CACTUS

ENSURING ROUND THE YEAR FEED SUPPLY

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P. Thirumurugan, S.M.K. Naqvi

DIVISION OF ANIMAL NUTRITION
National Innovation in Climate Resilient Agriculture
ICAR - CENTRAL SHEEP AND WOOL RESEARCH INSTITUTE
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CONTENTS

Introduction

Prickly pearcactus [Opuntiaficus-indica (L.) Mill.] an excellent natural bio-mass, is a fast growing xerophytes draught resistant plant and well adopted to arid and hot environment. Dry matter yield from opuntia may exceed 2000 kg/ha on uncultivated wastelands. Opuntia has been used as a drought feed and as forage for cattle feeding since early 19th century. In most of the instances it is still used as emergency feed during drought and scarcity. However, the genus appears in great genetic diversity as it is widely used in human (fruits and green vegetables) and animal diets (fodder) in African countries, Mexico and Latin America. A variety of edible and non-edible cactus belonging to Opuntia spp. are available in semi-arid, arid regions and even at hill tracts, but they are not generally practiced to feed animals in south-east Asian countries.

Arid and semi-arid regions of India are frequently exposed to seasonal and yearly fluctuation of rainfall that severely reduces the potential of conventional forage crops such as bajra, sorghum, maize, oats and beans. Perennial adapted crops are the best alternative to produce food for humans and feed for livestock. Rangelands in semiarid regions are usually the basis for livestock production systems. Rangeland productivity is usually low (< 5 t DM/ha/yr), with low forage potential (< 1 t DM/ha/yr of consumable forage), leading to low carrying capacity (12-15 ha to sustain an adult cow) (Dubeux et al., 2015). Global livestock population is increasing steadily in the past decades and, in some cases, leading to rangeland degradation. Water is another important limiting factor in drylands. Global projections of water use demonstrate increasing withdraws in the next decades, limiting its use for agriculture and livestock production.

It has been documented in a number of reports that tropical livestock production is faced with deficit of feed supply arising from fluctuations in environmental factors, which directly and indirectly limit the quantity of herbage available to animals either from natural grazingor crop residues. Thus, under such circumstances, animals have to survive on drought tolerant vegetation such as cactus (O.ficus-indica) pear. Further more,the semi-arid and arid regions of South-east Asian countries are more prone to drought and during this period both loss of life productivity and/or of animal life occur, mainly due to shortage of feed. In this scenario, cactus, more specifically Opuntiaspp. become one of the most prominent crops for the 21st Century. It's extremelydrought tolerance features, adaptability to poor soil conditions, and high biomassyield potential with acceptable palatability makes it suited for cultivation in arid and semiarid regions where there is inherent and frequent scarcity of feed resources.Described variously as "miracle plant", "dromedaryof the vegetation world", and "the bank of life", cactuscan contribute in ameliorating the livelihoods of ruralpopulations in dry areas.

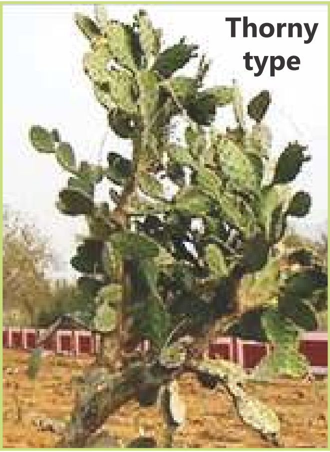
Cactus has traditionally been used for fruit productionIi South Africa, but currently feed production for livestock is replacing some of the fruit orchards (de Waal et al., 2013).Farmers and herders in NorthAfrica have long relied on it as a feed source for livestock,fencing material, and fruit for human consumption.Cactus is one of the major feed commodities for livestock feeding in the semiarid region of Brazil and it has potential to produce > 20 t DM/ha/yr and provide 180 t ha/yr of fresh good-quality water stored in the cladodes for the livestock (Dubeux et al., 2015). The high productivityof cactus under harsh conditions is mainly due to its CO2fixation, which enables it to convert water to dry mattermore efficiently than most forages (Nobel, 1995).This productivity is enough to produce forage to sustain fiveadult cows per year, at least 60-fold increase over the rangeland productivity. Thus, with small intensively cropped cactus orchards, it is possible to produce feed and lower the stocking rate from overstocked rangelands, reducing their degradation. The potential of cactus, however, is still underexploited.Even cactus with thorns can be used for live-stock feed after mechanical removal or burning out the thorns.

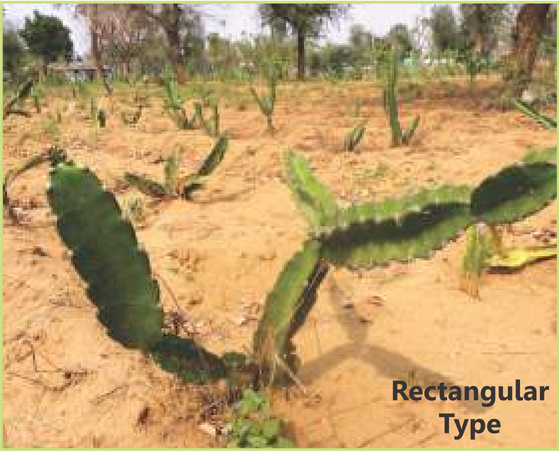
What is cactus?

Opuntia species of cactus belong to the family Cactaceae and in the desert some plants have thorns or needles to defend itself against predators.These plants are normally have a tough skin that helps retain water inside of the plant. The discovery of Crassulacean acid metabolism (CAM) metabolism in a group of cactus-type plants dates back to Roman times through persons who noted a morning acid taste of some common house plants. In 1815, Benjamin-Heyne described a 'daily acid taste cycle' with some succulent garden plants from India. Recent work has shown that the nocturnally formed acid is decarboxylated during the day to become the CO_2 for photosynthesis (Black and Osmond, 2003). CAM plants express the most plastic and tenacious photosynthesis known in that they can switch photosynthesis pathways and they can live and conduct photosynthesis for years even in the virtual absence of external H_2O and CO_2, i.e., CAM tenaciously protects its photosynthesis from both H_2O and CO_2 stresses.The CAM is first described forspecies of the family Crassulaceae, i,e, i) nocturnal uptake of CO_2 via open stomata, fixation by phosphoenolpyruvate carboxylase (PEPC) and vacuolar storage of CO_2 in the form of organic acids, mainly malic acid (phase I), and ii) daytime remobilization of vacuolar organic acids, decarboxylationand refixation plus assimilation of CO_2 behind closed stomata in the Calvin-cycle (phase III) (Luttge, 2004). Between these two phases there are transitions when stomata remain open for CO_2 uptake for a short time during the very early light period (phase II) and reopen again during the late light period for CO_2 uptake with direct assimilation to carbohydrate when vacuolar organic acid is exhausted (phase IV).

The range of temperatures tolerated by cacti is quite large, e.g. highest soil surface temperature tolerated by some cacti is 74 °C on the bare soil where they grow, the highest temperature tolerance known for higher vascular plants. The photosynthetic electron transport apparatus also tolerates longer periods at higher temperatures than any other vascular plant (Nobel and de la Barrera, 2003). Acclimation to high temperatures is associated with protein synthesis. The lowest temperatures tolerated bycacti are -10 °C by Opuntiaficus-indica and O. streptacanthaand -24 °C by O. humifusa (Goldstein and Nobel,1994).Deprivation of water for 4 months resulted in a massive loss of water from the cactuscladodes, but without irreversible tissue damage (Goldstein et al., 1991). It is noted that the root of spineless cactus can lose as much as 60% of its water contentbefore the cells collapse. In general, these adaptations enable cactus to convert water4–5 times more efficiently to DM than the most efficient grasses (Russell and Felker,1987). Cacti grow and survivein infertile and shallow soils, with highly efficient useof water, reflecting a unique root adaptation strategy.The success of Opuntia might be related to its distinctivereproductive biology, e.g. vegetative multiplication is moreefficient than sexual reproduction (Reyes-Ag¨uero et al., 2006) and its capability to grow rapidly generating high biomass yields.Besides these agronomic properties, other attributes such as ability to remain succulent during droughtand produce forage, fruit and other useful products, as well as its capacity in preventinglong-term degradation of ecologically weak environments have increased the importanceof cactus in arid and semi-arid regions.

Central Sheep and Wool Research Institute has established a cactus field in 2.5 ha area that harbours four different type of cactus (Opuntiaspp) namely native thorny, less thorny, thorn-less and rectangular types.All the four varieties are palatable with a variation in nutrient composition (Table 1). They exhibited different acidic pH of 5.53, 5.27, 5.09 and 5.55, respectively. The native thorny and less thorny varieties are adapted well to semi-arid Rajasthan and we have reports of sucessful propagation in Haryana, Maharastra, UP and other states. Central Arid Zone Research Institute, Jodhpur has sucessfully established a thorn-less variety of cactus with very good yield and palatability to livestock.





Cactus cultivation: Global scenario

In Mexico, the center of origin for cactus, intensive cactus orchards provide fruit and 'nopalitos' for human population. In these orchards the use of irrigation, organic and chemical fertilizer and pruning techniques, and control of pests and diseases are commonly practiced. In Mexico, an estimated area of 3 million ha of native cactus is extensively used by the population to obtain feed for livestock. In Italy, intensive orchards are found for fruit production, while in North Africa the major uses include fruit production and feed for livestock; and lately medicinal and cosmetic industries based on cactus are emerging. In South Africa, cactus has traditionally been used for fruit production, but currently feed production for livestock is replacing some of the fruit orchards (de Waal et al., 2013). In South America, Brazil has one of the largest areas of cultivated cactus developed for livestock feed, Peru has an intensive cochineal production on cactus plants, which is used for red dye production, while Chile and Argentina dedicate most of the cactus for fruit production, and for medicinal and cosmetic industries. Cactus is a multipurpose crop that provides multiple benefits for the society. During the dry season, cactus is sold as a feed commodity, because of the benefits it provides to livestock. It protects soil against erosion and provides feed for livestock and food for human (e.g. fruit, vegetable). Although good statistics on cactus cultivation are difficult to find, it is estimated that Brazil has 500 000 to 600 000 ha of cultivated cactus, mostly Opuntia and Nopalea. The area under cactus cultivation is increasing in many other countries, however precise data on area under cactus cultivation at global level are unavailable.

Forage cactus and its nutritive value

Prickly-pear cactus has low levels of DM (10–14%), CP (4–6%) and NDF (26.8%) (Melo et al., 2003). But, it is an excellent energy source, rich in non-fibrouscarbohydrates (NFC; 61.7%) and presents high DM digestibility coefficient (Wanderley et al., 2002). Besides,cactus pear contains significant levels of Ca, K and Mg (Sahoo et al., 2014).Cactus is generally low innutritive value due to imbalance of nutrients or presence of some anti-nutritive factors, e.g. cactus pear when used as a sole feed in large quantities caused bloat anddiarrhea in animals (Gebremariam et al., 2006).Studies have indicated that the digestibility of chopped cactus (opuntia cladodes) is comparable with high quality forages. The plant is extremely variable in its nutritivevalue, which depends mainly on species, variety, ageof plant, season and plant part (Hanselka and Paschal,1990). Nutritive value of various opuntia spp. wasexamined for animal feeding (Russell and Felker, 1987; Ben Salem et al., 1996; Sirohi et al., 1997; Misra et al., 2006; Sahoo et al., 2014). Cactus is not generally considered as a complete feed source. The thorn-less variety of Brazil has high digestibility (65-70%), rich in water soluble carbohydrates (45-55%), but low CP (3-7%), low fiber (NDF 25-30%) (Dubeux Jr (2016). Producers are aware of these limitations, but they highly value the energy and the water provided by cactus for their livestock.Gebremariam et al.(2006) also reportedlow CP and cell wall carbohydrates contents, but highly digestible andrich in non-structural carbohydrates (NSC).The high NSC in cactus could be used as source of readily available energy foranimals fed on crop residues (straws) that usually contain only about 10–20 g/kg DM of NSC. Since N utilization by therumen microflora is related to the amount of fermentable energy, the high NSC content in cactus could enable efficient microbial protein synthesis with probably a better P:E ratio. Nefzaoui et al. (1993) reported cactus to be a good supplement to ammonia or ureatreated straw since it provides the necessary soluble carbohydrates for the efficient use ofthe non-protein nitrogen arising from the treated straw in the rumen.Cactus is rich in Ca but has poor available P. it is also a rich source of carotenoids and other phytochemicals (Chaturvedi and Sahoo, 2013), which can be a part of ruminant diet during the periods of summer feed scarcity and unavailability during other natural calamities.

Data on chemical composition of freshly chopped cactus and its feeding to sheep in a series of experiments conducted at Central Sheep and Wool Research Institute, Avikanagar is depicted in table 1.

Table 1. Chemical composition and digestibility of cactus in the feeding of sheep as sole fodder

Components	Chemical composition (% DM basis)	Digestibility (%)
Dry matter	12.00 - 21.00	46.3-56.4
Ash	17.80-26.30	NA
Organic matter	73.70-82.20	51.2-59.5
Crude protein	8.30-11.50	31.5-61.8
Ether extract	2.18-3.45	58.7-69.5
Total carbohydrates	62.66-67.25	52.3-61.2
Neutral detergent fibre	43.80-57.20	46.1-48.8
Acid detergent fibre	22.90-34.56	32.8-35.5
Acid detergent lignin	2.42-4.85	NA
Gross energy (Mcal/kg)	3.85-3.95	48.3-55.6

NA, not applicable/analysed

Feeding of cactus and animal performance

Tegegne et al. (2007) tried to assess the optimal level of cactus pear in the feeding of sheep and recommended up to 60% substitution of pasture hay with cactus. They did not find any indication of seriousdigestive disturbances (diarrhoea and bloat) in sheepfed diets containing up to 80% cactus pear (equivalent to70% of DMI).A basal diet consisting of cactus and tef straw promoted body weight gain in sheepindicating their usefulness under conditions of feed scarcity (Degu et al., 2009). They also observed that supplementation of 145 g DM cotton seed cake and 149 g DM peanut cake resulted in better feed intake,BW gain and carcass traits in cactus–tef straw based feeding of sheep compared to supplementationwith 195 g DM of noug seed cake. It has always been demonstrated to include a readily fermentable energy for efficient utilization of rapidly degradable nitrogen in therumen.These fermentable carbohydrates represent fraction A (sugarsand organic acids of rapid degradability) and fractionB1 (starch, pectin and glucan), as classified by Sniffen et al.(1992). Costa et al. (2009) tried to incorporate increasing levels of cactus pear (O. ficusindica Mill) in the diet of dairy goats as a replacement of corn meal at 7, 14, 21 and 28% of DM and found linear increase in fresh matter and DM intake with mean values ranged from 2.03 to 13.48 kg/d and 1.95 to 2.31 kg/d, respectively. Although there was no effect on milk production, a linear reduction in milk fat was observed with increasing cactus pear levels. In a later experiment, Costa et al. (2012) even tried to replace corn with cactus pear to the tune of 25, 50, 75 and 100% levels on DM basis and found a quadratic response on intakes of DM, OM, CP, EE, total carbohydrates (TC), non-fiber carbohydrates (NFC), TDN and ME but a linear response for NDF and mineral matter intakes with increased levels of cactus pear in the diet. The maximum DMI from cactus pear was approximately 54% of total diet and animals showed selection preferential in both morning and afternoonfeedings, first ingested the cactus pear, followed bythe concentrate and finally the Tifton hay.This could be attributed to low fibre content, high palatability, and high passagerate of the cactus pear as the availability increased from 25 to 75% in the diet. Although the energy value of cactus pear is less thanthat of the corn, there was linear increase in digestibility of DM, OM, CP, NDF and TC, but daily weight gain and feed efficiency decreased. Above all, they found inclusion of cactus in the dietof sheep favoured a high digestibility of nutrients, improved the quality of forage, reduced thevoluntary intake of water, and thus may be considered an important source of fodder and waterreserves for use in semiarid regions.The semi-arid regions of Rajasthan and similar other parts of India, where soil and climate conditions make the production of cereal grains suchas corn difficult, the use of cactus pear forage as a substitutefor this cereal in feedlot sheep and in the diet of other livestock species seems justifiable.

Experiment 1 : First scientific evaluation at CSWRI (Sirohi et al., 1997) haveshown that opuntia from semi-arid regions in Indiacontain CP 92 g/kg DM, which is higher than the commonlyused dry roughages (straw, stovers and grasses)in ruminant feeding. They observed high N loss through urine leading to negative N balance.However,it contains enough moisture (80-90%), besides good amount of soluble nutrients (Table 1) to exert associative effect on intake and digestibility of nutrients.

Experiment 2 : Misra et al. (2006) included additional N through groundnut meal to make up the deficit and studiedfeed intake, digestion and utilization of nutrients, rumen fermentationand urinary excretion of purine derivative in sheep fed on opuntia in combination with cenchrus hay. They observed that 50 g groundnut meal supplementation improved feed intake, apparent digestibility of DM, CP and energy, nutritive value, plane of nutrition and N balance similar to cenchrus plus 200 g concentrate supplemented diet. Excretion of purine derivatives, microbial N as well as microbial protein supply and ruminal N and NH3-N was poor in sheep on opuntia diets, which improved with supplemental groundnut meal. In addition to impaired N utilization there was negative P balance which could be due to low P content (0.2%) of opuntia. This might have impaired protein utilization and microbial protein synthesis (Petri et al., 1989; Ternouth and Sevilla, 1990). Thus, Misra et al. (2006) advocated that opuntiadiets could be advantageous, when appropriate N supplyis emphasized, as sheep may have similar digestionthan those on common diets and may reduce considerablydrinking water consumption.

Experiment 3 : Another experiment on evaluation of supplemental prickly pear cactus in the feeding of sheep on a basal roughage diet of locally grown Cenchrus grasses in the semi-arid Rajasthan found to be deficient in meeting the CP requirements. Although the diet supported required DM and other nutrients intake, a higher excretion of N through urine unsettled the N utilization. The protein deficit was tried to make up through supplementation of 50 g solvent extracted groundnut cake or 200 g concentrate (18 % CP) per sheep per day and it proved to be adequate in maintaining energy:protein ratio with positive N balanceto support minimum production.

Cactus: a ready source of water in arid and semi-arid regions

Invariably, cactus cladodes is rich in moisture to the tune of 90% during rainy season and it declines to 75-80% during summer. The native thorny variety is relatively drier than less thorny and thorn-less types, but more resistant to adverse climatic conditions and drought conditions. The cladodes are in other words store house of water for livestock in arid and semi-arid regions.Animals do not voluntarily consume cactus plant in the field for its satiety or thirst. In the event of unavailability of feed resources, farmers looked for alternative forage resources and thus feeding of cactus in livestock has comes in to practice. Due to high moisture content, feeding of 2 to 3 kg freshly chopped cactus to sheep and goats can very well meet 1.5-2.5 L of their daily water requirements or in other wordswater requirement of around 1 L can be met through feeding of 1.20 kg of fresh opuntia without any adverse effect.

In day-to-day feeding practice, incorporation of cactus in the diet has drastic effect on water intake, and the supplemented sheep show negligiblefree water intake. BenSalem et al. (1996) noted that water intake was nil as thelevel of spineless cactus in sheep diet increased beyond300 g DM/day. According to De Kock (2001), woolsheep survived for 500 days on cactus cladodes alone.Tegegne et al. (2007) observed substantial contribution of cactus supplementation in satisfying the water requirement of sheep. Additionally, theydemonstrated thenutritional potential of cactus pear in mitigating feed andwater shortages prevalent during dry seasons and droughtperiods in dry areas of the tropics and sub-tropics.This is of paramount importance in arid and semiaridareas where availability of potable water is very scarce.

Making up drinking water deficit in summer scarcity

Tropical climates, such as that in India present characteristicarid and semi-arid regions with low precipitationthat reduces forage production and water availability.Therefore, performance is usually limited by forage availabilityand especially by the scarce water resources.Arid and semi-arid ecology is often vulnerable to variable periods of water scarcity and the water bodies are nearly dried up or may have scanty reserve of muddy and polluted water, merely unsuitable for drinking. Prickly-pear cactus (O. ficus-indica L. Miller) constitutes a potentialwater and food source for animals during the dry seasonand may reduce the negative effectsof drought on animal performance.Silanikove, (1989)reported eachpercentage increase in cactus pear reduced 80ml in waterintake, which is consistent with the existence of a linearrelationship between total water intake and dry matterintake in mammals, including goats. Therefore, this type of forage, which is adapted well tosemi-arid climate and is able to yield great amounts of fresh waterper cultivated surface hold promise to cater the need of voluntary water intake during summer. This beneficial role is because of its high moisture retaining properties in its cladodes, survivability in arid and semi-arid climate ably supported by its mucilage-rich composition.

Looking at this scenario an experiment on feeding ofcactusthat supposed to have enough moisture in these geographical regions was conducted in adult sheep to evaluate water and nutrient metabolism during summer/scarcity.

Experiment 4 : Amelioration of water deprivation stress vide feeding of prickly-pear cactus and its nutritional evaluation in the feeding of sheep during summer

Table 2. Chemical composition (% DM basis) of feedstuffs fed to rams

Constituents	Concentrate mixture	Opuntia	Cenchrus hay
Dry matter	95.04	12.23	93.03
Organic matter	94.58	73.70	86.75
Total Ash	5.42	26.3	13.25
Crude protein	12.19	8.29	8.75
Crude fat	2.42	3.61	3.12
Total carbohydrates	79.97	61.8	74.88
Neutral detergent fibre	38.39	57.17	69.86
Acid detergent fibre	6.00	25.92	48.70
Hemicellulose	32.39	31.25	21.16
Cellulose	5.68	17.09	38.35
Acid detergent lignin	0.26	1.58	7.26

Table 3. Nutrient intake in different treatment groups

Parameters	G1	G2	G3	Significance
Body weight (kg)	38.56	38.14	36.86	NS
Metabolic body weight	15.47	15.34	14.95	NS
Feed intake				
Cenchrus DM (g/d)	744b	606a	618a	*
Opuntia DM (g/d)	0b	178a	118a	**
Concentrate DM (g/d)	380	380	380	NS
Total DM (g/d)	1124	1104	1116	NS
DMI (g/ kg body wt)	28.78	28.98	30.30	NS
DMI (g/kgW0.75)	71.95	71.98	74.64	NS
Digestibility (%) of nutrients				
Dry matter	57.12	56.40	52.06	NS
Organic matter	58.98	59.50	54.48	NS
Crude protein	75.84a	81.85b	74.86a	*
Neutral detergent fibre	48.17	48.80	42.07	NS
Acid detergent fibre	36.64	32.79	23.43	NS
Cellulose	47.49	45.35	36.86	NS
Nutrient intake				
Crude protein (g/d)	111	109	110	NS
Crude protein (g/kg body wt)	2.85	2.86	2.99	NS
Crude protein (g/kgW0.75)	7.13	7.11	7.37	NS
DCP (g/d)	84.5	89.3	82.5	NS
DCP (g/kg body wt)	2.16	2.35	2.24	NS
DCP (g/kgW0.75)	5.40	5.82	5.52	NS
DOMI (g/d)	593	577	537	NS
DOMI (g/kg BW)	15.17	15.18	14.57	NS
DOMI (g/kgW0.75)	37.92	37.68	35.91	NS
ME (MJ/d)	8.84	8.91	8.16	NS
ME (MJ/kg body weight)	0.226	0.235	0.222	NS
ME (MJ/kgW0.75)	0.566	0.582	0.546	NS
% DCP of ration	7.52	8.09	7.40	**
% TDN of ration	52.16	54.32	48.60	NS

G1 (Control)- concentrate mixture 300 g + cenchrus hay ad libitum with ad libitum clean drinking water; G2- similar feeding as in G1 plus chopped cactus free choice with water less amount as it was available through cactus; G3- similar feeding as in G2 with 30% less water

Table 4. Water and nitrogen retention in different treatment groups

Parameters	G1	G2	G3	Significance
Water Balance				
Fresh water intake (ml/d)	5056c	4032b	3000a	**
Water intake through concentrate (g/d)	20	20	20	ND
Water intake through cenchrus (g/d)	56	46	46	NS
Water intake through opuntia (g/d)	0b	851a	852a	**
Total Water intake (g/d)	5132b	4948b	3918a	**
Water outgo in faeces (g/d)	988	1435	1247	NS
Water outgo in urine (g/d)	555b	483ab	411a	*
Total water outgo (g/d)	1543	1918	1657	NS
Retention (g/d)	3589c	3031b	2260a	*
Water retention (%)	69.97	61.38	57.72	NS
N balance				
N intake (g/d)	17.83	17.45	17.63	NS
N outgo in faeces (g/d)	4.34	3.17a	4.42b	*
N outgo in urine (g/d)	5.65	5.8b	4.44a	*
N retention(g/d)	7.84	8.48	8.76	NS
NB/NI (%)	43.97	48.38	49.64	NS
NB/NA(%)	58.16a	59.32a	66.28b	*

G1 (Control)- concentrate mixture 300 g + cenchrus hay ad libitum with ad libitum clean drinking water; G2- similar feeding as in G1 plus chopped cactus free choice with water less amount as it was available through cactus; G3- similar feeding as in G2 with 30% less water

There was increase in TDN/ME content of the diet besides providing 15-20% of total DM intake in the feeding of sheep (Table 3). Feeding of cactus at an average of approximately 1.5 kg to each sheep provided 850 ml of potable water (Table 4). The faecal moisture content was higher but no incidence of diarrhea was recorded. Accordingly, although excretion of water through faeces was higher, more significantly, sheep tried to conserve water by reducing excretion through urinary route. Sheep fed on cactus showed higher CP digestibility (Table 3) and over all N utilization was not affected (Table 4) as it was observed in earlier experiments.

It was observed that 1.0 kg of freshly chopped/chaffed cactus provided 0.88 L of water to sheep and thereby, it compensated mild water restriction (by 1 L) without any significant effect on feed intake (Sahoo and Meena, 2014).

Increased water consumption due to cactus supplementation did notresult in proportional effect on water outflow/loss viafaeces and urine. An increased excretion through digestive route coincided with comparatively moist faecal pellets. From our previous experience, it may be concluded that cactus can very well be included in the daily feeding of sheep and other animals, when appropriate N supply is emphasized. This would serve a dual purpose of supporting feed and water scarcity at times of deficit in arid and semi-arid regions of the country.

Animals fed withhigh cactus diets attain most of their water from feed (Gebremariam et al., 2006; Vieira et al., 2008).Costa et al. (2012) observed diminished voluntary water intake by 25.6 g/d for each percent of cactus pear in the diet, viz. a decline from 4.9 to 2.3 kgof water/day when the proportion of cactus pearvaried from 0 to 100%.This behaviour most likely resultedbecause cactus pear contains a considerable amount ofwater in its tissue, which led to a decrease of direct waterintake at the water troughs and it demonstrates the importance ofthe cactus pear as a source of water in water scarce semiarid and arid regions of the country.

On-farm trial on cactus feeding to sheep and goats in the arid and semi-arid regions of India during summer

Prickly pear cactus (Opuntiaspp) has been observed to be adapted well to hot and arid/semi-arid environment and is thus considered as a fast growing xerophytes drought resistant plant. It has been used as a famine feed and as emergency feed during scarcity. Based on observations of on-farm trial and its acceptability by sheep, a demonstration experiment was conducted to evaluate cactus feeding as a strategic supplementation to conventional feeding practice in the sheep flock belongs to a local farmer of the region (Chanda kiDhani, Avikanagar, Malpura, Rajasthan) to cater the need of feed and water. The nutrient composition of cactus promised 847 ml of water and 153 g of DM from 1.0 kg fresh opuntia feeding. The acceptability and intake of cactus was observed daily from the residue after offer of 10-12 kg of freshly collected and chopped (4-8 cm) cactus to 10 sheep. All the animals got adopted to cactus feeding in 2 to 3 days and the consumption varied from 7 to 10 kg fresh cactus with an average intake of 8.8±0.7 kg. Accordingly, the DM intake was calculated at 135 g that provided 14.5 g CP and shared 19% of total DMI (712 g/animal/d). Through cactus feeding, there was indirect water intake of 7.5 L for a flock of 10 animals with the provision of only 0.88 kg cactus per animal and this would

account to 75 L of water for a flock of 100 sheep and may thus be considered a significant contribution to the farmers of the region exposed to longer period of summer water scarcity. Above all, successful adaptation of sheep and goats to cactus feeding could serve to meet both feed and nutrient requirement as well as water scarcity in the arid and semi-arid regions.

Using succulent feeds like cactuspear may reduce wastage of energy animals spend toreach watering points and allow animals to graze andbrowse away from the watering points thereby reducing over-grazing, land degradation and utilization of foragesin areas further from waters.

Feeding of native thorny cactus

Thorny cactus is usually used as fence material by the farmers to prevent entry of wild as well as domestic animals to their cultivated field/crop area. The thorny variety of cactus (Oputiapolyacantha), native to semi-arid Rajasthan can also be fed to sheep during scarcity period. It has 76.6% moisture and could be fed to sheep after burning the thorns followed by chaffing. An amount of 1.4 litre water and 424 g of DM was made available to sheep through feeding of native thorny cactus.The thorn can be burnt out by fire and then chopped for feeding to sheep. It contains little less moisture (75-82%) and higher DM, thus providing more gut fill. The composition of other nutrients are similar to less thorny type and it also recorded similar consumptionpattern in sheep fed during summer.

Since dry matter intake andwater intake are inter-dependent, the low performancesof small ruminants under dry conditions could be partlydue to water availability and quality. Collection of thorny cladodes from farm boundary and feeding after mechanical removal or burning of thorns followed by chaffing/chopping provides an opportunity to the farmers to supply water as well as feed negating decline in feed intake and production performance.

Processing of thorny cactus prior to feeding

Cactus silage

The cactus can be harvested during monsoon when grazing resources are available in plenty and also during other resource-rich season(s) and preserved as silage for feeding during scarcity. The high moisture content of cactus needs prolonged wilting, which often leads to spoilage and hence farmers can opt for making mixed silage by incorporating dry forages. Looking at the need of supplementary protein feeding, it is recommended to incorporate leguminous or protein-rich dry forages, e.g. Ardu leaves, Kutti from Chana/Cowpea/Guar etc. so as to balance the minimum moisture content in making of good quality silage (i.e. 35-40%).An intake of 3.0-4.0 kg cactus silage was recorded in adult sheep that provided 900-1200 g DM and may thus be considered as above maintenance ration that can support minimum production (e.g. 40-50 g/d growth).

Development of mixed silage with cactus offers a lot many possibilities to design variety of mixed crop silages for a range of production and provides wide opportunity to ensure round the year feed supply. This will also help immune production decline in the event of climatic irregularities and adverse environmental conditions and natural calamities thereby sustaining whole-farm productivity. Some of the cactus mixed silages with their chemical characteristics are depicted in table 5.

Table 5. Physio-chemical characteristics and nutrient composition of different cactus silages

Parameters	**Cactus silage**	
	Type 1	Type 2
	(Cactus 80: Ardu 20)	(Cactus 80: gram straw 20)
Nutrient composition (% of DM)		
DM	25.84	28.61
OM	85.12	82.92
CP	8.70	8.36
EE	5.90	3.56
NDF	51.68	54.53
ADF	35.04	38.60
DM Digestibility (%)	56.41	54.32
Physio-chemical charasteristics		
pH	4.10	4.27

Parameters	Cactus silage	
	Type 1	Type 2
	(Cactus 80: Ardu 20)	(Cactus 80: gram straw 20)
Lactic acid (g/100 g)	0.28	0.32
Acetic acid (mM/L)	28.32	26.55
Propionic acid (mM/L)	0.56	0.81
Butyric acid (mM/L)	1.75	2.08
Isobutyric acid (mM/L)	2.56	2.19
Valeric acid (mM/L)	0.40	0.32
Isovaleric acid (mM/L)	0.11	0.16
Total VFA (mM/L)	33.70	32.11

Experiment 5.Feeding of cactus (opuntiaficusindica) silage in sheep to combat nutritional scarcity under climate change scenario in semi-arid tropics

cactus silage (Cactus 80% + dry Ardu (Allanthusexecelsa) leaves 20% fresh matter basis) was prepared in 120 -150 kg double layer polythene bag. Six adult male Malpura sheep were fed andthe feeding trial continued for four weeks. Animals were fed individually with adlibitum weighed quantity of silage and the left over was recorded daily to calculate their feed intake. Feed samples were periodically collected and DM was recorded as per standard procedure. Fresh ad libitum water was provided all the time. The silage was having a good acidic aroma with pH 4.38. The silages found acceptable by sheep after initial adaptation that took 2-3 days. During the first week average feed DM consumption (g/day) was 571 ±16. Subsequently, DM intake from silages increased and averaged at 702 ±4.0 g/d. The effect on total antioxidant capacity in plasma significantly

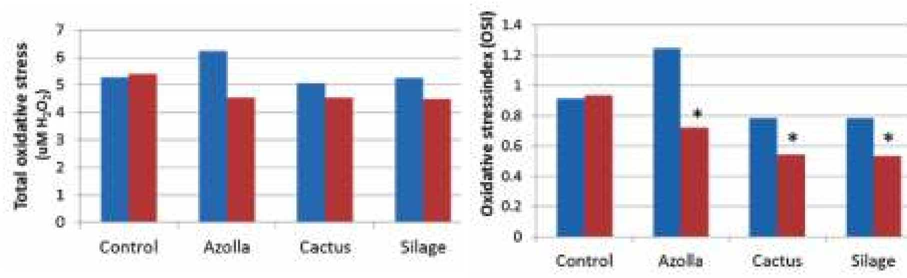


Figure: Total oxidative stress and oxidative stress indes in sheep fed with cactus and silage

increased in cactus and silage supplemented groups while Figure: Total oxidative stress and oxidative stress indes in sheep fed with cactus and silage oxidative stress Index decreased.

The Cactus silage showed good palatability and DM intake and is definitely a new concept that can address feed biomass availability during scarcity. Use of Cactus that is not generally fed other than the summer season and abundant availability during monsoon provides ample opportunity to store in the form of silage to feed during unavailability/scarcity of other feed resources. The experiment showed good acceptability of the silage by the sheep and therefore, production decline during scarcity can be checked to augment future animal productivity.

Advantages of cactus silage

It was observed that mixing cactus and browse in silage making improved both dry matter content and N content in the product. Cactus can serve as a link between legume forage and hays by supplying a degradable source of organic matter. Also, cactus-browse silages improve microbial protein flow to the lower gut for digestion thus increasing amino acid supply for maintenance, growth and production. Poor quality roughage utilization is improved with the addition of cactus browse silages as supplements. These silages could be used in livestock feeding to improve livelihoods in drier and resource constrained farming communities. These findings offer farmers in marginal areas opportunities for conservation of forage and maintaining their animals in periods of feed scarcity.

Cactus ensiling has been evaluated at the laboratory level and to our knowledge this technique is still not adopted at the farm level. ÇürekandÖzen (2004) evaluated the nutritive value of cactus cladodes which were chopped (1-2 cm), wilted (DM content 35%) and then ensiled. Based on pH and organic acids contents, the quality of this silage was found acceptable. However, its nutritive value was low. It might be advantageous to ensile cactus mixed with other ingredients. Abidiand coworkers (2009) ensiled fresh cactus cladodes with olive cake and wheat bran. Replacing oaten hay with this silage had no effect on digestible nutrient intakes but decreased the average daily gain of concentrate supplemented lambs from 50 to 37 g. Cactus ensiling seems a simple technique, but its adoption would depend largely on the benefit to cost ratio, amongst others including the technology transfer efforts. In addition to feed shortage, water scarcity compromises livestock performances in dry areas. Because of its succulence, cactus could overcome this constraint. Indeed, ruminants do not need to drink water when receiving cactus cladodes (ca. 35 g dry matter/kg metabolic weight) (Ben Salem and Abidi, 2009).

Other possible usage of cactus


Cactus with maize


Cactus with tree legumes

Alley cropping: Properly managed, alley cropping involving cereals/legumes and cactus as shrubs allows diversification and promotes sustainabilityin both crop and livestock production.Thebenefits from cactus–barley cropping system have beenevaluated in Tunisia and the positive results are due tothe change of the micro-environment created by alleycropping with cactus, which creates a beneficial "windbreak" role, both reducing water loss and increasing soil moisture (Ben Salem and Smith, 2008). The barley crop stimulated an increase in thenumber of cactus cladodes and fruits, while the cactusincreased the amount of root material contributing to thesoil organic matter.

Farm boundary: native thorny cactus can be planted on farm bonds or bonds in agricultural fields, which protects stray animal stresspass and at the same time provides feed and water to his livestock.

Human food: Young cladodes derived from several Opuntia species are used in some Latin American countries as vegetables.

Rich source of phytochemicals and anti-oxidants: Cactus as a succulent fodder provides -carotene and other phytochemicals that can act as antioxidants for protection against stress.

Medicinal and therapeutic value: Cladodes have numerous medicinal applications (e.g. regulation of weight and blood sugar, or to maintain fibre intake).

Controlling GI parasitism: Preliminary study by the authors showed promising inhibitory effect on growth of Haemonchuscontortus infective larvae. Feeding of cactus exhibited a suppressing effect on faecal egg count (FEC) and may thus be considered a useful strategy of biological and non-invasive tool for the control of gastrointestinal parasitism.

Enhancing meat quality: Inclusion of cactus in the diet reported to have desirable effect on enhancing linoleic acid content thereby improving meat quality Ben Salem and Abidi, 2009)

Industrial and other uses: Cactus is also used industrially, for fuel production, as a protecting agent against corrosion, as a building material to improve stability and compressibility and clarification of waste water (cactus hydrocolloids) (Stintzing and Carle, 2005).

Possible undesired effects of cactus in livestock feeding

We have observed increase in faecal moisture content, but no cases of loose faeces or diarrhea during our series of studies at CSWRI, Avikanagar. Sole feeding of cactus may sometimes lead to digestivedisturbances such as diarrhea and distended tympanicabdomen (Tegegne et al., 2005). Cactus pear associatedwith other fiber sources increases DM levels in diet andkeeps normal conditions in the rumen, thus preventingsuch undesired effects (Sahoo et al., 2014). Supplementationwith cactus pear did not reduce rumen pH, since thehigh mucilage and mineral levels stimulated saliva productionand pH buffering (Ben Salem et al., 1996).However, because of its high ruminaldegradability and laxative effect, feeding high levels ofcactus may result in digestive problems and eventuallyreduce animal performance. Inclusion of non-bloatforages can be an effective strategy to reduce the incidenceof digestive disturbances associated with feeding largeamounts of cactus. The concept of mixed silage involving cactus may be another option, which facilitates harvesting and use of cactus during rainy or green pasture available season in silage making for future feed banking.

A high sugar content of cladodes had no detrimentaleffect on rumen fermentation(Ben Salem and Smith, 2008).Rather, this chemical properties has added advantages as an additive to initiate early fermentation process while making a silage. Cactus has high level of oxalates (7–15%), which may interfere Ca metabolism making it unavailable for the rumen microfloraand host animal but ruminantsconsume large amounts of cactus cladodes without any serious effect on ruminalfermentation or intoxication being observed.The association of a fibrous feedstuff (e.g. straw orhay) with cactus is recommended to promote normalrumination and to avoid digestive disturbances and may thus be considereda cost-effective supplement for sheepfed on low quality diets (Sahoo et al., 2016).

Another important consideration could be identification and selection of cactus that are more palatable and more productive. Often, undesirable species of cacti and undefined cactus in the feeding of livestock may lead to toxicity due to intrinsic harmful phytochemicals.

Use of dry forage mixture while feeding high moisture cactus is considered a useful management strategy. It overcomes possible N deficit, Ca: P imbalance, low feed intake due to rumen fill effect arisen from voluminous cactus cladodes and other nutrient imbalances. Additionally, its succulent nature corrects voluntary feed intake depression arisen from the feeding of low quality crop residues and due tohyperthermia state during summer.

Conclusion

Some of the potential application of cactus in agro-livestock production are summarized below:

- **Feed and nutrient supply:** Cactus cladodes can be fed after chaffing/chopping as succulent forage resource during summer feed scarcity thereby meeting feed and nutrient supply
- **Source of potable water:** Cactus can meet partial/complete water requirement of animals during adversity/unavailability of potable water
- **Associative effect:** Cactus can be fed in adjunct to low quality crop residues to enhance feed intake and harnessing associative effect on nutrient digestibility and utilization
- **Feed banking:** Cactus can be stored as good quality palatable silage to cater the need during scarcity
- **Source of phytochemicals:** Cactus is a rich source of carotenoids and other phytochemicals that can be explored as nutraceuticals (e.g. natural dewormer) and in other industrial uses
- **Human food:** The cladodes and more specifically its flowers are being used as human food (e.g. laxative drink, juice,etc.)

A potential solution to forage production from aridand semi-arid rangelands is the development of productionsystems based on indigenous species withrelatively low water requirements.Cactus is a tremendous resource for semiarid regions, providing multiple benefits for the society; however, it is still underexploited. Pressure on natural resources in semiarid regions, because of human overpopulation, leads to degradation of rangelands. Establishing cactus might alleviate the pressure on rangelands, providing feed for livestock in these regions. Cactus is also an excellent plant for reclamation of degraded lands. It has high potential for capturing carbon, both above and below the soil. Policy makers must be made aware of this potential, and development of cactus in semiarid regions must be promoted. Success stories on cactus utilization can be easily found in different parts of the world, and they may serve as a lesson for semiarid areas where cactus is still underutilized.

Peculiarity of this plant that exhibits crassulaceanacid metabolism (CAM) and uses water very efficiently enabling it to withstand drought and extremeheat may too have futuristic application in the event of climate change and global warming.In the absence of legume shrubs, the provisionof protein feedstuffs (e.g. oil cakes, meals, seeds) by smallholders is not easy due to their high cost and availability. Increasing the proteincontent of cactus cladodes should thus be investigated.

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Cactus

Dromedary of the vegetation world

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