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Cactus Pear:
Cultivation and Uses

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FORWARD

Climate change has become one of the biggest challenges for the sustainable crop production. Prolonged droughts and desertification are the major issues faced by Indian hot arid zone where rural poor and smallholders are most heavily affected. Therefore, the crops which can withstand to such conditions like; drought, high temperatures and poor soils need more emphasis. Cactus crops are gaining increasing interest across the globe, in particular cactus pear or prickly pear (Opuntia ficus indica (L) Mill.) because of its unique characteristics which provide resilience to the harsh ecological conditions. Cactus pear can be grown on land where no other crops are able to grow; it can be used to restore degraded land. It is the only crop that can be relied on when everything else fails. Thus, it is environment friendly crop which can withstand long periods of drought.

Even today cactus pear is treated as underutilized crop in India, though it has multiple utility. Cactus cladode is rich in pectin, mucilage, minerals, polyphenols, nicotiflorin, vitamins, polyunsaturated fatty acids and amino acids. Cactus nopal pulp has numerous compounds (dietary fibre, vitamin C, phenolic compounds) with the potential to provide important benefits like intestinal, cardiovascular, hepatic health, antioxidant activity and cancer prevention. The most important economic species in the world is Opuntia ficus-indica (L.) Mill.

Presently, it is grown in Mexico, Malta, Spain, Sicily, Italy, Greece, Libya, Tunisia, Morocco, Algeria, Lebanon, Syria, Egypt, Saudi Arabia, Yemen, Israel, Chile, Brazil, Turkey, France, Bulgaria, Portugal, Albania, Cyprus and United States. Cultivated of cactus pear was started long back in many countries of the world but, in India, its commercial cultivation is yet to start. Few year back research work on planting methods, performance of various accessions, exploitation and uses of vegetable type cactus and biomass production was initiated at CIAH, Bikaner. Micropropagation technique of spine-less, vegetable type cactus pear (nopal cactus) was standardized by ICAR-CIAH, Bikaner recently in 2009 and its morphological and nutritional evaluation was done under green house conditions. Further several value added and culinary products from cactus pear have been developed at CIAH, Bikaner for making this crop more remunerative. The field

evaluation of this nopal cactus is being carried out with other cactus pear existing germplasm at CIAH farm. The cultivation of vegetable type for human consumption is depends on selection of the spineless varieties. The most important species for nopales production is Opuntia ficus-indica (L.) Mill. Now-a-days, it is parts of kitchen gardens in arid and semi-arid regions due to nutritional and medicinal properties. Cactus is alternative resource to meet the food supply and nutritional health requirements.

I hope that the compilation made by the authors will be useful to the readers.

(P.L. Saroj)
Director

Contents

1. INTRODUCTION, HISTORICAL IMPORTANCE AND CURRENT SITUATION

Introduction

Climate change has become one of the biggest challenges for the sustainable crop production. Prolonged droughts and desertification are among the issues faced by Indian hot arid zone where the rural poor and smallholders are most heavily affected. People have to survive in these types of conditions; thus their crops need to withstand such harsher calamities viz., drought, high temperatures and poor soils. Cactus crops are gaining increasing interest across the globe, in particular cactus pear or prickly pear (*Opuntia ficus-indica* (L) Mill.) because of its unique characteristics which provide resilience to the harsh ecological conditions. Cactus pear can be grown on land where no other crops are able to grow; it can be used to restore degraded land. It is the only crop that can be relied on when everything else fails. Cactus plant and its cladode, fruits are popularly known by several names such as prickly pear, cactus pear, Indian fig opuntia, Barbary fig, spineless cactus, nopal cactus etc. The young cladode is called nopal and the fruit is tuna. Nopal word is especially known for its culinary exploitation of cladodes in the form of vegetable, salad, pickle etc. Now days many of the cactus are ornamental plants which can be grown in a small pot. Some of the varieties are poisonous and some have small leaves and showy colourful blooms. Cactus pear is grouped as CAM plant (Crassulacean Acid Metabolism), a photosynthesis mechanism evolved in some plants as an adaptation to arid conditions. In a plant using full CAM, the stomata in the leaves remain shut during the day to reduce evapotranspiration, but open at night to collect carbon dioxide (CO_2). At night carbon dioxide is stored as 4 carbon acid malate in cell vacuoles. The malate is transported to chloroplasts where it is converted back to CO_2 during day which is used in the process of photosynthesis. The cactus pear plants though shallow rooted but have capacity to absorb and store water in its parenchyma even under unfavorable climatic conditions due to high mucilage production in both cladode and fruits. Besides, peculiar adaptations to water scarcity and high as well as low temperature is because of reduced leaf tissues and cuticular wax covering of cladodes and fruit surfaces. Even today cactus pear is treated as under utilized crop in India, though it has multiple utility (Saroj et al, 2017). The cactus pear fruit is an oval, elongated berry, with a thick pericarp and a juicy pulp and, in general, many hard seeds generally known as tuna. The fruits are of different colours, such as red, purple, orange, yellow and green in colour which show the presence of various antioxidants.

The high sugar and low acid blend of the fruit makes it delicious and palatable. The pericarp of ripe fruits accounts for 33% to 55%, while the pulp is 45% to 67%, and seeds 2% to 10%. The pulp is the edible part of the fruit and is composed of water (84% to 90%) and reducing sugars (10% to 15%). The pH value of fruits ranged (5.3 to 7.1) and the very low acidity (0.05% to 0.18% in citric acid) of the pulp, which strongly influences the processing operations. Sugars range from 10°Brix to 17°Brix and are mainly of the reducing type (Stintzing et al., 2003). Cactus cladode (nopal) is rich in pectin, mucilage, minerals, polyphenols, nicotiflorin, vitamins, polyunsaturated fatty acids (palmitic acid, oleic acid, linoleic acid, linolenic acid etc.) and amino acids (glutamine,

leucine, lysine, valine, arginine, phenylalanine and isoleucine). The nopal contains antioxidants and various flavonoids, particularly quercetin 3-methyl ether, a highly efficient radical scavenger. Chemical characterizations of nopal have studied by several workers and reported that it contains vitamins and minerals. Dehydrated nopals contain high levels of potassium content. Considering the lactose intolerance in certain parts of the population, nopals could be an alternative as source of calcium. Cactus nopal pulp has numerous compounds (dietary fibre, vitamin C, phenolic compounds) with the potential to provide important benefits like intestinal, cardiovascular, hepatic health, antioxidant activity and cancer prevention. The fresh young pads so called nopal are excellent source of proteins including essential amino acids and vitamins. The value added products of cactus pear could also supplement to nutritional security and human health. The succulent vegetative parts are called as pads or cladodes which are modified stem (Kumar et al., 2017).

The propagation and cultivation of spineless varieties may provide the feed stuffs to domestic animals during summer season in arid ecosystems, when there is lack of forage/grass due to harsh climatic conditions. Even today cactus pear is treated as underutilized crop in India, though it has multiple utility. In general, no special treatments (fertilizer application, pruning and treatment against pests and diseases) are necessary for cactus establishment and cultivation. Supplemental irrigation may be applied during early period of establishment on first year. Cacti are ready for commercially use after 3- 4 years of planting. A well managed cactus orchard can remain productive for about 4-5 decades.

Historical importance

Cactus word derives from the Ancient Greek word kaktos, a name used for a plant having spines and whose identity is not certain. The genus is named for the Ancient Greek city of Opus, where, according to Theophrastus, an edible plant which could be propagated by rooting its leaves. The people of Hispaniola Island (now Haiti and the Dominican Republic) in the Caribbean Sea, introduced tuna (red fruits of Opuntia) to the Spaniards after arriving to their land in 1492 (Kiesling, 1999). The use and cultivation of cactus pear was started to long back, when the Spaniards arrived in the Americas. For the first time the cactus plants and its fruits were recorded by the Indian chroniclers, which carried cacti to Spain and that time these were being used as ornamental plants. Cactus pear was part of the Aztec culture (Josh et al, 2017); the Aztec army flag shows an eagle over a cactus pear eating a snake and the empire capital called as Tenochtitlan meaning 'Cactus pear over a rock' (now Mexico City). The same picture is also depicted on the first page of Codex Mendoza representing the centre of the universe. The conquistadors began to eat the fruits. The first author, Oviedo y Valdes (1515), which described the fruit and the plant of cactus pear and wrote that his fellows "knew and ate that fruit with pleasure"in Hispaniola (Josh et al, 2017). Other authors were also mentioned the success of this crop among local peoples and the Spaniards. The red dye (nocheztli) was greatly appreciated by the Spaniards, who called it grana cochinilla. The dye is rich in carminic acid and is extracted from the body of the cochineal bug *(Dactylopius coccus)* that lives and feed on the cladodes of cactus pear. The

red dye was highly rated for its commercial qualities (Josh et al, 2017). According to Cervantes de Salazar, "a great quantity of dye at a high cost was imported by Spain" (Donkin, 1977). At the end of the 16th century, it was the most desired import commodity from America. In India, the insect was reported in 1795 and in Europe at the beginning of the 19th century. In 1853, there were 14 breeding centres in Algeria and in 1850-1860 the Canary Islands were already exporting double the quantity coming from America (FAO, 2013). Cactus pear was first reported in the natural and general history of the Indies autherd by Gonzalo Fernando Oviedo y Valdes in 1536. He wrote;"I can not make up my mind whether it is a tree or one of the most frightful monsters among trees"(Donkin, 1977). Cactus pear and Cochineal insect were spread to Peru by the Spaniards (De Acosta, 1590). According to De Acosta, 1590, in Argentina red fabric dye and clothes were made using cochineal bug. The first document on medicinal use of cacti and its derivatives was in Medicine in Natural Paraguay written by Jose Sanchez Labrador, 1771-1776. He explained the use of cochineal insect for fevers and insanity, the fruit used as refreshment and seeds as an astringent. There was evidence of the presence of cacti in Europe by the 17th century, in a xylograph showed the cactus pear among other plants in the Garden of Eden. In Mediterranean regions, where the climatic conditions was favourable, cacti quickly naturalized and became one of the most common and representative elements of the landscape. Opuntias spread to South Africa (1772), India (1780), China (1700) and Indochina during the 18th century (Donkin, 1977). During 19th century, use of the cacti as an icon became very popular in arts, cartoons, marketing and even in politics (Josh et al, 2017). Recently, prickly pear cactus was renamed as cactus pear.

Current scenario

Cactus pear is now-a-days part of the agricultural systems and natural environment. The most important economic species in the world is *Opuntia ficus-indica* (L.) Mill. Presently, it is grown in Mexico, Malta, Spain, Sicily, Italy, Greece, Libya, Tunisia, Morocco, Algeria, Lebanon, Syria, Egypt, Saudi Arabia, Yemen, Israel, Chile, Brazil, Turkey, France, Bulgaria, Portugal, Albania, Cyprus, United States (Kauthale et al, 2017). The area covered under cactus cultivation is presented in table 1.

Table 1. Current world scenario of cactus cultivation

S.N.	Country	Cultivated area (000 ha)
1.	Brazil	600
2.	Tunisia	600
3.	Mexico	230
4.	Morocco	150
5.	Algeria	150
6.	Italy	70
7.	Other South American Countries	75

S.N.	Country	Cultivated area (000 ha)
8.	Other North American countries	16
Total		1891

Source: International Cactus Pear Workshop: Development of a cactus pear agro-industry for the sub-Sahara Africa Region Bloemfontein, South Africa, 27-28 January 2015.

It can be found growing well from sea level to 5100 meters above sea level in Peru and from Canada to Patagonia and Argentina. The first record of modern cactus pear cultivation techniques using the best varieties were found in Mexico, Zacatecas, San Luis Potosi, Aguascalientes, Jalisco and Guanajuato in the 1940s and 1950s. Cactus pear is now the most reliable and even profitable option for utilizing rainfed semi-arid lands in the semi-arid regions of central Mexico. It is the crop of choice over corn or dry beans in areas exposed to drought, while in slightly improved areas, it supplemented the income of the growers (Josh et al, 2017).

Cultivation of cactus pear was started long back in many countries of the world but, in India, its commercial cultivation is yet to start. In India 33 Opuntia clones were introduced by Dr. Peter Felker, Texas, USA at the Nimbkar Agricultural Research Institute at Phalton, India in 1987 as a part of an Indo-US collaborative research programme on Opuntia. All the introduced clones grown well under the semi arid agro-climatic conditions of western Maharashtra and it was reported that some clones produced fruits also (Singh, 2003). Till so for (Kauthale et al, 2017), it is at the research stage with limited field trials initiated by Central Arid Zone Research Institute (ICAR- CAZRI), Jodhpur and in Kutch district of Gujarat in few select areas with the support of International Center for Agricultural Research in the Dry Areas (ICARDA). The comprehensive work on Cactus was started by NARI with the collection of good number of imported accessions. However, the work could not be pursued to its logical end. During the last two decades the research was conducted by many public sector research Institutes in India especially those are working in arid agricultural crops, but the outcome of this work is yet reach to the farmers.

Recently, in India the research work on Cactus pear has been undertaken by various Research Institutions viz., ICAR-CAZRI, Jodhpur supported by ICARDA, ICAR-CIAH, Bikaner ICAR- IGFRI, Jhansi, ICAR- CSSRI , Karnal. Field adaptation trials on farmers field are being conducted through ICARDA programme by CAZRI and in Bundelkhand region by IGFRI and CAFRI. NDDB actively involved in spreading cactus among dairy farmers of Gujarat (Kauthale et al, 2017). Trials on planting seasons and irrigation management with cactus in various cropping models are in progress at CAZRI. Recently, research work on planting methods, performance of various accessions, exploitation and uses of vegetable type cactus (Kumar et al., 2017) and biomass production, was made at CIAH, Bikaner, CAFRI, Jhansi and CSSRI, Karnal. BAIF Development Research Foundation, Pune, a non-government organization initiated a comprehensive work on Cactus with the financial support of NABARD in 2015. The initiative was to cultivate this new crop on the farmer's field after standardizing the production technology with the aim to cultivate cactus for food and fodder, but later on the research at BAIF was focused mainly on providing an

alternate fodder crop to the farmers living in arid and semi-arid regions of India and to address their livelihood issues (Kauthale et al, 2017).

Micropropagation technique of spine-less, vegetable type cactus pear (nopal cactus) was standardized by ICAR-CIAH, Bikaner recently in 2009 and its morphological and nutritional evaluation was done under green house conditions (Saroj et al, 2017; Kumar et al., 2017). The field evaluation of this nopal cactus is being carried out with other cactus pear existing germplasm at CIAH farm. The cultivation of vegetable type (nopal cactus pear) for human consumption is depends on selection of the spineless varieties. The most important species for nopales production is *Opuntia ficus-indica* (L.) Mill. Now-a-days, it is parts of kitchen or family gardens in arid and semi-arid regions due to nutritional and medicinal properties.

Several cacti have been successfully used in land reclamation and rehabilitation programmes and recently have been used in lead-contaminated waters as a bioaccumulator in bioremediation programmes. It is a suitable model crop for attaining productivity and sustainability with minimal ecological or environmental impact to meet the growing world demand for food due to continuous increasing population. The similar point applied to *O. ficus-indica* and other species as these are alternative resources to meet the food supply and nutritional health requirements. Cactus is a special and environment friendly crop which can withstand long periods of drought. It is a factor that may become significant in region of the world with declining water resources and increasing desertification as a result of human population growth and global warming.

2. ORIGIN, TAXONOMY AND GEOGRAPHICAL DISTRIBUTION

The domestication of cacti was began about 8000 years ago but archaeological references indicated that the cacti which were used 8000 years ago can not be associated directly with *Opuntia ficus-indica* and others reported that the domestication of opuntias were took place in the south of the meridional Mexican highlands . Various species were reported and supposed to be ancestors of cultivated *Opuntia ficus indica*, particularly *O. megacantha* and *O. streptacantha* (Josh et al., 2017). Later on Griffiths (1914) considered *O. megacantha* Salm-Dyck as wild thorny progenitor of modern cultivated *O. ficus indica* and also supported by molecular studies (Griffith, 2004) but Benson (1982) considers *O. megacantha* as a synonym of *O. ficus-indica* in the spiny form and he also discarded from the type of variety or form. Other authors also followed the reasoning given by Benson (1982). Cactus pear have originated in Mexico and distributed in arid and semi arid regions of the world, such as Australia, Africa, USA, Mediterranean basin and South East Asia. The future of arid and semi-arid regions of the world largely depends on the sustainable development of agricultural systems based on the use of suitable crops for these areas. Suitable crops are those that successfully cope with climatic variabilities such as water shortage, high temperature, poor soils and easy management to provide food and forage to poor farmers and herders. Cacti can fit most of the above described requirements (FAO, 2013).

The taxonomy of the cactus is complex. Tournefort in 1700 coined the scientific name Opuntia in view to their resemblance to spiny plants that grew in the town of Opus in Greece. Cactus is commonly known as prickly pears having about 130 genera and 1,500 species of cactaceae. Cacti exist in a wide range of shapes and sizes. *Pachycereus pringlei* is the tallest (19.2 m) cactus while *Blossfeldia liliputiana* is the smallest one having only about 1 cm diameter at is maturity. About 300 species of the genus Opuntia are known till today. Out of which only 10 to 12 species have been utilized for different purposes such as fruits, tender cladodes, fodder and cochineal for dye production. The species mostly cultivated and utilized for fruit production are: *Opuntia ficus-indica, Opuntia xoconostle, Opuntia amyclae, Opuntia streptacantha* and *Opuntia megacantha*. Wild species which are used namely *Opuntia robusta, Opuntia hyptiacantha* and *Opuntia leucotricha*. *Opuntia ficus-indica* is the most widely cultivated species throughout the world.

Wide spread distribution of genus Opuntia is due to its peculiar adaptations to water scarcity and sun irradiation such as (a) CAM metabolism (Crassulacean Acid Metabolism), (b) the reduction of leaf tissues (3) cuticular waxes covering the cladodes and fruit surfaces, and (4) its capacity to regenerate from root calluses, pads, fruits, seeds, tissue culture and grafting which allow them to grow year round and stay evergreen despite harsh environmental conditions. Cacti are widely distributed throughout the Americas from Canada to Chile; in the southern United States, all Central American and Caribbean countries and the South American countries of Argentina, Bolivia, Brazil, Colombia, Peru and Venezuela. Cacti species both wild as well as cultivated also grows in Angola, Australia, India and South Africa. These countries have the most extensive dry lands on the planet and more than 5 billion hectares (ha) of arid and semi-arid zones regions. People and animal beings living in these regions look for plant species that can adapt, grow and provide food and materials round the year (FAO, 2013). Opuntia plants are distributed and native to many environmental regions, ranging from deserts below sea level to high altitudes such as the Peruvian Andes and from the tropical regions of Mexico, where temperatures always reported above 5 ^{o}C, to areas in Canada that can fall to -40 ^{o}C in winter. Its wide spread adaptability is the main cause for considering this species as a highly valuable resource for a wide variety of ecological zones (FAO, 2013).

3. MORPHOLOGY AND BOTANICAL DESCRIPTION

Cactus plants are characterized for their flattened stems, their nopales/ cladodes and fruits edibility; having glochids, rudimentary leaves on new nopales and the seeds with a pale covering. The buds (called areoles) can be found on both sides of the cladodes and capable of developing new cladodes. The root system of cactus is very complex because it has several types of roots viz., tap root, rain root/absorbing roots, root spurs and root formed from areoles which develops as and when required by plant for its survival and growth. It has shallow and fleshy tap root system penetrates about 30 cm into deep ground horizontally. A peculiar characteristic of cactus root system is that it develops a special kind of roots called 'rain roots' which appear

within few hours of light rains to absorb the rain water and disappear as and when soil dries. The flowers are sessile, actinomorphic, hermaphrodite and solitary; normally develop on the upper edge of the cladode. Flowers are large similar to the spines and branches arise from areoles. Many cactus species bloom at night because they are pollinated by nocturnal insects and small animals mainly moths and bats. Fruit is an oval, elongated, fleshy berry known as tuna and varying in shape, size and colour and has a consistent number of hard seeds. The fruits are of different colours, such as red, purple, orange, yellow and green in colour. Cladodes have two types of spines; large and small, so called glochids which easily detached from the plant and penetrate in skin.

4. GENERAL CONSTITUENTS OF CACTUS

4.1. Nopal/cladode

Cactus nopals are rich in pectin, mucilage, minerals, polyphenols, nicotiflorin, vitamins, polyunsaturated fatty acids (palmitic acid, oleic acid, linoleic acid, linolenic acid etc.) and amino acids (glutamine, leucine, lysine, valine, arginine, phenylalanine and isoleucine). The nopal contains antioxidants and various flavonoids, particularly quercetin 3-methyl ether, a highly efficient radical scavenger. Nopals are characterized by high malic acid contents due to a CAM-based diurnal rhythm. Chemical characterizations of nopal have studied by several workers and reported that it contains vitamins and minerals. Dehydrated nopals contain high levels of potassium content. Considering the lactose intolerance in certain parts of the population, nopals could be an alternative as source of Calcium. Cactus nopal pulp has numerous compounds (dietary fiber, vitamin C, phenolic compounds) with the potential to provide important benefits like intestinal, cardiovascular, hepatic health, antioxidant activity and cancer prevention. The fresh young pads so called nopal are excellent source of proteins including essential amino acids as well as vitamins (Saroj et al., 2017). Several workers have reported that high levels of amino acids especially proline, taurine and serine are found in nopal.

4.2. Fruit

The high sugar and low acid blend of the fruit makes it delicious and palatable. The pericarp of ripe fruits accounts for 33% to 55%, while the pulp is 45% to 67%, and seeds 2% to 10%. The pulp is the edible part of the fruit and is composed of water (84% to 90%) and reducing sugars (10% to 15%). The pH value of fruits ranged (5.3 to 7.1) and the very low acidity (0.05% to 0.18% in citric acid) of the pulp, which strongly influences the processing operations. Sugars range from 10°Brix to 17°Brix and are mainly of the reducing type (Saroj et al., 2017).

5. USES OF CACTUS SPECIES

Cacti *(Opuntia spp.)* have been used for centuries as common vegetables and medicines by Native Americans and Mexicans to treat a variety of ailments and disorders. The nutritional and medicinal properties of the fresh cactus cladodes have long been known. The bark is a tonic and diuretic, the fruits have cooling and tonic properties and the young buds and the milky juice are astringent (https://books.google.co.in/books?isbn=0124080642). Some of the common and popular names used for the plant and the fruit of the cactus pear such as 'fruit for the poor', 'future plant', 'Green gold', 'treasure under its spines', 'world vegetable dromedary', 'sacred plant' and 'monster tree' telling the importance of cactus in the work and lives of people because of its resistance to drought and high temperatures and adaptability to poor soils. Various applications of cactus pear have been reported in several *Opuntia species*. Active ingredient extracted from its fruits and cladodes have been used in treatments of diabetes, cholesterol, immune system, wound healing and protecting brain tissues from glucose and oxygen deprivation, treating hypoglycemic effects in diabetic patients by maintaining blood glucose to normal levels. Flavonoids obtained from cladodes and fruits have antioxidant properties. Diet supplemented with its fruits decreases oxidative stress by improving antioxidant status. Nopal cactus has been used in Sicily folk medicine for years to treat gastric ulcers. If fruit consumed along with seeds can cause constipation but without the seeds it has laxative effect. Ethanol extracted from fruits and cladodes suppressed the paw edema in laboratory animals and had a potential inhibitory effect against leukocyte migration which is an important mechanism for development of inflammatory diseases (Kauthale et al, 2017). The cactus pear plant provides many opportunities for processing fruit and cladodes. The fruits and cladodes can be preserved and processed using different technologies and practices.

A number of traditional foods are prepared from cactus pear, including fruit-based products: jams, juices and nectars; dried fruit; juice concentrates and syrups; and liquors. Pickles, juices, jams and a number of other minimally processed products can be made from cladodes (FAO, 2013).Cacti have been used as live biofencing material for protecting fields from wild animals. Different types of cactus species are being used for research purposes mainly as fodder in arid, semi- arid, rainfed and drought prone areas. However, few institutes like CIAH, Bikaner, CAZRI, Jodhpur, CAFRI, Jhansi, CSSRI, Karnal the focus has recently shifted to the production of vegetable type, spineless cactus genotypes for human consumption as well as animal fodder.

5.1. Uses of tender cladodes (nopales)

Peoples of Mexico and other southwestern countries eat the fresh young cactus pads (nopales) as raw or after cooking, used in soups stews, salads and in marmalades. They are sliced into strips and fried with eggs and jalapeños and served as a breakfast treat. Nopales are generally sold fresh in Mexico and sliced to the customer's desire on the spot. For export purpose, they can also be found canned or bottled and less often dried (Kauthale et al, 2017). The presence of Selenium in cladodes coupled with minerals, total phenolics and antioxidant capacity suggested that

Cactus pear can be useful as a nutraceutical food for improving human nutrition and health by developing immunity against ailments and diseases. Nopals showed protective effect in oxidative stress caused by various genotoxic agents such as mycotoxins, aflatoxins and cytotoxic drugs, such as cis-platinum. Nopals decrease the inflammatory response caused by different stimuli and showed positive effects on wound healing of the skin and the gastric mucosa. All of these effects are related to the antioxidant potential of nopals active principles like polyphenols and flavonoids, all substances with radical scavenger effect. Significant amount of α, β and g nopals noticed in cladode which could be a good source of tocopherols (Vitamin E). Nopal mucilage is being used in foods, as fat replacer in food products and flavour binder.

Use as a food/ vegetable

Tender nopales (tender cladodes of vegetable type, spineless cacti) can be consumed during the early stages of growth (till light green in colour). Cactus nopal is suitable to use as fresh. It was observed that nopales can be harvested regularly at an interval of 15-20 days when they reach 10 to 15 cm in length and about average weight of 30 g/nopal which can provide an average yield of 1.5 kg tender nopales/plant/year. Cactus nopales are an important part of the human diet and are also used as feed for livestock. A number of potentially active nutrients and their multifunctional properties are found in nopal which makes it suitable for the production of health-promoting food and food supplements. Mainly nopales are consumed fresh form in Mexico and canned or pickled nopales exported to particularly Southwestern United States and Texas. Opportunities of several economic products such as fruit, squash of fruit, pickle, ready to serve drinks, colour from fruit and cochineal, cladodes for culinary and salad were prepared at ICAR-CIAH, Bikaner and demonstrated to several beneficiaries which can satisfy the product diversification need, increased shelf life and improved human health.

Use as an animal feed

Livestock production remains the main source of income for rural populations living in drylands. It is a key component of resilient production systems and is an indicator of wealth. However, the sector faces many challenges including feeding constraints and climate change. Adapted perennial species are a potential option for improving fodder availability in dry areas. Water scarcity is another important limiting factor in drylands, threatening the sustainability of livestock-based systems (Jose et al., 2017). In these harsh conditions, cactus becomes one of the most prominent crops for the 21st century. Cactus is a succulent and drought-tolerant species which can produce more than 20 tonnes dry matter/ ha/ year and provided 180 tonnes/ha/ year of water stored in its cladodes representing a cost-effective option for livestock watering (Dubeux et al., 2015b). The importance of cactus pear with respect to animal fodder has been evaluated by many workers and giving techniques for proper utilization as livestock feed. Cactus pear cladode quality does not deteriorate on storage and it maintains green colour as well as vitamin A level and can provide an excellent source of fodder during the drought periods. Fruits of the cactus pear are edible and weight varied from 110g - 160 g which contain 12 to 15 % sugar content (Felkar et al. 1997).

Cacti are a good source of animal feed than any other conventional fodder crops due to their better water use efficiency and rain use efficiency. Cactus pear have a great scope in producing large amount of fodder for livestock in arid and semi-arid regions. The dry matter content of Opuntia is less than 15%. It has low protein content about 4% crude protein, low phosphorus and fibre content about 10% of the dry matter. However, it is rich in energy, calcium and ash. As such, cactus is energy feed source. Since fibre content is low and protein is lower than the maintenance requirement for ruminants (about 7% of the dry matter), Cacti need supplementation with nitrogen sources and fibrous feed like straws from cereals for optimum animal performance. Since cladodes are highly succulent (~85% water) thus animals can survive for a long time without water in areas where water is a problem. A cow consuming 40 kg of fresh cactus per day will also consume 35 litres of water per day simultaneously. Thus, cacti are suitable fodder crops for animals living in arid and semi-arid ecosystem (Kauthale et al, 2017). It is reported that a daily ration of 40 kg of cactus, 0.5 kg of mineral salts, and 0.5 kg of protein supplement is sufficient to permit excellent live weight gain, reproduction, and lactation from nursing cattle. However, the potential of cactus crop remains underexploited in India. Major cactus species such as Opuntia ficus-indica and Nopalea cochenillifera with different varieties have been released in different countries (Brazil, Mexico, South Africa, Tunisia etc.) are being used as fodder for livestock. The forage potential of cactus in arid and semi-arid regions of India is not exploited so for. There are good opportunities to develop cactus-based livestock production systems, promote human livelihood security and thereby reducing the pressure on cultivated land.

Use as a nutrition

The nutritional benefits of cactus are currently thought to be related to their antioxidant properties. Several health benefits of cactus nopales and fruits are mainly due to its nutrition and vitamin content, which includes riboflavin, vitamin B6, copper, iron, fiber, vitamin-A, C, K, calcium, potassium, magnesium, and manganese. The cactus pear total antioxidant activity is two times higher as compared to other fruits. Hundred gram content of cactus nopal on Daily Value (DV) contains dietary fiber (14% DV), vitamin C (23% DV) and the dietary mineral, magnesium (21% DV). Cactus is often used in making appetizers, soups and salads through entrees, vegetable dishes and breads to desserts, beverages, candy, jelly, or drinks in Mexico. Cactus showed a vitamin C content ranging from 180 to 300 mg/kg. Cactus pear fruits content higher vitamin C than other common fruits, such as apple, pear, grape, and banana, while other vitamins, such as carotenoids, thiamin, riboflavin, and niacin are in trace. The lipids, protein, minerals, and fiber, do not differ significantly from other tropical fruits. The large quantity of insoluble fibre present in the seeds provides the major source of fibre in when the whole peeled fruit is ingested. Lipids are present in the peel, pulp and seeds. Peel, which is a by-product, gives appreciable amounts of polyunsaturated fatty acids, mainly linoleic acid, α-tocopherol, sterols, β-carotene and vitamin K1. Linoleic acid also found both in pulp and seed oil, while pulp oil predominates in terms of γ- and α-linolenic acids, the latter being detected only at very low levels. The fruit has a high content of free amino acids, particularly proline and glutamine, the highest level being that of nutraceutical taurine, up to 572.1 mg/L.

Now-a-days, nopales are commonly used in Mexican cuisine in different kinds of dishes and also an important part in New Mexican cuisine. Nopales are an important source of certain organic compounds like phytochemicals and polysaccharides which contributed to the health boosting power of nopales. Flour made from older cladodes that can be a good source of calcium for populations where, the availability of dairy products is complicated and also in people with difficulties in digesting dairy products.

Use as a medicine

Cactus nopals have also been reported to be beneficial to health. These effects are demonstrated in the treatment of several diseases. Traditionally cactus nopal has been used for the treatment of burns, wounds, edema, hyperlipidemia, obesity and catarrhal gastritis. Selenium present in nopales, coupled with minerals, total phenolics and antioxidant capacity suggested that Cactus pear can be useful as a nutraceutical food for improving human nutrition and health through fighting multiple ailments and diseases. Nopales showed protective effect in oxidative stress caused by various genotoxic agents such as mycotoxins, aflatoxins and cytotoxic drugs, such as cis-platinum. Nopales decrease the inflammatory response caused by different stimuli and showed positive effects on wound healing of the skin and the gastric mucosa. All of these effects are related to the antioxidant potential of fruits and nopales active principles like polyphenols and flavonoids, all substances with radical scavenger effect. Significant amount of α, β and g nopals noticed in cladode which could be a good source of tocopherols (Vitamin E). Alcoholic extracts are indicated for anti-inflammatory, hypoglycemic, and antiviral purposes. Therapeutic potential has been suggested for metabolic syndrome, rheumatism, cerebral ischemia, cancers, virological and bacterial infections. Nopal extracts may lower cholesterol level and convey antiulcer and anti-inflammatory mechanisms and the water extract remarkably improves wound healing. Nopals provide several health benefits such as in weight loss, prevent cancer, improve skin health, protect heart health, regulate and improve digestion, treatment for whooping cough, boost the immune system, optimize metabolic activity, build strong bones, cure insomnia, and reduce inflammation throughout the body. Cactus pulp and juice are used in treating wounds and inflammation of the digestive and urinary tracts in Mexican folk medicine. Nowadays, cactus nopal is amongst the majority of products recommended by Italian herbalists that may be effective in reducing glycemia (Feugang, et al., 2006).

5.2. Uses of fruits

Now-a-days, world-wide, the most commercially use of *Opuntia ficus-indica* is for its large, coloured and sweet fruits. The fruits are of different colours, such as red, purple, orange, yellow and green in colour which show the presence of various antioxidants. The high sugar and low acid blend of the fruit makes it delicious and palatable (Saroj et al, 2017).The fruits have small spines on the outer skin which need careful removal before consumption. The fruits have a taste similar to a juicy and sweet watermelon. Today, parthenocarpic (seedless) cactus pear cultivars are also available. Jams and jellies from fruits are prepared, which resemble strawberries and figs

in colour and flavour (Kauthale et al, 2017). The high sugar and low acid blend of the fruit makes it delicious and palatable. The pericarp of ripe fruits accounts for 33% to 55%, while the pulp is 45% to 67%, and seeds 2% to 10%. The pulp is the edible part of the fruit and is composed of water (84% to 90%) and reducing sugars (10% to 15%) (Stintzing et al., 2003). Traditionally cactus pear fruit was eaten as fresh, which has the advantage of maintaining the nutritional value when the fruit is properly stored. For home consumption, special care needs to be taken when peeling the fruit because of the spines. Before peeling the fruit, hands and cutting utensils should be thoroughly washed. Once the fruit is peeled it should be consumed immediately or stored in a refrigerator for no more than two to three days. The fruit's low acidity and high pH make it quick to ferment, at which point it becomes inedible and can no longer be kept safely. In the home, fresh cactus fruit is often consumed as a juice or in desserts, either separately or combined with other fruits (FAO, 2013).

Fruit leather is prepared after removing the seeds from fruits; the pulp can be dehydrated in thin films or leathers to produce a chewy natural product. Fruit leathers are popular in the Arab countries and in the United States and are made from a variety of fruits. Fruit leather is one of the attractive products made from cactus pear fruit pulp. This product is yet to be manufactured on an industrial scale.

6. FUNCTIONAL PROPERTIES OF NOPALES/CLADODES

Functional compounds are those that help in preventing diseases in human and animal beings. The nopals of cactus pear provide interesting sources of functional compounds, including fibre, mucilage, betalains and carotenoids, minerals and vitamins with antioxidant properties, such as vitamin C. These compounds are valued for their contribution to a healthy diet and also as ingredients for designing new food. These compounds can be included in a new range of foods known as functional foods, which are as foods or beverages that provide physiological benefits. They enhance health, help to prevent or treat disease and/or improve physical or mental performance with the addition of one or more functional ingredients. Cactus nopales as a vegetable or as an ingredient in food stuffs play the functional role in living beings are briefly described under here. Nopales are very fibrous and contain a large amount of dietary fiber which is play a greater role for the digestion system, because it adds bulk to bowel movements that make them easier to pass through the smooth muscles of the digestive tract. Cactus stimulates peristaltic motion for bowels movement along the digestive tract and reduces the symptoms of both diarrhea and constipation. Furthermore, excess fiber in the body can actively reduce the amount of cholesterol, thereby protecting your heart health as well (https://www.organicfacts.net.) Flour obtained from cladodes by dehydration and milling process has applications in the industries like baking, cookie and pasta etc. and for the production of valuable health product for improving the digestion of soluble fibre, which helps people suffering from constipation. Cactus nopales provide an important source of this type of fibre (FAO, 2013).

Nopales have a number of components which can reduce weight. Fiber makes the stomach feel full and inhibited the release of ghrelin hormone, which is known as hunger hormone. Thus, overeating is reduced by eating cactus cladodes in any form such as in the form of vegetable, salad, pickle etc. This has very low saturated fat and cholesterol and also has great metabolic potential. Therefore, the whole body works normally without gaining increase in weight. Vitamins like riboflavin, vitamin B6 and thiamin present in it also makes metabolic process quickly and maximizes the fat burn and the transformation of food to usable energy. The most important characteristic of nopales for improving health status is of its minerals and vitamins. Nopales constituted several vitamins viz., thiamin, riboflavin, niacin, and vitamin-B6 which are very important for cellular metabolism, normal, regulated enzyme function throughout the body. If body organ systems and hormonal balance makes optimized, then whole body will run more efficiently and thus will increase weight loss, promotes healthy muscle gain, boosts repair and maintenance of organs and finally good functioning of the entire body. Cactus nopales contain a good amount of mineral contents, preferably calcium, which is an essential part of developing strong bones and repairing bones as and when any damage occurs. Nopales also constituted with magnesium content which is a very useful mineral for inducing feelings of sleep for people suffering from insomnia, chronic anxiety or restlessness. Presence of normal magnesium content in the body induces the optimum release of serotonin in the human body which resulted in increase in melatonin levels and also has a slightly sedative effect. Therefore, reduces nerve function and feel calms the whole body, thus helping to fall asleep.

Nopales possess the antioxidant and phytochemical characteristics which makes them a good defensive mechanism against premature aging symptoms, such as wrinkles and age spots. After cellular metabolism the free radicals left which can seriously impact the skin. So, eating fresh nopales or in any processed product skin looks and feel healthy, young and refreshed.

7. OTHER BENEFITS AND MISCELLANEOUS USES

Cactus pear is cultivated for about hundreds of years as a food crop, a defensive hedge, rearing cochineal insect for production of dye, as a fodder crop and as a standing buffer fodder for animals during drought periods. It plays a key role in erosion control mechanism and land rehabilitation programmes particularly in arid and semi-arid regions of the world, a shelter and refuge. Cactus nopals have been long back used as natual, herbal medicine to treat diseases such as ulcer, allergies, fatigue, rheumatism, antiuric and as diuretic agent. Alleviating effects towards alcohol hangover symptoms cactus pear have been used very recently and associated with reduced inflammatory responses after excessive alcohol consumption. Nopales products played as preventive and therapeutic effects against alcoholism and alcohol addiction. The flavonoids which are extracted from cactus nopales, quercetin 3-methyl appears to be the most potent neuroprotector. Cactus pear are also cultivated as a host plant for rearing cochineal insects from which red and purple coloured dyes is produced which was very much valuable to early 16 through late 19 century.

8. SPECIES AND VARIETIES/CULTIVARS

Cactus pear is a creeping or upright shrub that can grow up to 3.5–5 metres height; a dicotyledonous, polyploid angiosperm belongs to family Cactaceae, representing about 1600 species divided into 130 genera. The most popular and widespread genus is Opuntia which covers more than 300 species among which over 100 species have been found in wild habitats in Mexico, 60 of them being endemic (Saroj et al., 2017). Opuntia genus have species with chromosome number ranging from diploid to octaploid (2n= 22, 44, 66, 88). On the basis of utilization, Opuntia genus can be categorized into 3 major groups.

I. Cultivated species, subgenus Opuntia

Opuntia ficus-indica (L.) Mill.

Plants have 3–5 metres height with yellowish glochids. Flowers are 7- 9 cm long and orange to yellow in colour. Fruit is pyriform shape, red, yellow and orange in colour with fleshy pulp and thin skinned. Fruit length and width varied from 5-10 cm and 4-8 cm, respectively. According to Pinkava et al. (1992), this species can be heptaploid (2n=77) or octaploid (2n=88). Young and tender cladodes of this species known as nopales/ nopalitos in Mexico and used as vegetable for human consumption and as fodder for livestock feed; fruits are very sweet and appreciated as dessert. Cultivation of this species is mainly in tropical and sub-tropical America and Mediterranean countries. Now, the cultivation of this species has been spread in arid and semi-arid parts of the world (Pareek et al., 2001).

Opuntia albicarpa

Plants of this species attain a height of about.52-5 metre, well defined stem having length of 1-1.2 m with dark brown glochids. Flowers are yellowish orange in colour. Fruit shape is pyriform to obovate, 6-9 cm long, 5-6 cm wide, yellowish-green whitish covered by a thin layer of wax with abundant seeds. This species is considered as early fruiting type and cultivated in the Mexico, Guanajuato, Hidalgo, Taxcala, Zacatecas etc (Pareek et al., 2001).

Opuntia robusta Wendl.

Plants having very short trunk, green, glaucous, covered with a layer of wax and have numerous glochids. Spines are 0 to 12 in numbers at a place. Flowers are yellowish-green, shiny. Fruit is purple or white in colour and globous to elliptical in shape. There are 3 varieties of this species which are common *viz., O. robusta var. robusta* having circular joints on stem and globoid, purple coloured fruits; *O. robusta var. guerana* with obovoid spiny joints, white coloured fruits and *O. robusta var. larreyi* having obovoid joints which are spineless and with purple coloured fruits.

II. Cultivated species, subgenus Nopalea

Opuntia cochenillifera (L.) Mill. species is falls in this group only. Plants having 6-7 metres height

densely branched, glabrous with well defined stem. Generally spines are absent but sometimes present on older joints. Flowers are tubular, 5-6 cm long, red pupureous and almost do not open at anthesis. Fruits are obovate tuberculate, red coloured, spineless and 4-5 cm long. This species is propagated by seeds or cladodes in the tropical and sub-tropical American countries. In Mexico, it is used for rearing cochineal insect; hence the name probably came The pericarpel of the flowers are used as vegetable for human and fodder for livestock. A special kind of tea is made from its flowers which are used as medicine for teething babies. In the semi- arid areas of the Brazil, its cladodes are used as fodder for animals while as vegetable and salad purpose after removing glochids in the Israel (Pareek et al., 2001).

Wild species, subgenus Opuntia

In this category various kinds of species comes such as *Opuntia hyptiacantha* Web., *O. lindheimeri* Engelm., *O. jaconostle* Web., *O. matuadae* Schemv., *O. tomentosa* SD. *etc.* which have importance for breeding point of view. *O. tomentosa* also has two main varieties viz., *O. tomentosa* var. *tomentosa* and *O. tomentosa* var. *herrerae*.

It has a wide range of cultivars around the world depending on agro-climatic suitability and adaptability. The important cultivars are Rosa Pilona, Burrona, Amarilla Montesa, Fafayuco, Copena Cardona from Mexico; Rosa, Bianka, Gialla from Italy; B.S. 1, Ofer from Israel *etc.*

9. SOIL AND CLIMATIC REQUIREMENTS

The ideal conditions for cactus pear cultivation are sunny warm summer and cool dry winters where temperature does not fall below -5 °C during spring and early summer and annual precipitation between 300-600 mm. Cactus has wide range of adaptability and can grow in any types of soils. It grows in different types of soils in the natural habitat. Basically, cactus pear is a drought resistant crop and thieves well in deserted and semi-arid areas having sandy soils. Higher rainfall is unsuitable for cactus cultivation. Generally, it is susceptible to frost but some clones are also found to be cold hardy in nature. It can survive and perform well under alkaline, heavy, gravely and rocky soils also have option for acidic soils. Many cacti thrived well in harsh, dry, sandy arid and semi-arid environments. Deserted soils support only those cacti which are very suited for arid-climatic conditions. But, there are tropical cacti which flourish in rain forests. It means soil and climatic requirements for cacti are varied according to variety/ genotype suitability. (Pareek et al., 2001). The optimal range for nocturnal CO_2 uptake for cactus pear is 25/15°C day/night temperature. Higher or lower day/night temperature ranges, result in a sharp decrease of carbon assimilation which leads to poor plant growth and production (Nobel, 2002) and low crop value. High temperatures (> 30°C) during the fruit development period affect fruit shape if they occur during the initial stages of growth and shorten the third stage of fruit growth, when most of the growth the edible flesh occurs which advanced the early ripening with small fruits, low firmness and sugar content. High temperatures during fruit development enhance

fruit sensitivity to low (< 8°C) temperatures during post-harvest storage, reducing post harvest storage and shelf-life period (Inglese et al., 2002).

10. CULTIVATION OF CACTUS PEAR

10.1. Selection of suitable clone and site for cultivation

The selection of suitable cactus clone/ accession/ cultivar depends upon the purpose *i.e.* vegetable, fodder or fruit for which cultivation is being done. ICAR-Central Institute for Arid Horticulture (ICAR-CIAH), Bikaner has identified 6 promising genotypes of cactus pear which are suitable for vegetable (nopal production), fruit and fodder and 3 spiny genotypes, which are prolific fruit bearing type. Formal orchards with spineless (vegetable type) cultivars/varieties should be considered only close to household (Fig. 1), where human presence provides sufficient safety to damaging pests such as wild animals as well as domestic ruminants and squirrels.

Figure 1. Vegetable type, spineless cactus plantation in backyard garden

Vegetable type genotype is easier to handle and better for human and animal consumption. Low cost green house and net houses are also suitable for safe cultivation of this genotype. Plantations in isolated areas are more practical with spiny varieties (Saroj et al, 2017).

10.2. Planting season

Cactus can be planted in the field during July– September and February- April. But in green house it can be planted round the year. Maximum plant survival was found where planted during July– September under field condition.

10.3. Mode of propagation

10.3.1. Vegetative propagation

Cactus pear is propagated vegetatively through mature cladodes of 5-6 months old during the months of February- April and July – September. In green house it can be propagated round the year. Curing of cladodes should be done after removal from mother plant. Keep the detached cladodes under shade for about two weeks so that proper healing and dehydration may take place for better conservation and establishment under field condition. Cactus pear plants propagated vegetative by cladodes are prone to foot rot disease which leads to severe mortality in field plantation. Therefore, tissue culture is a feasible alternative option for rapid multiplication of healthy and pathogen free plants on large scale.

10.3.2. Micropropagation

The protocol was developed successfully at ICAR-CIAH (Singh et al. 2006 & 2009), Bikaner for mass multiplication of thorn-less, vegetable type elite genotype (which was collected under germplasm collection programmes) through tissue culture using single bud explant. Physiologically mature buds on cladodes were collected and single bud segment was used for culture initiation. Maximum multiple shoots (8shoots/explant) formation was achieved on MS medium supplemented with 30 g sucrose, 8 g agar and 2 mg BA+ 0.1 mg NAA per liter. Multiple shoot clumps are further subjected to culture for shoot elongation medium devoid of plant growth regulators. The elongated shoots were rooted cent per cent under *in vitro* conditions with media containing IBA or NAA (Fig. 2).

Figure 2. Tissue cultured plants of spineless, vegetable cactus pear

10.4. Nursery/ green house planting

Black polythene bags or small plastic pots are suitable for this purpose (Fig. 3). Propagation medium plays key role in establishment and survival of cactus because it is well known that cactus is very sensitive to water logging condition. Therefore, selection of suitable medium is necessary. A proportion of Soil, sand and FYM (40:30:30) is the best medium for cactus.

Figure 3. Planting of cactus pear cladodes in black polythene bags and small pots for propagation

10.5. Establishment of green house unit

After successful development of tissue culture technique at ICAR-CIAH, Bikaner a green house unit of cactus has been established (Fig. 4). Since demand of cladodes of vegetable type cactus pear is increasing day by day. Therefore, we are at CIAH establishing a field repository in open condition (Fig. 5).

Figure 4. Green house unit established for tissue cultured cactus pear genotype

Figure 5. A view of field repository of vegetable type cactus pear at ICAR-CIAH, Bikaner

10.6. Field planting

Physiologically matured cladodes of identified and selected vegetable type, spine less clone should be used for planting. Curing of freshly harvested cladodes should be done after removal from mother plant. Keep the detached cladodes under shade for a minimum of two weeks so that proper healing and dehydration may take place for better conservation and establishment under field condition. Before planting cladodes can be treated with fungicide such as bordeaux mixture or mancozeb @ 2g/liter water to protect them from rotting. Cactus pear spacing depends on its variety/ clone/ genotype, whether it is compact or spreading in nature. The pads should be planted upright in the field keeping 1/3rd lower portion in the soil. Various institutions have given several planting distances viz., 5 x 4 m, 4 x 3 m, 4 x 2 m, 3 x 3 m, 3 x 2 m and 2 x 1 m. But, We at ICAR-CIAH, Bikaner has adopted a closer plant spacing 1 x 0.6 m for vegetable type, spine less clone on drip irrigation method because it was reported that cactus can be grown successfully at a close plant spacing.

10.7. Water management

Cactus pear is very sensitive to water therefore optimum irrigation should be provided during early stages of growth. Cactus plants do not irrigate immediately after planting. Light watering should be done after 2-3 days of planting and there after irrigation should be given at 10-15 days interval up to one year. Fully established plantation requires light irrigation for better yield. There is no need of irrigation in areas where summer rains are good because cactus has highest water use and rain use efficiency among other drought hardy crops. Monthly irrigation except during monsoon season was found beneficial for cladode growth and development.

10.8. Manures and fertilization

Nutrient requirement of cactus pear is low but nutrient deficiencies can cause great losses to plant health and economic yield. Winter application of manures and fertilizers has been reported very effective in obtaining new cladodes as well as fruits. Cactus pear responds very quickly to application of manures and fertilizers as we observed that application of NPK grade (19:19:19) 3-5 gram per liter was found beneficial in new sprouting of cladodes after every picking of cladodes/ fruits under green house condition. Cactus pear reacts very well to organic manures which also improve the soil structure, nutrient content and water-holding capacity. Generally, 6-10 tonnes per hectare well decomposed FYM is to be incorporated into the soil before planting Kauthale et al. (2017) recommended the application of 5 MT well decomposed Farm Yard Manure and 60:30:30 kg NPK per hectare at the time of planting for suitable growth of the cactus plantation. Application of 20 kg Nitrogen is useful in enhancing the new sprouting after every harvest for production of cladodes either for nopal or fodder purpose.

11. GROWTH AND DEVELOPMENT

11.1. Growth stages of nopal/cladode development

There are six different stages of nopal/cladode development observed, such as bud stage, bud burst and growing stage, bud transformation into nopal, complete transformation stage, nopal/ tender/edible stage and mature pad/non-edible stage (Fig 6).

Figure 6. Different growth stages of nopal development

11.2. Flower and fruit development

In general flowering occurs in cactus pear species 2-3 years after planting. But in nopal cactus flowering and fruiting occurred even first year of planting under green house as well as field condition at ICAR-CIAH, Bikaner (Fig. 7).

Figure 7. Flowering and fruiting in nopal cactus under greenhouse and field condition

Flower and vegetative bud initiation occur simultaneously on corner side of the cladodes. Flower production take place on cladodes of more than six month old mostly from terminally and sub-terminally also. Time required from vegetative bud initiation to nopal/ edible stage of cladode was recorded 15-20 days which weighed from 22- 46 g/nopal, while flower bud took 30-40 days and it required almost 75-90 days for ripening of fruits (Fig. 8).

Figure 8. Mature fruits of cactus pear genotype Bikaner Local, vegetable type and Solan collection 1 ready for harvest

Cactus plants flowered once a year in Italy while in some other countries (Chile and the USA) twice and fruit take about four months from fruit set to reach harvest maturity. Fruit growth follows a double sigmoid pattern in terms of fresh weight, and a pronounced gain in dry weight occurs for the peel during stage I and for seeds in stage II. During stage III of the fruit development period core development occurs. Cladodes are strong sinks during the sigmoidal growth period

that occurs during the earlier 4-5 weeks of their development. At this stage they switch to a linear growth in terms of dry weight accumulation and from being sinks for carbohydrate they become sources. Fruit and cladode growth implies a substantial translocation of stored carbohydrates from basal cladodes. In fact, when more than five fruits develop on a one year old fruiting cladode, an extensive import of assimilates occurs, particularly during Stage III of fruit growth. Cladodes become more productive when dry weight exceed the minimum dry weight for a particular surface area by at least 33 g. High planting densities lead to an extremely high accumulation of dry matter in the vegetative growth, but deeply affect allocation of resources to the fruit. It was reported (Nieddu and Spano, 1992) that in cultivar Gialla 74 % flower buds arise from margin of outer cladode, while 17 % from central one. Out of which, 23 % was produced during the month of May and 76 % in June. Cactus pear bears male, female and hermaphrodite flowers. Flowering started during spring season and continued for about 15, 14 and 8 weeks in male, female and hermaphrodite flowers, respectively.

12. EVALUATION OF CACTUS PEAR

12.1. Evaluation of tissue cultured culinary cactus pear under green house

Vegetable type (spine less) genotype is easier to handle and better for human consumption because it contains high levels of betalains, taurine, calcium, magnesium and antioxidants which are nutraceutically rich and are important in nutritional security and human health. Tissue cultured plants were produced in our institute laboratory and their morphological (Table 2) and nutritional evaluation on growth and development of vegetable type cactus pear has performed under green conditions at ICAR-CIAH, Bikaner. It was observed that nopales (tender cladode of vegetable type cactus pear) can be harvested regularly at an interval of 15-20 days when they reach 10 to 15 cm in length and about average weight of 30 g/nopal which can provide an average yield of 1.5 kg tender nopales/plant/year (Fig. 9).

Figure 9. Greenhouse grown tissue cultured, spineless, vegetable cactus ready for harvest

It was noted that one plant of cactus pear yielded 5 nopales of above described characteristics in a period of one month. These cactus nopales have also been evaluated for their nutritional composition (Table 3) like dry matter, Ash content, mucilage content, Total phenolic, flavonoids and total antioxidant activity. It was observed (Kumar, et al., 2017) that it contains 91-93% moisture and only 7-9% dry matter. it contains ash 13-15% (DWB) and 1.0% (WWB), Mucilage 15-22% DWB, Total phenolics 4.5-7.0% (DWB), flavonoids 190-220 µg/g and Total antioxidant activity 10-16 mg Equi. to Vit C/g (DWB).

Table 2. Morphological observations on nopal Cactus pear (vegetable type)

Serial/ Plant Number	**Number of cladode/ plant** (04.02.17)	**Number of cladode/ plant** (4/3/17)	**Days required to reach edible stage**	**Weight of nopal at edible stage** (g)	**Length of nopal** (cm)	**Width of nopal** (cm)
1	17	22	23	36.32	16.5	8.0
2	16	22	18	22.52	12.0	6.5
3	16	23	23	39.34	16.7	9.0
4	18	21	18	33.20	13.3	8.2
5	22	29	19	30.73	13.7	7.5
6	25	31	18	22.21	12.0	6.4
7	11	16	24	46.31	18.0	8.7
8	08	11	23	36.94	16.0	7.0
9	19	23	20	27.86	15.4	6.0
10	14	19	19	23.61	13.0	7.0
Average	16.6	21.7	20.5	31.90	14.66	7.63

Table 3. Nutritional evaluation of vegetable type cactus pear

S. N.	**Nutrient content**	**Unit**
1	Moisture content	91-93 %
2	Dry matter	7-9 %
3	Ash content	13-15 % (dry weight basis) 1 % (wet weight basis)
4	Mucilage	15-22 % (dry weight basis)
5	Total phenolics	4.5-7.0 mg/g (dry weight basis)
6	Flavonoids	200 µg/g (dry weight basis)
7	Total Antioxidant Activity mg Equi. Vit C/g (dry wt.)	10-16 µg/g (dry weight basis)

12.2. Field evaluation of different cactus pear genotypes

Five genotypes of cactus pear were evaluated under field condition for field establishment, growth, flowering and fruiting (Fig. 10). In spine less vegetable type genotype field establishment was recorded 76.93 % with 23.04 % mortality of the plants remaining genotypes showed 100 % establishment and 0.00% mortality rate. 'Solan Collection' genotype sprouted first followed by clone 1270, vegetable type, clone 1271 and at last 'Bikaner Local Collection'. Average plant height was recorded highest (56.60 cm) in clone 1271 followed by Solan Collection (53.30 cm), Clone 1270 (45.20), Vegetable type (43.90 cm) and lowest (41.30 cm) in Bikaner Local Collection. Maximum number of cladode (16-32) per plant was found in Solan Collection while minimum (7-10) in Bikaner Local (Table 4).

Table 4. Field evaluation of different cactus pear genotypes

Genotype	Field	Morta-lity (%)	Spro-uting	Avg. plant height (cm)	No. of cladode/ plant	Flowe-ring	Fruit per plant	Use
Vegetable type/nopal cactus	76.93	23.04	III	43.90	6- 23	Occurred	1-9	Vegetable, salad, pickle, squash, animal feed, edible, fruit production
Clone 1270	100	0.00	II	45.20	4- 14	Occurred	1-3	Suited for animal feed
Clone 1271	100	0.00	IV	56.60	4- 7	No flowering	-	Animal feed, biofencing
Solan Collection	100	0.00	I	53.30	16- 32	Occurred	1	Biofencing, fruit production
Bikaner Local Collection	100	0.00	V	41.30	7- 10	Occurred	1-8	Biofencing, fruit production

Flowering and fruiting was not observed only in one genotypes i.e. Clone 1271 after one year of planting Nopal cactus i.e. spineless, vegetable type flowered first followed by Bikaner Local. Maximum number of fruits per plant was noted in genotype nopal cactus while minimum in Solan Collection. Genotype suitable for human consumption as well for animal feed was vegetable type or we can say this genotype of cactus pear is multipurpose and others either suited for animal feed or used as biofencing (Table 4). The vegetable type, spine less genotype bears good flowering and fruiting under green house as well as under field condition. However, the fruits could not be set due to lack of pollination under green house condition. Further it was noted that physiological problem of heterostyly of stigma condition seems to be a barrier in fruit setting under greenhouse.

Earlier Pareek et al. (2003) evaluated 51 clones of cactus which were obtained from Texas in pots at CIAH, Bikaner. Clone 1308 was sprouted first (24th day) while clone 1379 took 135 days for sprouting. The average cladode weight was ranged from 66.8 g to 1300 g. Only 3 clones (1269. 1270 and 1271) were flowered after 3 years of planting but fruiting occurred in clone

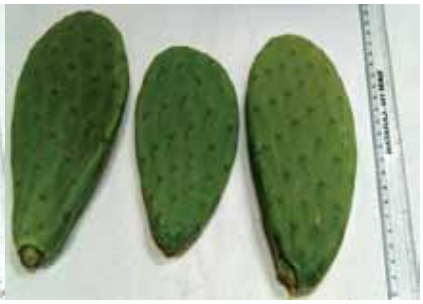
1270 and 1271. Singh and Singh (2001) conducted a study on growth, cladode yield and quality of vegetable type cactus under Agra (UP) agro-climatic conditions and reported that clone 1308 (vegetable type) was better in all growth, yield and quality attributes than the Nopalea type. Planting of cladodes in East-West direction keeping 1/3 portion under the soil significantly increased the number of roots/pant, cladode length, early sprouting and biomass production in clone 1270 which is a fodder and fruiting type cactus pear (Singh et al. 2002).

Very recently, 30 plants of vegetable type cactus pear along with Mount Abu Collection, clone 1308 and 1269 were planted in the field and evaluated for growth and survival. Clone 1308 sprouted first than other genotypes. Plant survival was good under field condition and growth of clone 1269 was better than other genotypes.

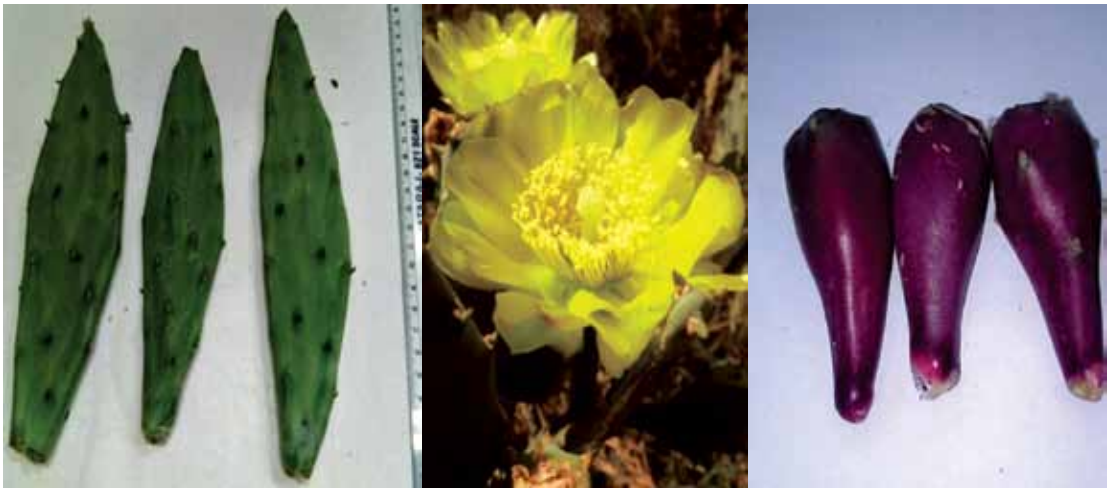
Cladode, flower and fruit variability in cactus pear genotypes available at CIAH, Bikaner

Spineless, vegetable type cactus pear

Cladodes of clone 1270



Cladodes of clone 1271



Cladodes, flowers and fruits of Solan collection 1

Cladodes of Solan collection 2 and its fruits

Cladodes of Bikaner Local, its flower and fruits

Figure 11. Variability of different cactus pear genotypes existing at ICAR-CIAH, Bikaner

13. HARVESTING AND YIELD

Harvesting is mainly depends upon the purpose for which cactus pea is cultivated. Harvesting period and number of pickings is varying according to need of the cactus product. For the ease we have categorized it according to need of the cactus product here under.

13.1. Nopal/vegetable yield

It has a very high yield potential. Tender nopals of cactus pear are harvested for vegetable purpose during the early stages of growth, when they reach 10 to 15 cm long and about average weight of 30 g/nopal. As the cladode ages the fibre content increases and become more difficult to process there after these are suitable for animal feed. Under greenhouse nopales can be harvested regularly at 15-20 days intervals with an average yield of 1.5 kg tender nopales per plant per year.

13.2. Fodder/animal feed yield

Prickly pears can be a good alternative forage crop on land marginal that is presently not useful for other crops. For getting optimum yield and nutrition it is advised to harvest cladodes at their full size and maturity because at that time cladodes contain lowest water content and thereby having maximum nutrient content. Cactus pear becomes one of the most prominent crops for the 21st century. It is a succulent and drought-tolerant plant species that can produce more than 20 tonnes dry matter per hectare per year and provide 180 tonnes of water per hectare per year stored in its cladodes, representing a cost-effective option for livestock watering (Dubeux et al., 2015b). Vegetable clone 1308 can yield biomass production of 80–90 tonnes per hectare per year. In some of the American and African countries young cladodes of this clone is used as vegetable. At this much levels of productivity, it is possible to produce sufficient fodder to sustain 5 adult cows per year. However, the potential of cactus pear remains underexploited. There are two major cactus species which are utilized for fodder purpose i.e. *O. ficus-indica* (L.) Mill. and *Nopalea cochenillifera* Salm-Dyck., with several varieties released in several countries of the world. There are reports of the successful use of cactus as a feed source in countries ranging from Brazil and Mexico to South Africa and Tunisia, usually supported by strong research and extension programmes (Josh, et al., 2017).

13.3. Fruit yield

Fruit yield mainly depends on climatic conditions, cultivar, plant age and management practices. Although, cactus pear started bearing of fruits after one year of planting but commercial yield is obtained after 4-5 years. The improved varieties yielded 10-12 mt/ha fruits and 10-150 mt/ha fodder per year. After picking fruits are graded as A, B and C grades according to size. Unripe, under sized, damaged and infected fruits should be discarded. Surface waxing is done for increasing shelf life of fruits before packing. Generally fruits are packed in well labelled, perforated card board cartons for marketing (Pareek, 2001). Considering the dry weight of the fruits and current-year cladodes at harvest, the growth ratio of the 1-year-old cladodes and a total amount of 300 fruits and 130 current year cladodes (in the first and in the second flush), the proportion of annual dry matter allocated to the fruits (Harvest Index = HI) is 35% for the first flush and 45% for the second flush. Differences between the first and the second flush depend on the higher fruit dry weight and the lower cladode dry weight measured for the second flush. Garcia de Cortazar and Nobel (1992) reported a significant increase of vegetative vs. reproductive growth as a result of high density planting systems. In Italy, the highest yields come from orchards made of 300-400 plants per hectare with 50-60 kg fruits per plant per year that means 400-500 fruits per plant on 90-100 fertile cladodes.

Competition between fruit vs. cladode growth as well as the reduction of the number of new cladodes following SFR can be sources of plant alternate bearing behavior that also changes with genotype. It depends on the reduction of fertile cladodes from a scarce vegetative growth of the previous year. The number of flower per fertile cladode is more stable year by year but

depends on cladode age, being highest in one year old cladode. One solution could be the increase of the number of plant per hectare and the other could be topping the plants every two or three years to improve cladode development from the lower part of the canopies.

14. POST-HARVEST MANAGEMENT AND STORAGE

Cactus pear fruit follows non-climacteric respiration rhythm. Respiration rate declines during fruit development and is not different for fruit harvested at different stages of ripeness. The respiration rates of the fruit are temperature-dependent. The fruit also produce very low amounts of ethylene (about 0.2 µ L/ kg/ ha at 20°C) which is not sensitive to ethylene exposure, but exposure at warm temperatures will enhance yellowing. The postharvest life of cactus pear can be significantly limited by physical damage and the fruit bruise easily during harvesting operations. Stem-end damage is considered the most serious type of physical injury, as it leads to attacks by pathogens, which result in decay. Stem-end damage can be eliminated by careful harvesting or twisting fruit from the stem. Alternatively, fruit may be cut with a small piece of stem attached and then either packed without further treatment or cured (15 to 20°C with airflow) so that the stem dries and falls off before packaging. Storing the fruit at low temperature is very effective in reducing deterioration of visual appearance (shiny surface) due to water loss. Cactus pear fruit are perishable and without refrigeration, they senesce rapidly and become susceptible to infections by microorganism, especially Penicillium spp. and Alternaria spp. (Berger et al., 2006). They are commonly room-cooled, but may also be forced-air cooled. Cooling may be delayed if fruit undergoes a curing treatment. Fruit can be maintained for two to fi ve weeks at 5 to 8°C and 90 to 95% RH, depending on variety, ripeness stage, and harvest season. Factors that limit fruit storage life include decay, water loss and chilling injury (CI). Techniques to reduce decay and weight loss include the application of fungicides, waxes and plastic packaging, respectively. Heat treatments, natural waxes and edible films are being considered. High-gloss fruit waxes are especially useful when the fruit have been brushed to remove the glochids.

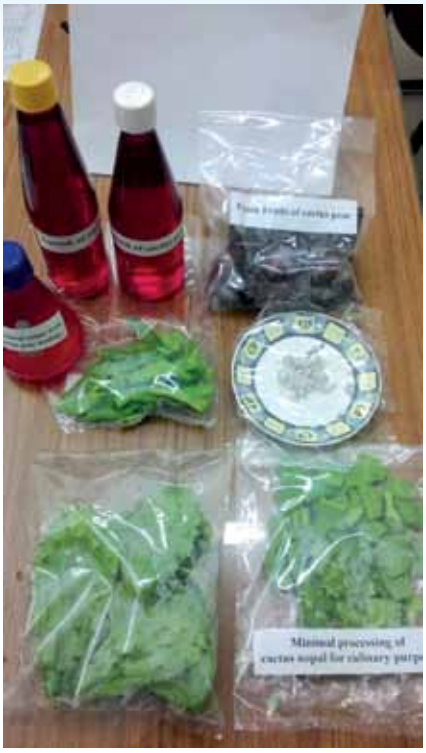
15. VALUE ADDED PRODUCTS

The fruit of cactus is seasonal; nopales (young cladodes) are not, although they are highly perishable because of their high water content. To make fruits and nopales available for longer periods of the year out of season, it is essential to preserve them to prevent deterioration. Raw materials (fruits and cladodes) are deterioration by several factors such as enzymatic changes (which often affect texture); chemical changes (which affect sensory characteristics such as colour, aroma and flavour); nutritional changes (which lead to a loss in nutritional value); and physical changes (such as dehydration). Out of these, the most damaging is biological changes (microbiological attacks by bacteria and fungi or by pests and rodents), which compromise the safety of foods and the health of the ultimate consumers. To reduce or avoid the deterioration, much can be done and many technologies are available that can be used to both cactus pear fruit

and cladodes. Some of these have been known and used for many years, while others have been developed recently on an experimental or pilot scale. Many have shown potential for application at industrial level. The cactus pear plant provides many opportunities for processing fruit and cladodes. Like other fruit crops, the fruit and cladodes of cactus pear can be preserved and processed into various products using different technologies and practices. Different kinds of processed products are prepared from cactus viz., jams, juices, nectars; dried fruit, juice concentrates and syrups and liquors. Pickles, juices, jams and a number of other minimally processed products can be made from cladodes/nopales.

Opportunities of several economic products such as fruit, squash of fruit, pickle, ready to serve drinks, colour from fruit and cochineal, cladodes for culinary and salad based on fruits and nopales/cladodes were explored and demonstrated to several beneficiaries at CIAH, Bikaner (Fig. 12).

A brief description of value added products made from cactus fruits and cladodes are presented here under.



Syrup, minimal processed nopal, fresh fruits, cochineal insect (in plate) for dye preparation
Figure 12. Different products of cactus pear made at CIAH, Bikaner

Cladode for culinary and salad

Tender cladodes of vegetable type, spineless cacti called nopales can be consumed during the early stages of growth. Cactus nopal is suitable to use as fresh. It was observed that nopales can be harvested regularly for culinary purposes at an interval of 15-20 days when they reach 10 to 15 cm in length either in the form of sole vegetable, mix vegetable or as salad (Fig. 13). Cactus nopales are an important part of the human diet and are also used as feed for livestock. A number of potentially active nutrients and their multifunctional properties are found in nopal which makes it suitable for the production of health-promoting food and food supplements. Peoples of Mexico and other southwestern countries eat the fresh young cactus pads (nopales) as raw or

Mix vegetable Salad

Figure 13. Culinary exploitation of spineless, nopal cactus pear at CIAH, Bikaner

after cooking, used in soups stews, salads and in marmalades. They are sliced into strips and fried with eggs and jalapeños and served as a breakfast treat. Nopales are generally sold fresh in Mexico and sliced to make salad on the demand of customer on the spot.

Flours/powders from cladodes

Cladode flour is obtained by dehydrating and milling the de-spined, washed and cut cladodes. The flour has applications in the baking, cookie and pasta industries and also for the production of pelletized dietary fibre. Dietary fibre is a valuable health product for improving the digestion of soluble fibre, which helps people suffering from constipation. Cactus pear leaves provide an important source of such fibre. Physical and chemical characteristics of flour prepared using a mixture of cladodes of different ages (1-3 years old) were analysed by Saenz et al. (1997d) and reported that it contained 43 percent total dietary fibre, of which 28.45 percent was insoluble fibre and 14.54 percent was soluble.

Fruit leather

Fruit leather is prepared after removing the seeds from fruits; the pulp can be dehydrated in thin films or leathers to produce a chewy natural product. Fruit leathers are popular in the Arab countries and in the United States and are made from a variety of fruits. Fruit leather is one of the attractive products made from cactus pear fruit pulp. This product is yet to be manufactured on an industrial scale.

Candied/glazed product

A special form of dehydration is the production of candies or glazed products, which can be produced from chopped mature cladodes and/or fruits. In France, whole cactus pear fruits are glazed and eaten as a dessert (FAO, 2013).

Squash/ juice from fruits and cladodes

Squashes/ juices are concentrated products made from cactus fruits/ cladodes.These drinks are very attractive when coloured fruits are used for the purpose. An attractive drink (squash and juice) was made from fresh cactus fruits at CIAH, Bikaner which is very tasty and beneficial for health point of view because it contains good quantity of antioxidants which is very useful for health.

In Namibia, an excellent concentrate is made from red fruits of cactus. Red-fruit nectars mixed with other juices were available in Californian markets until a few years ago. However, this product was discontinued and now a fresh cactus pear red fruit puree (22–24 ^{o}Brix) is offered. In Chile, fresh unprocessed cactus pear juice is widely consumed at home and in ecological restaurants (FAO, 2013).

Colorants from fruit

The fruits of cactus pear are of different colours, such as red, purple, orange, yellow and green in colour which show the presence of various antioxidants. Betalains are pigments found in red and purple cactus pear fruit which are widely used in the food industry. Mainly these betalains are extracted from beetroot, hence the name betalains came. Cactus pear fruit offers an alternative source of betalains. The characterization of betalains in fruits has revealed that these pigments possess antioxidant properties. Thus, cactus fruit is enriched with antioxidant properties that can potentially prevent or delay cell damage in the human body. In general, the distribution of nutrients and antioxidants in the cactus pear fruit is an indication that the consumption of whole fruit is more beneficial from health point of view because more potentially nutraceutical active ingredients are absorbed and used by our bodies (https://books.google.co.in/books?isbn=0124080642).

Jam and jelly

Jams and jellies are made from the fruits of opuntia in many countries which resemble like strawberries and figs in color and flavor. Jam is one of the most popular and widely accepted products made from cactus fruits and consumed on a large scale worldwide. It is very easy to make and available in market in different types. It is obtained through concentration by boiling fruit pulp with sugar, pectin and citric acid, to ensure adequate gelling. Generally, preservatives (sodium sorbate and/or potassium benzoate) are added in order to conserve quality once the pack has been opened. Jam is a concentrate products made from cactus pear fruits in Mexico, the United States, Italy and Argentina. More recently, production of cactus pear fruits jam has also begun in Chile. Jams are also produced commercially from the cladodes and jelly is made from fruit in Italy, Mexico and the United States. In Mexico, a traditional product 'melcocha' a type of jam made from Opuntia streptacantha, although jam is also made from different types of Opuntias (Corrales and Flores, 2003).

Colour from fruit and cochineal

A red coloured dye is prepared from cochineal insect at ICAR-CIAH, Bikaner which reared and fed upon cactus plant (Fig. 14). Red colour of animal origin i.e. Carmine/Cochenille Carmine dye is extracted from Cochineal (*Dactylopius* coccus Costa) insect living on Opuntia as a parasite which was originated from tropical and subtropical South America as well as Mexico and Arizona.

Figure 14. Cochineal insect reared on nopal cactus, cochineal for dye preparation (in plate) and cochineal dye

Cochineal dye was used by the Aztecs and Mayas of Central and North America long years back. During colonial times this dye became one of most valuable export commodities in Mexico. Although, cactus and cochineal dye were exported to Southern Europe and many countries of Africa and Asia, the most of the cochineal dye is till today produced in Latin America with Peru being the main producer in the whole world. In the United States since January 2011, carmine and cochineal are to be listed by name on the list of ingredients and the declared as "added color" is no longer allowed. Carmine colour is thermal stable and its colour closely resembles that of cured meat.

Pickle from nopal

A wide variety of pickle from cactus nopales can be found in domestic markets of Mexico. More than 25 different brands are available, made with a variety of spice mixes and packed in plastic bags, cans and jars. Pickled nopales are also made in Texas, where they are known as 'sweet and hot cactus' or 'kosher dill cactus'. Tender nopales are blanched and conserved in vinegar (maximum 2 % acetic acid) and flavoured with spices with or without added vegetables and other condiments. The mixture is packed in jars and then sterilized in an autoclave or water bath, cooled, drained and left to dry before finally being labelled (Corrales and Flores, 2003).

Other miscellaneous products

Mexican people have used cactus pear to make an alcoholic drink called colonche from thousands of years. A prickly pear-flavored liqueur 'Ficodi' is produced in Sicily and in Malta, a liqueur called bajtra is made from cactus fruit, which can be found growing wild in most of the fields. On the Saint Helena Island, the prickly pear also gives its name to locally distilled liqueur called 'Tungi Spirit' (https://en.wikipedia.org/wiki/Opuntia ficus-indica). In the last few years some new products made from cactus pear fruits and cladodes to increase the industrial alternatives and used at rural levels and satisfying the demand of consumers for healthy food and natural food ingredients. Some dehydrated products from coloured fruits, vinegars and toppings are alternatives to be produced at low cost with simple technologies. Cactus powder made from older cladodes was studied as a source of dietary fibre. In general, the soluble fibre content is found low in vegetables which are a positive feature in cactus pear fibre as a food ingredient. Purple cactus pear fruits as source of betalains could be an alternative to artificial red colorants generally considered as potentially hazardous to human health (Saenz, 2015). It is planted in hedges around the field to provide a cheap and effective soil and air erosion control in the Mediterranean basin. Soil physical properties, nitrogen and organic matter are considerably improved under those hedges and adjacent areas. Structural stability of soil is enhanced, reduced runoff and erosion and enhanced water storage capacity and permeability of the soil. It is an ingredient in adobe to bind and waterproof roofs. *O. ficus-indica* as well as other species of Opuntia is cultivated to serve as a host plant for rearing cochineal insects

which produced desirable attractive red and purple dyes. Mucilage from cladodes may work as a natural nontoxic dispersant for oil spills (https://en.wikipedia.org/wiki/*Opuntia ficus-indica*). Cactus pear has value in food and beverage industry, textile industry, livestock feed industry, construction industry, pharmaceutical industry, natural additives industry, cosmetic industry, food supplements industry and role in energy sector, importance for tourism sector etc.

16. ECONOMIC RETURNS

It has been proved from the intensive R&D efforts made at ICAR-CIAH, Bikaner that cactus pear can be cultivated successfully in arid region with enhanced nutrition and income from the different products of nopal cactus pear. Further, round the year production can be taken under low cost green house condition. Under greenhouse, nopales can be harvested regularly at an interval of 15-20 days with an average yield of 1.5 kg tender nopales per plant per year. Thus, the farmer can get regular income from this crop. Preliminary studies indicated that Rs 150 to 200 per plant per year may be obtained from different fresh products of vegetable nopales, fruits and processed items (such as squash, RTS, pickle, jam, candied products etc.) from a full grown plant after 3-4 years of planting. Thus, a farmer can get an income of Rs 500 to 600 per square metre area under green house condition with an estimated benefit cost ratio of 3:1 (Kumar et al, 2017).

17. PESTS, DISEASE AND DISORDERS

17.1. Pests of economic importance

Several pests *viz.,* domestic ruminants, squirrels, insects, rodents, birds *etc.* have been found associated in damaging the cactus pear. A number of insect species such as ants, bugs, thrips, moths, beetles, flies, scales etc. cause damage to opuntia world-wide. In India, spine less, vegetable type, less thorny fodder type genotypes are severely damaged by wild animals as well as domestic ruminants and squirrels. Therefore, formal orchards with spineless (vegetable type) varieties should be considered only close to household, where human presence provides sufficient safety to damaging pests. Phycitid moth (*Cactoblastis cactorum* Berg.) and cochineal insect (*Dactylopius opuntiale* Cockerell) are most damaging pests of opuntia. The other pests of economic importance are armoured scale and med fly whose larvae infest the fruits at a larger scale in many cactus species. At present phycitid moth is found all over the cacti growing areas of the world and causes severe attack and damage on young plants. Attack was observed only on cladodes but in acute cases it also damage fruits.

Cochineal bug, *Dactylopius opuntiale*

Cochineal bug is a major pest of cactus which causes death of the plant in acute condition. But it also reared in many countries for production of pink coloured dye. The economic importance of it can be understand that it was introduced in South Africa, Australia, India, Sri Lanka etc. in order to improve the dye industry. Cochineal bug causes damage to whole parts of the plant such as cladodes, fruits and stem. It appears like cotton scale and affected cladodes and fruits detached automatically from the plants either mature or immature. These cladodes and fruits fell down and loss their economic value.

Management

There was noticed that extreme temperature and sunlight reduced the infestation of the cochineal bug when severely attacked nopal cactus plants (vegetable type, spineless) was shifted from geen house to open condition at CIAH, Bikaner. The spray of imidacloprid 17.5 SC @ 0.5 ml/l of water at 15 days interval was found effective in managing of this insect. Although some bicontrol agents such as ladybird (*Exochomus flaviventris* Mader), Australian coccinellid (*Cryptolaemus montrouzieri* Mulsant) and a fungal pathogen (*Entomophtora lecanii* Zimm.) were found effective in controlling of the pest. Spraying of acephate chemical @ 2g/ litre at weekly intervals starting from early attack of the bug significantly contolled and killed the cochineal bug population and saved the nopal cactus plants under green house at CIAH, Bikaner.

17.2. Diseases and disorders of cactus pear

Cactus pear has high water content in its cladodes, that is why attacked by several dieases caused by fungi, bacteria, nematodes, yeast, viruses etc. which caused damage to plants and reduce the biomass and fruits yield. Physiological disorders are caused due to the environmental and nutritional imbalance, genetic causes and faulty agrotechniques resulting low production and productivity. The major diseases are bacterial spot, Armillaria root, stem and foot rot and wilt. An experiment was conducted by Nallathambi et al. (2005) on foot rot *(Phytophthora nicotianae)* in cactus pear genotypes under arid conditions and observed that this disease was major hindrance in establishment of cactus pear. They have reported that 23.5% foot rot incidence occurred in germplasm colections during the month of August and November and soil drenching with 0.1% Ridomil and dipping of cut ends of cladodes in fungicide at the time of planting found efffectinve in controlling of foot root.

18. FUTURE UTILIZATION AND OPPORTUNITIES OF CACTUS CULTIVATION

Cactus pear traditionally has been used as a valuable health promoting food crop and also has applications in pharmaceutical industries. It has several uses and immense potential to be the

food of future. Cactus fruits are popular in several countries and contains important nutritional and health components such betalains, polyphenols and dietary fibre. Although, human interest is increasing with the fruits, recently research also has been carried out to know about its bioactive components and functional properties which have been generated. There are so many future uses of the cactus have been suggested, such as nopal pulp use for the production of shampoos, conditioners, face and body lotions, soaps, hair gels, sun protectors and bio-ethanol production. Cactus juice extracted from cladodes is one of the most commonly used additives in earthen plaster or improving house paint and mucilage found to purify water. Veterinary phytotherapy using Opuntia appeared to be a promising field of research and applicability. Cactus plant can be used for rearing of Cochineal insect for production of attractive red and/ or pink colour dye. Human health concerns about artificial food additives have opened the door of popularity of this dyes and the demand is increasing which encourage the rearing of cochineal insect is a golden opportunity for this crop.

Different new processing technologies have been developed but great challenges are still remain. Therefore, it is important to continue research onto this wonderful crop. There are several opportunities and advantages of growing cactus pear as a crop discussed hereunder in key points.

a. Different food products and alcoholic and non-alcoholic drinks can be made from young nopales (to promote food and beverage industry)
b. Supplements and feed from nopales and waste from fruit processing, including peel and seeds (for livestock feed industry)
c. Gastric mucosal protectants from mucilage extracts, tablets and capsules of nopal powder and flower extracts (for pharmaceutical industry)
d. Creams, shampoos and lotions from nopal (for cosmetic industry)
e. Fibre and flours from nopales (food supplements industry)
f. Gums from nopales and colorants from fruits (natural additives industry)
g. Binding compounds from mucilage/nopales (importance in construction industry)
h. Biogas from digestion of nopales and factory waste streams, alternatively, lignified nopals burned as fuel-wood (role in energy sector)
i. Soils, organic materials and improved drainage from the use of cactus products (as an agricultural inputs)
j. Artisan crafts can be made from lignified nopales (importance for tourism sector)
k. Use of natural colorants, such as carmine from cochineal insects (role in textile industry)

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