PLANTA DANINHA

SBCPD
SOCIEDADE BRASILEIRA DA
CIÊNCIA DAS PLANTAS DANINHAS

<http://www.sbcpd.org>

ISSN 0100-8358 (print)
1806-9681 (online)

Literature Review

Cactus Pear: a Weed of Dry-Lands for Supplementing Food Security Under Changing Climate

Pera de Cacto: Uma Planta Daninha de Terras Secas para Suplementação de Segurança Alimentar sob Mudança Climática

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ABSTRACT - Climate change characterized by global warming and frequent occurrence of prolonged drought spells has necessitated the cultivation of multi-purpose crops which are temperature and drought hardy. This paper evaluates the production potential of cactus pear [*Opuntia ficus indica* (L.) Mill.] as an alternate and low-cost forage crop along with the recent advancements in its cultivation and utilization as food crop for supplementing the food security of rapidly increasing populace. The botanical, ecological and physiological traits enabling cactus pear to survive under harsh agro-climatic conditions have been objectively elaborated. A variety of impediments hampering its wide-scale cultivation and future breeding needs for improving the biomass production and nutritional quality have also been identified. The potential of cactus pear to reduce desertification along with imparting sustainability to modern, commercial and profitable agriculture in dry-lands makes it an exceptional plant. Its annual biomass (stems called cladodes) yield of 40-50 t ha^{-1} with an appropriate agronomic management may sustain 5-6 adult cows supporting a family of 12-16 people. However, its slow growth, less fruit yield, poor nutritional quality of forage and the fear of cactus pear becoming a noxious weed restricts its popularized cultivation and thus demands a comprehensive genetic improvement and agronomic technology package.

Keywords: *Opuntia ficus indica*, cladodes, emergency water supply, forage bank, Indian fig.

*RESUMO - As mudanças climáticas caracterizadas pelo aquecimento global e frequente ocorrência de períodos prolongados de seca têm demandado o cultivo de culturas multiúsos, que são resistentes à temperatura e à seca. Neste artigo é avaliado o potencial de produção de pera de cacto [**Opuntia ficus indica** (L.) Mill.] como uma cultura de forragem alternativa e de baixo custo, juntamente com os recentes avanços em seu cultivo e utilização como cultura de alimentos para complementação da segurança alimentar de uma população em rápido crescimento. As características botânicas, ecológicas e fisiológicas que permitem que a pera de cactos sobreviva sob condições agroclimáticas adversas, têm sido objetivamente elaboradas. Uma variedade de impedimentos que dificultam o cultivo em larga escala e as futuras necessidades de melhoramento da produção de biomassa e da qualidade nutricional também foram identificadas. O potencial da pera de cacto para reduzir a desertificação, juntamente com a sustentabilidade para a agricultura moderna, comercial e rentável em terras secas torna uma planta excepcional. Seu rendimento de biomassa anual (caules chamados cladódios) de 40-50 t ha^{-1} com manejo agronômico adequado pode sustentar 5-6 vacas adultas alimentando uma*

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Received: February 19, 2018
Approved: August 7, 2018

Planta Daninha 2020; v38:e020191761

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Doi: 10.1590/S0100-83582020380100040

família de 12-16 pessoas. Entretanto, o crescimento lento, o menor rendimento da fruta, a qualidade nutritiva pobre da forragem e o medo de a pera do cacto tornar-se uma planta daninha nociva restringem seu cultivo popularizado, exigindo assim um melhoramento genético abrangente e um pacote de tecnologia agronômica.

Palavras-chave: *Opuntia ficus indica*, cladódios, abastecimento de água de emergência, banco de forragem, figo indiano.

INTRODUCTION

Under changing climate, sustainable productivity of dry-lands (arid and semi-arid) depends on the cultivation of drought resistant crops and development of sustainable cropping systems (Santini and Carlos, 2013). Dry-lands cover 40% of the global area and sustain more than 2 billion inhabitants, characterized with precipitation to evapotranspiration ratio of 0.05-0.65 (Grunwaldt et al., 2015). Climate change induced rising temperatures along with frequent and prolonged drought spells have further aggravated the problems of arid regions due to shallow soils with low water storage capacity (Bariagabre et al., 2016). Thal, Thar, Cholistan and Kharan in Pakistan are characterized with increased duration, intensity and frequency of drought that cause shortage or even absence of water, food and feed leading to malnutrition, hunger and even death (Diniz et al., 2017). Food security of rapidly increasing human population in these regions is compromised owing to shortage of forages which result in low productivity of ruminants. This situation requires cultivation of crops that have moderate to high carrying capacity, high potential for rapid utilization and quick recovery after severe consumption. In addition, crops must have drought tolerance, rapid establishment, minimum production costs, high tolerance against soil toxicities and erratic weather conditions along with being safe for ruminant health (Neffar et al., 2013).

Cactus pear [*Opuntia ficus indica* (L.) Mill.] is also known as Indian fig, Barbary fig and prickly pear (Volpe et al., 2018). It is not only able to tolerate drought (Diniz et al., 2017), but also greater biomass accumulator. Its resource conversion ability is five times greater than C_3 grasses and three times higher than C_4 broadleaf crops owing to Crassulacean acid metabolism (CAM) (Abidi et al., 2013; Cano et al., 2017). Its high potential to grow on severely eroded soils where other crops fail to germinate makes it suitable to be grown as food and forage crop in deserts (Lucivania et al., 2018). It is widely distributed across the arid areas of Brazil (0.60 Mha), Mexico (0.23 Mha), Algeria (0.15 Mha), Tunisia (0.61 Mha), South Africa (0.53 Mha) and on a smaller scale in Argentina (Grunwaldt et al., 2015).

Cactus pear may be grown as a strategic crop for combating desertification by reducing or partially controlling the soil erosion through its extensive root system (Maurizio et al., 2018). Its wide-scale cultivation offers protection to local fauna due to its ability to grow and reproduce in scarce rainfall and high temperatures (Ramos et al., 2013; Ciriminna et al., 2017). It remained superior under arid environment for providing the digestible energy, carbohydrates, abundant water, minerals and numerous vitamins (Ben-Salem and Ennouri, 2013; Nefzaoui et al., 2014). Cactus pear is marginally utilized as forage, food, beverages, and medicine, dyeing clothes and for various religious practices (Silva et al., 2016). However, it continues to remain an underutilized natural resource despite huge potential to supply abundant amounts of forage to large ruminants, triggering economic activities in sandy areas while contributing to food security of millions across the arid areas.

Although, there have been numerous studies for determining the nutritional quality of cactus pear but as per our knowledge, there has been no systematic review study focusing on agronomic technology package of spineless cactus pear and future breeding needs to promote its cultivation in arid regions. The objective of this review study is to systematically analyze the botanical and eco-physiological traits of cactus pear which enable it to thrive under severe and prolonged spells of drought and high temperatures. In addition, the potential of spineless cactus pear to serve as a food for human, forage and an emergency source of moisture for ruminants was also assessed. An appropriate agronomic management plan was evaluated for obtaining the maximum biomass of cactus pear under varying agro-climatic conditions along with the future breeding needs for utilizing it to supplement the food security of people living in dry-lands.

BOTANY OF CACTUS PEAR

Cactus pear belongs to division Magnoliophyta and class Magnoliopsida, while its order and family are Caryophyllales and Cactaceae respectively. Genus *Opuntia* has around 300 species, of which 104 are of Mexican origin, while the number of its sub-genera reaches to eleven (Scheinvar, 1995). There are four cultivated species of cactus including *O. albicarpa*, *O. ficus indica*, *O. robusta* and *O. cochenillifera*. *Opuntia ficus-indica* (cactus pear) is the most common and widely known genus of *Opuntia* (Majure et al., 2017).

It is an angiosperm and dicotyledonous plant which has developed a number of physiological, anatomical and phonological adaptations that make it more suited to grow efficiently in arid areas. Mechanism of asynchronous reproduction characterized by ability to continue reproductive stage over a longer period of time combined with the trait of succulence and crassulacean acid metabolism (CAM) have enabled it to survive prolonged spells of drought for years (Lima et al., 2016). Its stems are called cladodes while its fruit (red, orange, yellow or purple colour) is referred to as nochtli. Cactus pear is perennial shrub and may grow up to the height of 20 meters (Reis et al., 2014). The root system of cactus pear is horizontal which rarely penetrates deep into the soil and mostly remains 30 cm below the soil (Tiznado-Hernández et al., 2010). In cross-sectional view, the outer layer of root is epidermis having single cell layer with very few root hair. In the core of root, there is cortex made of multilayers of cells with abundant intercellular spaces through which CO_2 and O_2 movement occurs by diffusion (Yang et al., 2015). Whenever there is rainfall, numerous roots are developed from shallow roots of cactus pear called as rain roots, which assist in making cactus pear more hydrated than the soil. Its stem is oblong shaped having a thick waxy layer of epidermis which prevents water loss by solar radiation (Soni et al., 2015).

The cladodes (stems) of cactus pear are also called as pads or paddles and contain about 90% water and 10% dry matter. These are the photo-synthetically active organs where photo-synthates are produced, stored and trans-located to plant sinks. Cladodes or pads can be flat (platyopuntias having more than 120 species) or cylindrical (cylindropuntias having around 40 species); however flattened pads have been reported to harness more light energy than cylindrical cladodes (Ervin, 2012; Gebresamuel and Gebre-Mariam, 2012). On cladodes, a bud like structure (areole) is present which has meristematic cells and give rise to new cladodes that are referred to as glochids. These are very loosely bonded to cladodes and may detach on a gentle touch. Leaves are produced by young cladodes and are ephemeral with little photosynthesis (Isaac, 2016). Leaves of cactus pear develop into specialized spines while these are mistakenly understood as leaves that are actually stems (Gebresamuel and Gebre-Mariam, 2012). Cactus pear fruit is classified as false fruit as it is comprised of floral tube which contains ovary within it. There is large number of hard seeds dispersed within the pulp of fruit (Padrón et al., 2011; Robertson et al., 2011).

ECO-PHYSIOLOGY

Crassulacean acid metabolism (CAM) for gaseous exchange and nocturnal stomatal opening at the coolest time of the day may be constituted as the physiological bases of ecological success of cactus pear in harsh climates (Lee, 2010). Under moderate temperatures and wet conditions, CO_2 uptake starts at late afternoon and maximized few hours after dusk. A sharp rise in CO_2 uptake occurs at dawn when light facilitates the incorporation of CO_2 into carbohydrates (Sharafi et al., 2012). The up-taken CO_2 in CAM plants is bonded to 3-C compounds to form 4-C organic acids like malate (Liguori et al., 2013; Torres-Ponce et al., 2015). Overnight, the organic acids are stored in large vacuoles and subsequent release of CO_2 from the stored organic acids causes decrease in the acidity of tissues during the day. This trapped CO_2 owing to closure of stomata during the day is the only that gets incorporated into photosynthetic products in the chlorenchyma tissues (Liguori et al., 2014). The water use efficiency (ratio of CO_2 fixed in photosynthesis to water lost through transpiration) of cacti was recorded to be 0.022 (1.14 mol m^{-2} day^{-1} CO_2 fixed at the loss of 51 mol m^{-2} day^{-1}) which was triple than maize and sugarcane, while 5-fold higher than wheat, rice, cotton, alfalfa etc. (Saenz, 2013). Insects have been reported to be efficient pollinating agents for cactus pear besides birds and bats on a smaller extent (Padrón et al., 2011). Mycorrhizal interactions between its roots and microbes have been observed (Ervin, 2012) but so far, no detailed characterization has been done. The potential of cactus pear for fixing atmospheric nitrogen through biological nitrogen fixation (Silva et al., 2016) needs to be evaluated under varying simulated climatic conditions.

UTILIZATION IN HUMAN FOOD

Cactus pear fruit (nochtli) is of red color having the weight of 80-140 g of which 55% is edible portion (Cano et al., 2017). It is rich in carbohydrates, vitamins, amino acids and various minerals (Table 1) which are needed in a variety of metabolic processes going on in human body (Becerra-Jiménez and Rade-Cetto, 2012). It helps in reducing oxidative damage of lipids due to vitamin C presence in abundance that assists in maintaining the redox balance (Bensadón et al., 2010). It has been discovered that human anti-oxidant levels may be improved over a period of time by adding its fruit in diet (Yahia and Mondragon, 2011). It may also be utilized as a natural colorant for ice cream and yoghurt preparation because of the presence of a pigment called belatins (Fernandez-Lopez et al., 2010). It is being used for making pulp and juice as it contains about 42% juice (Alimi et al., 2012). The consumption of cactus pear fruit was effective to regulate the sleep clock, blood pressure and served as a strong stimulant of CNS (central nervous system) (Fernandez-Lopez et al., 2010). Oil extracted from cactus pear fruit has been reported to reduce cholesterol level in a short period of time (Ciriminna et al., 2017). In Mexico, daily intake of cactus pear has been 10-18 g $person^{-1}$ $year^{-1}$despite the fact that it does not constitute a complete food in itself (Hahm et al., 2011). However, it is gaining popularity in many countries including Canada, Japan, Italy, Turkey and USA for having low caloric values and higher dietary fiber content (Contreras-Padilla et al., 2012).

Cladodes may be utilized as vegetable particularly those harvested during first year of plantation as older cladodes become hard limiting its utilization in human food. Pruning is usually required to cut closely spaced cladodes which may fulfill the shortage of vegetables in arid regions (Rodrigues et al., 2016). In addition, young and immature cladodes usually during first year may also be pickled (Contreras-Padilla et al., 2012). Cactus pear pads utilized as vegetable has been reported to be helpful in lowering the body weight along with being effective for lowering the blood glucose level of diabetic patients (Carreira et al., 2016). Cladodes have also been identified to have a protective influence against fatty liver (Ribeiro et al., 2010). It was also found to have a positive impact for the persistent constipation owing to its strong laxative properties (Andrade-Ceto and Wiedenfeld, 2011). However, the problems of dermatitis (skin irritation) and conjunctivitis have been reported in humans by eating cactus pear as vegetable and fruit (Zhao et al., 2011). The nutritional composition of cactus pear fruit and cladodes are illustrated in Tables 1 and 2.

Table 1 - Nutritional status of cactus pear fruit for human utilization

Quality trait	Value	References
Ascorbic acid (mg 100 g^{-1})	14-15	Zhao et al., 2011; Torres-Ponce et al., 2015; Mokoboki et al., 2009
Beta-carotene (mg 100 g^{-1})	330-340	Rodrigues et al., 2016; Cano et al., 2017
Pectin (mg 100 g^{-1})	5.50-15.00	Becerra-Jimenez and Rade-Cetto, 2012; Selmi et al., 2013; Zegbe et al., 2014
Mucilage (mg 100 g^{-1})	3.70-8.50	Gebresamuel and Gebre-Mariam, 2012; Alimi et al., 2014; Soni et al., 2015
Antioxidant (Betanin and Isobetanin) (mg 100 g^{-1})	80-90	Andrade-Ceto and Wiedenfeld, 2011; Yahia and Mondragon, 2011; Fernandez-Lopez et al., 2010

Table 2 - Nutritional status of cactus pear paddles (cladodes) as vegetable for human utilization

Quality trait	Value	References
Energy (Kcal)	16-18	Sakly et al., 2014; Isaac, 2016
Protein (g kg^{-1})	1.32-1.38	Ben-Salem and Ennouri, 2013
Carbohydrates (g kg^{-1})	3.30-3.35	Chiteva and Wairagau, 2013; Liguori et al., 2014
Dietary fiber (g kg^{-1})	2.20-2.38	Bensadon et al., 2010
Sodium (mg kg^{-1})	21-24	Rojas-Molina et al., 2012
Calcium (mg kg^{-1})	161-164	Ben-Salem and Ennouri, 2013
Iron (mg kg^{-1})	0.59-0.62	Hahm et al., 2011

NUTRITIVE VALUE OF CACTUS PEAR CLADODES TO SERVE AS FORAGE

Cactus pear also known by the name of forage palm can be promoted as a forage crop for arid regions (Guevara et al., 2011). It has an extraordinary efficacy for converting water to dry matter of digestible energy (Fotius et al., 2014). It is the only known forage having live storage capability as it continues to grow after harvesting without deterioration in quality, (Liguori et al., 2014). Its pads may be dried and ground using a hammer-mill having 6 mm sieve to make meal for subsequent use during drought.

The nutritional quality of cactus pear depends on the age, season, climate, species, variety, soil fertility and agronomic management (Chimsa et al., 2013). It ashes (10-25% of dry matter) contained calcium (85%), sodium, magnesium and potassium in the form of silica and salts along with vitamin A (Pessoa et al., 2013). Traces of iron and aluminum have also been reported in its ashes (Selmi et al., 2013). Digestibility of cactus pear is directly dependent on the age of cladodes. The digestibility of cactus pear dry matter (70-82%) tend to be higher owing to low lignin content (50-80 g kg^{-1} of dried matter) (De Wall et al., 2013) compared to forage sorghum (112-180 g kg^{-1} of dried matter) (Iqbal et al., 2018a, b, c) and canola (110-129 g kg^{-1} of dried matter) (Iqbal et al., 2018d). The crude protein content is low (4-8%) with high fiber content (9-20%). Another study has reported its crude protein (CP) as 50 g kg^{-1} of dried matter while ruminants need CP at least 70 g kg^{-1} of dried matter (Soni et al., 2015). Protein quality of cladodes is satisfactory and resembled to barley grain in composition. Neutral detergent fiber (459 g kg^{-1} of dried matter) of spineless cactus pear has been found to be the lowest while acid detergent fiber (287 g kg^{-1} of dried matter) is on higher side in comparison to spiny species with dry matter degradation of 768 g kg^{-1} of dried matter (Cordova-Torresa et al., 2015). Overall, the gross energy content are in the range of 3000-4000 kcal kg^{-1} of dry matter with digestible energy of 1800-2000 kcal kg^{-1} (Cordova-Torresa et al., 2015). The detailed nutritional quality of cladodes for utilization as forage has been described in Table 3.

Ruminants usually consume 20-40 kg pads per day, while it may go up to 80 kg during the drier seasons for fulfilling the water requirement (Meraz-Maldonado et al., 2012). In addition, cladodes supplemented with corn-meal or cotton meal may fulfill 70% of animal's daily requirement, however it has been suggested to restrict it to 20-30% of daily consumption on dry matter basis (Chiteva and Wairagau, 2013). Holstein cows were reported to lose weight when cladodes made 73% of their daily feed intake. Other studies suggested replacing alfalfa hay up to 30% with cactus pear forage (Cordão et al., 2013). Small ruminants being fed on cactus pear forage have also been reported to suffer from diarrhea owing to high concentration of minerals (Andrade - Montemayor et al., 2011). This problem may be solved through the addition of molasses in chopped cactus pear (Ben-Salem and Ennouri, 2013). However, more in-depth studies are needed for determining the impact of cactus pear forage on ruminant's performance in terms of milk and meat production.

EMERGENCY SOURCE OF WATER FOR RUMINANTS

Typically pads of cactus pear contain more than 90% water which may serve as an emergency source of water for ruminants during water scarcity conditions in arid and semi-arid regions. It has been reported that small ruminants (sheep and goat) having sufficient quantities of cladodes

Table 3 - Nutritional status of cactus pear cladodes (nopales) for utilization as forage for ruminants.

Quality trait	Value	References
Organic matter (%)	81-87	Cordão et al., 2013; Isaac, 2016
Dry matter (%)	7.5-11.5	Guevara et al., 2011; Carreira et al., 2016
Digestibility (%)	70-82	Cordova-Torres et al., 2015
Protein (%)	3.6-8	Hernandez-Urbinola et al., 2010; Lima et al., 2016
Neutral detergent fiber (%)	23-27	Mokoboki et al., 2016
Acid detergent fiber (%)	12-16	Ramos et al., 2013
Lignin content (%)	8-12	Cordova-Torres et al., 2015
Total ash (%)	10-25	Soni et al., 2015
Fat (%)	1-2	Meraz-Maldonado et al., 2012
Non-fiber carbohydrates (%)	33.3-48.6	Ribeiro et al., 2010
Calcium (%)	8-50	Lima et al., 2016
Carotenoids (μg 100 g^{-1})	29-31.3	Isaac, 2016
Ascorbic acid (mg g^{-1})	13-14.5	Grunwaldt et al., 2015; Torres-Ponce et al., 2015
Gross energy (kcal kg^{-1})	3000-4000	Fotius et al., 2014
Digestible energy (kcal kg^{-1})	1800-2000	Mokoboki et al., 2016

intake may survive up to 1.5 years without drinking water (Soni et al., 2015). This conclusion has been seconded by another study which suggests that cactus pear forage intake by sheep decrease the water intake of sheep by 93% (Isaac, 2016). However, other studies have differed by stating that animal health deteriorates when cactus pear solely provided the drinking water for a period of over 96 days (Pessoa et al., 2013; Lima et al., 2016).

IMPROVED AGRO-TECHNOLOGY PACKAGE FOR CACTUS PEAR CULTIVATION

Cactus pear has the potential to thrive well on a range of sandy to clay and clay-loam to sandy-loam soils provided its plantation is completed before rainfall (Ben-Salem and Ennouri, 2013; Isaac 2016; Lucivania et al., 2018). Transplanting of cladodes immediately after rain helps in establishing roots of the new plants and thus, before the start of monsoon rainfall was found to be the most suitable transplanting time (Grunwaldt et al., 2015).

Plantation at high plant density may be effective for improving biomass production per unit land area. However, for restoring pasture and rangelands, plantation at lower plant density has been recommended (Andrade - Montemayor et al., 2011; Lima et al., 2016). Varieties having high vigor, good health and reasonably higher potential for yield like South African cultivars including skinners court, Malta, Algerian, turpin, Meyers etc. (Swart et al., 2003) must be selected as per local agro-climatic conditions. As it is propagated through vegetative means, the planting material of cactus pear is a cutting comprising of two cladodes, of which 50-75% portion must be buried; however single cladodes cuttings may also be used in case of short supply (Soni et al., 2015; Bakali et al., 2016). Cutting must be performed on joints with a sharp knife as large wounds may become infested with pathogens (Liguori et al., 2014). In order to avoid the rotting of cladodes ends, these must be shade dried for few days to heal the wounds or treat with lime or copper sulphate solution. Shallow holes are made for burying the cladode cuttings.

Cuttings sown in rows or furrows having the spacing of 2-6 meters with cladodes-cladodes spacing of 1-2 meters have been reported to perform better than other planting geometries (Diniz et al., 2017). The optimum plant population has been found to be 2500 plant per hectare which may yield 120 and 160 tons per hectare in fifth and seventh year respectively (Lucivania et al., 2018). However for fertile soils, 40000 plants per hectare has been suggested, but higher plant plantation requires intensive management (Lima et al., 2016). In contrast, spineless cacti have been remained more productive when sown as 24 plants m^{-2} by yielding 40 t ha^{-1} of forage under mild drought (Meraz-Maldonado et al., 2012). In contrary, Silva et al. (2016) have reported that the planting density of 160000 per hectare recorded the highest dry matter yield (48 t ha^{-1})

especially with 40 tons of bovine manure application per two years. However, arid regions have recorded 5-15 ton per hectare of biomass only. There are contradictory findings regarding sowing in East-West or North-South direction (Santos-Do et al., 2016). In addition, inoculation of cladodes with free-living N-fixing bacteria (sp. *Nostoc*) has been helpful in boosting the protein content along with providing protection again bacterial rot attack (Soni et al., 2015).

Cactus pear intercropping with sorghum has resulted in improved water use efficiency owing to lesser evapotranspiration which results in higher dry matter production (Lima et al., 2018). In addition, sorghum-cactus pear intercropping reduced the time taken to harvesting from 19 to 17 months for irrigated cactus pear (Carvalho et al., 2017; Imorim et al., 2017). Besides, cladodes length and width along with plant height and plant girth are linearly correlated to green matter yield which has direct relationship to dry matter yield (Nedar et al., 2013). First two years of plantation require pruning of closely grown cladodes which may be utilized as vegetable or forage (Ribeiro et al., 2010). Composted organic manures (20 t ha^{-1}) or chemical fertilizers (220 kg N and 120 kg P ha^{-1}) were effective in increasing the biomass along with protein content up to 10% of dry matter (Saenz, 2013).

As far as harvesting systems are concerned, direct feeding of spiny *Opuntia* by livestock results in severe mechanical injury which may lead to death (Vilela et al., 2010). Removal of upper edge of cladodes having the highest concentration of spines serves the purpose but results in wastage of cladodes. Harvesting may also be done through grazing or cut and carry methods, however a propane weed burner must be used to singing off spines before using as forage (Santos-Do et al., 2016). Although, the burning of thorns of harvested pads with kerosene stoves was effective but sometimes it resulted in burning of cladodes along with the spines (Rodrigues et al., 2016). In order to avoid this problem, spineless species have been developed and recommended to be grown. However, spineless cactus pear is needed to be protected from rodents and animals by erecting net-wire fences.

IMPLICATIONS

Due to high endurance to drought (Bakali et al., 2016; Amorim et al., 2017), cactus pear has the potential to become a noxious weed posing serious threats to cultivated areas by making the prevalent chemical, cultural, mechanical and biological control methods ineffective. In addition, the genetic resources of native plant species may also be polluted owing to its invasion in irrigated areas. Furthermore, slow growing habit and comparatively lesser hardiness to heat and cold of spineless cactus pear (*O. ficus indica* L. Mill.) continue to hamper its wide-scale cultivation in arid regions. Besides, it must be protected from rodents and herbivores by erecting wooden fences, wire nets or boundary walls. In contrast, spiny cactus pear does not need such protection rather requires mechanical or burning of thrones before utilization as vegetable or forage which multiplies the cost of production. It cannot tolerate water logging and soil salinity which further reduces its growth and development. Low protein content (4-5%) of cactus pear grades it poor forage on animal nutrition scale. The oxalate crystals presence reduces the provision of calcium to animals being fed on cactus pear forage. Furthermore, higher moisture content reduces the shelf life of cladodes considerably owing to being prone to microbial invasion which hinders its transportation to far-flung areas without preserving.

FUTURE BREEDING NEEDS AND TRENDS

Cactus pear with spineless pads should not be the sole goal of future breeding programs due to the fact that spines are the biggest impediment in cladodes utilization as forage. Previous studies suggested that spineless cactus pear never existed in wild while spineless species tend to revert back to spiny form gradually, despite the fact that this inheritance mode has not been identified to date (Selmi et al., 2013). Spiny cactus pear have been found to be more rigorous, hardy, aggressive and better adapted to propagation and spread under unfavorable climatic conditions, while these characteristics are scant in spineless plants. Similarly, plant productivity may be significantly improved through breeding as suggested by differential growth of seedlings obtained from self and cross breeding. This differential growth has been attributed to alteration in photosynthesis rate and nutrient uptake (Amorim et al., 2017). However, producing more cladodes and quick recovery from pruning might serve as a crucial trait to be achieved and manipulated through breeding tools. In addition, the size of cladodes is a genetically controlled attribute (De Wall et al., 2013) and cultivars having medium sized cladodes need to be developed for sowing in closer spacing.

Animal performance is directly linked to the nutritional quality of the feed and protein content along with the digestibility that occupies the vital position in determining the feed value. The age of cladodes determined the protein content which increased with maturity having 2.8-5.1% protein on an average (Lima et al., 2018). Although protein content may be improved through appropriate agronomic management and optimal plant nutrition strategy, yet the genetic gains in terms of higher protein content must be obtained through selection and breeding. In addition, insect-pest resistance may be developed among cactus pear cultivars as it would be more viable economically and biologically to chemical control particularly against insects (stinky bugs, armored scale insect, wild cochineal, caterpillars, grasshoppers, ants etc.) and diseases (bacteria caused soft black rot and fungus caused cladode rot). Lastly, cold tolerance is another trait that must be the included as a strategic target of future genetic programs in order to enhance its tolerance to freezing temperatures. Thick integuments (epidermis, cuticle, thick walled cells and pads having crystals bearing layers) have the potential to impart resistance to heat and cold. However, it is the need of hour to focus on breeding to achieve thicker cuticle.

Cactus pear being a CAM plant has higher water and nutrient use efficiencies compared to C_3 crops and C_4 broadleaf plants. Both spiny and spineless cultivars have the potential to yield considerably higher quantities of green forage biomass with up to 10% protein contents if an appropriate agronomic management plan is followed with respect to transplanting time, planting geometry, fertilization and weeding. Appropriate agronomic management may lead to substantial increase in forage yield of cactus pear for bridging the gap between forage supply and demand in arid regions especially during forage scarcity periods. During drought, cactus pear may serve as a source of emergency water supply along with providing dry matter for ruminants. It may play a strategic role in conserving the ecosystem owing to its adaptability to limited growth resources. However, extensive agronomic and breeding research must be done to increase the production potential and nutritional quality of cactus pear for its cultivation in dry lands. The drastic impacts of climate change and global warming might be neutralized through wide-scale adaptation of cactus pear by reducing desertification and producing food and forage in arid areas.

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