IN VITRO EVALUATION, INTAKE AND *IN VIVO* DIGESTIBILITY OF COMPLETE DIET BASED ON SPINELESS CACTUS (*Opuntia ficus indica*) IN SHEEP

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CERTIFICATE

This is to certify that the thesis entitled "***IN VITRO EVALUATION, INTAKE AND IN VIVO DIGESTIBILITY OF COMPLETE DIET BASED ON SPINELESS CACTUS (Opuntia ficus indica) IN SHEEP"*** submitted by **Ms. ARPITHA, R., I.D. No. MVHK 1504** in partial fulfillment of the requirement for the award of the degree of **MASTER OF VETERINARY SCIENCE** in **ANIMAL NUTRITION** of the KARNATAKA VETERINARY, ANIMAL AND FISHERIES SCIENCES UNIVERSITY, BIDAR, is a record of bonafide research work carried out by her during the period of her study in this University under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar titles.

Place: Bengaluru,

Date : August, 2017

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Affectionately Dedicated to

My Beloved Parents

and

Prof. K. Chandrapal Singh

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LIST OF ABBREVIATIONS

ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
AOAC	Association of Official Analytical Chemists
ARC	Agricultural Research Council
BW	Body Weight
CFM	Compounded Feed Mixture
CP	Crude Protein
DMI	Dry Matter Intake
DM	Dry Matter
EE	Ether Extract
FMS	Finger Millet Straw
ME	Metabolisable Energy
MJ	Mega Joule
NDF	Neutral Detergent Fiber
NRC	National Research Council
OMI	Organic Matter Intake
OM	Organic Matter
RDP	Rumen Degradable Protein
RIVIGP	Rumen *In Vitro* Incubation by Gas Production
SC	Spineless Cactus
SOD	Switch Over Design
TA	Total Ash
TDN	Total Digestible Nutrients
RUP	Rumen Undegraded Protein

INTRODUCTION

I. INTRODUCTION

Among different livestock production systems, small ruminant rearing could be considered as the most sustainable enterprise to provide supplementary income and livelihood to small land holders and landless rural holds. The population of sheep is 78.16 and 16.87 million in India and Karnataka, respectively (GOI., 2012). Generally, production efficiency of small ruminants in tropics has been low due to low feed resource availability and plane of nutrition. India has been facing a deficiency of 35.6 per cent of green fodder, 10.9 per cent of dry crop residues and 44.0 per cent of concentrate feed ingredients (ICAR, 2013). The deficiency is aggravated due to the ever increasing demand of the arable land used for cultivation of food crops, which further shrink the available land for fodder production. The Indian arid and semi-arid regions are characterized by the persistent low availability of forage during most parts of the year.

Among all weather related crisis, drought is considered one of the major threat for livestock sustainability. Drought situation due to decreasing rain fall and increasing temperatures are regular feature in semi-arid and arid regions of Southern India, especially northern districts of the state of Karnataka. Sustaining and augmenting the productivity of ruminants in these regions therefore necessitate research on exploring alternative options of forages.

Animal nutritionists have been facing the challenges of identifying alternate forages which are drought-resistant and of high nutritional value. Spineless cactus or Opuntia (*Opuntia ficus indica*), is a drought resistant xerophytic plant, used as a conventional fodder for feeding livestock in the South American and African countries

(Shoop *et al*., 1977). Cactus belongs to the family *Opuntidae*, with nine major species identified, out of which four varieties have been propagated as forage type and *Opuntia ficus indica* has been a predominant variety of spineless cactus, recognised as a fodder for livestock feeding (FAO, 2001).

A remarkable feature of spineless cactus is its potential for producing large quantities of green, succulent fodder under relatively unfavorable climatic conditions (De Kock, 1980). With an advantage of minimum agronomical input for its propagation, the productivity of spineless cactus has been comparable to most conventional crops and forages. The annual yield of spineless cactus (dry matter) per hectare has been reported to be 10 tonnes in arid zones, 10 to 20 tonnes in semi-arid zones and 20 to 30 tonnes in sub-humid areas under optimum management (Le Houerou, 1992).

The succulent pads or cladodes of spineless cactus are palatable to livestock with the reported daily intake of chopped cactus, ranging from 2.5 to 11.0 kg in sheep (Valdes and Flores, 1967; Ben Salem *et al*., 1996; Sirohi *et al*., 1997; Costa *et al*., 2012). The chemical composition of spineless cactus revealed that it contained 10 per cent dry matter (DM), 4 to 10 per cent crude protein (CP), and 30 to 40 per cent neutral detergent fibre (NDF) (FAO, 2001). Previous studies have reported that spineless cactus could be a valuable forage for livestock, providing a major source of water (89.9 per cent) and energy (8.4 MJ ME per kg DM) in the diet of ruminants (Ben Salem *et al*., 2002; Abidi *et al*., 2009). Voluntary intake of water by lambs significantly decreased from 1226 ml to 6 ml per day when spineless cactus replaced 80 per cent of the hay in the diet (Tegegne *et al*., 2007).

The energy content of spineless cactus is about 75 per cent of grains like maize or barley. The high energy and low NDF content makes it a suitable replacement for compounded feed mixture. Compared to most crop residues and nonlegume forages, the protein content of spineless cactus has been very low (Abidi *et al*., 2009; Batisa *et al*., 2003). Nevertheless, the crude protein content of spineless cactus could be raised from 4.50 per cent to 10.0 per cent through application of nitrogen (N) fertilizer. An increase in the yield of 200 to 300 per cent N has also been reported following moderate nitrogen and phosphorous application (De Kock, 1980). Misra *et al*. (2006) and Degu *et al*. (2009) observed that supplementation of organic source of nitrogen (N) such as groundnut cake based diets improved the performance of growing lambs.

Earlier experiments have conducted studies incorporating spineless cactus as a source of roughage or concentrate ingredient in the diet of sheep. While, Gabremariam *et al.* (2006) substituted spineless cactus replacing tef straw in the diet of sheep whereas Abidi *et al.* (2009) and Costa *et al.* (2012) replaced cereals such as corn or barley in the diet with spineless cactus. The production responses of sheep in previous studies have been equivocal due to different feeding regimen and plane of nutrition, and hence the optimum levels of inclusion of cactus in the diet have not been clearly defined. Furthermore, there is paucity of literature in India on the nutritional evaluation and utilization of spineless cactus in feeding small ruminants. Therefore, this experiment has been taken up to evaluate the optimum level of inclusion of spineless cactus in the diet of adult sheep.

The objectives of the present study are:

1. To evaluate diets based on spineless cactus (*Opuntia ficus indica*) by chemical and *in vitro* methods.
2. To study the intake of spineless cactus and diet based on cactus in sheep.
3. To assess the *in vivo* digestibility of nutrients in diet based on spineless cactus in adult sheep.

REVIEW OF LITERATURE

II. REVIEW OF LITERATURE

Spineless cactus is one of the under-utilized and lesser known fodder plants in India, though widely recognized for its propagation in harsh environment with a huge biomass production potential. In situations of feed and fodder scarcity, in semi-arid and arid zones, especially during dry season, feeding management strategies involving cactus cultivation and its utilization perhaps sustain the livestock productivity to a great extent. In this chapter, literature on the previous studies carried out on spineless cactus involving agronomical, productivity, nutritional evaluation and performance in small ruminant production has been reviewed.

2.1. Feed and fodder status

2.1.1. Feed and fodder status in India

India accounts for 2.29 per cent of the total land area of the world, but it is harboring about 10.71 per cent of the livestock population of the world (GOI, 2016). It has been estimated that there is a shortage of 35.6 per cent green fodder, 11.0 per cent dry crop residues and 43.8 per cent of concentrate feed ingredients in the country (ICAR, 2013). Projected livestock feed demand in 2020 is in the order of 526 million tonnes of DM, 56 million tonnes of concentrate feed and 855 million tonnes of green fodder (Dikshit and Birthal., 2010).

The major reasons for shortage of feed and fodder has been the increasing pressure on land for growing food grains, oil seeds and pulses and that adequate attention was not given for production of fodder crops. The area of permanent pasture and grazing lands is about 10.27 million hectares and this is gradually diminishing whereas, the area under fodder cultivation is only about 4 per cent of the cropping area (GOI, 2008).

India comprises an arid zone which covers about 31.7 m hectare which spreads over seven states and constitutes 11.8 per cent of its geographical area. The climatic condition of arid zone is characterized by extremes of temperature, high wind velocity, sandy soil, low and erratic annual rainfall (100-400mm), with very high frequency of drought (GOI, 2008). Drought is considered as one of the biggest threat to livestock sustainability among all weather related crisis. So failure of crops due to insufficient rainfall and non-availability of fodder in drought like situation force many farmers in to economic crisis.

2.1.2. Feeds and fodder status in Karnataka state

The livestock feed and fodder availability in Karnataka is low as well. Out of 29 districts, six districts belonged to the category of adequate feed DM availability. Five districts belonged to moderately adequate and 10 districts belonged to deficient DM available categories. Crop residues contributed to 72.6 per cent of total DM availability in the state, while green grass and concentrate contributed 23.6 and 3.81 per cent, respectively. The mean DM availability for the state was 56.5 per cent indicating the deficiency to the extent of 43.5 per cent (Biradar and kumar, 2013). Therefore, in order to bridge the gap between the availability and demand of livestock feed, there is a need for an increased use of non-conventional feed resources including alternate green fodder sources for sustainable livestock production. *Opuntia* or Spineless cactus plant offers one such promising feed, as potential forage for feeding ruminant livestock.

2.2 Spineless cactus

2.2.1 History of cactus

Spineless cactus (*Opuntia ficus indica)* was originated from Central and Southern Mexico between 1848 and 1870 (Griffith., 2004). De Kock (1980) and, Carle and strintzing (2005) described *Opuntia* as “Miracle plant”, “Dromedary of the vegetation world”, “The bank of life”, "Camel of the plant world", "Living fodder bank" and "Nature’s fodder bank" as it contributed to livelihood of rural population. In the nineteenth century, the cultivation of the cactus in dry areas assumed greater importance in agriculture, since a larger part of the land is destined to become arid or semi-arid due to climate change (Snyman., 2006).

2.2.2 Taxonomy

The genus *Opuntia* belongs to the family *Cactaceae*, order *Centrospermae* and subfamily *Opuntiodeae*. It grows wild, essentially in tropical and subtropical regions. In the order of domestication, *Opuntia streptacantha* is the wildest, followed by *Opuntia hyptiacantha*, *Opuntia Megacantha* and *puntia albicarpa.* (Anderson *et al.,* 2001). Griffith (2004) observed that *Opuntia ficus indica* (Spineless cactus) was the most domesticated and cultivated species, propagated commercially and distributed worldwide.

2.2.3 Morphology

Cacti are characterised by oval or rhombic cladodes (pads), bearing fewer and smaller spines and red coloured fruit. Cactus plant tissue comprise a large and complex polysaccharides, composed of D 1-4 galacturonic acid units (homogalacturonans) interrupted by L-rhamnose residues with side-chains of neutral sugars, especially D-galactose and L-arabinose (Mohnen.,2007). The mucilage is the result of the polymerization of monosaccharides associated with uronic acids. This complex hydrocolloid forms a viscous substance responsible for retaining water in cactus (Gonzalez., 1989).

2.2.4. Spineless cactus as an alternative fodder resource

Opuntia or spineless cactus (*Opuntia ficus indica*) is a drought resistant plant convenient to cultivate and considered a potentially important feed for livestock particularly during low feed availability (Shoop *et al.*, 1977). A succulent cactus pad consists of approximately 900 g water/kg which enables the plant to survive for long periods with little or no rain. The most remarkable characteristic of spineless cactus is its tremendous potential for producing large quantities of green, succulent fodder, under relatively unfavorable conditions. The succulent pads can then serve as a source of drinking water for livestock. Additionally, spineless cactus is high in energy, soluble carbohydrates, calcium and vitamin A, but low in crude protein, fibre, phosphorus and sodium (Le Houerou, 1992).

2.2.5 Spineless cactus cultivation

Spineless cactus grows well on deep, light textured soils, including coarse sands except clay and is tolerant to pH up to 8.5 (Le Houerou, 1992). They are drought tolerant and thrive in areas of 200 mm rainfall. It can also be grown in arid lands receiving 120 to 150 mm rainfall with supplemental irrigation facility.

Spineless cactus responds to application of N and phosphorus fertilizer. The CP content of fodder in spineless cactus can be raised from 4.5 per cent to 10 per cent through application of nitrogenous fertilizer. A production increase of 200 to 300 per cent has also been observed following moderate N and phosphorus application (De Kock, 1980). Field trials conducted in Mexico and other countries showed that fertilizers induce higher yields of cladodes and fruits. Higher N application from 0 to 160 kg/ha increased the number of new cladodes of *Opuntia engelmannii* in Texas. The individual cladodes were also thicker, leading to 12 per cent weight enhancement per cladode at the higher N level (Karim *et al*., 1996).

According to Gonzalez (1989), *Opuntia indheimeri* showed increased protein levels of 3.1, 4.2 and 4.4 per cent units in response to applications of 67, 135 and 224 Kg N per hectare, respectively. The efficiency of fertilizers and manures in semi-arid environments is strongly influenced by soil moisture also. Therefore, fertilization should be done in those years and seasons in which there is more rainfall or when there is facility for irrigation. Dubeux Jr. *et al.* (2006) also reported a positive linear effect of N fertilization on plant N concentration. The N concentration in cladode was 6.7 g per kg at 0 kg N per hectare per year, while it was 13.9 g per kg at 300 kg N per hectare per year. The high productivity of cactus under harsh conditions is mainly due to its carbon dioxide fixation, which enables it to convert water to dry matter more efficiently than most forages (Nobel, 1995).

2.2.6. Water requirement

Spineless cactus use water more efficiently than conventional fodder crops. According to De Kock (1980), cactus uses 267 kg water/kg DM, while pearl millet, barley, sorghum, wheat uses 400, 500, 666 and 750 kg of water respectively, for producing one kg of DM. The waxy cuticle on its stem which is relatively thick, generally 5 to 30 µm helps to prevent water loss from the plant (North *et al*., 1995). In addition, the stomatal frequency is low for spineless cactus generally 20 to 30 stomata per square millimeter (Conde., 1975). The cladodes contain a large volume of whitish water-storage parenchyma, which acts as a water reservoir. De Kock (1980) noted that the root of spineless cactus can lose as much as 60 per cent of its water content before the cells collapse. The roots of *Opuntia ficus indica* spreads in a shallow region with mean depth of 15 cm, facilitating a quick response to light rainfall. New roots will be formed within 24 hours of wetting of a dry soil (Nobel, 1996). These features improve the efficiency of opuntia in conserving water.

2.2.7. Productivity

Nobel (1991) compared the productivity of *Opuntia ficus indica* with four highest yielding crops which had an average productivity of 38 t/ha/year, four fastest-growing trees having 41 t/ha/year, and opined that in arid and semi-arid regions the biomass productivity during less rainfall is important. Under such circumstances those plants having crassulacean acid metabolism (cactus) has advantage, with opuntia producing up to 10 t of DM/ha/year in arid zones, 10-20 t in semi-arid zones and 20-30 t in sub-humid areas under optimum management conditions (Le Heourou, 1992)

The productivity of *opuntia* depends on the location, climatic conditions, soil type, planting density and degree of fertilization. Nobel (1991) reported that the DM productivity of *opuntia ficus indica* could reach 50 t/ha/year. Mizrahi *et al*. (1997) reported productivity of 40 to 50 t/ha/year of DM for spineless cactus with 240000 plants/ha without water or soil fertilization. This level of productivity was also confirmed by Dubeux Jr. *et al*. (2006) who reported DM yield from 6 to 17 tons per hectare with density of 5000 plants per hectare and 19.4 to 33.7 tons DM yield per hectare with the density of 40,000 plants per hectare.

Singh (2003) reported that the average duration for initiation of growth in most species of opuntia plantation was 82 days. The same author reported that after two years of growth, the average number of cladodes per plant was 13.87 and the weight of cladodes was 362 g. Total biomass yield per plant was 16.2 kg. The productivity of cactus was 30 t/ha at Jodhpur, India, which had the potential to maintain 8 to 24 sheep in drier (150 to 350 mm of rainfall) areas and 64 to 80 sheep in relatively wetter (350 to 450 mm) areas.

Classens and wessels (1997) recommended a fertilizer application of 50 kg N/ ha, 16 kg P/ha and 40 kg K/ha for optimum production. Under rain-fed conditions, average annual productivity for Opuntia species was about 15 t/ha/year or more (Noble, 1991). However, under well irrigated conditions, average annual dry matter productivity was in the range of 40-50 t/ha/year have been reported (Noble, 1991).

2.3. Chemical composition

The chemical composition of spineless cactus depends on the cladode age. Young cladodes of *Opuntia ficus indica* grown for commercial fruit production in Spain had 10.6 to 15.0 per cent protein, while in mature cladodes it varied from 4.4 to 11.3 per cent (Retamal *et al*., 1987). Similarly, Gregory and Felker (1992) reported that the CP content decreased as the age of *Opuntia ficus indica* increased. The CP content at 1st, 2nd, 3rd and 4th year was 11.5, 5.74, 5.50 and 5.65 per cent, respectively. Compared to mature 12 year old cladodes, 2 year old cladodes had substantially higher nitrogen, potassium and manganese, but lower sodium, calcium and iron. This was attributed to age and higher metabolic activity of young cladodes (Nobel, 1983). In contrast, Gregory and Felker (1992) reported that *Opuntia ficus indica* had similar protein contents in all age classes. It was also observed that total carbohydrate content increased considerably during cladode growth.

Season has a profound impact on the chemical composition of *Opuntia ficus indica*. According to Retamal *et al.* (1987), the highest values of moisture content, free reducing sugars, starch and protein were detected in spring (92.5 per cent; 103 mg per g; 226 mg per g and 14.8 per cent, respectively) in young cladodes, while ash content, ether extractive and calorific content presented the highest values at the end of the season (29.8 per cent; 36 mg per g and 14.5 MJ per kg, respectively). Highest concentrations of nitrogen, phosphorus and potassium and lowest calcium content was recorded during winter (Esteban-Velasco and Gallard, 1994)

Ben Salem *et al*. (2002) reported chemical composition of opuntia grown in Tunicia as 101 g/kg DM, 698 g OM /kg DM, 77 g CP /kg DM, 278 g NDF /kg DM, 72 g calcium /kg DM, 0.8 g sodium/kg DM, 1 g phosphorous /kg DM and 8 g magnesium /kg DM. Tien and Beynen (2005) reported that the spineless cactus contained (g/kg) DM, 177; CP, 12; crude fat, 33; ADF, 28; Ash, 40 and NFE, 64 for those grown at Vietnam. While opuntia grown in Ethiopia as reported by Tegegne *et al.* (2005) had (g/kg) 122, DM; 50.6, CP; 11.9, EE; 239, NDF; 162, ADF; 30.6, ADL; 109, CF and 199, Ash. In another work conducted at Ethiopia, Gebremariam *et al.* (2006) reported water content of 880 g/kg fresh weight. The cactus pads had high ash (mineral content), especially calcium (45 g/kg DM), but the phosphorus concentration was 2.6 g/kg DM, making the ratio of calcium to phosphorus 17:1. The soluble carbohydrate of cactus was over 251 g/kg DM and the CP content was 83 g/kg DM. In India, the chemical composition of spineless cactus as reported by Sirohi *et al*. (1997) for DM, CP, Ash, NDF, ADF were 12.5, 9.20, 20.2, 38.5 and 18.9 per cent, respectively and gross energy of 4.2 MCal / kg DM, while Misra *et al*. (2006) reported DM, CP, Ash, NDF and ADF values to be 21.8, 12.6, 17.2, 46.6 and 39.3, and gross energy of 3.9 MCal/kg DM.

Batisa *et al.* (2009) analyzed eight cultivars of opuntia for their chemical composition. They reported that NDF and starch concentrations were not influenced by cultivar and averaged 249 g/kg and 198 g/kg, respectively. Neutral and acid detergent insoluble protein concentrations were similar for all cultivars and averaged 223 g/kg and 87 g/kg of CP, respectively.

Ben Salem *et al*. (1996) have reported that cactus to be rich in readily available carbohydrates, which could serve as a source of energy for animals. Due to this, cactus could be used as a supplement for animals on poor quality roughage such as straw and the combination of cactus with cereal straw could be a nutritionally satisfactory solution for maintaining small ruminants in arid zones.

2.3.1. Mineral composition

Opuntia ficus indica has been generally reported to be high in calcium content (Nobel, 1977; De Kock, 1980; Retamal *et al*., 1987). The calcium content of young cladodes was higher than either middle-aged or old cladodes. The young cladodes also contained high magnesium content (Retamal *et al*., 1987).

Mineral content (mg/g) of opuntia as reported by Retamal *et al*. (1987) was calcium, 182; sodium, 3.66; magnesium, 91 and potassium, 185.7, while Ben Salem *et al*. (2002) reported mineral content (g/kg) as calcium, 72; sodium, 0.8; phosphorus, 1.0 and magnesium 8.3. Tegegne *et al*. (2007) reported calcium and phosphorus levels as 47.6 and 3.0 mg/g DM respectively while those reported by Abidi *et al*. (2009) was calcium, 70.2; phosphorus, 1.8; potassium, 4.4; sodium, 6.7 and magnesium, 0.43 mg/g DM. Batisa *et al.* (2009) reported mineral composition of opuntia for calcium, phosphorus, magnesium, potassium and zinc as 19.60, 1.17, 9.39, 0.03 and 0.046 mg/g of dry matter, respectively.

Batisa *et al*. (2003) analyzed ten varieties of spineless cactus for chemical composition and reported that the ash content of cactus ranged from 10.4 to 13.3 per cent and calcium content ranged from 2.8 to 4.2 per cent. The average mineral composition of spineless cactus in Brazil was reported as 10.7 per cent. Water deficiency and high levels of calcium compounds in arid and semi-arid soils lead to the accumulation of high quantities of calcium solutes in its pads. This process allowed the plant to extract, through osmosis, as much water as possible from the soil. Excess calcium was not a problem, but an unbalanced calcium: phosphorus ratio required correction. Most authors report a calcium: phosphorus ratio of about 35 (FAO, 2001).

2.4. *In vitro* evaluation

2.4.1. Energy value

De Kock (1980) reported that the total digestible nutrient (TDN) content of spineless cactus was 65 per cent. Gross energy content of most cacti species ranged from 3500 to 4000 kcal/kg DM. Digestible energy is about 2000 kcal, which was comparable to a medium quality grass. Taasoli *et al.* (2011) reported ME content of cactus as 8 MJ/kg DM which was about 80 per cent of ME content of barley (10-11 MJ/kg DM). The estimated ME content of cactus pear by Tegegne *et al.* (2007) showed that it was moderate in ME content (8.6 MJ/kg DM), while Costa *et al.* (2012) reported slightly higher value (9.2 MJ ME/kg DM). High energy content was attributed to the soluble sugar content of the cladodes.

2.4.2. *In vitro* digestibility

Minson (1988) and Minson (1990) observed that the *in vitro* DM digestibility (IVDMD) of the cladodes of opuntia were above the mean values reported for tropical grasses (30 to 75 per cent), temperate grasses (45 to 85 per cent), tropical legumes (36.0 to 69.3 per cent) and temperate legumes (60.7 per cent). None of the IVDMD values was below the digestibility level recommended for different ruminants kept for different production purposes. The *in vitro* organic matter digestibility (OMD) as reported by Firew *et al*. (2006) were in the range of 600–700 g/kg DM for cactus. These values are similar to those observed with common forage crops. Spineless cactus and alfalfa hay did not differ significantly in DM digestibility in 96-hour *in vitro* trial. The *in vitro* DM digestibility values were 63.8 per cent and 63.7 per cent for prickly pear and alfalfa, respectively while it was 53.0 per cent for hay pellets.

2.4.3. Gas production

Batisa *et al.* (2003 a) reported average potential gas production of three varieties of opuntia as 202.3 ml/g DM, average rate of gas production as 6.7 per cent/h and the lag time as 0.6 h. But Abidi *et al.* (2009) reported lower value for rate of gas production of *Opuntia ficus indica* of about 3 per cent and 4 per cent/h in summer and winter respectively. The same authors reported a potential gas production of 139 ml/0.5g DM of opuntia. The potential gas production reported for cacti was comparable to those reported for legumes (clover and alfalfa) and grass (timothy) forages and the values for rate of gas production were in agreement with the values reported for ten different hays (Kazhaal *et al*., 1995). Tegegne *et al*. (2007) reported that about 85 per cent of the gas (54 ml/200 mg DM) was produced in 24 h when the total time of incubation was 72 hours. Cactus pear replacement of pasture hay improved rate of degradation from 5.4 to 8.4 per cent per hour in 80 per cent cactus supplemented diets.

2.5. *In Situ* evaluation

Shoop *et al*. (1977) reported that the digestion of prickly pear was more rapid than either hay pellets or alfalfa hay. Of the total digestion of prickly pear during 48 hours of incubation, 80 per cent occurred within 16 hours, whereas only 73 per cent and 71 per cent occurred within 16 hours for hay pellets and alfalfa hay, respectively. However, in the 48-hour nylon-bag trial, prickly pear was slightly higher (3.5 percentage points) in dry matter digestibility than alfalfa hay. The nylon bag dry matter digestibility was 52.9 per cent for 16 hour incubation and 66.4 per cent for 48 hour incubation. The IVDMD of grass-hay pellets was about 11 percentage points lower than that of prickly pear. Ben Thlija (1987) and Batisa *et al*. (2003a) reported *in situ* DM disappearance of 760 to 800 g/kg for spineless cactus following 48 hours of ruminal incubation. High ruminal DM degradability of cacti was likely due to their high nonstructural carbohydrate and low lignin contents. The degradation rates were also high (7.0 to 10.0 per cent/h) for different cactus cultivars. The NDF degradability was 63 per cent following 48 hours of *in situ* ruminal incubation.

In a study conducted by Ben Salem *et al*. (1996), cactus was supplemented in the diet at levels of 0, 150, 300, 450 and 600 g DM using three rumen canulated sheep. The values of the soluble fractions (per cent degradable DM) were 23.3, 19.2, 20.1, 11.4, and 13.2 for the supplemented levels, respectively. The slowly degradable fractions were 52.0, 48.5, 39.4, 43.8 and 41.8 and the rate of degradation was 0.0281, 0.0306, 0.0289, 0.0308 and 0.0298, (per cent per hour) respectively. In case of degradable NDF, the values for soluble fraction (per cent) were 18.9, 12.8, 12.9, 4.60 and 4.10, for slowly degradable (per cent) fraction were 67.2, 59, 43.9, 50.9 and 52.4 and degradability rates were 0.0192, 0.0279, 0.0314, 0.0335 and 0.0291 (per cent per hour), respectively. The effective degradability of DM and NDF were significantly decreased by spineless cactus supplementation indicating an impairment of cellulolytic activity in the rumen. However, the rate of degradation was not affected by spineless cactus supplementation. The cellulolytic activity measured by the *in sacco* technique clearly showed some depression in fiber degradation. Ciliate protozoa had a negative effect on the number of bacteria in the rumen and thus on ruminal cellulolytic activity (Gouet *et al*., 1986). High levels of minerals in spineless cactus were also attributed as a limiting factor for microbial growth in the rumen.

Ben Salem *et al*. (2002) reported that the degradability of cactus, untreated straw, urea-treated straw and concentrate (wheat bran and barley 50:50 ratio) after 48 hours as 75.5, 38.4, 45.5, 62.5. Rapidly degradable fraction for DM (per cent) was 39.9, 9.90, 15.1, and 32.5. The slowly degradable fraction (per cent) was 49.3, 43.7, 41.6 32.9 and undegradable fraction (per cent) was 11.8, 46.4, 43.3, 34.6. The fractional degradation rate (per cent/h) was 2.81, 2.28, 2.73, and 7.72. The reported effective degradability (per cent) was 47.5, 25.8, 32.0 and 54.2.

Batisa *et al*. (2003a) used fresh cactus materials which were cut into pieces of 1.0 cm x 0.5 cm x 0.5 cm. for *in situ* evaluation The average soluble fraction, slowly degradable, rate of degradation and effective degradability (per cent) for DM were 9.92, 83.1, 8.75, 62.6 where as for CP (per cent) it was 7.60, 81.7, 8.95 and 64.9. The main carbohydrate fractions in cacti were the rapidly (sugars and organic acids) and the slowly degradable fractions. The results suggested that cacti contained considerable amounts of soluble sugars and organic acids. Total digestible nutrients concentrations were similar in the cactus varieties and averaged 667 g/kg which was equivalent to that of good quality alfalfa hay. The non protein nitrogen (NPN) and neutral detergent and acid detergent insoluble protein values for cacti were not affected by variety and averaged 406 g/kg, 178 g/kg, and 82g/kg of CP respectively. True protein content was similar for the three cactus varieties and averaged 511 g/kg of CP. The results of the *in situ* study revealed high ruminal nutrient degradabilities of spineless cacti, particularly that of DM. The average effective degradability for CP was 64.9 per cent.

Batisa *et al*. (2009) stated that the effective ruminal degradability of DM was similar for all eight cultivars analyzed and averaged 701 g/kg. Slowly degradable NDF fraction and ruminal effective degradability of NDF were not influenced by cultivar and averaged 697/kg and 503 g/kg, respectively. The average values of DM degradability for soluble fraction, slow degradable fraction, rate of degradation and lag time were 307, 578, 10.8, and 0.14 while in the case of NDF degradability, the soluble fraction, rate of degradation and effective degradability (per cent) were 103, 6.7 and 50.3, respectively.

2.6. Intake assessment

2.6.1. Intake of spineless cactus

The intake of fresh cactus in sheep was 2.5 to 9.0 kg/day (FAO 2001) while Valdes and Flores (1967) observed higher intakes in sheep fed with *Opuntia ficus indica* (11 kg/day) than with *Opuntia robusta* (6.5 kg/day). Similar results were observed by Nefzaoui and Ben Salem (2001). Since the gut fill value was low, feeding cactus enhanced the intake of fibrous feeds like straw. Addition of dry feeds also prevented diarrhea.

Nefzaoui *et al*. (1993), concluded that the voluntary intakes of spineless cactus (450 g/DM/day) by growing sheep was not affected when the amount of straw was increased from 300 to 600 g/day. Similar results were obtained by Ben Salem *et al*. (2002) who conducted experiment with Barbarine wethers to study the effect of supplementing urea on cactus using untreated or urea treated straw. Irrespective of dietary treatments, sheep consumed about 500 g of cactus DM, corresponding to approximately 5 kg of fresh cactus. Nitrogen supplement from urea treatment of straw had no effect on cactus intake.

Ben Salem *et al*. (1996) fed male sheep with body weight of 40 kg with wheat straw *ad libitum,* and 0, 150, 300, 450, or 600 g DM per day of spineless cactus (*Opuntia ficus indica*). Sheep fed with straw were able to consume up to 560 g DM of spineless cactus at maximum straw level of 716 g DM. Animals receiving diets containing up to 500 g of spineless cactus (DM) did not show any digestive disturbance. The increased DMI in these studies were ascribed to the high soluble fraction of DM in cactus pear as feeds rich in fermentable components could increase passage and out flow rate, and in turn the feed intake (Orskov, 1991). Similar results were obtained by Tegegne *et al*. (2005) who conducted feeding trial using male sheep to investigate the effect of cactus pear on DMI in barley straw based diets. Cactus inclusion increased total DMI by 38.5 per cent.

Sirohi *et al.* (1997) estimated the intake of spineless cactus along with cenchrushay or baru hay (*Sorghum helepense*) in comparison with control diet containing concentrate mixture and *Cenchrus* hay. Animals maintained on spineless cactus fed *ad libitum* with Cenchrus hay or Baru hay consumed 6·31 and 4·27 kg fresh chopped opuntia daily, amounting to 0·79 and 0·54 kg DM per head respectively, during the 30-day feeding trial period. Total DMI assessed from spineless cactus plus roughage with cenchrus and baru hay was 0·95 and 0·90 kg per head, respectively, whereas the DMI of the control animals amounted to 1·14 kg per head. Firew (2001) reported intake of only 3kg/day of fresh cactus in Highland sheep. The low intake of cactus in this was said to be due to the small size of the experimental animals and/or the contribution in DMI by other dietary ingredients.

Gusha *et al.* (2014) studied the intake and growth rate of male goat kids receiving diets comprising fresh spiny cactus *(Opuntia megacanta)* mixed with browse legume hay or cactus plus *leucaena leucocephala meal* or cactus with *gliricidias epium* meal or cactus with *pennisetum purpureum* meal . It was concluded that inclusion of fresh cactus significantly improved the intake of poor quality roughage in goats kids. Further, the study recommended the use of cactus during the periods of feed deficit especially in small holder sector.

Misra *et al*. (2006) reported that diets with cactus pear forage were advantageous when the availability of nitrogen was adequate. The intake of NDF linearly increased with the proportion of cactus pear in the diet ($P < 0.05$). The intake of TDN and ME by sheep was quadratically related ($P < 0.05$) to the proportion of cactus pear in the diet. The maximum ME intake (11.4 MJ/day) reached when the diet was supplemented at the level of 43.5 per cent with cactus pear.

Tegegne *et al*. (2007) reported an increase in DMI of cactus up to 60 per cent replacement of hay by cactus. The increase in DMI corresponding to cactus pear replacement of pasture hay was not due to increase in diet digestibility but rather due to the low fiber content of cactus pear and its high palatability and passage rate. The increase in total OM intake as a result of supplementation with cactus pear was due to the higher DMI. At 80 per cent replacement, the DMI was low, which was due to high moisture content in cactus. The low dietary CP level also contributed to the low DMI in sheep fed 80 per cent replacement of hay with cactus (Van Soest, 1994).

Vieira *et al.* (2007a) conducted a trial using Alpine bucks fed cactus based diets, to find out the effect of replacing cactus with Bermuda grass hay. Bermuda hay was fed at 150, 250, 350 and 450 g/kg of the diet DM. Addition of Bermuda hay reduced the digestive problems. The spineless cactus intake was 765, 670, 572 and 473 g DM respectively, for the above four diets. Regressing DM intake of spineless cactus on Bermuda grass hay levels suggested that minimum level of 150 g supplementation of grass hay was sufficient to maximize cactus intake.

In a feeding trial using twenty-four yearling male sheep, Degu *et al.* (2009) investigated the effect of supplementing different protein supplements viz. cottonseed cake, naug seed cake and peanut seed cake in a diet based on tef straw and cactus. The protein supplements were offered at iso nitrogenous levels of 10 g of nitrogen (62.5 g CP) per head per day. Sheep supplemented with cottonseed cake and naug seed cake had a higher intake level of 155 g DM of cactus than peanut cake.

Mattos *et al*. (2000) observed that cactus pear associated with other fiber sources increased the DMI of the diets and maintained normal conditions in the rumen, thus preventing undesired effects. Supplementation with cactus pear did not reduce the rumen pH, since the high mucilage and mineral levels stimulated saliva production and facilitated pH buffering (Ben Salem *et al*., 1996).

Santos *et al*. (2010) conducted an experiment in which Santa Ines rams (average body weight 43.9±6.39 kg) were fed with 740 g/kg DM spineless cactus (*Opuntiaficus-indica* Mill, cultivar Gigante), Bermuda grass tifton hay (*Cyndondactylon* Pers.) and Soyabean hull. Replacing corn with Bermuda grass hay or soyabean hulls had no effect on intake of DM, OM, CP or total carbohydrates. Regardless of feeding Bermuda grass hay or soybean hulls or the corn, animals consumed more than 800 g/day of spineless cactus DM.

Costa *et al*. (2012) conducted a study in which corn was replaced with cactus pear in the diet at 0, 25, 50, 75, and 100 per cent on dry matter basis using forty-five non-castrated male lambs of the Santa Ines breed, with an average live weight of 27.5 kg. The DMI and OMI showed a quadratic relationship ($P<0.05$) with increased levels of cactus pear in the diet. The maximum DMI occurred with 54.0 per cent of cactus pear replacement, where the intake of DM reached 1.49 kg/day. It was noted that during meals both in morning as well as afternoon feedings, the animals first ingested cactus pear, followed by concentrate and finally the tifton hay. Factors including low fiber content, high palatability, and high passage rate of the cactus pear contributed to their greater intake. There was an increase in mineral intake with increasing levels of cactus pear in the diet most likely due to the high content of minerals present in the cactus pear. The CP intake was maximum at 45.9 per cent of cactus pear replacement.

Gusha *et al.* (2014) conducted a trial on effect of co-ensiling *Opuntia ficus indica* with dry forage legumes and observed a significantly ($P<0.05$) higher dry matter intake (DMI), OM intake and digestibility of OM (DOM) and microbial protein yield in goats fed cactus-forage legume silage diets than those fed *Pennisetum purpureum* hay alone.

2.6.2. Water intake

Water scarcity and high temperatures are characteristics of dry areas. Since dry matter intake and water intake are inter-dependent, the lower performances of small ruminants under dry conditions could be partly due to reduced water availability. In the absence of watering points, the animal will spend more time in selecting and consuming plants rich in water. Except for cactus, there may not be any succulent plant that can withstand the conditions of dry and hot areas. De Kock (1980) mentioned that sheep kept in pens could go without water for more than 500 days if they have daily access to sufficient quantities of fresh cactus.

Ben Salem *et al*. (1996) reported that when the cactus intake levels were 0, 150, 300, 450, or 600 g DM per day, the water intake levels were 2.42, 1.49, 0.14, 0.11 and 0 kg, respectively. In another experiment, Ben Salem *et al*. (2002) reported that sheep given cactus (Cactus+urea treated Straw, Cactus+Atriplex and Cactus+ untreated Straw) drank significantly ($P<0.001$) less water than those on the control diet (untreated Straw+

concentrate). Total water consumption (the sum of water drunk and water provided by feeds) was substantially lower for cactus diets than the control diet.

Gebremariam *et al.* (2006) reported that sheep fed on the highest inclusion of cactus, consumed the least, whereas those fed zero cactus consumed the highest quantity of water. The water intake was about 1.5 per cent of body weight when Tef straw was replaced at 75 per cent by cactus on DM basis.

Tegagne *et al*. (2007) fed forty male yearling sheep with a body weight of 19.5 kg on pasture hay and increment levels of cactus replacement of hay. The water intake on control diet was 1226 ml/day which was significantly different from 60 ml/day in 80 per cent cactus substituted group.

Vieira *et al*. (2007a) reported that when cactus DM was replaced by incremental levels of Tifton hay, the water intake increased according to the increase in Tifton hay. Vieira *et al*. (2007b) fed spineless cactus at 37 to 77 per cent of DM of feed in alpine bucks and found that the creatinine clearance and urinary sodium excretion were similar for all dietary treatments while potassium excretion decreased linearly ($P<0.05$) as the level of cactus cladodes in the diet increased. Feeding cactus cladodes caused diuresis and reduced urinary potassium. Diuresis associated with cactus cladode consumption was attributed at least in part to excessive water intake from feed. Water overload was usually associated with increased urine output (Fenske, 2006). Ben Salem and Smith (2008) observed that Cacti also possess diuretic properties. Feeding of fresh cactus alleviated the problems of watering livestock. Similarly, Mendez-llorente *et al*. (2008) reported that . cactus source of water to meet needs of the body.

Costa *et al.* (2012) found that the voluntary water intake of the sheep diminished ($P<0.01$) by approximately 25.6 g/day for each percent of cactus pear in the diet. This intake declined from 4.9 to 2.31 kg of water/day when the proportion of cactus pear replacement of corn increased from 0 to 100 per cent in the diet.

Gusha *et al*. (2014) found that lambs drunk more water when fed diets with *Pennisetum purpureum* grass meal compared to the diets containing spineless cactus. Cactus could partially fulfill the requirement of water. Water intake of lambs decreased as *Opuntia leucotrichia* increased in diets containing different levels varying from 0 per cent to 40 per cent on dry matter basis.

Thus, it is evident that cactus has a definite advantage in feeding livestock during dry season when there is scarcity of feed and water, normally been encountered in semi-arid and arid zones.

2.7. Body weight

Terblanche *et al*. (1971) reported that feeding cactus alone caused weight loss in Merino sheep. Similarly, Ben Salem *et al*. (2002) reported that sheep fed diets with cactus and untreated tef straw grew less than those fed cactus and urea treated tef straw ($P<0.01$). Therefore, cactus-straw based feeding systems require supplementation with protein or nitrogen sources to support animal performance. Ben Salem *et al*. (2004) concluded that in the presence of nitrogen source (soybean), cactus pear replaced barley grains without any effect on growth rate of sheep. Similar results were obtained by Tegegne *et al*. (2005) who found that if the straw is urea-treated, cactus pear could replace wheat bran. Sheep given urea treated straw along with cactus (40 per cent) and those fed urea treated straw along with cactus (20 per cent) and wheat bran (20 per cent) consumed the same amount of DM. However, sheep fed diet containing wheat bran gained higher body weight (75.5 g per day) compared to those without wheat bran (38 g per day). This was be attributed to the relatively high protein and phosphorus content of wheat bran.

A study by Nefzaoui *et al*. (1993) demonstrated that cactus was a good supplement to ammonia or urea-treated straw, since it provided the necessary soluble carbohydrates for efficient use of the non-protein nitrogen in the rumen. However, sheep gained lower live weight gain at higher replacement (75 per cent) which was explained by the higher moisture content in cactus which limited the total DM intake. It was explained that feeds with a particularly high content of water bound within plant tissues promote a lower DMI than comparable feeds of lower water content (McDonald *et al*., 2002). Thus, cactus could safely replace straw by up to 50 per cent on DM basis with positive weight gain and no digestive disturbances, provided that it was supplemented with organic nitrogen sources.

Atti *et al*. (2006) conducted an experiment with twenty one kids in three groups, to compare a control group of kids fed oat hay and concentrate (control), with 50 per cent of the concentrate in control diet replaced by feeding cactus *ad libitum* and another group fed soybean meal replacing concentrate (protein) in the second group. The animals in the control group showed higher body weight gain than other two treatment groups. Kids in the second group recorded a lower cactus intake than those fed soybean meal. Differences in performance observed between animals receiving various diets were associated with the energy content. The energy content was low for soybean diet than for the two other diets leading to lower body weight gains.

Gebremariam *et al*. (2006) reported that, when tef straw was replaced by spineless cactus at 25, 50 or 75 per cent, there was a significant difference (P<0.05) between the treatment groups in daily live weight gain. The highest gain was found in sheep fed on 50 per cent cactus replacement and the least weight gain in sheep fed zero per cent replacement. The increased live weight gain in sheep fed on cactus diets was explained by the associative effects of higher total DMI and soluble carbohydrates contained in the cactus.

Tegegne *et al*. (2007) reported that the maximum body weight of 33 g/day was attained when 20 per cent of the pasture hay was replaced by cactus. The low body weight gain was attributed to the presence of oxalate in cactus pear (Ben Salem *et al*., 2005), wide Ca to P ratio (16:1) and lack of fermentable nitrogen (Van Soest, 1994).

Mendez-llorente *et al*. (2008) conducted an experiment in which oats hay was replaced on DM basis by *Opuntia leucotrichia* at 0, 10, 20, 30 and 40 per cent levels. Although the diets were iso caloric and iso nitrogenous, dry matter intake in opuntia fed groups was lower leading to lower body weight gains. Abidi *et al*. (2009) replaced barley with *opuntia* on iso energy basis and fed to lambs. There was no significant difference between barley and cactus fed animals in average daily body weight gains. There was no negative effect of cactus on hay intake, diet digestibility or N balance with inclusion of cactus in the diet.

Degu *et al.* (2009) compared diets containing opuntia and different oil cakes supplying same amount of nitrogen. They observed that the oil cake supplemented sheep had higher ($P<0.001$) final body weight gain. Supplementation with cotton seed cake and peanut cake resulted in higher ($P<0.001$) daily body weight gain than the non-supplemented sheep. Sheep supplemented with cottonseed cake had higher ($P<0.001$) daily BW gain than noug seed cake supplemented ones. The ratio of protein to the mean daily body weight gain attained by sheep in the feeding trial was 0.9, 1.78 and 1.10, respectively for cottonseed cake, noug seed cake and peanut cake respectively.

Costa *et al*. (2012) reported that when maize grain in the concentrate mixture was replaced by cactus on dry matter basis at 0, 25, 50, 75 and 100 per cent levels, the average daily gain (ADG) decreased from 255 to 210 g/day between the diets with 0 and 100 per cent of cactus pear, respectively. The reduction of the metabolisable energy supply in the diet (2.30 to 2.05 Mcal of ME/kg DM) and the reduction in ME intake in the treatment diets led to a marginal reduction in the weight gain of the sheep. It was observed that for each additional percentage unit of cactus, there was a reduction of approximately 0.378 g in the daily weight gain.

Gusha *et al*. (2014) compared the performance of goats fed cactus based diets supplemented with either *Leucaena leucocephala*, or *Pennisetum perpurium*. Higher body weight gain was recorded with the cactus diet supplemented with *Leucaena leucocephala* compared to *Pennisetum perpurium*. This was attributed to the supplementary effect of cactus with the legume in the mixture. Cactus provides adequate energy, while browse legume provided the much needed CP, hence improving rumen degradation and overall performance.

2.8. Digestibility of nutrients

Ben Salem *et al*. (1996) reported that cactus inclusion in diet increased nutrient digestibility of straw-based diets fed to sheep at higher levels of inclusion and with no effect at low inclusion rates. While, Vieira *et al.* (2007 a) reported that when 150, 250, 350 and 450 g of *Opuntia ficus indica* DM was replaced by tifton bermuda grass hay on DM basis, the *in vivo* digestibility of DM, OM, NDF were not affected. In contrast, Misra *et al*. (2006) reported lower DM and CP digestibility for hay supplemented with cactus than for hay supplemented with concentrates in sheep. The spineless cactus cladodes are highly digestible. The *in vivo* average digestibility values obtained in sheep varied from 60 to 65 per cent, 60 to 70 per cent, 35 to 70 per cent and 40 to 50 per cent, for DM, OM, CP and crude fibre (CF), respectively (FAO, 2001).

Ben Salem *et al*. (2002) stated that increasing the nitrogen content of the cactus-based diets with urea treatment of straw increased the content of apparently digestible DM, OM, CP and NDF by 100, 100, 120 and 290 g/kg, respectively. There was further improvement when atriplex (Xerophytic plant containing 19 per cent CP) was provided. The rate of increase of CP digestibility was more prominent with atriplex supply than urea-treated straw. However, the overall digestibility of the control diet (Urea treated straw with barley and wheat bran) was significantly higher than that of cactus based diets. Apparent digestibilities of DM, OM, CP and NDF increased as the nitrogen level in the diet was raised. There was a positive effect of N supplementation on apparent NDF digestibility of cactus-based diets. Nitrogen supply had probably enhanced microbial activity in the rumen and encouraged microorganisms to degrade more feed (Leng, 1990).

McMillan *et al*. (2002) compared the digestibility of spined cactus and spineless cactus across season. Digestibility varied between prickly pear species, but was similar between seasons. Digestibility of DM and OM of spineless prickly pear was 79 and 83 per cent respectively, which was greater than spined prickly pear.

Tegegne *et al*. (2005) found that the DM digestibility was increased by 10 per cent units when sheep group fed with untreated straw was supplemented with cactus at 40 per cent level. In urea treated group the increase was 5 per cent units. Gebremariam *et al*. (2006) stated that when tef straw was replaced by spineless cactus at 25, 50 or 75 per cent, the apparent digestibility coefficient for DM increased ($P<0.05$) as the level of cactus increased in the diet. Organic matter digestibility also increased from 46 per cent to 54 per cent from the lowest to the highest cactus inclusion rate, whereas the apparent digestibility for CP, NDF and ADF decreased ($P<0.05$) as the level of cactus in the ration increased.

Misra *et al*. (2006) stated that the apparent digestibility of DM, OM, CP and gross energy were lower ($P<0.05$) in sheep fed opuntia diets than opuntia diets supplemented with groundnut cake. The NDF and ADF digestibility did not differ significantly among groups. Stimulatory effect of amino acids, peptides and branched chain VFA on growth of rumen microorganisms (Gorosito *et al*., 1985) and subsequent increase in nutrient digestibility was expected with groundnut cake supplemented diet. Organic N supplements led to an increase in ruminal ammonia and enhanced the net production of branched chain fatty acids (Broudiscou *et al*., 1999). Low apparent digestibility with opuntia diets was attributed to the depressed microbial activity due to lower ruminal ammonia, which hampered fiber utilization (Preston and Leng, 1987; Ben Salem *et al*., 1996).

Mendez-llorente *et al*. (2008) fed five iso nitrogenous and iso caloric diets supplied with 0, 10, 20, 30 and 40 per cent of cactus (*Opuntia leucotrichia*) on DM basis to male lambs. The digestibility of DM, OM, NDF and ADF were similar across treatments. However, CP digestibility was higher in lambs fed 40 per cent cactus. Degu *et al*. (2009) reported that the apparent digestibility coefficient of DM and OM of the basal diet increased as a result of noug seed, cotton seed and Peanut cake supplementation in cactus based diets which showed that an organic source of nitrogen increases the apparent digestibility of DM and OM.

Abidi *et al*. (2009) replaced barley grain by cactus on iso energy basis. The digestibility of DM, OM, CP and NDF were not affected by cactus replacement. In contrary, Costa *et al*. (2012) reported that when maize grain was replaced by cactus on DM basis at 0, 25, 50, 75 and 100 per cent, the coefficients of digestibility of the DM, OM, CP, and NDF increased linearly with increasing levels of cactus pear in the diet. The digestibility of OM varied from 73.37 to 83.2 per cent. The digestibility of CP varied similarly, from 74.53 to 86.62 per cent. There were no associative effects and the digestibility of nutrients increased with the inclusion of cactus pear in the diets. The digestibility of NDF increased linearly ($P<0.001$) with increasing levels of cactus pear in the diet. The digestibility of NDF increased from 56.58 to 77.53 per cent and from 0 to

100 per cent cactus pear inclusions, respectively. Cactus pear has a high content of soluble carbohydrates, such as pectin, which is rapidly fermented in the rumen.

Santos *et al*. (2010) stated that when corn was replaced by *Cyndondactylon* hay and soyabean hull in Santa rams, were fed high cactus diets, the *in vivo* digestibility of DM, OM, CP, NDF, and total carbohydrates were not affected by fiber source. However, replacing corn with soybean hulls increased digestibility due to the high fermentability of corn in the diet.

The literature reviewed on the production and nutritional evaluation of spineless cactus has revealed that a great potential exists to sustain and augment the productivity of small ruminants by efficient utilization of spineless cactus. The response of the intake, digestibility and performance of small ruminants due to feeding of spineless cactus have been equivocal, depending on the type of diet or supplements used, and hence, the optimum levels of incorporation in the diets have not been defined. Not much work has been carried out in India to utilize spineless cactus and the literature available has been very scanty. Therefore, further research is necessary to achieve improved productivity and higher efficiency of performance by utilizing spineless cactus in feeding management of small ruminants.

Table 2.1. Chemical composition of Spineless cactus on DM basis (g/kg DM) as reported in literature by various authors

Authors	DM	CP	EE	TA	NDF	ADF	ADL	Ca	P	ME
Gabremarian *et al.*(2006)	120	83	-	275	392	263	50	45	2.6	-
Misra *et al*.(2006)	218	126	14	172	416	393	54	-	-	-
Tegegne *et al*.(2007)	122.3	50.6	11.9	198.9	238.8	162.5	30.6	47.6	3	8.6
Vieira *et al*.(2007a)	86.1	39.1	20.1	118.1	346.6	188.6	-	-	-	-
Abidi *et al.*(2009)	127	38	-	-	251	-	-	-	-	-
Degu *et al.*(2009)	86	63.3	6.5	231.4	238.5	140.2	21.9	-	-	-
Tasooli *et al*.(2011)	147	88	10.1	311	261	183	-	-	-	8.14
Costa *et al.*(2012)	108.3	39.5	16.5	-	311.6	216.8	-	-	-	8.36
Costa *et al.*(2016)	101	51	11	186	586	274	-	-	-	-
Ajith *et al.*(2017)	91.4	49.2	20.4	185	270	142	51	45.2	8	8.82

DM - Dry matter; CP - Crude protein; EE - Ether extract; TA- Total ash; NDF - Neutral detergent fiber; ADF - Acid detergent fiber; ADL- Acid detergent lignin; Ca- Calcium ; P- Phosphorous ; ME- Metabolizable energy(MJ /kg of DM).

MATERIALS AND METHODS

III. MATERIALS AND METHODS

The present study was conducted to assess the intake of complete diet based on spineless cactus in adult sheep and evaluation of the diets by *in vitro* method. The study was carried out at the Department of Animal Nutrition, Veterinary College, Karnataka Veterinary, Animal and Fisheries Sciences University (KVAFSU), Bengaluru. The intake assessment trial was conducted at Instructional Livestock Farm Complex (ILFC), Veterinary College, Bengaluru.

The experimental plan consisted of:

1) Chemical and *in vitro* evaluation

2) Intake assessment trial, and

3) *In vivo* digestibility trial

3.1. Chemical evaluation

3.1.1 Collection and processing of Spineless cactus for analysis

Spineless cactus (*Opuntia ficus indica*) cladodes were procured from the plantation at Livestock Research and Information Center (LRIC), Konehalli, Tumakuru. The cladodes were sliced into three mm thickness and dried in a forced hot air oven at 60˚C for 48 hours for estimating partial DM. The dried sample was ground in a Willey mill to pass through 1 mm sieve and stored in air tight polyethylene containers until analyzed.

3.1.2. Analysis of dietary feedstuff

The dietary feedstuff included spineless cactus, finger millet straw (FMS) and a compounded feed mixture (CFM). The CFM contained 80 per cent maize, 15 per cent wheat bran, 2 per cent urea, 2 per cent mineral mixture and 1 per cent common salt (Table 3.2). Sufficient quantities of all the feedstuff were procured, ground in a Willey mill to pass through 1 mm sieve and stored in air tight polyethylene containers until analyzed.

The DM content in the samples was analysed by drying to a constant weight in a hot air oven at 105°C. The ash content in the samples was estimated as residue obtained after incineration of samples at 600°C for 3 hours. Crude protein (N X 6.25) was analyzed using Gerhardt digestion and distillation unit that agrees with macro kjeldahl standards (AOAC, 2005). The ether extract (EE) content in the samples was analyzed after extraction with petroleum ether using the procedure of AOAC (2005). The NDF, ADF and Acid detergent lignin (ADL) were determined according to the methods described by Van Soest *et al*. (1991).

3.1.3. Preparation of experimental diets

Based on the chemical composition and metabolisable energy (ME) content (Section, 3.2.2) of the dietary feedstuff, complete diets (D1 to D9) were prepared by using FMS and CFM in the ratio of 40:60. On the basis of the estimates of chemical analyses and ME content of these diets were used, to calculate the optimum level of replacement of the FMS and CFM by spineless cactus and diet D10 was prepared.

The description of the diets are as follows:

D1 - FMS (40 %) + CFM (60 %)

D2 - FMS (32 %) + CFM (60 %) + Spineless cactus (08 %)

D3 - FMS (28 %) + CFM (60 %) + Spineless cactus (12 %)

D4 - FMS (24 %) + CFM (60 %) + Spineless cactus (16 %)

D5 - FMS (20 %) + CFM (60 %) + Spineless cactus (20%)

D6 - FMS (40 %) + CFM (48 %) + Spineless cactus (12 %)

D7 - FMS (40 %) + CFM (42 %) + Spineless cactus (18 %)

D8 - FMS (40 %) + CFM (36 %) + Spineless cactus (24 %)

D9 - FMS (40 %) + CFM (30 %) + Spineless cactus (30 %)

D10- FMS (20 %) + CFM (30 %) + Spineless cactus (50 %)

The diet D1 comprised FMS and CFM (without spineless cactus) and served as control. The diets D2, D3, D4 and D5 contained 20, 30, 40, and 50 per cent respectively of the FMS replaced (part by part) by spineless cactus while, the diets D6, D7, D8 and D9 contained 20, 30, 40, and 50 per cent respectively of the CFM replaced (part by part) by spineless cactus. Diet 10 contained 50 per cent each of the FMS and CFM replaced by spineless cactus. The results of chemical analyses and *in vitro* studies obtained was used for selecting the optimum level of replacement of the FMS and CFM by spineless cactus in intake assessment trial.

3.2. *In vitro* evaluation

All the dietary ingredients and complete diets (D1 to D10) were subjected to rumen *in vitro* incubation for gas production (RIVIGP) and the ME (MJ/kg DM) was estimated by using procedures of Menke and Steingass (1988) as follows.

3.2.1. Donor cow and collection of rumen fluid

A lactating dairy cow producing 3 kg of milk per day, fitted with a flexible rumen canula of large diameter (Bar Diamond, Inc. USA), receiving a basal diet consisting of FMS and CFM (maize 60 per cent, wheat bran 35 per cent, mineral mixture 2 per cent, urea 2 per cent and salt 1 per cent) was used as the donor cow for collection of rumen fluid. The FMS and CFM were fed separately. Six kg FMS was offered in small portions four times a day, starting at 09.00 hours. The CFM was offered 3.0 kg per day in two equal portions at 05.00 and 13.30 hours. Rumen fluid was collected in the morning between 04.45 hours and 05.00 hours before offering CFM.

3.2.2. Metabolisable energy (ME) determination

The ME content of the dietary ingredients and complete diets were determined by rumen *in vitro* incubation and gas production technique (RIVIGP) according to Menke and Steingass (1988) using the following equations:

For Compounded feed mixture, Complete diets and Spineless cactus:

$$ME = 1.06 + 0.1570\ GP + 0.0084\ CP + 0.022\ EE - 0.0081\ TA$$

For Finger millet straw:

$$ME = 2.2 + 0.1357\ GP + 0.0057\ CP + 0.0002859\ EE^2$$

Where,

ME = Metabolisab1e energy, MJ/kg DM.

GP = Corrected Net Gas production, ml/200 mg. DM.

CP = Crude protein, g/kg. DM.

EE = Ether extract g/kg. DM. and

TA = Total ash, g/kg. DM.

3.3. Assessment of the intake of spineless cactus by adult sheep

3.3. Feeding trial

A feeding trial was conducted to assess the intake of spineless cactus in sheep fed diet containing FMS and CFM. The objective of the experiment was to estimate the maximum potential of daily intake of spineless cactus by adult sheep when fed on the complete diet comprising on FMS and CFM.

3.3.1. Location

The feeding trial was conducted at Instructional Livestock Farm Complex (ILFC), Veterinary College, Bengaluru. The farm is situated in a semiarid region located at an elevation of 899 m above mean sea level, 13˚01' of North latitude and 77˚35' of East longitude with mean annual rain fall of 540 mm. Permission for using the animals for the experiment was duly taken from Institutional Animal Ethics Committee (IAEC) constituted as per the Article No. 13 of the CPCSEA rules laid down by Government of India.

3.3.2. Particulars of animals and experimental design

Six adult Bannur crossbred rams ranging from 24 to 60 months of age were selected. The rams were divided into two groups consisting of three rams each of comparable body weight and age. The feeding trial was carried out in two periods comprising six weeks each, in a switch over design. Each period comprised of a base line (adjustment) period of two weeks followed by intake measurement period of four weeks. The particulars of the animals used in the experiment are presented in Table 3.1. The description of the treatments and the periods are as follows.

	Weeks	Group 1	Group 2
Period I	1-6	T1	T2
Period II	7-12	T2	T1

3.3.3. Housing and procurement of feed ingredients

The experimental rams were housed in shed and provided similar managemental care. All the rams were individually dosed with Albendazole, (broad spectrum antihelmenthic) and Poron (ectoprasiticide) before starting the trial. Quantity of FMS and concentrate ingredients sufficient for entire duration of trial were procured in a single batch and stored. Spineless cactus was harvested daily, chopped to a size of one centimeter thickness and three centimeter length and offered to the experimental rams.

3.3.4. Dietary treatments

The diet of the experimental rams was made from FMS, CFM and the Spineless cactus. The ingredient composition (per cent) of CFM is given in Table 3.2. The two groups of rams were allotted randomly to two treatment diets as follows.

Group 1: Diet T1 – Finger millet straw (40 per cent) + Compounded feed mixture (60 per cent). This group served as control.

Group 2: Diet T2 – 20 per cent of the Finger millet straw + 30 per cent of the Compounded feed mixture + Spineless cactus (*ad libitum*)

The diets for the experimental rams were formulated individually to meet the ME and CP requirement for maintenance as per ARC (1984). Dietary ingredients were offered to individual rams in group 1 (control) in calculated quantities with FMS fed at 1 per cent of the body weight and the CFM fed at the rate of 1.5 per cent of the body weight. In order to replace the FMS and CFM by spineless cactus in Group 2, the quantities of FMS (20 per cent) and CFM (30 per cent) in the diet offered was restricted to 50 per cent of the calculated quantities. Spineless cactus was offered *ad libitum*.

The rams were offered daily quantities of FMS and CFM in separate troughs. Fresh spineless cactus cladodes were chopped to approximate size of one centimeter thickness and three centimeter length, and offered *ad libitum*. The Spineless cactus was offered at 08.00, 14.00, and 18.00 hours while FMS were offered at 08.00, 16.00, and CFM offered 12.30 hours and 15.30 hours. Measured quantity of clean drinking water was provided in separate plastic troughs at 07.00 and 14.30 hours of the day.

3.3.5. Dry matter intake

Daily intake of FMS, CFM and spineless cactus were recorded. Samples of FMS, CFM and spineless cactus offered daily and left over were collected and, weekly samples pooled and preserved for analysis at the end of feeding trial. Feed DMI was calculated by deducting the left over from the daily offered quantities of FMS, CFM and spineless cactus. Dry matter was estimated by drying samples at 105° C for 10 hours in a hot air oven

3.3.6. Body weight

The rams were weighed on the first and the last day of each period at 09.00 hours before having access to feed or water. A platform digital scale of 50 kg capacity was used.

3.4. Digestion trial

A digestion trial was conducted using all the rams, for 5 days during the last week of each period, using total collection method. Daily intake of FMS, CFM and spineless cactus and output of dung were merasured. Samples of feed offered and residue were collected every day and pooled for chemical analysis. The rams were harnessed with the faecal collection bags during the collection period and the dung void was collected periodically and stored in plastic containers.

3.4.1. Sampling, analysis and calculations

Dung voided by each ram over 24 hours was weighed at 08.30 hours. After proper crushing and mixing, 1/10th of total collection was sub sampled. The pooled sample for five days from individual rams was dried in a forced hot air oven at 60^{o}C, air equilibrated, ground in a Willey mill to pass through 1 mm sieve and stored in air tight polyethylene containers until analyzed. Samples of feed ingredients, ort, and faeces were analysed for DM, Ash, CP, NDF and ADF as described in section 3.1.2.

3.4.2. Digestibility of nutrients

The digestibility of DM and nutrients was calculated as the difference between intake and outgo. The apparent digestibility co-efficient (per cent) of nutrients was calculated using the formula:

$$\frac{\text{[(quantity of nutrient intake (g per day)–(quantity of nutrient out go in dung (g per day)]}}{\text{Quantity of nutrient intake (g per day)}} \text{ X 100}$$

3.5. Statistical analysis

The experiment was conducted in a switch over design, comprising two periods and two treatments. The experimental data on DMI, nutrient intake, body weight and digestibility were subjected to statistical analysis by t-test (unpaired) as per the procedure described in Snedecor and Cochran (1989). GraphPad Prism (2007, Version 5.01) software was used for the data analysis.

Table 3.1. Particulars of rams used in the Intake assessment trial

	Ram Number	Age (months)	Body weight (Kg)
Group 1	00B1	60	35.2
	0042	28	17.9
	0040	26	17.5
	Mean ± SE	**38.0± 11.0**	**23.5± 5.83**
Group 2	00A1	56	33.4
	0044	32	21.2
	00K1	24	15.7
	Mean ± SE	**38.3± 10.6**	**23.4± 5.23**

Table 3.2. Ingredient composition (per cent) of compounded feed mixture

Ingredient	Parts
Maize	80
Wheat bran	15
Salt	01
Urea	02
Mineral mixture*	02
TOTAL	**100**

*The Mineral mixture used was MinlMix® containing calcium, 22%; phosphorous, 9%,; magnesium sulphate, 0.2%; potassium iodide, 0.02%; ferrous sulphate, 0.6%; copper sulphate , 0.5%; cobalt sulphate, 0.02; , zinc sulphate, 0.2%; selenium , 0.02mg .

RESULTS

IV. RESULTS

4.1. Chemical composition

4.1.1. Chemical composition of dietary feedstuffs

The chemical composition, energy values and protein fractions of ingredients viz. finger millet straw (FMS) (*Eleusine coracana*), spineless cactus and compounded feed mixture (CFM) are presented in Table 4.1. As per cent of DM, FMS contained 91.4, 4.95, 1.26 and 8.60 OM, CP, EE and TA, while that for spineless cactus was 86.1, 7.11, 3.01, and 13.9 per cent, respectively. The NDF, ADF and ADL contents of FMS (as per cent of DM) were 75.3, 44.5 and 4.71, while it was 39.8, 26.2 and 4.92 per cent for spineless cactus, respectively. The ME contents were 7.42 and 8.82 MJ/kg DM. The RDP and UDP contents (as per cent of CP) were 53.1, 46.9 and 69.2, 30.8, respectively. The OM, CP, EE and TA content of CFM, (as per cent of DM) were 95.9, 15.8, 3.28 and 4.10, respectively. The NDF, ADF and ADL contents (as per cent of DM) were 22.0, 8.50 and 1.01, respectively. The ME content (MJ/kg DM) of the CFM was 13.1. The RDP and UDP contents (as per cent of CP) in CFM were 64.3 and 35.7.

4.1.2. Chemical composition of diets

The chemical composition and energy values of diets are presented in Table 4.3. The Diet D1 was control (no cactus), while in diets D2, D3, D4 and D5, FMS was replaced by spineless cactus at 20, 30, 40 and 50 per cent, respectively. In diets D6, D7, D8 and D9, the CFM was replaced by spineless cactus at 20, 30, 40, 50 per cent, respectively. Diet D10 contained 50 per cent of total diet replaced by spineless cactus comprising 25 per cent of FMS and 25 per cent of CFM.

The OM, CP, NDF and ADF content on DMB of D1 diet (control) was 94.1, 11.5, 43.3 and 22.9 per cent, respectively. The OM decreased from 93.7 to 93.04 per cent with substitution of FMS with spineless cactus, while the organic matter decreased from 92.9 to 91.6 per cent with substitution of CFM with spineless cactus. The NDF decreased from 40.5 to 36.2 per cent with substitution of FMS with spineless cactus but increased from 45.5 to 48.7 per cent with substitution of CFM with spineless cactus. The CP content increased marginally from 11.6 to 11.9 per cent and decreased from 10.4 to 8.9 with the increasing level of spineless cactus replacing FMS and CFM, respectively.

4.2. *In vitro* Rumen fermentation

4.2.1. Gas production and metabolizable energy content

The gas produced (ml/200 mg DM) by the RIVIGP from FMS, CFM and spineless cactus are presented in Table 4.1. The corrected gas produced during 24 hour period of FMS, CFM and Spineless cactus were 49.9, 75.2 and 54.3, respectively. The ME (MJ/kg DM) content predicted from rumen *in vitro* gas production technique and from chemical composition of FMS, CFM and Spineless cactus were 7.42, 13.1 and 8.82, respectively (Table 4.1).

The gas produced (ml/200 mg DM) by the RIVIGP in complete diets, D1 to D10 are presented in Table 4.2. The corrected gas produced during 24 hour period for the complete diet D1 was 60.6 and the ME content (MJ/kg DM) determined by RIVIGP was 11.4. The ME content of diets D2 to D5, increased from 11.5 to 11.8 with the increasing level of spineless cactus (20 to 50 per cent) replacing the FMS, while in the diets D6 to

D9, the ME (MJ/Kg DM) content decreased from 10.8 to 10.4 with increasing level of spineless cactus (20 to 50 per cent) replacing the CFM.

4.3 Assessment of intake of spineless cactus by adult sheep

Intake assessment trial

4.3.1. Dry matter intake (DMI)

The mean DMI of FMS, CFM and spineless cactus are presented in Table 4.3. The total DMI (g per day) for T1 and T2 groups were 549 and 484 respectively. The intakes of DM as a per cent of body weight were 2.32 and 2.02 respectively and DMI (g) per kg metabolic body weight for treatments were 51.1 and 44.6 respectively. There was significant difference in total DMI (as g per day, per cent of body weight and g per kg metabolic body weight) between the treatment groups. The roughage to CFM ratio of experimental groups T1 and T2 were 46:54 and 27:73, respectively. The mean intake of spineless cactus (DM, g per day) was 207 (equivalent to fresh spineless cactus intake of 2.43 kg per day). The DMI of spineless cactus expressed as per cent of body weight was 1.05 and as g per kg metabolic body weight was 10.9.

4.3.2. Nutrient intake

4.3.2.1. OM, NDF and ADF intake

The mean organic matter intake (OMI), (g per day) for T1 and T2 groups over 06 weeks are presented in Table 4.3. The total OMI (g per day) for T1 and T2 groups were 514 and 437, respectively. The intakes of OM as a per cent of body weight were 2.17 and 1.82, respectively. The OMI (g) per kg metabolic body weight for treatments were 47.9

and 40.4, respectively. There was significant difference in OMI (as g per day, per cent body weight or as g per kg metabolic body weight) between the treatment groups.

The mean intake of NDF (g per day) for T1 and T2 groups over 06 weeks are presented in Table 4.3. The NDF intake (g per day) for T1 and T2 groups were 255 and 213, respectively. The intakes of NDF as a per cent of body weight were 1.08 and 0.89, respectively. The NDF (g) per kg metabolic body weight for treatments were 23.8 and 19.7, respectively. There was no significant difference in the NDF intake (as g per day, per cent body weight and g per kg metabolic body weight) between the treatment groups.

The mean ADF intake (g per day) for T1 and T2 groups over 6 weeks of each period are presented in Table 4.3. The total ADF intakes (g per day) for T1 and T2 groups were 137 and 125, respectively. The intakes of ADF as a proportion of body weight were 0.58 and 0.52, respectively. The ADF intakes (g) per kg metabolic body weight for treatments were 12.8 and 11.5, respectively. There was no significant difference in ADF intake (as g per day, per cent body weight and g per kg metabolic body weight) between the treatment groups.

4.3.2.2. Energy, Crude protein, RDP and RUP intake

The mean energy and protein intake for the two treatment groups are presented in Table 4.4. The intake of energy (ME, MJ per day) was 5.74 and 4.91 for group T1 and T2 respectively. The CP intake (g per day) in groups T1 and T2 was 59.3 and 44.0, respectively. For the respective groups, the rumen degraded protein (RDP) and rumen undegraded protein (RUP) (g per day) intake was 39.0, 20.3 and 30.8, 13.2. The intake of energy was not significantly different between the treatment groups.

4.3.2.3. Water intake

The mean water intake (kg per day) for T1 and T2 groups over 6 weeks are presented in Table 4.5. The mean water intake (kg per day) for T1 and T2 groups was 1.24 and 0.618, respectively. Water intake per kg DM for treatments T1 and T2 was 2.45 and 0.22, respectively. The water intake in terms kg, per kg feed DM consumed was significantly lower in group T2 compared to group T1 ($P<0.05$).

4.4. Body weight change

The mean body weight change over 6 weeks of intake assessment trial period is presented in Table 4.6. The mean initial and final body weight (kg) of rams for T1 and T2 groups were 23.5 and 23.8, 23.8 and 24.1, respectively. The mean body weight change (kg) of the rams in groups T1 and T2 were 0.333 and 0.250 respectively. The average body weight gain (g) per day for T1 and T2 groups during intake assessment trial period was 7.94 and 5.95, respectively. The differences between the two treatment groups for total body weight gain or average body weight gain per day were statistically non-significant.

4.5. Digestion trial

4.5.1. Apparent digestibility of nutrient

The mean intake (g per day) and apparent digestibility (per cent) of DM, OM, CP, NDF and ADF for T1 and T2 treatment groups during digestion trial are presented in Table 4.7. The mean apparent digestibility (per cent) of DM, OM, CP, NDF and ADF for T1 and T2 groups were 68.9 and 76.2; 71.1 and 78.1; 70.8 and 75.2; 59.5 and 63.5; 53.9

and 58.2, respectively. The apparent digestibilities was higher in group 2 fed T2 diet compared to group 1 fed control diet (T1) ($P<0.05$). Higher digestibility of OM with diet T2 resulted in higher DOMDM content of T2 diet compared to T1 (73.3 vs 67.1 per cent). The digestibility of CP, NDF and ADF were similar between the groups.

Table 4.1. Chemical composition[1] (per cent DM), energy and protein fractionation of Compounded feed mixture, Finger millet straw and Spineless cactus

Parameter	Compounded feed mixture	Finger millet straw	Spineless cactus
Dry matter	89.7	95.2	8.5
Organic matter	95.9	91.4	86.1
Crude protein	15.8	4.95	7.11
Ether extract	3.28	1.26	3.01
Total ash	4.10	8.60	13.9
Neutral detergent fiber	22.0	75.3	39.8
Acid detergent fiber	8.50	44.5	26.2
Acid detergent lignin	1.01	4.71	4.92
Energy values and protein fractions			
Gas production[2] (ml/200mg DM)	75.2	49.9	54.3
ME[3] (MJ/kg DM)	13.1	7.42	8.82
CP (%)	15.8	4.95	7.11
RDP[4] (% of CP)	64.3	53.1	69.2
UDP[5] (% of CP)	35.7	46.9	30.8

[1] Mean of two replicates. Variations in duplicate measurements were within ±3% of the mean.
[2] rumen *in vitro* incubation gas production (24h, ml/200mg DM)
[3] Determined by RIVIGP (Menke and Steingass, 1988).
[4] Determined by *in situ* procedure (Singh *et al*., 1995).
[5] 100-RDP % (Per cent of CP).

Table 4.2. Chemical composition[1] (per cent DM), gas production[2] and energy content[3] of the experimental diets

Variable	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Dry matter	91.2	90.8	92.2	92.1	92.7	91.8	92.3	91.6	90.9	92.0
Organic matter	94.1	93.7	93.7	93.2	93.04	92.9	92.3	91.7	91.6	90.1
Crude protein	11.5	11.6	11.9	11.8	11.9	10.4	9.90	9.27	8.90	9.40
Neutral detergent fiber	43.3	40.5	39.1	37.6	36.2	45.5	45.1	48.5	48.7	41.8
Acid detergent fiber	22.9	21.4	22.0	21.0	19.2	25.02	26.1	26.1	28.2	23.5
Gas production (ml/200mg DM)[2]	60.6	61.1	61.4	62.7	65.5	65.5	59.2	57.1	52.8	52.9
ME (MJ /Kg DM)[3]	11.4	11.5	11.5	11.6	11.8	10.8	10.8	10.6	10.4	9.82

[1] Mean of two replicates. Variations in duplicate measurements were within ±3% of the mean.
[2] rumen *in vitro* incubation gas production (24h, ml/200mg DM)
[3] Determined by RIVIGP (Menke and Steingass, 1988).
Diets :D1-FMS (40 %)+CFM (60 %) ;D2 - FMS (32 %) + CFM (60 %) + Spineless cactus (08 %); D3 - FMS (28 %) + CFM (60 %) + Spineless cactus (12%); D4 - FMS (24 %) + CFM (60 %) + Spineless cactus (16 %); D5 - FMS (20 %) + CFM (60 %) + Spineless cactus (20%); D6 - FMS (40 %) + CFM (48 %) + Spineless cactus (12 %); D7 - FMS (40 %) + CFM (42 %) + Spineless cactus (18 %); D8 - FMS (40 %) + CFM (36 %) + Spineless cactus (24 %) ; D9 - FMS (40 %)+CFM (30 %)+Spineless cactus (30 %); D10- FMS (20 %)+CFM (30 %) +Spineless cactus (50 %)
(FMS=Finger millet straw; CFM= Compounded feed mixture)

Table 4.3. Daily mean intake of dry matter and nutrients of experimental groups in Intake assessment trial

Parameter	T1	T2	SEM
Finger millet straw			
g per day	252[a]	132[b]	44.84
per cent of body weight	1.07[a]	0.55[b]	0.036
g per Kg Metabolic body weight	23.5[a]	12.2[b]	0.657
Compounded feed mixture			
g per day	296[a]	144[b]	49.66
per cent of body weight	1.25[a]	0.60[b]	0.102
g per Kg Metabolic body weight	27.6[a]	13.3[b]	2.121
Spineless cactus			
g per day	0.00[a]	207[b]	10.01
per cent of body weight	0.00[a]	1.05[b]	0.056
g per Kg Metabolic body weight	0.00[a]	10.9[b]	1.220
Total DMI			
g per day	549[a]	484[b]	22.15
per cent of body weight	2.32[a]	2.02[b]	0.080
g per Kg Metabolic body weight	51.1[a]	44.6[b]	1.838
Organic matter			
g per day	514[a]	437[b]	20.30
per cent of body weight	2.17[a]	1.82[b]	0.075
g per Kg Metabolic body weight	47.9[a]	40.4[b]	1.708
Neutral detergent fiber			
g per day	255	213	9.336
per cent of body weight	1.08	0.89	0.034
g per Kg Metabolic body weight	23.8	19.7	0.782
Acid detergent fiber			
g per day	137	125	5.757
per cent of body weight	0.58	0.52	0.022
g per Kg Metabolic body weight	12.8	11.5	0.489
Roughage : CFM*	**46:54**	**27:73**	

T1: Control diet; T2: 50 per cent of the diet replaced by spineless cactus (25 per cent of finger miller straw and 25 per cent of compounded feed mixture)

[ab]Means within a row not sharing a common superscript letter differ ($P<.05$)

*comprised CFM and spineless cactus

SEM: Standard error of means.

Table 4.4. Daily mean intake of energy and protein in experimental rams in Intake assessment trial

Parameter	T1	T2	SEM
ME (MJ/day)	5.74 (4.78)	4.91 (4.79)	0.248
Crude protein (g/day)	59.3 (35.4)	44.0 (35.8)	6.784
Rumen degraded protein (g/day)	39.0 (35.4)	30.8 (35.8)	4.951
Undegraded dietary protein (g/day)	20.3 (0)	13.2 (0)	0.834

T1: Control diet; T2: 50 per cent of the diet replaced by spineless cactus (25 per cent of finger miller straw and 25 per cent of compounded feed mixture)
Values in parenthesis indicate the requirements as stipulated by the ARC (1984)
Mean values do not differ significantly between treatments
SEM: Standard error of means

Table 4.5. Daily mean voluntary intake of water in experimental groups during Intake assessment trial

Parameter	T1	T2	SEM
Water intake			
Per day (kg)	1.24[a]	0.618[b]	0.034
Per kg feed DM (kg)	2.45[a]	0.22[b]	0.030

T1: Control diet; T2: 50 per cent of the diet replaced by spineless cactus (25 per cent of finger miller straw and 25 per cent of compounded feed mixture)
[ab]Means within a row not sharing a common superscript letter differ ($P<0.05$)
SEM: Standard error of means.

Table 4.6. Body weight change of experimental rams during Intake assessment trial

Parameter	T1	T2	SEM
Initial body weight (Kg)	23.5	23.8	0.201
Final body weight (Kg)	23.8	24.1	0.196
Body weight gain (Kg)	0.333	0.250	0.059
Average daily gain (g/day)	7.94	5.95	0.635

T1: Control diet; T2: 50 per cent of the diet replaced by spineless cactus (25 per cent of finger miller straw and 25 per cent of compounded feed mixture)
Mean values do not differ significantly between treatments
SEM: Standard error of means

Table 4.7. Daily mean intake and apparent digestibility of nutrients (per cent) in experimental groups during the Digestion trial

Parameter	T1	T2	SEM
Dry matter			
Intake (g per day)	549[a]	489[b]	13.40
Digestibility (%)	68.9[a]	76.2[b]	0.994
Organic matter			
Intake (g per day)	514[a]	442[b]	23.2
Digestibility (%)	71.1[a]	78.1[b]	0.937
Crude protein			
Intake (g per day)	59.2	44.7	7.01
Digestibility (%)	70.8	75.2	2.73
Neutral detergent fiber			
Intake (g per day)	255	213	22.3
Digestibility (%)	59.5	63.5	2.31
Acid detergent fiber			
Intake (g per day)	137	125	6.71
Digestibility (%)	53.9	58.2	2.85
DOMDM (%)	67.1[a]	73.3[b]	0.485

T1: Control diet; T2: 50 per cent of the diet replaced by spineless cactus (25 per cent of finger miller straw and 25 per cent of compounded feed mixture)
[ab]Means within a row not sharing a common superscript letter differ ($P<0.05$)
DOMDM – Digestible organic matter in dry matter
SEM: Standard error of means.

DISCUSSION

V. DISCUSSION

The present investigation was conducted to study the nutritional value of spineless cactus (*Opuntia ficus indica*) on the assessment of intake in adult sheep fed straw based diets. The optimum level of inclusion of spineless cactus in the diet of adult sheep and its effect on the feed intake and digestibility of nutrients was studied.

5.1. Chemical composition of Dietary feedstuffs

The chemical composition, energy values and protein fractions of dietary ingredients viz. finger millet straw (FMS), compounded feed mixture (FMS) and spineless cactus fed to experimental sheep are presented in Table 4.1. The composition of OM, CP, NDF and ADF in the CFM were similar to the values reported by Vikram *et al*. (2014), who used the same composition of ingredients in the CFM in their experiment. The ME content of CFM was high (13.1 MJ/kg DM) due to high proportion of the maize (80 per cent) used (Table 3.2) corroborated with the reported value of Biradar *et al*. (2014). The chemical composition, ME and protein fractions of the FMS were in agreement with those reported by Krishnamoorthy *et al*. (1995). The CP content of FMS was similar (4.95 per cent) to the values reported by Vikram *et al.* (2014). The CP (4.95 per cent), RDP (53.1 per cent of crude protein) and UDP content (46.9 per cent) of FMS was comparable to the value reported by Biradar *et al*. (2014). The proportion of RDP (64.3 per cent of CP) and UDP (35.7 per cent of CP) in CFM was also similar to those reported by Ajith *et al.* (2017).

The DM content of spineless cactus was low (8.5 per cent) (Table 4.1). Evidently, the biomass production per unit weight of fresh spineless cactus could be estimated to be very low. The high moisture content of spineless cactus (91.5 per cent) nevertheless, could be advantageous to provide ample water to the livestock to meet the water needs of the body. De Kock (1980) observed that sheep reared in pens could be managed without water for more than 500 days if they have daily access to sufficient quantities of fresh cactus. Ben Salem *et al*. (1996), Gebremariam *et al.* (2006) and Vieira *et al*. (2007b) also reported a significant decrease in the voluntary intake of water of sheep with the increased level of feeding cactus in their diets. These findings are the results of recent study concluded that spineless cactus could be a potential source of water to meet needs of the body particularly during hot and humid seasons, and in situation of draught.

The CP content of the spineless cactus was 7.11 per cent (Table 4.1). The CP value for spineless cactus obtained in this experiment was higher than those reported by Batisa *et al.* (2009) and Ajith *et al.* (2017), but lower than those reported by Ben Salem *et al.* (2002), Tegegne *et al.* (2005), Tien and Beynen (2005), Gebremariam *et al.* (2006), and Misra *et al*. (2006). Such Variation in the CP content has been attributed to the fertility of the soil since De kock *et al.* (1980) and Karim *et al.*(1996) observed increased CP content in cactus on nitrogen fertilization of soil. The protein content of the cactus reported in the study was comparable to most non-legume forages (Krishnamoorthy *et al.* 1995) and therefore the diets based on spineless cactus are liable to be deficient in protein. Earlier studies concluded that the supplementation of nitrogen in the form of urea or other organic proteins in the diet was obligatory to meet the protein requirement of adult sheep, especially when high proportions of cactus was included in the diet (Tegegne *et al*., 2005; Degu *et al*., 2009 and Gusha *et al*., 2014).

The NDF and ADF content in spineless cactus were 39.8 and 22.0, respectively (Table 4.1). Similar values were previously reported by Costa *et al*. (2012), Misra *et al*. (2006), Gabremanian (2006) and Vieira *et al* (2007a). The NDF value observed in this study is in the range of 31 to 41 per cent as reported (Costa *et al*., 2016; Misra *et* 2006; Vieira *et al*., 2007a), while, Tegegne *et al*. (2007) and Ajith *et al*. (2017) reported lower values. Similarly, the ADF content (22.0 per cent) for spineless cactus observed herein was higher than the values reported by Tegegne *et al*. (2007) and Ajith *et al.* (2017). The NDF and ADF content of the cactus was much lower than forages or crop residues (Van Soest, 1994; Krishnamoorthy *et al*., 1995; Manjunatha *et al*., 2000) nevertheless, higher than the cereals or concentrate feeds (Misra *et al*., 2006; Gabremariam, 2006; Vieira *et al*., 2007a).

The ME content of spineless cactus was 8.82 MJ/kg DM (Table 4.1) which agrees with those reported by Tegegne *et al*. (2007) and Ajith *et al*.,(2017) who reported values of 8.61 and 8.82 MJ ME/kg, respectively. The ME content of cactus was about 75% of the value reported for maize grain (Krishnamoorthy *et al.*, 1995).

Earlier studies have reported that spineless cactus could be incorporated in the diet substituting cereal grains such as barley, corn or concentrate mixture (Abidi *et al.*, 2009; Santos *et al*., 2010; Costa *et al*., 2012; Ajith *et al*., 2017) or roughages such as pasture hay or tef straw (Misra *et al*., 2006; Tegegne *et al*., 2005). The ME, NDF or ADF content of spineless cactus in the present study was find to be intermediate to the concentrate or roughage suitable to substitute for either concentrate or roughage ingredients in the diet of ruminants.

5.2. Spineless cactus based diets

Based on the chemical composition and ME content (Table 4.1) of the ingredients, ten diets were formulated to contain varying levels of spineless cactus in the diets (Section 3.1.3). The roughage to concentrate ratio of all the diets were maintained at 40:60. Diet D1 comprised FMS and CFM, and served as control. In diets D2, D3, D4 and D5, the FMS was replaced by spineless cactus (part by part) at 20, 30, 40 and 50 per cent, respectively, equivalent to 0, 8, 12, 16 and 20 per cent of the total diet. Similarly in diets D6, D7, D8 and D9, the CFM was replaced by spineless cactus (part by part) at 20, 30, 40 and 50 per cent, respectively. equivalent to 12, 18, 24 and 30 per cent of the total diet. Diet D10, spineless cactus was included in the diet replacing 50 per cent each of FMS (20 per cent) and CFM (30 per cent), thus substituting 50 per cent of the total diet. Diets were evaluated for chemical composition (Table 4.2), ME determination and rate of fermentation *in vitro* (Table 4.3).

Considering the composition of diets D2, D3, D4 and D5, since the OM content was low in spineless cactus, the OM content (per cent) decreased from 93.7 in diet D1 to 93.04 in diet D5. The higher CP content of spineless cactus (7.11 per cent), compared to FMS, resulted in the increase of CP from 11.6 in diet D2 to 11.9 in diet D5. The low OM content of spineless cactus also decreased the OM of diets from 92.9 in diet D6 to 91.6 in diet D9. Similarly, the low CP content of spineless cactus (7.11 per cent) resulted in the decrease of CP from 10.4 in diet D6 to 8.9 in diet D9. The NDF (36.2 to 48.7 per cent) and ADF (19.2 to 28.2 per cent) content of all the diets (D1 TO D10) were adequate and met the minimum recommended levels for optimum ruminal fermentation (Van Soest, 1994)

5.3. *In vitro* evaluation

5.3.1. Potential gas Production

The gas produced (ml/200 mg DM) by the RIVIGP from FMS, CFM and Spineless cactus were presented in Table 4.1. Potential gas production of FMS was 49.9ml which agrees with values reported by Ajith *et al*. (2017). The potential gas production of spineless cactus was 54.3 ml which also corroborated with the values of Batisa *et al*. (2003a), Abidi *et al*. (2009) and Ajith *et al*. (2017). The potential gas production increased from 61.1 ml in diet D2 to 65.5 ml in diet D5 whereas, it decreased from 59.2 ml in diet D6 to 52.8 ml in diet D9. The potential gas production (ml) in diets D1 and D10 were 60.6 and 54.6, respectively.

5.3.2. Metabolisable energy content

The ME (MJ/kg DM) content predicted from rumen *in vitro* gas production technique for FMS was similar with those reported by Krishnamoorthy *et al*. (1995) and Biradar *et al*. (2014). The ME content of the spineless cactus was 8.82 MJ/kg DM. Taasoli *et al.* (2011) reported ME content of spineless cactus as 8 MJ/kg DM which is lower than the values recorded in this study, while Tegegne *et al*. (2007) reported 8.6 MJ/kg DM of ME, similar to the present study. The ME content (MJ/kg DM) increased from 11.5 in diet D2 to 11.8 in diet D5 due to higher ME content of cactus. In diets D6 to D10, the ME content (MJ/kg DM) decreased from 10.8 in diet D6 to 10.4 in diet D9 owing to the higher ME content of CFM. The ME content of 9.82 MJ/kg DM in diet D10 seemed adequate to meet the requirement of adult sheep for maintenance at optimum levels of feed intake.

5.3.3. Rumen degradable protein

The soluble protein content (per cent of CP) of diet D1 and D10 were 41.3 and 31.4 respectively (Appendix 1) Krishnamoorthy and Singh (1985) suggested that the optimum soluble protein content of the feedstuff should be in the range of 30 to 42 per cent for maximum efficiency of nitrogen utilization and microbial protein synthesis. Therefore, the levels of soluble protein in diets D1 and D10 were adequate for optimum activity of rumen microbes and meeting the requirement of ruminants.

The RDP content of diets D1 and D10 were 69.3 and 70.6 per cent respectively. (Appendix 1). The RDP content of both the diets were found to be adequate to meet the requirement of protein (NRC, 2001).

5.4. Assessment of the intake of spineless cactus by experimental rams

5.4.1. Intake assessment trial

The objective of this experiment was to evaluate the nutritional value of spineless cactus by assessing the intake of spineless cactus in adult sheep fed straw based diets. Spineless cactus was substituted in the diet replacing 20 per cent each of the FMS and CFM (30 percent), equivalent to 50 per cent of the total diet.

The experiment consisted of two groups of rams fed treatment diets viz. group 1 fed a control diet (T1) comprising FMS (20 per cent) and CFM (30 per cent) of the diet to meet the maintenance requirement, and group 2 fed calculated quantities of 50 per cent of the FMS and 50 per cent of the CFM and, spineless cactus fed *ad libitum* (T2). The basis for substituting 50 per cent each of 20 per cent FMS and 30 per cent of CFM with spineless cactus in the diet is as follows.

The chemical and *in vitro* analysis of the diets replacing FMS (diet D2 to D5) and CFM (diets D6 to D9) with spineless cactus showed that the ME and CP content were adequate in the diets with maximum replacement levels of 50 per cent FMS (diet D5) and CFM (diet D9). Hence, diet D10 was formulated to contain 50 per cent of the control diet (diet D1) replaced by spineless cactus (FMS, 20 % + CFM, 30 % + Spineless cactus, 50 %). Further, evaluation of diet D10 revealed that the ME, CP, RDP, UDP and the soluble protein content was adequate to meet the requirement of adult sheep. Therefore, it was decided to replace 50 per cent each of 20 per cent FMS and 30 per cent of CFM by spineless cactus in the diet (T2).

The diets for the experimental adult rams in control group (T1) were formulated individually to meet the energy and crude protein requirement for maintenance as per ARC (1984). Dietary feedstuffs were offered in calculated quantities with FMS fed at 1.0 per cent of the body weight and the CFM fed at the rate of 1.5 per cent of the body weight. The ratio of roughage: concentrate ratio was maintained at 40:60. In order to replace both the FMS and CFM by spineless cactus in group 2, the quantity of FMS and CFM offered was restricted to 20 per cent and 30 per cent, respectively of the calculated quantities. Spineless cactus was offered *ad libitum*.

5.4.2. Dry matter intake

The total DMI was 549 and 484 g per day for T1 and T2 groups, respectively (Table 4.3). There was a significant difference in the DMI (g per day, as per cent body weight or g per kg metabolic body weight) between the two treatment groups. The DMI of control group (T1) was similar to those reported by Gebremariam *et al.* (2006) who fed the sheep on Tef straw based diets in their experiment.

In group T1 (control), the intake of FMS and CFM was 46:54 (against 40:60). In group T2, the amount of FMS and CFM offered was restricted to 20 percent and 30 per cent of the total diet respectively of the calculated quantities. Obviously, The intake of FMS and CFM (g per day, as per cent body weight or g per kg metabolic body weight) was significantly different between the two groups. Rams of group T2 were offered spineless cactus *ad libitum*. It was expected that the animals in this group would consume spineless cactus in such quantities equivalent to the replacement of FMS (20 per cent) and CFM (30 per cent). Against the expected 50 per cent of total DMI by the cactus in group T2, the intake of cactus was 42.8 per cent. Spineless cactus was considered as a CFM component and consequently, the ratio of roughage: CFM was shifted to 27:73.

The mean daily intake (DM) of spineless cactus per day was 207g, equivalent to a 2.43 kg of fresh cactus. The DMI of cactus as per cent of body weight was 1.05. The intake of spineless cactus depends on the age, body weight, dietary regime and adaptation of the animals for feeding spineless cactus (Ben Salem *et al*., 1996). The intake of fresh spineless cactus ranged from 3 kg to 8 kg as reported by Sirohi *et al*. (1997), Ben Salem *et al*. (2002), Tegegne *et al*. (2007) and Santos *et al*. (2010). The intake was high in these studies since the diet consisted mainly of spineless cactus and hay. Gebremariam *et al*. (2006) and Degu *et al*. (2009) supplied concentrate feed along with spineless cactus and consequently the intake level was lower (2.7 kg and 1.5 kg, respectively). Similarly the intake of spineless cactus was possibly low (2.43 kg) in this study, due to the higher rate of feeding CFM (0.6 per cent of the body weight).

5.4.3. Nutrient intake

5.4.3.1. OM, NDF and ADF intake

The intake of OM was significantly higher in group 1 (control) than group 2 (Table 4.3). The OM intake of group 1 (diet T1) was similar to the reported values of Gebremariam *et al*. (2006), but lower than that reported by Degu *et al*. (2009). The NDF and ADF intake as per cent body weight and as g per kg metabolic body weight was similar to that reported by Sirohi *et al.* (1997). The intake of NDF and ADF (as g per day or per cent body weight or per kg metabolic body weight) was similar between the two group.

5.4.3.2. Energy, Crude protein, RDP and RUP intake

The daily mean intake of energy and protein of the experimental rams are presented in Table 4.4. The requirement of energy and protein for the rams were calculated for maintenance requirement in g per day as per ARC (1984). The mean intake level of energy and protein exceeded the requirements of ARC (1984) in both the groups. The intake of RDP was marginally low for group T2 (intake of 30.8g against the requirement of 35.8) (Table 4.4). However, the intake of RUP was higher in group 2 (13.2 g intake against 0.0 g requirement) and expected to recompense to meet the CP requirement.

5.4.3.3. Water intake

The mean daily water intake (kg) was 1.24 and 0.618 for T1 and T2 groups, respectively (Table 4.5). Water intake when expressed as kg, per kg feed DMI, the intake was 2.45 and 0.22 for groups T1 and T2 respectively. The water intake was significantly lower in group T2 compared to group T1 ($P<0.05$). The average intake of water in control group was similar to that reported by Tegegne *et al*. (2007). Significant lower intake of water in group T2 ($P<0.05$) compared to group T1 indicated that the spineless cactus was a potential source of water, to meet the water requirement of the animal. De Kock (1980) observed that sheep kept in pens could be maintained without water for more than 500 days if they have daily access to sufficient quantities of fresh cactus and reported a linear decrease in the voluntary intake of water with increasing levels of cactus inclusion. Gebremariam *et al*. (2006) and Gusha *et al*. (2014) observed a linear decrease in the intake of water with increase in level of cactus inclusion in the diet. These observations and the findings of the present study imply that the spineless cactus in the diet can serve as a source of water to meet the need of the body in sheep.

5.5. Body weight change

The body weight (average daily gain, g) was 7.94 and 5.95 for groups T1 and T2 respectively, with no significant difference between the treatment groups (Table 4.6). The observed increase in body weight corroborated with the earlier reports of Costa *et al*. (2012) in Santa Ines sheep. Marginal weight gain of experimental rams in both the groups in the experiments is suggestive of adequate ME intake to meet the maintenance requirement and that the animals were in positive energy balance.

5.6. Digestion trial

5.6.1. Apparent nutrient digestibility

The digestibilities of DM and OM in the diet of group T2 were higher than group T1 ($P<0.05$) (Table 4.7). while the digestibility of CP, NDF and ADF were not significantly different among the treatment groups. In accordance with the results of this study, Costa *et al*. (2012) also noticed higher digestibility of OM with higher levels of cactus inclusion in the diet of growing Santa lambs, wherein, the cactus replaced 50 per cent of the corn in the diet. Higher digestibility of OM in the group T2, resulted in higher digestible organic matter content compared to group T1 (73.3 per cent vs 67.1 per cent). Digestible organic matter in dry matter are comparable to TDN in ruminants (Van Soest,1994) and therefore increased DOMDM content facilitated the animals of group T2 to meet energy requirement at low DMI (Table 4.3) .

5.7. Overall discussion

The overall results of the present study indicated that Spineless cactus (containing 8.82 MJ, ME/kg) could be a source of energy for inclusion in the diet of adult sheep. While substituting the spineless cactus in the diet (group T2), the FMS (20 per cent) and CFM (30 per cent) was offered at 50 per cent of calculated requirement and that the spineless cactus was fed *ad libitum.*

Inclusion of cactus in the diet significantly decreased the voluntary intake of water (*per se* or per unit feed DM intake) in group T2. Thus spineless cactus could be a passable source of water (91.5 per cent) to meet the water need of the body. The ME content in the diet T2 (9.8 MJ, ME/kg DM) was adequate to meet the requirement of complete diet for adult sheep. Cactus can be good source of calcium, zinc, iron and manganese. The increased digestibility of DM and OM in group T2 could be possibly due to higher level of Zinc (Hedemann *et al*., 2006). The low CP content of the spineless cactus (7.11%) resulted in decreased CP content of the diets (9.42 per cent). The rumen degraded protein content of diets (70.1 per cent of CP) was optimum to meet the requirement. The DMI of T2 group was significantly lower compared to T1 group (549 vs. 484 g). The roughage to CFM ratio was 46:54 in T1 group (control). Considering the cactus as a source of concentrate, the roughage to CFM ratio was shifted to 27:73 in T2. The ME and CP provided in diet of group T2 was adequate to support the maintenance requirement (ARC, 1984) of adult sheep. A marginal increase in body weight of 5.95 g per day, indicated a positive energy balance of the animals to meet the maintenance requirement of ME and CP. The total CP intake was adequate to meet the requirement (44 g intake as against 35.8 g requirement, ARC 1984). While the RDP intake was adequate in group T1 (39 g intake as against 35.4 g requirement, ARC 1984), the RDP intake was marginally lower in group T2 (intake of 30.8 g vs. 35.8 g of requirement). This warrants supplementation of NPN or other protein sources to make up the requirement of RDP, when cactus is included in the diet. The UDP supplied in the diet in excess of the requirement, could be expected to counter the marginal deficiency of RDP, to meet the total CP requirement. In the present study, the mean intake of fresh spineless by adult sheep (mean body weight of 24.0 kg) was 2.43 kg per day. The DMI as per cent of body weight was 1.05. The digestibility of OM was higher in diet T2 resulting in the higher content of DOMDM (72.3 per cent) compared to T1 (67.1 per cent) thus increasing the energy density of the diet.

Considering the overall performance of the animals in terms of feed intake, digestibility and body weight change, it was concluded that spineless cactus could replace 42.8 per cent of the total diet, substituting FMS (20.5 per cent) and CFM (22.3 per cent) in the diet of adult sheep.

SUMMARY

VI. SUMMARY

A study was conducted to evaluate the nutritional value of Spineless cactus (*Opuntia ficus indica*), to assess the intake and performance of adult sheep fed straw based diets. The experiments consisted of chemical and *in vitro* evaluation of diets containing spineless cactus, an intake assessment trial and an *in vivo* digestibility trial. The spineless cactus was substituted in the diet to replace 50 per cent of each of the finger millet straw (FMS) and compounded feed mixture (CFM) (diet T2), and the effect of feeding such a diet on the feed intake, digestibility and adequacy of meeting the maintenance requirement of adult sheep was compared with a control diet (T1).

The chemical analyses of spineless cactus revealed that it contained 91.5 per cent moisture; 7.11 per cent crude protein; 3.01 per cent ether extract; 39.8 per cent neutral detergent fibre; 26.2 per cent per cent acid detergent fibre; 13.9 per cent Ash and Metabolizable energy of 8.82 MJ/kg DM. Based on the ME and chemical composition of the dietary ingredients, ten complete diets (D1 to D10) were prepared by mixing FMS and CFM in the ratio of 40:60.

The descriptions of the diets are as follows:

D1 - FMS (40 %) + CFM (60 %)

D2 - FMS (32 %) + CFM (60 %) + Spineless cactus (08 %)

D3 - FMS (28 %) + CFM (60 %) + Spineless cactus (12 %)

D4 - FMS (24 %) + CFM (60 %) + Spineless cactus (16 %)

D5 - FMS (20 %) + CFM (60 %) + Spineless cactus (20%)

D6 - FMS (40 %) + CFM (48 %) + Spineless cactus (12 %)

D7 - FMS (40 %) + CFM (42 %) + Spineless cactus (18 %)

D8 - FMS (40 %) + CFM (36 %) + Spineless cactus (24 %)

D9 - FMS (40 %) + CFM (30 %) + Spineless cactus (30 %)

D10- FMS (20 %) + CFM (30 %) + Spineless cactus (50 %)

The diet D1 comprised FMS and CFM (without spineless cactus) and served as control. The diets D2, D3, D4 and D5 contained 20, 30, 40, and 50 per cent respectively of the FMS replaced (part by part) by spineless cactus while, the diets D6, D7, D8 and D9 contained 20, 30, 40 and 50 per cent, respectively of the CFM replaced (part by part) by spineless cactus. Diet 10 contained 50 per cent each of the FMS and CFM replaced by spineless cactus. The results of chemical analyses and *in vitro* studies obtained from this study were used for optimum level of replacement of the FMS and CFM by spineless cactus in intake assessment trial. The ME values obtained by RIVIGP showed that the inclusion of spineless cactus in complete diets did not affect the ME values. *In situ* evaluation of the diet (D10) revealed that replacing spineless cactus will maintain adequate levels of RDP: UDP ratio, as per the requirement of ruminants (NRC, 2001).

An intake assessment trial was conducted to assess the optimum level of inclusion of spineless cactus in the diet for maintenance of adult sheep. The diet of the experimental rams was made from FMS, CFM and the Spineless cactus.

The two groups of rams were allotted randomly to two treatment diets as follows.

Group 1: Diet T1 – Finger millet straw (40 per cent) + Compounded feed mixture (60 per cent). This group served as control.

Group 2: Diet T2 – 20 per cent of the Finger millet straw + 30 per cent of the Compounded feed mixture + Spineless cactus (*ad libitum*)

The diets for the experimental rams were formulated individually to meet the ME and CP requirement for maintenance as per ARC (1984). Dietary ingredients were offered to individual rams in Group 1 (control) in calculated quantities with FMS fed at 1 per cent of the body weight and the CFM fed at the rate of 1.5 per cent of the body weight. In order to replace the FMS and CFM by spineless cactus, in Group 2, the quantity of FMS (20 per cent) and CFM (30 per cent) offered was restricted to 50 per cent of the calculated quantities. Spineless cactus was offered *ad libitum* to group 2.

The total DMI was 549 and 484 g per day for T1 and T2 groups, respectively. There was a significant decrease in the DMI (g per day, as per cent body weight or g per kg metabolic body weight) in group 2 fed T2 diet compared to group 1 fed control diet. The daily dry matter intake as per cent body weight was 2.32 and 2.02 for T1 and T2, respectively. The mean daily intake (DM) of spineless cactus per day was 207g, equivalent to a 2.43 kg of fresh cactus. The DMI of cactus as per cent of body weight was 1.05.

The mean intake of energy and protein exceeded the requirements of ARC (1984) in both the experimental groups. The intake of RDP was marginally lower for group T2 (intake of 30.8g against the requirement of 35.8). However, the intake of RUP was higher in group 2 (13.2 g intake against 0.0 g requirement) and expected to recompense to meet the CP requirement. The average body weight gain (g) per day for T1 and T2 groups was 7.94 and 5.95, respectively. A marginal increase in body weight of experimental animals indicated a positive energy balance of the animals to meet the maintenance requirement of ME and CP.

The voluntary intake of water was significantly lower in group 2 fed spineless cactus (T2) (0.618 kg per day) compared to control group (1.24 kg per day) ($P<0.05$). Therefore spineless cactus provided a major source of water to meet the water need of the animals.

The mean apparent digestibility (per cent) of nutrients for T1 and T2 groups with respect to DM, OM, CP, NDF and ADF were 68.9 and 75.2; 74.1 and 78.1; 70.8, and 75.2; 59.5 and 63.5; 53.9 and 58.2, respectively. There was no significant difference between the treatments except for dry matter and organic matter digestibility which was higher in group T2, wherein, spineless cactus replaced 50 per cent each of the CFM and FMS in the diet. The higher digestibility of DM and OM in group T2 resulted in the higher content of DOMDM (72.3 per cent) thus increasing the energy density of the diet, to meet the requirement.

The mean intake of spineless cactus (DM, g per day) was 207 (equivalent to fresh spineless cactus intake of 2.43 kg per day). The DMI as per cent of body weight was 1.05. Considering the overall performance of the animals in terms of feed intake, digestibility and body weight change, it was concluded that spineless cactus could replace 42.8 per cent of the total diet, substituting FMS (20.5 per cent) and CFM (22.3 per cent) in the diet of adult sheep.

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ABSTRACT

VIII. ABSTRACT

This experiment was conducted to study the nutritional value of spineless cactus (*Opuntia ficus indica*) on intake potential and performance of adult sheep fed straw based diets. The optimum level of inclusion of spineless cactus in the diet of adult sheep and its effect on the feed intake and digestibility of nutrients was studied. The spineless cactus contained 91.5 per cent moisture, 7.1 per cent CP, 39.8 per cent NDF and 26.2 per cent ADF. The ME content was 8.82 MJ/kg DM. In a Switch over design experiment comprising two periods of six weeks each, six rams averaging 23.5 kg body weight were selected and divided into 2 groups of three each. Group 1 received a control diet (T1) containing finger millet (*Eleusine coracana*) straw (40 per cent) and a CFM based on corn (60 percent). Group 2 was fed diet T2 comprising FMS (20 per cent) and CFM (30 per cent) with spineless cactus (fed *ad libitum*) replacing 50 per cent of the diet. There was no significant difference in the intake of dry matter or nutrients between the treatment groups. The average daily body weight gain (g per day) was 7.94 and 5.95 for groups T1 and T2, respectively with no significant difference between the two groups. The marginal increase in body weight of experimental animals indicated a positive energy balance of the animals to meet the maintenance requirement of ME and CP. The digestibility of organic matter was higher in rams of group T2 compared to groups T1 ($P<0.05$), resulting in higher total digestible organic matter with cactus inclusion in the diet. The voluntary water intake was significantly lower in rams of group T2 compared to group T1 ($P<0.05$). It was concluded that the spineless cactus could be included in the diet of adult sheep replacing 20.5 per cent of the FMS and 22.3 per cent of the CFM, equivalent to 42.8 per cent of the total diet.

APPENDIX

IX. APPENDIX

Protein fractionation of experimental diets estimated by *in situ* evaluation

Variable	Diet 1	Diet 10
Crude protein (% of total DM)	11.5	9.4
[1]Soluble protein (% of total DM)	41.3	31.4
[2] Rumen degradable protein (% of Crude protein)	69.3	70.6
[3] Rumen undegradable protein (% of Crude protein)	30.7	29.4

Diet 1: Control; D1-FMS (40 %)+CFM (60 %) ; Diet 10: D10- FMS (20 %)+CFM (30 %) +Spineless cactus (50 %)

(FMS=Finger millet straw; CFM= Compounded feed mixture)

1Dry matter disappearing in 0.1hr of incubation (a)

[2]a+b(Kd/Kd+Kp)

Where, a = Soluble fraction

b = Degradable fraction

Kp is the rate of passage, taken as 0.056/h

Kd Rate of degradation

[3]100-(RDP)