cosmetics). They also provide shelter and food for various wildlife species living in arid environments. The term cactus (*Cactaceae*) refers to a group of approximately 1,600 species in 130 genera subdivided in the three subfamilies Pereskioideae, Opuntioideae and Cactoideae. The most common and widespread *Opuntia* genus has more than 300 species. Cactus was largely ignored by the scientific community until the beginning of 1980, when there was a surge in research and symposia, resulting in a large number of publications. This renewed interest is to be ascribed in part to the multi-functionality of cactus fruits, pads and flowers. Recent data has, in fact, revealed the high content of some chemical constituents, which can give added value to cactus products. Additionally, some of the constituents show promising characteristics in terms of functionality. Cacti can grow in severely degraded soils, which are not suitable for other crops. *Opuntia* spp. have a great capacity to withstand severe dry conditions and are ideal for favorably responding to global environmental changes. Their root characteristics avoid wind and rain erosion, encouraging their growth in degraded areas. The importance of cacti is reinforced with regard to the wide range of possible use of cacti. Indeed, they can be used: (i) as forage, (ii) as vegetable where young cladodes are consumed fresh or cooked, (iii) as fruit where a sustainable horticultural system is achieved in several countries (Italy, Tunisia, Morocco, South Africa, Mexico, Chile, etc.), (iv) as cochineal where carminic acid, a natural red dye accepted by health authorities worldwide is obtained, (v) as processed foods where a potential market for fruit, and "nopalitos" to produce concentrated foods, juices, liquors, semi-processed and processed vegetables, food supplements and the cosmetics industry might be a significant source of income, and (vi) for medicinal applications: Promising results for the treatment of gastritis, diabetes, hypercholesterolemia, and for obesity.

Key words: Opuntia, arid zones, desert control, ruminant feeding, anti-oxidants, red dye, climate change.

The poor are the most dependent on agriculture in the drylands, so they are hit hardest by desertification and drought. They are frequently blamed as agents of land degradation through 'soil mining'- growing crops and grazing livestock without replacing the nutrients and ground cover that are removed, due to their limited financial resources. This blame may be misplaced. The poor frequently initiate sustainable land management practices, especially when markets for high-value crops emerge as long as the right technologies, infrastructure and policies are in place. Their ability to invest in the future is undermined, though by policies that subsidize food imports, place taxes on the agricultural sector to support urban priorities, and neglect rural infrastructure and institutions (Winslow *et al.*, 2004). Dryland environments are fragile. Their vegetative cover is sparse; when removed through overgrazing or excessive tillage, exposed soils quickly erode and lose fertility, and the surface-sealed soils cause water to be lost as runoff. Sustainable solutions that preserve and enhance soil cover and organic matter such as mixed crop-tree-livestock systems, water harvesting and conservation, and the judicious use of manure and inorganic fertilizers

Table 1. Estimated land areas utilized for raising cacti, mainly Opuntia ficus indica, for forage and fodder (Data are from Le Houérou (1992), Nobel (1994), and various MOA reports)

Region or country	Land area utilized, x 1000 ha
Brazil	600
Other South American countries	75
Mexico	230 + 3 million ha Wild
Other north American countries	16
South Africa	2
Italy	70
Tunisia	600
Algeria	150
Other WANA countries	300
Total	2 million ha cultivated + 3 million ha wild

at economically-optimal rates are showing success in many countries. Often these investments reduce rather than increase smallholder's risk (Winslow *et al.*, 2004).

The Cactaceae family includes about 1600 species, native from America, but worldwide disseminated. The most known is Opuntia genera; *Opuntia ficus indica* is cultivated in more than 20 countries (Table 1). Cacti have been consumed by humans for over 9000 years. From underused crop, cacti recei\ed an increasing importance during the last few years. Thus, from 1998 to 2000 more than 600 researchers published over 1100 articles on cacti.

Cacti: Astonishing Plants

Cacti and *Opuntia* spp. in particular can prevent or reverse desertification through different ways. Cacti are drought-tolerant species; they are used in watershed management and in water harvesting and its efficient use, in wind and water erosion control, in rangeland and marginal land rehabilitation, in cropland management and crop diversification to contribute alleviating poverty and providing better livelihood to the rural poor in dryland areas.

The species of the *Opuntia* spp. subgenus have developed phenological, physiological and structural adaptations favorable to their growth and survival in arid environments, in which water is the main constraint limiting the development of most plant species. Among these adaptations stand out its asynchronous reproduction, and its CAM metabolism, which combined with structural adaptations such as succulence, allow this plant to continue the assimilation of carbon dioxide during long periods of drought and in this way reach acceptable productivity levels even in years of severe drought.

CAM plants water use efficiency (WUE)

CAM plants (Agaves and Cacti) can use water much more efficiently with regard to CO_2 uptake and productivity than do C3 and C4 plants (Nobel, 2009). Biomass generation per unit of water is on an average about 3 times higher than for C4 plants and 5 times higher than for C3 plants (Tables 2 and 3, Fig. 1).

In contrast to C3 and C4 plants, net CO_2 uptake in CAM plants occurs predominantly at night (Nobel, 2009). As stated by Nobel (2009), the key for the consequences between noctural gas exchange by CAM plants and C3 and C4 plants is temperature. Temperatures are lower at night, and lower temperatures reduce the internal water vapor concentrations in CAM plants, and this is the key to their better WUE. This is why CAM plants are so well suited to arid and semi-arid habitats.

Table 2. WUE of CAM plants compared to C3 and C4 plants (adapted from Larcher, 1986)

Photosynthetic metabolism	WUE (kg of water/kg of DM)
C3	400-1000
C4	250-500
CAM	100

Table 3. Comparative water use efficiency (WUE) and transpiration rate (TR) for C3, C4, and CAM plants (adapted from P.S. Nobel, 2009)

	C3	C4	CAM
WUE*	0.0013-0.005	0.0025-0.010	0.013-0.040
TR**	200-800	100-400	25-80

WUE: Ratio of the CO_2 fixed in photosynthesis divided by the water lost via transpiration,
TR: Amount of water lost by transpiration divided by the CO_2 fixed in photosynthesis.

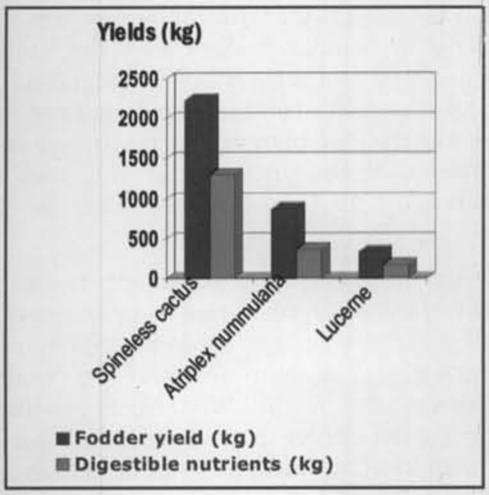

Fig. 1. Compared WUE between cactus, atriplex & lucerne (yields per unit of 25 mm rainfall) (from de Kock, 1991).

Drought and heat tolerance

C3 and C4 plants suffer irreparable damage once they lose 30% of their water content. Many cacti can survive an 80 to 90% loss of their hydrated water content. This is because CAM plants take advantage of three abilities (Nobel, 2009):

- to store a lot of water,
- to shift water around among cells to keep crucial metabolism active, and
- to tolerate extreme cellular dehydration.

These abilities are due to cacti specificities as the extra thickness of the cuticles providing efficient barrier for water loss, the presence of mucilage and the daytime stomatal closure. In addition, cacti have an asynchronous development of various plant organs, so that even under the worst conditions some part of the plant is not affected.

It is well known that cacti grow in desert where temperatures are extremely high. It has been reported by many authors (Nobel, 2009) that many agaves and cacti can tolerate extremely high temperatures up to 60 and 70°C.

Cacti to mitigate climate change

A full chapter has been devoted to this aspect by Park Nobel (2009) in his recent book "Desert Wisdom Agaves and Cacti CO_2, Water, Climate Change".

In view of the specific phenological, physiological and structural adaptations of cacti developed above, it can be assessed that they are well positioned to cope with future global climate change. *Opuntia ficus indica*, for example, can generate a carbon sequestration of 20 tons of dry matter (equivalent to 30 tons of CO_2) per ha annually under sub-optimal growing conditions as those prevalent in North Africa arid regions. In this regard and as stated by Drennan and Nobel (2000) and Nobel (2009), agaves and cacti with their substantial biomass productivities and their high WUE should be considered for the terrestrial sequestration of atmospheric CO_2 in underexploited arid and semi-arid regions. Such regions, which occupy 30% of the Earth's land area, are poorly suited to C3 and C4 crops without irrigation.

Cacti for Developing Marginal Dry Areas and Combating Desertification

Soil and water conservation

Land degradation occurs in all continents and affects the livelihoods of millions of people, including a large proportion of the poor in the drylands. Dry zones, with annual moisture deficits greater than 50%, cover approximately 40% of the earth's land surface. More than 70% of all dry areas suffer from desertification, currently accounting for 36 million sq. km.

Water and soil are the most precious renewable natural resources. Drought avoidance and coping strategies such as choosing drought-tolerant crops, low plant densities, water conservation and water harvesting are imperative. However, only a small fraction of rainfall becomes usable soil moisture. Only 1 to 10% of the rain that falls in the drylands ends up in the tissue of natural vegetation and crops of economic significance.

Water is the major cause of desertification in the catchments. The water erosion is accelerated by tillage on slopes and gully margins. Soil productivity is rapidly declining.

Several methods like water harvesting strips, contour ridges, gully check structures, biological control of rills and small gullies by planting cactus, have been tested, and have given good results. The contour ridges, consisting of parallel stone ridges, are built 5 to 10 m apart to stop runoff water (and the soil it carries) from damaging downstream areas. Each ridge collects runoff water from the area immediately upstream/uphill, and the water is channeled to a small plantation of fodder shrubs or cactus. Indeed with a combination

Fig. 2. Example of management used in Tunisia for the protection of watershed.

of well designed ridges and cactus, farmers are able to meet a large proportion of their fodder requirements.

In the countries of North Africa, particularly Tunisia, cactus is successfully associated with water harvesting structures. Planted according to contour lines, cactus hedges play a major role in preventing erosion (Fig. 2). Soil physical properties are considerably improved under these hedges and in immediate adjacent areas, with an improvement in organic matter and nitrogen as compared to non-treated fields. 40 to 200% increase in organic matter and nitrogen have been reported. Top-soil structural stability is enhanced, susceptibility to surface crusting, runoff and erosion are reduced, while permeability and water storage capability are improved. Marginal lands have been cheaply rehabilitated in Tunisia and Algeria by contour planting of cacti (Nefzaoui and El Mourid, 2009).

Comparing different cultivation systems, such as downhill planting, contour planting, reduced weeding, and intercropping with contour hedges, it was found that soil annual losses (0.13 to 0.26 t ha^{-1}) are the lowest with the last system. Cactus planting in contour hedges may help retaining up to 100 t ha^{-1} soil annually (Margolis *et al.*, 1985). Experiments conducted in Brazil and Tunisia show clearly that planting cactus in agroforestry system is more efficient for soil and water conservation than conventional land use (Table 4).

Massive dust storms in the Sahara can move 66 to 220 million tons of fine sediment each year. Wind erosion is a major cause of soil degradation on agricultural lands in arid and semi-arid areas throughout the world. Wind damages land by removing the lighter, more fertile, and less dense soil components, such as organic matter, clays, and silts. Reduced soil productivity is not the only agricultural impact of wind erosion. Blowing sediment cuts and abrades plants, reduces seedling survival and growth, lowers crop yields, and increase susceptibility to diseases and the spread of plant pathogens.

In arid lands prone to wind erosion, cactus, planted alone as biological barrier or together with physical barriers (i.e. cement) is an easy, cheap and efficient way to prevent and to control top-soil loss and to facilitate the accumulation of wind-borne deposits (Nefzaoui and El Mourid, 2009).

The scattered results obtained so far indicate a lack of research in this domain. Development actions have been mainly based on assumptions and observations gathered by practitioners. There is an urgent need to reinforce the on-going research activities with a sound research initiative to investigate all the benefits to gain and to assess the efficiency of the technologies associated with the use of cacti as a key species to help controlling desertification and adapting to global warming.

Rangeland and marginal land rehabilitation

Cacti and *Opuntia* in particular are some of the best plants for the reforestation of arid and

Table 4. Comparison of soil losses (t ha^{-1} y^{-1}) under different crops in semi-arid NE Brazil (Margolis et al., 1985)

Crop type	Soil preparation phase	Cultivation phase	Harvest until next growing season	Total soil loss	C factor
Bare soil	7.19	8.20	13.71	29.10	1.000
Cotton	2.42	1.77	6.72	10.91	0.392
Maize	1.51	0.68	3.75	5.94	0.199
Maize + beans	1.36	0.55	2.02	3.93	0.119
Opuntia ficus indica	0.48	0.02	1.48	1.98	0.072
Perennial grass	0.00	0.02	0.01	0.03	0.001

Table 5. Productivity of natural and improved rangelands in Tunisia (Nefzaoui and El Mourid, 2009)

Rangeland type	Productivity (forage unit per hectare)*
Natural rangeland in Dhahar Tataouine, Tunisia (100 mm rainfall)	35-100
Private rangeland improved by cactus crop in Ouled Farhane (Sidi Bouzid, Tunisia)	800-1000
Cooperative rangeland improved by shrubs planting (*Acacia cyanophylla*), Guettis, Tunisia	400-500

* One forage unit is equivalent to energy content of one kg barley grain.

semi-arid lands because these can survive under scarce and erratic rainfall and high temperature.

Rangelands are facing several problems with regard to their institutional, social, economical and technical management. The number of small ruminants has been increasing in most of the arid areas. Several techniques were investigated to increase rangeland productivity. They included rotational grazing, shrub planting, reseeding, fertilizer application, scarification, etc. Some of these techniques show significant results under favorable conditions. Impressive results are obtained with fast growing shrubs (*Acacia cyanophylla, Atriplex nummularia*) or cactus (*Opuntia ficus indica*) planting in Central Tunisia where average annual rainfall is 200-300 mm (Table 5).

Rangelands can also be diversified, providing alternatives to the overgrazing of fragile native vegetation. Drought-tolerant fodder trees and shrubs and cactus accumulate biomass over the rainy season, serving as 'fodder banks' to help animals survive the dry season. Cacti (*Opuntia*), saltbushes (*Atriplex*), and wattles (*Acacia*) have been successfully introduced in West Asia/North Africa. Spineless cactus (*Opuntia ficus indica*) is showing promise in large plantations in Algeria and Tunisia (Fig. 3). The higher water content of cactus aids in feed intake and digestion (Nefzaoui and Salem, 2002). Agricultural wastes on-farm or from urban processing centers (straw, rice bran, date pulp, whey, brewer's grain, wheat bran, corn gluten, etc.) can be compacted into nutritious 'feed blocks' and transported to the drylands (where feasible), sparing the need to graze fragile vegetation. These approaches need to be accompanied by measures to avoid environmental hazards such as overtillage for sowing range species, soil and water supply degradation around feed and watering stations, and the unwanted spread of alien species which could affect native biodiversity.

Cropland management and cactus-barley alley cropping

Spread of cereal cropping into rangelands together with the replacement of fallow practice is one of the major reasons for declining soil fertility and increased wind erosion.

One way of combating degradation resulting from arable mono-cropping is the introduction of adapted perennials like forage legumes, shrubs/fodder trees and cactus in the cropping system.

Alley cropping is an agroforestry practice where perennial crops are grown along with arable crops. The practice is such that shrubs/trees or cactus are grown in wide rows with arable crops grown in the inter-space. Alley cropping is a form of hedgerow intercropping. Leguminous and fast

Fig. 3. Improved rangeland using Opuntia ficus indica in Central Tunisia (average rainfall: 300 mm) where biomass produced increased from 100 to 1000 forage units (Nefzaoui and Ben Salem, 2002).

growing tree/shrub species are preferred for this practice due to their soil improving attributes, i.e. nutrient recycling, suppressing weeds, and controlling erosion on sloping land. This technology has the advantage of enabling the farmer to continue cultivating the land while the tree/shrub species planted in intermittent rows help to maintain the quality of the soil. Cactus may serve in this system as windbreak, resulting in improved grass/cereal yields. Wide alley may allow animals to graze biomass strata or cereal stubbles during summer. In the latter case, cactus pads may be harvested

Table 6. Total biomass change and barley crop yield in Sidi Bouzid (Tunisia) (Alary et al., 2007)*

Treatment	Natural rangeland	Barley crop (alone)	Cactus crop (alone)	Alley cropping (cactus + barley)
Above-ground biomass (t ha^{-1})	0.51	0.53	1.87	7.11
Underground biomass (t ha^{-1})	0.33	0.11	1.80	1.98
Barley grain yield, (t ha^{-1})		0.82		2.32
Barley grain + straw + weeds (t ha^{-1})		4.24		6.65

* Average annual rainfall in Sidi Bouzid is 250 mm. No fertilizer was applied to the treatments.

and given directly to grazing animals as energy supplement of low quality stubbles (Alary *et al.*, 2007; Nefzaoui and El Mourid, 2009).

Alley cropping can provide additional income and also make better use of the space available between trees and add protection and diversity to agricultural fields (Table 6, Fig. 4).

Regional initiative: Green wall for Sahara

Concerned with the precarious situation due to desertification, the President of Nigeria and immediate past Chairman of the African Union, H.E. Olusegun Obasanjo, proposed at the Sahel Saharan Summit held in Ouagadougou, Burkina Faso, a Green Wall for Sahara Project from Mauritania in the West to Djibouti on the East Coast of Africa to save the African environment, conserve the eco-system and reverse the desertification process (Fig. 5). The participating countries in the Green Wall for Sahara Project include: Liberia, Guinea Bissau, Central African Republic, Cote d'Ivoire, Togo, Nigeria, Benin, Gambia, Burkina Faso, Ethiopia, Senegal, Sudan, Chad, Mali, Eritrea, Mauritania, Morocco, Somalia, Tunisia, Niger, Djibouti, Libya and Egypt. The Secretariat of the project is located at the African Union Commission (Nefzaoui and El Mourid, 2009).

Cactus: Multipurpose Plant

Opuntia spp. present various alternatives to its exploitation. These are as follows.

As fruit: A cultivation policy must be defined aiming to achieve high yields and high quality. To achieve both objectives a sustainable horticultural system is required. The potential market for this product is extensive, but little exploited, so better marketing strategies and post-harvest technology are required. Due to their management requirements, *Opuntia* spp. require extensive labor, which is an important variable in developing countries (Inglese *et al.*, 2009).

As forage: Since they grow in severely degraded lands, their utilization is important because of their abundance (900,000 ha) in areas where only few crops can grow. Also cacti present high palatability, digestibility, and reduce the drinking water needs of animals; however, they must be combined with other foods to complete the daily diet, because they are poor in proteins, although rich in carbohydrates and calcium (Nefzaoui and Ben Salem, 2002).

As vegetable: They are consumed fresh mainly in Mexico and by Mexicans living in the USA; however, Mexican exports to Europe and Asia are increasing, which shows an increasing demand in non-traditional markets, which should be adequately explored.

As cochineal: Carminic acid, a natural red dye accepted by health authorities worldwide, is obtained. Yield depends on plant density and irrigation and fertilizers applied. Cochineal constitutes a significant alternative because of its profitability and intensive use of labor, but the market for this product has large price fluctuations, which makes investment decisions difficult (Portillo *et al.*, 2009).

Industrialization: It is feasible to industrialize cladodes, fruit and nopalitos. This potential market

Fig. 4. Example of alley-cropping technique using Opuntia ficus indica and barley crop.

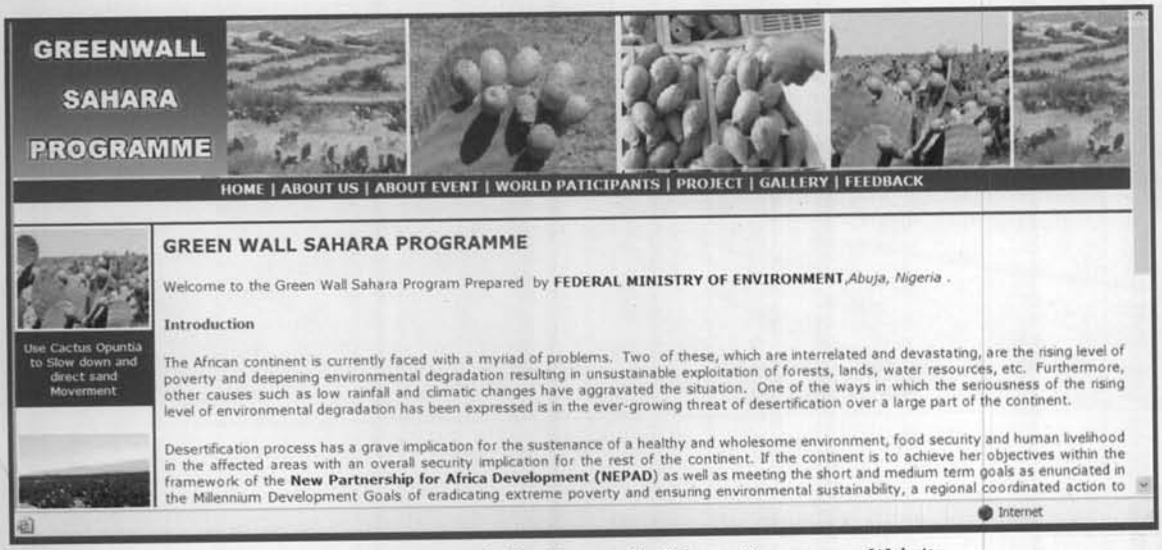

Fig. 5. View of the home page of the Greenwall Sahara Programme Website.

deals mainly with concentrated foods, juices, liquors, semi-processed and processed vegetables, food supplements and the cosmetic industry. It is feasible, but it requires work and investment to develop the market (Saenz, 2002, 2006).

Medicinal applications: There is some experiment with promising results on the use of "nopalitos" for gastritis; for diabetes due to the reduction of glucose in blood and insulin; for hypercholesterolemia by reducing total cholesterol, LDL cholesterol and triglycerides serum levels; and for obesity (Nefzaoui *et al.*, 2007).

Economic prof:les have been developed from the main exploitation alternatives, and reveal that they are viable with adequate investment returns. These projects bring additional benefits, such as the generation of employment, environmental improvement, etc., which do not represent income for investors, but they do contribute to humanity.

Fruit

Cactus pear is cultivated for fruit production since the Aztec time. Main producers today are Mexico, Italy, South Africa, Tunisia, Morocco, Peru, Israel, and Chile. Orchards for fruit production involve inputs like supplemental irrigation, pruning, and appropriate fertilizers (Fig. 6). Fruit yields are extremely high and may reach 30 t ha^{-1}. Harvest and post-harvest techniques are well developed in producing countries (Inglese *et al.*, 2002). The most appreciated fruits in the international market have a yellow-orange flesh, such as "Gialla" variety in Italy and "Directeur" in South Africa. Red-purple or pink fruits, such as "Algerian" in South Africa, "Rossa" in Italy, or "Rojo pelon" in Mexico are also highly appreciated (Inglese *et al.*, 2002). The fruit quality is quite similar to orange or papaya (Table 7). Recent findings show that cactus fruit has a high content of anti-oxidants and other neutraceuticals. Cactus pear fruits have a broad color range, and therefore, cactus pear juice preparations are expected to be a suitable coloring foodstuff for low acid products such as ice-cream or yogurt. Pectins with enough galacturonic acid content are abundant in the fruit and can be used as food or cosmetic additive. Pectins in cactus fruit have

Table 7. Compared nutritive value of cactus pear fruit to orange and papaya

Component	Cactus pear	Orange	Papaya
Water, %	85.0	87.8	88.7
Carbohydrates, %	11.0	11.0	10.0
Fiber, %	1.8	0.5	0.8
Lipids, %	0.1	0.1	0.1
Proteins, %	0.5	0.4	0.6
Ca, mg/100 g	60.0	40.0	20.0
Vitamin C, mg/100 g	30.0	50.0	50.0

Fig. 6. Opuntia ficus indica orchards fro fruit production in Italy (left) and South Africa (right).

a very low degree of methoxylation, suggesting that it can be used as a gelling agent for low caloric food (Figs. 6 to 8).

For minimally processed products, scalded pads are immersed in cold water to fix color, drained and manually cut into cubes before being packaged for the local markets. Freshly cut strips or cubes, manually packaged into polyethylene bags, are widely consumed in Mexico (Figs. 9 to 13). Pickled products are also made from scalded and cut pads, which are mixed with salt, spiced vinegar, carrot, pepper and other vegetables, and sterilized to ensure product safety (Saenz, 2006).

Agri-food and nopalitos

Juice from cactus fruit is made through pressing, addition of citric acid and sugar and pasteurizing after the bottling process. Various types of liquor are prepared in Italy and Latin American countries (Saenz, 2006).

Many brands of jellies, marmalades and dried sweets are prepared and sold in Latin America, South and North Africa. Juice obtained from the strained pulp is considered to be a good source of natural sweetener and colorants (Figs. 9 to 13). Cactus pear represents a viable alternative to red beet for food coloring purposes: it neither exhibits negative sensorial impact nor high nitrate levels, but offers a dehydrated pad, milled into powder. It is now getting into the US and European markets. Pads are widely used as a dietary supplement to increase fiber content in the human diet and other beneficial purposes such as weight reduction, decrease in blood sugar and prevention of colon cancer. The world market for pills made from powdered cactus is growing at a fast pace and small-scale producers could well benefit from this trend. Dried cladode powder contains about 43% fiber, 28.5% of which is insoluble. Some commercial products based on cladode powder are already marketed as "Cactu fibra" and "Nutra Sweet" in Mexico. These products are prepared with young cladodes (3-6 months), which have low content of insoluble fiber. This powder is also used to prepare several foods, as biscuits, creams, and other types of desserts (Saenz, 2006).

Fig. 7. Cactus cultivars for fruit production from Mexico where 50 commercial cultivars were registered in 2007 (Mondragon, 2009).

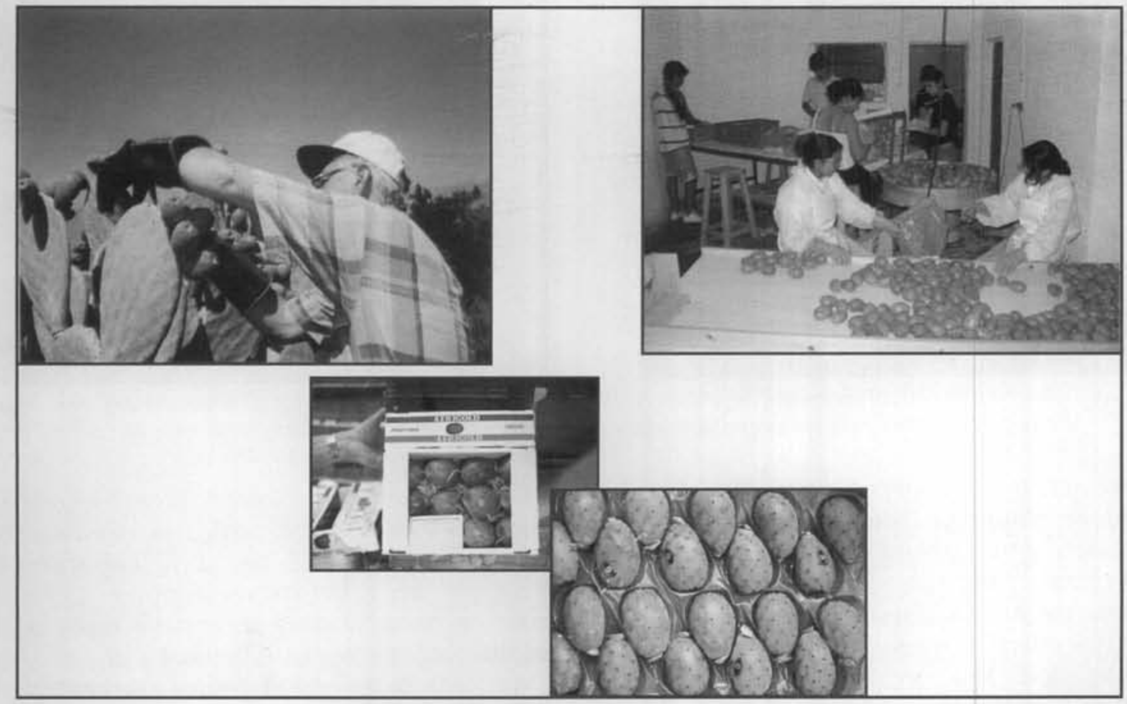

Fig. 8. Cactus fruit harvesting (top left), cleaning and conditioning (top right) and packaging are key steps for appropriate marketing.

Forage

Opuntia spp. used for animal feeding are abundant, easy and cheap to grow, palatable, and able to withstand prolonged droughts (Shoop *et al.*, 1977). Such characteristics make them a potentially important feed supplement for livestock, particularly during drought and periods of low feed availability. The cladodes constitute the major biomass of an *Opuntia* and can be fed to livestock as fresh forage or stored as silage for later feeding (Castra *et al.*, 1977). In any case, the idea of using cactus to feed livestock is not recent and goes back to the 18th century (Griffith, 1905; Curtis, 1979; Le Houérou, 1992; Russell and Felker, 1987; Clovis de Andrade, 1990; Barbera *et al.*, 1992; Flores Valdez and Aguirre Rivera, 1992).

Cactus cladodes and waste fruits are cost-effective feed for ruminant animals. Benefits of using cactus as feed are well documented (Nefzaoui and Ben Salem, 2002). Large areas of cactus are available year-round in Algeria, Mexico, and especially Brazil and Tunisia and serve as an emergency feedstock in case of drought (Table 1). In many arid regions, farmers make extensive use of cacti as emergency forage to prevent the disastrous consequences of frequent and severe droughts.

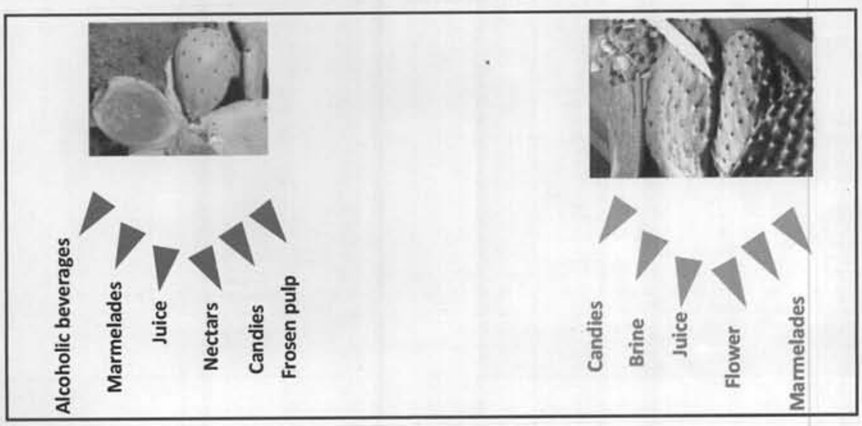

Fig. 9. Major commercial products obtained from cactus fruit (left) and cladodes (right).

Fig. 10. *Different commercial presentations and trade marks of tender processed cladodes and fruits.*

The nutritive quality of *Opuntia* cladodes depends on plant type (species, varieties), cladode age, season, and agronomic conditions (e.g., soil type, climate, and growing conditions). Cacti cladodes are an unbalanced feed nutrient wise, but a cost-effective source of energy and water. Cladodes are low in crude protein, fiber, phosphorus, and sodium (Nefzaoui and Ben Salem, 2002). Therefore, diets containing cactus should be balanced for these nutrients by appropriate supplements. On a fresh weight basis water content may be nearly 90%. The ash content of cladodes is high, mainly because of the high calcium content. Cladodes also have high levels of oxalates (about 13% of the dry weight, and 40% of it is in soluble form). The crude protein is often below 5%, but can be up to 10% of the dry weight. The fiber content is also relatively low, (10% of the dry weight). The nitrogen-free extract, which includes monomeric and polymeric sugars, is about 60% of the dry weight. Cladodes' low content of phosphorus (about 0.3% of the dry weight) and sodium (about 0.01%) requires supplementation when they are fed to animals (Table 8).

Fig. 11. *Some commercial presentations of candies made with cactus fruit and tender cladodes.*

Fig. 12. *Some commercial presentations and trade marks of beverages made with cactus fruit and tender cladodes*

Animals can consume large amounts of cladodes. For instance, cattle may consume 50 to 70 kg fresh cladodes per day, and sheep 6 to 8 kg per day. Cladode consumption can have a laxative effect, leading to a more rapid passage of the food through the animal's digestive tract. This leads to poorer digestion, especially when the cladodes constitute more than 60% of the dry matter intake; supplementing with fibros feed (e.g., straw or hay) can alleviate such laxative effects (Nefzaoui and Ben Salem, 2002).

The energy content of cladodes is 3,500 to 4,000 kcal kg^{-1} dry matter, just over half of which is digestible and comes mainly from carbohydrates (Table 9). In arid and semi-arid regions of North Africa, cereal crop residues and natural pastures generally do not meet the nutrient requirements of small ruminants for meat production. Cladodes can provide a cost-effective supplementation, such as for raising sheep and goats on rangelands. For instance, when diets of grazing sheep are supplemented with cladode cakes, the daily weight gain increases nearly 50% (145 g average daily body gain). When cladodes are supplied to grazing

Fig. 13. *Fresh juice prepared from fruits of different cactus varietiess.*

Table 8. Chemical composition of Opuntia cladodes (after Nefzaoui and Ben Salem, 2002)

Species	Water (% of fresh weight)	Ash	Crude protein	Crude fiber	N-free extract	Ca	P	K	Na
		% of dry weight							
O. englemannii	85		2.9			8.3	0.04	3.0	
O. lindhymeri									
O. ficus indica									
Various	89	17	4.8	10.9	65				
California	90		10.4		64	6.3	0.03	1.2	0.003
Chile	89		8.9			3.9	0.01	2.0	0.003
Tunisia	87	27	3.8	8.6	58	8.7	0.04	1.1	0.050

goats that have access to alfalfa hay, the milk yield is increased by 45% (to 436 g day^{-1}). When cladodes are associated with a protein-rich feedstuff, they may replace barley grains or maize silage without affecting body weight gains of sheep and cattle. For instance, milk yield for lactating goats supplied with 2.2 kg alfalfa hay day^{-1} is actually slightly higher (1.080 g day^{-1}) when 0.7 kg cladodes replace an equal mass of alfalfa (Fig. 14).

The dry matter intake of straw steadily increases as the amount of cladodes supplied increases. Because of the low gut fill of cladodes, an increase of cactus in the diet does not necessarily reduce the intake of other components of the ration. This is of great importance for arid zones where livestock is fed mainly with straw or cereal stubble, which are low quality coarse feeds that have poor intakes, resulting in low animal daily weight gains.

The cactus improves rumen fermentation. Sheep rumen fluid pH is not affected by up to 600 g dry matter of cladodes per day, and remained at 6.9 (Ben Salem *et al.*, 1996). The cladodes are rich in fermentable carbohydrates, and their consumption probably enhances salivation (Tables 10 and 11). Compared with a cactus-free diet, the highest supply of cladodes doubles the concentration of ammonia nitrogen in the rumen of sheep fed diets based on straw or acacia. This leads to ammonia concentrations near optimal for microbial growth and fiber digestion in the rumen. Adding cladodes to the diet can increase the volatile fatty acids (such as propionic acid) by up to 30%, reflecting the increased intake of soluble carbohydrates.

Water scarcity can depress feed intake, digestion, and therefore weight gains of sheep and goats. Thus, supplying livestock with water during the summer and during drought periods is crucial in hot arid regions. Animals consume considerable energy to reach water points. Therefore, the high water content of cladodes is beneficial in dry areas. Animals given abundant supplies of cladodes require little or no additional water (Nefzaoui and Ben Salem, 2002).

Investigation jointly conducted by INRA Tunisia and the University of Catania (Italy) showed that the consumption of cactus cladodes increases the amount of omega 3 (CLA) in lambs and kids meat

Table 9. Energy content of Opuntia cladodes compared to other forages in total digestible nutrients (TDN)

Forage	TDN[1] (% DM)	TDN[2] (% DM)	Author
Opuntia	64.33	65.91	Mendes Neto *et al.*, 2003
Opuntia	–	63.73	Melo *et al.*, 2003
Opuntia	–	61.13	Magalhães, 2002
Bermuda grass	59.94	53.11	Mendes Neto *et al.*, 2003
Sorghum silage	–	52.07	Melo *et al.*, 2003
Corn silage	59.56	–	Rocha Jr. *et al.*, 2003
Elephant grass	49.59	–	Rocha Jr. *et al.*, 2003
Sugar cane	60.57	–	Rocha Jr. *et al.*, 2003

1 – Digestibility trial; 2 – NRC 2001.

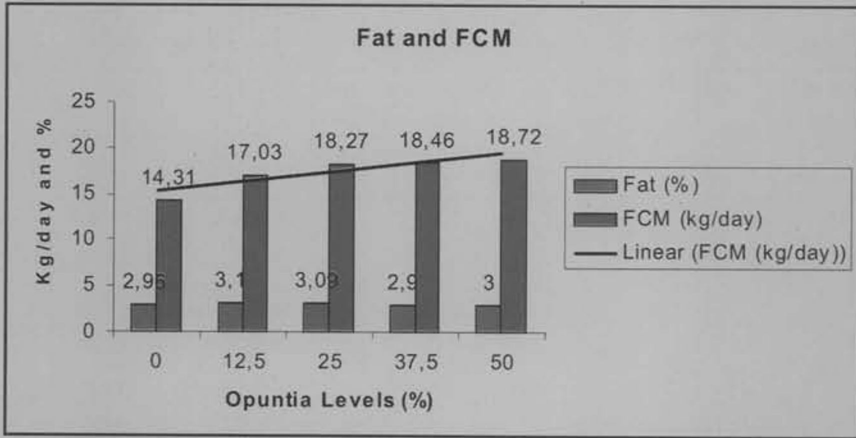

Fig. 14. Opuntia cladodes in replacement of Bermuda grass (Tifton hay) (Cavalanti, 2005) for dairy cattle in North East Brazil.

(Abdi *et al.*, 2009). This encouraging result is of high importance and meets the ultimate goal, which is of human health concern. Indeed, it is established now that CLA is the only fatty acid shown unequivocally to inhibit carcinogenesis in experimental animals. Other positive effects of CLA are the (i) reduction of cancer risk, (ii) reduction of diabetes, and (iii) reduction of arteriosclerosis.

The method of utilization of cladodes for livestock will differ according to circumstances, such as available labor, facilities, and extent of cactus available. Although grazing of cladodes *in situ* is the simplest method, it is not the most recommended and care should be taken so that the animals do not overgraze the plants. The most common method is to cut and carry. Cactus cladodes may be ensiled and used when needed. It is cheapest to store cladodes as parts of living plants instead of ensiling or drying (Fig. 16).

Red dye, cosmetic and medicinal uses

Red dye and cosmetic uses: Shampoo, lotions, creams, and soaps are produced from cactus pads: Natural colorants from plant sources are receiving growing interest from both food manufacturers and consumers to replace of synthetic dyes. Betalains present in fruit peel and pulp, but also in the flowers represent a potential healthy alternative. Red dye from fruits and fruit's skin are extracted and used in agrifood and pharmaceuticals (Saenz, 2006).

Cactus cochineal is produced by drying and milling adult female *Dactylopius coccus Costa*, parasitic insects that host on cactus pads (Fig. 17). To obtain 1 kg of cochineal, 140,000 insects are required that may contain up to 50% pigment (carmine) of their total weight. The hectare yield usually adds up to 100-200 kg. Cochineal (carmine)

Table 10. Effect of supply of spineless cactus (O. ficus indica var. inermis) on intake and digestibilities by sheep fed straw-based diets in Tunisia (Nefzaoui and Ben Salem, 2002)

	Amounts of cladodes consumed (g dry matter per day)				
	0	150	300	450	600
Dry matter intake, g day^{-1}					
Straw	550	574	523	643	761
Cactus + straw	550	724	823	1093	1278
Total digestibility					
Organic matter	45	50	54	58	59
Crude protein	50	55	54	59	64
Crude fiber	53	51	53	52	47
Digestible intake (% of maintenance requirements)					
Organic matter	93	123	158	193	212
Crude protein	52	52	64	93	111
Protozoa (104 per ml)	3.5	9.3	13.0	17.7	13.1
Degradability of cellulose, %	85	72	57	55	56

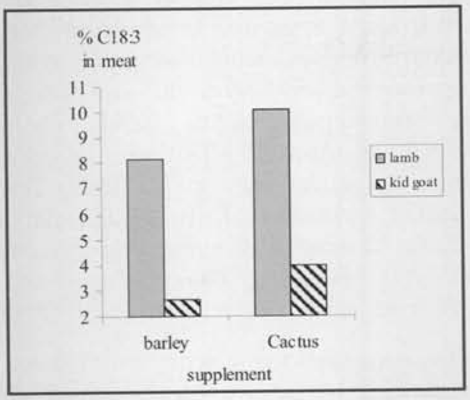

Fig. 15. Effect of feeding cactus on CLA contents (omega 3) in lambs and goats meat (Abidi et al., 2009).

is a pigment blend mainly consisting of carminic acid. The predominant component carminic acid (E 120; C.I. natural red 3) (Portillo *et al.*, 2009) (Fig. 18) is used for all kinds of food with pH values usually above 3.5. Carmine is one of the very few pigments considered safe enough for use in eye cosmetics. A significant proportion of insoluble carmine pigment produced annually is used in the cosmetics industry for hair and skin care products, lipsticks, face powders, rouges, and blushes. A bright red dye and the biological stain carmine used in microbiology is often made from the carmine extract, too. The pharmaceutical industry uses cochineal to color pills and ointments (Portillo, 2009). Today Peru, the Canary Islands, and Chile are the main producers, followed by Mexico, Bolivia, South Africa and Argentina.

The *Opuntia ficus indica* seeds' cold pressed oil is of high quality, thanks to its more than 75% of unsaturated fatty acids, its 1085 mg kg^{-1} of tocopherols, and its Delta7 sterols, very seldom encountered in vegetal oil and well known for their revitalization properties. Apart from its chemical properties, this oil is very well absorbed by the skin. Its texture and its exceptional touch will be incomparable for cosmetic products (**Fig.** 19). AquaCacteen, an ultra-refined cactus extract from *Opuntia*, is being commercialized for the cosmetic industry. AquaCacteen cactus extract is a highly effective moisturizing and soothing ingredient, suitable for all skin care products - with limitless capabilities (Ennouri *et al.*, 2005).

Medicinal uses: In recent years there has been a global trend toward the use of natural phytochemicals present in fruits, vegetables, oilseeds and herbs, as antioxidants and functional foods. Natural antioxidants can be used in the food industry, and there is evidence that these substances may exert their antioxidant effects within human body. Cactus has a global distribution and is an important nutrient and food source (Nefzaoui *et al.*, 2007).

The growing demand for neutraceuticals has resulted in an increased effort in developing natural products for the prevention or treatment of human diseases. According to several studies both cactus fruit and cladode are rich source of important nutrients, such as betalains, amino compounds including taurine, minerals, vitamins, as well as antioxidants. The cactus pear (*Opuntia* spp.) appears to be an excellent candidate for inclusion in food. Although Native Americans have realized its antidiabetic and anti-inflammatory properties, *Opuntia* spp. has hardly been considered in the development of health-promoting food, most

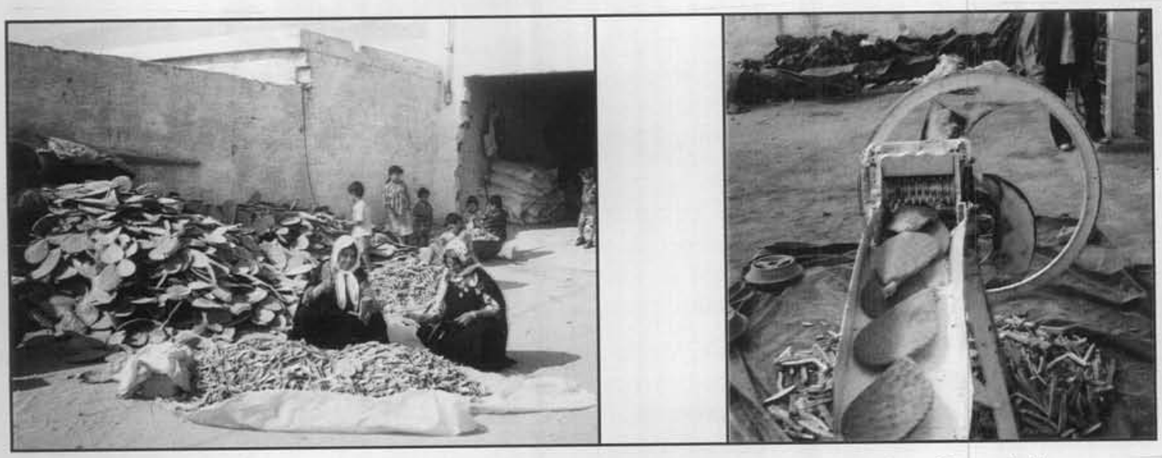

Fig. 16. Cactus pads being shopped at farm level before feeding using simple tools and household labor (left) or simple-designed choppers (right).

Fig. 17. Dactylopius coccus Costa, parasitic insect that host on cactus pads have been used since Aztec time and up today is considered as "the perfect red".

probably due to the scattered information available (Saenz, 2006; Stintzing and Carle, 2004; Munoz *et al.*, 1995).

Cactus still serves as therapeutic agent and in folk medicine. Several cactus species have been used for the treatment of gastritis, fatigue, dyspnoe, and liver injury following alcohol abuse. The Aztecs used it for medicinal purposes as described in the Aztec Herbal of 1552. They referred to it as "nohpalli." Today the Mexicans still call the cactus plant "nopal". In Italy, a review on folk veterinary medicine describes *Opuntia ficus indica* as an important plant for ethnoveterinary.

Deep inside the African Kalahari Desert, grows an ugly and bitter cactus called the Hoodia Gordonii. It thrives in extremely high temperatures, and takes years to mature. The San Bushmen of the Kalahari, one of the world's oldest and most primitive tribes, had been eating the Hoodia for thousands of yea.s, during long hunting trips. South African scientists found the plant contained a previously unknown molecule, which has since been christened P 57. The license was sold to a Cambridgeshire bio-pharmaceutical company, Phytopharm, who in turn sold the development and marketing rights to the giant Pfizer Corporation.

In Italy, cactus flowers have served as a diuretic. A tea made from the blossoms has treated colitis. In Israel, researchers found that the dried flowers may be used to treat enlarged prostate.

Medical research teams, mainly in Italy, Mexico, Germany, South Korea, United States, South Africa, and more recently in Tunisia and Morocco, are working actively on medicinal uses of cactus products (pads, fruit, flower). Results are encouraging and already commercial products are being marketed. Strong evidence shows that cactus has anti-oxidant capacity, anti-inflammatory and analgesic properties, anti-ulcerogenic effect and healing properties, hypoglycemic and anti-diabetic effects, anti-hyperlipidemic and cholesterol lowering effect, diuretic effect, anti-cancer effect, and anti-viral effect (Lee *et al.*, 1999; Tesoriere *et al.*, 2005a and 2005b; Kuti, 1992; Galati *et al.*, 2002, 2003; Munoz de C.avez, 1995; Wolfram *et al.*, 2002, 2003; Feugang, 2006; Bwititi *et al.*, 1997, 2000; Ahmad *et al.*, 1996; Zou *et al.*, 2005).

Anti-oxidant capacity: Cactus fruits show high anti-oxidant capacity due to high vitamin C content and more important due to high flavonoids and betalains contents (Stintizing *et al.*, 2005). Clinical tests demonstrated that cactus flavonoids exert neuroprotective effects. Vitamin C did not account for more than 40% of the anti-oxidative capacity. It has been shown that cactus fruit consumption reduces LDL hyperoxides by 50% and positively affect the body's redox balance, decreases oxidative damage to lipids, and improves anti-oxidant status in healthy human. The flavonoids fraction of the fruit juice, together with vitamin C and betalains could, synergically, counteract many degenerative processes (Lee *et al.*, 1999, 2002a, 2002b).

Anti-inflammatory and analgesic properties: Cactus cladodes are used in folk medicine as cicatrizant. Recent studies have evocated the analgesic and anti-inflammatory actions by using either the fruit extract, the lyophilized cladodes, or the phytosterols from fruit and cladodes of the genus *Opuntia*. A beta-sitosterol as the active anti-inflammatory

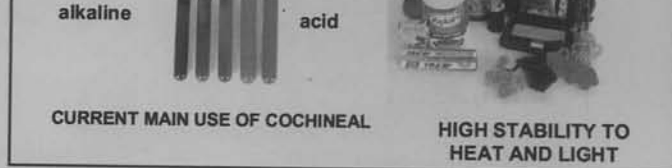

Fig. 18. The red dye produced from cochineal has a wide range of "red colors" and is used agro-industries, medicines, and cosmetics (Portillo, 2009).

Fig. 19. A wide range of commercial cosmetic products from cactus pads are marketed in many countries.

principle from the stem extract was identified. Extract from the cladodes showed similar effect as acetylsalicylic acid without toxic effects, even at high dosages (Galati *et al.*, 2003; Park *et al.*, 2001).

Anti-ulcerogenic effect and healing properties: In Sicily folk medicine, *Opuntia ficus indica* (L.) Mill. cladodes are used for the treatment of gastric ulcer. Clinical studies showed that the consumption of cladodes has a protective action against ethanol-induced ulcer, probably due to carbohydrate-containing polymers, having mixture of mucilage and pectin. The preventive administration of the fruit juice inhibited the ulcerogenic activity of ethanol in rat. The protective effect was ascribed to the cladodes' hydrocolloid acting as a buffer, spreading out on the gastric mucosa and increasing mucus production by enhancing the number of secretory cells (Galati *et al.*, 2002, 2003; Lee *et al.*, 2001, 2002).

Hypoglycemic and antidiabetic effects: The cactus cladodes stable have been used traditionally to treat diabetes in Mexico. Human studies in the 80's demonstrated glucose and insulin levels in people eating cladodes.

It has been demonstrated that cladodes and to a lesser extent the fruits have an anti-hyperglycemic effect that was proposed as alternative to oral antidiabetics, thereby preventing insulin resistance. The hypoglycaemic effect seemed to be related to improved sensibility of the pancreatic cells with a concomitant improved glucose usage. These effects deserve special attention since the populations of developed countries are increasingly suffering from obesity and diabetes symptoms urgently requiring effective countermeasures. The efficiency of cactus cladodes in lowering blood sugar was observed in both fried and raw materials (Wolfram *et al.*, 2002).

An amazing effect of cacti in controlling appetite has been recently reported in several media and it may change the life of people suffering from obesity. It is perceived as a new miracle diet ingredient. Imagine an organic pill that kills the appetite and attacks obesity. It has no known side-effects, and contains a molecule that fools your brain into believing you are full. This pill is already sold through internet and it is manufactured from a cactus ugly plant with a bitter taste named *Hoodia gordonii*.

Anti-hyperlipidemic and cholesterol lowering effect: Experimental evidence suggests that cactus cladodes reduce cholesterol levels in human blood and modify low density lipoprotein (LDL) composition. This effect is generally attributed to the high fiber content of the cladodes, although other active ingredients (such as beta-carotenes, vitamin E and beta-sitosterol) may also be involved.

Table 11. Intake, digestibility, nitrogen balance, and growth for lambs on straw-based diets supplemented with conventional feeds (barley and soybean meal) and alternative feeds (spineless cactus and Atriplex nummularia) (Nefzaoui and Ben Salem, 2002)

Quantity	Supplments			
	Soybean meal		Atriplex	
	Barley	Opuntia	Barley	Opuntia
Organic matter intake (g per kg metabolic weight ($kg^{0.75}$)	68	85	81	94
Digestibility, %				
Organic matter	70	71	68	75
Protein	73	71	71	73
Fiber	68	69	68	74
Retained nitrogen (g day^{-1})	9.4	9.5	7.5	12.2
Average daily weight gain (g day^{-1})	108	119	59	81

Moreno Alvarez, M.J., Medina, C., Antón, L., García, D. and Belén Camacho, D.R. 2003. Uso de pulpa de tuna (*Opuntia boldinghii*) en la elaboración de bebidas cítricas pigmentadas. *Interciencia* 28: 539-543.

Nefzaoui, A. and Ben Salem, H. 2002. Forage, fodder, and animal nutrition. In *Cacti, Biology and Uses* (Ed. P.S. Nobel), Chapter 12. University of California Press, USA.

Nefzaoui, A. and El Mourid, M. 2007. Cash from cactus. *ICARDA Caravan* No. 24, pp. 7-9.

Nefzaoui, A. and El Mourid, M. 2009. Cacti: A key-stone crop for the development of marginal lands and to combat desertification. *Acta Horticulturae* 811: 365-372.

Nefzaoui, A., Nazareno, M. and El Mourid, M. 2007. Review of medicinal uses of cactus. In Proceedings of the International Symposium on Perfume, Aromatic and Medicinal Plants from Production to Valorization SIPAM 2006. Jerba (Tunisia), pp. 664-678. Revue des Régions Arides, special issue, IRA Medenine Tunisia.

Nobel, P.S. 1994. *Remarkable Agaves and Cacti.* Oxford University Press, New York.

Nobel, P.S.. 2009. Desert Wisdom, Agaves and Cacti, CO_2, Water, Climate Change. iUniverse, New York, Bloomington. ISBN: 978-1-4401-9151-0. 198 pp.

Nobel, P.S. and De la Barrera, E. 2003. Tolerances and acclimation to low and high temperatures for cladodes, fruits and roots of a widely cultivated cactus, *Opuntia ficus-indica. New Phytologist* 157: 271-279.

Park, E.H., Kahng, J.H. Lee, S.H. and Shin, K.H. 2001. An anti-inflammatory principle from cactus. *Fitoterapia* 72: 288-290.

Portillo, L. 2009. Biogeography of Dactylopiidae and human factor. *Acta Horticulturae* 811: 235-240.

Russell, C.E. and Felker, P. 1987. The prickly pears (*Opuntia* spp. Cactaceae): A source of human and animal food in semiarid regions. *Economic Botany* 41: 433-445.

Sáenz, C. 2002. Cactus pear fruit and cladodes: A source of functional components for foods. *Acta Horticulture* 581: 253-263.

Sáenz, C. 2006. Utilizacion agroindustrial del nopal. Boletin de servicios agricolas de la FAO, 162: 164pp.

Shoop, M.C., Alford, E.J. and Mayland, H.F. 1977. Plains prickly pear is a good forage for cattle. *Journal of Range Management* 30: 12-16.

Stintzing, F.C. and Carle, R. 2004. Functional properties of anthocyanins and betalains in plants, food, and in human nutrition. *Trends in Food Science Technology* 15: 19-38.

Stintzing, F.C. and Carle, R. 2005. Cactus stems (*Opuntia* spp.): A review on their chemistry, technology, and uses. *Molecular Nutrition Food Research* 49: 175-194.

Tesoriere, L., Butera, D., Allegra, M., Fazzari, M. and Livrea, M.A. 2005b. Distribution of betalain pigments in red blood cells after consumption of cactus pear fruits and increased resistance of the cells to ex vivo induced oxidative hemolysis in humans. *Journal of Agriculture Food Chemistry* 53: 1266-1270.

Tesoriere, L., Fazzari, M., Allegra, M. and Livrea, M.A. 2005a. Biothiols, taurine, and lipid-soluble antioxidants in the edible pulp of Sicilian cactus pear (*Opuntia ficus-indica*) fruits and changes of bioactive juice components upon industrial processing. *Journal of Agriculture Food Chemistry* 53: 7851-7855.

Wolfram, R.M., Budinsky, A., Efthimiou, Y., Stomatopoulos, J., Oguogho, A. and Sinzinger, H. 2003. Daily prickly pear consumption improves platelet function. *Prostaglandins Leukot Essent Fatty Acids* 69: 61-66.

Wolfram, R.M., Kritz, H., Efthimiou, Y., Stomatopoulos, J. and Sinzinger, H. 2002. Effect of prickly pear (*Opuntia robusta*) on glucose- and lipid-metabolism in non-diabetics with hyperlipidemia ? A pilot study. Wiener Klin Wochenschr 114: 840-846.

Zou, D.M., Brewer, M., Garcia, F., Feugang, J.M., Wang, J., Zang, R., Liu, H. and Zou, C.P. 2005. Cactus Pear - A natural product in cancer chemoprevention. *Nutrition Journal* 4: 25.