

Use of cactus pear (*Opuntia ficus-indica*) as forage in the diet of small ruminants

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Abstract

Pitacas, F. I., Reis, C. M. G. & Rodrigues, A. M. (2026). Use of cactus pear (*Opuntia ficus-indica*) as forage in the diet of small ruminants. *Bulg. J. Agric. Sci.*, 32(3), 728–740

The use of cactus pear (*Opuntia ficus-indica* (L.) Miller) has proven to be a viable alternative for feeding small ruminants, particularly in arid and semi-arid regions. It serves as an accessible source of water and nutrients, partially replacing more expensive and less available feeds, especially during periods of feed scarcity. This review examines the nutritional value and chemical composition of cactus pear cladodes and their application in small ruminant feeding. Additionally, general aspects related to planting systems, biomass production, and cladode storage are discussed. Three examples of diets incorporating *Opuntia ficus-indica* cladodes in small ruminant feeding are presented: Assaf sheep breed, fattening lamb, and Saanen goat breed. In these diets, the proportion of fresh *O. ficus-indica* cladodes varied between 51.3% and 79.2%. A literature review was conducted to evaluate the impact of cactus pear cladodes on meat and milk production and quality.

In general, *O. ficus-indica* cladodes exhibit low levels of dry matter (DM), crude protein (CP), and neutral detergent fibre (NDF). However, they are an excellent source of energy, rich in non-fibrous carbohydrates, and have a high DM digestibility. Given the importance of DM, CP, and NDF in ruminant nutrition and the high-water content of cladodes, *O. ficus-indica* can be effectively integrated into diets when animals have access to dry forage and a high-CP feed source. The use of *O. ficus-indica* represents a promising option for feeding small ruminants, offering a sustainable solution to reduce dependence on imported feeds and contributing to a lower carbon footprint, without compromising meat and milk production or quality.

Keywords: animal nutrition; cactus pear; cladodes; diets; forage; prickly pear

Abbreviations: ADF – Acid detergent fibre; CAM – Crassulacean Acid Metabolism; CP – Crude protein; DWG – Daily weight gain; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; ESACB – School of Agriculture of the Polytechnic Institute of Castelo Branco, Portugal; LW – Live weight; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates; TDN – Total digestible nutrients.

Introduction

In the Cactaceae family, the genus *Opuntia* is one of the most representative of the Opuntioideae subfamily, with *Opuntia ficus-indica* (L.) Miller being the species of greatest economic importance worldwide. Its domestication centre is

located in Mexico (Griffith, 2004). The cactus pear was introduced to the Iberian Peninsula by Spanish conquistadors in the late 15th and early 16th centuries (Barbera et al., 1992; Casas and Barbera, 2002), and subsequently spread throughout the Mediterranean basin (Le Houérou, 1996).

Opuntia ficus-indica is cultivated for its fruits, which are

a source of antioxidant compounds (Angulo-Bejarano et al., 2014), and its cladodes represent an interesting alternative for animal feed, providing energy, water, and minerals during periods of food and water scarcity (Andrade-Montemayor et al., 2011). It is also used to produce young cladodes for human consumption, known as “nopalitos” in Mexico (Sáenz, 2000), cochineal dye (Anderson, 2001), and as a medicinal plant (Kaur, 2012). The betaxanthin and betacyanin pigments present in the fruits can be used as natural colorants in food products (Gengatharan et al., 2015); the seed oil has applications in the food, pharmaceutical, and cosmetic industries (Ramadan and Mörsel, 2003; De Wit et al., 2016); and the physicochemical properties of the cladodes make them suitable for biogas and bioethanol production (Jigar et al., 2011; Sánchez et al., 2012). The cactus pear also plays an important role in erosion control and land rehabilitation, particularly in arid and semi-arid regions, while also serving as shelter and a food resource for wildlife (Le Houérou, 2002). Additionally, it can be considered a potential carbon sink, absorbing and retaining excess CO₂ in areas where it can establish itself, often where no other vegetation grows (Nobel and Bobich, 2002).

Semi-arid regions are characterized by seasonal and irregular precipitation, ranging from 250 to 500 mm per year, with vegetation primarily composed of shrubs, cacti, and grasses. The main economic activity in these regions is livestock farming, predominantly goat husbandry, due to goats feeding habits and their ability to adapt to low rainfall and limited food availability (Andrade-Montemayor et al., 2011). Poor forage quality, insufficient food supply, and water scarcity are among the main factors directly affecting animal production in these areas (Tegegne et al., 2007).

In recent years, there has been growing interest in *O. ficus-indica* due to its significant role in arid and semi-arid regions. In these areas, the use of *O. ficus-indica* cladodes as forage for ruminants has become crucial, especially during prolonged droughts with high summer temperatures, which lead to low forage availability. The species has developed several adaptations that enable it to thrive in harsh conditions by providing highly digestible energy, water, and minerals. When combined with a protein source, it constitutes a complete feed (García et al., 2001). The ecological success and agricultural usefulness of *Opuntia* spp. are largely derived from their daily stomatal opening pattern. *Opuntia ficus-indica* exhibits nocturnal stomatal opening, during which net CO₂ fixation occurs along with minimal water loss through transpiration, as part of the CAM physiological process (Nobel, 1988).

In Mediterranean countries, many regions face severe droughts, particularly during the long summers, and global

warming is expected to have a profound impact on these areas. Due to its morphological and physiological characteristics, as well as its multiple economic uses, cactus pear presents a viable alternative crop for these regions, well-suited to drought, irregular rainfall, and poor soils prone to erosion. Cactus pear also plays a stabilizing role in agriculture by preventing livestock loss during drought periods, protecting natural pastures from overgrazing, increasing farm income, and alleviating rural poverty. Although low in fibre and crude protein (CP), *O. ficus-indica* has good palatability, high-water content, and high in vitro digestibility, often being the only source of green forage during the dry season (Silva and Santos, 2007; Ben Salem and Ennouri, 2013).

A commonly used strategy to enhance the performance of ruminants in Mediterranean and semiarid regions is proper feed management during periods of forage scarcity. In some cases, cactus pear has been used as forage for sheep (Ben Salem and Smith, 2008; Rekik et al., 2010; Costa et al., 2012a), dairy goats (Costa et al., 2009; Andrade-Montemayor et al., 2011), and dairy cows (Silva and Santos, 2007; Vilela et al., 2010). Additionally, some authors have evaluated cactus pear as a water source for sheep (Tegegne et al., 2007) and dairy goats (Costa et al., 2009).

Given the renewed interest in *Opuntia ficus-indica* among farmers and small ruminant producers, it is essential to evaluate its chemical composition and compare it to other forages to optimize its use as fodder. This manuscript aims to explore the potential of cactus pear as animal feed and its role in small ruminant nutrition. It examines the nutritional value and chemical composition of cactus pear cladodes, along with their application in small ruminant feeding. Additionally, planting systems, biomass production, and cladode storage are discussed. Three examples of diets incorporating *O. ficus-indica* cladodes are presented. A review of the literature evaluates the impact of cactus pear cladodes on meat and milk production and quality.

Planting systems

Species of the genus *Opuntia* are propagated clonally by placing cladodes on the soil, which root from the areoles, thus generating new plants. The cladodes should be between 1 and 4 years old, free of wounds, and collected from healthy and vigorous plants. The cladodes are separated from the mother plant by making a clean cut with a sharp knife at the joint area. The base of the cladodes is disinfected and left to air-dry in the shade to undergo a healing and suberization process, sealing potential points of water loss (Inglese et al., 2002).

In fruit production orchards, plant spacing varies considerably depending on the hemisphere, country, and environ-

mental conditions. In Italy, planting distances are generally wide, ranging from 6×6 m (278 plants ha^{-1}) to 4×6 m (416 plants ha^{-1}) (Inglese et al., 2002). In other Mediterranean regions, narrower planting frameworks are used. For example, in Israel, a spacing of 1.5 m between plants within the row and 4 m between rows (1,666 plants ha^{-1}) is employed to increase fruit production during the initial stages of orchard development (Nerd et al., 1991). In fruit orchards, plants are pruned annually to regulate sugar allocation among different sink points within the canopy and to maximize light penetration, promoting cladode growth, floral bud formation, and fruit development. Additionally, pruning facilitates pest control, fruit thinning, and harvesting (Inglese et al., 2002). The cladodes removed during pruning can serve as a valuable feed source for livestock.

Intensive plantations for forage production are limited to a small number of countries, occurring mainly in northeastern Brazil and some areas of Mexico (Dubeux et al., 2017). To maximize yield in *cut-and-carry* forage production systems, a narrow spacing of approximately 1.2×1.2 m is recommended. However, for direct grazing, a spacing of 1.0 to 1.5 m between plants within the row and 3 to 5 m between rows is preferable (Felker et al., 2006). In Brazil, recent spacing recommendations for forage production are 1.6×0.2 m for *Opuntia* and 1.2×0.2 m for *Nopalea* (Dubeux et al., 2017). Maintenance fertilization using mineral and organic fertilizers is a key management practice and should be performed after each harvest, considering the high nutrient removal due to cladode harvesting.

In Brazil, the common *O. ficus-indica* varieties used for animal feed are ‘Gigante’ and ‘Redonda’. However, an outbreak of the cochineal insect (*Dactylopius opuntiae* Cockerell) has led to changes in varietal recommendations. Recently, producers in the region have opted for insect-tolerant varieties such as ‘Orelha de Elefante Mexicana’ (*Opuntia* spp.) and ‘Miúda’ [*Nopalea cochenillifera* (L.) Salm-Dyck] (Dubeux et al., 2017). Under similar environmental conditions, *N. cochenillifera* generally exhibits higher concentrations of dry matter (DM), water-soluble carbohydrates, and *in vitro* organic matter digestibility, along with a lower crude protein content compared to *O. ficus-indica* (Dubeux et al., 2021).

Biomass production

Intensive forage production systems from cacti are limited to a small number of countries, mainly in northeastern Brazil and some areas of Mexico (Dubeux et al., 2017). *Opuntia ficus-indica* is particularly attractive as animal feed due to its efficiency in converting water into dry matter and, consequently, into digestible energy. The most notable fea-

ture of this species is its enormous potential to produce large amounts of green and succulent forage, even under relatively unfavourable conditions (Nobel and Bobich, 2002). The cactus pear provides a continuous and valuable supply of fresh forage during the dry season, thanks to its succulent, evergreen vegetative structure, a characteristic rarely found in other forage species.

Biomass production depends on various factors such as genotype, planting density, environmental conditions, and agronomic practices. *Opuntia ficus-indica* can produce more than 20 tons of dry matter per hectare per year and provide 180 tons of water per hectare per year, stored in its cladodes, which represents an economical option for animal hydration (Dubeux et al., 2015). Among agronomic practices, irrigation is one of the most important factors. The same authors mention that the use of drip irrigation (only 10 mm per month) allows for annual dry matter yields of up to 19.6 tons per hectare in a region where cactus pear would not grow well due to low rainfall and high night-time temperatures.

In the semi-arid region of northeastern Brazil, in small agricultural holdings with intensive production systems, dense populations (> 40,000 plants per hectare) of *O. ficus-indica* and *Nopalea cochenillifera* are commonly observed for forage production. In these systems, for well-managed crops, dry matter productivity varies between 10 and 25 tons per hectare per year, although in research centres, dry matter productivity of up to 30 tons per hectare per year has been recorded (Dubeux et al., 2013).

In a study with *O. ficus-indica*, Cortázar and Nobel (1992) obtained a dry matter yield of 5.5 tons per hectare in the second year after planting, under irrigation conditions and with a density of 2 500 plants per hectare. According to the same authors, when well-irrigated and fertilized, this species can achieve a growth rate of 47 tons per hectare per year, a value higher than the typical biomass yields of maize. Productivity without supplemental irrigation in semi-arid and arid conditions ranges from 9–15 and 3–15 tons per hectare per year, respectively, values higher than those of other low-water-consumption crops (Le Houérou, 1996). In another study (Reis et al., 2018), a dry matter productivity of 3.9 tons per hectare was obtained with a density of 2 667 plants per hectare (0.27 plants per square meter) with the cultivar ‘Gialla’ in the second year after planting.

Cladode harvesting and storage

In Northeast Brazil, cladodes for animal feed are typically harvested after two years of growth, and the chemical composition of the collected material is a mixture of cladodes of different ages (Dubeux et al., 2021). The plants are supplied to animals as fresh forage in a *cut-and-carry* sys-

tem. After harvest, the cladodes are transported to storage, cut, and mixed with other feed (Dubeux et al., 2017). This method helps prevent waste and overgrazing. The cladodes can be stored fresh or preserved, either as silage or dried.

Santos et al. (1998) studied the effect of experimental treatments involving three storage intervals for *O. ficus-indica* after harvest: 0, 8, and 16 days. Throughout the study period, they generally observed only small variations in the content of DM, ether extract (EE), CP, mineral extract, and non-nitrogenous extract. They also found no effects of the storage periods on the intake of fresh *O. ficus-indica*, silage, or compound feed by the animals. The data suggested that lactating cows could receive *O. ficus-indica* stored for up to 16 days without compromising their performance.

In another study, Santos et al. (2024) investigated the effect of different storage periods (0, 8, 16, 24, 32, 40, 48, and 56 days) on the chemical composition and deterioration rate of *O. ficus-indica* cladodes. The study confirmed that cladodes can be stacked and stored in a shaded, well-ventilated area for up to 24 days without significant losses in dry matter, crude protein, crude fibre, or water-soluble carbohydrates, although some deterioration may occur (< 25%). Cladodes can even be stored for up to 56 days without changes in crude protein and neutral detergent fibre levels. However, water-soluble carbohydrate concentrations begin to decline after 24 days, which may be related to cellular respiratory activity.

The absence or minimal variation in the chemical composition of *O. ficus-indica* during storage periods can be attributed to the morphophysiological characteristics of this species, which follows the CAM pathway (Santos et al., 1998). Neri et al. (1993) observed that young cladodes did not undergo rapid degradation of reserve polymers, as seen in C3 and C4 plants, after being separated from the parent plant. The same authors also noted that both visible senescence signals and the physiological changes associated with this process are delayed more under light storage conditions than in darkness. Harvesting cladodes in large quantities and storing them for at least two to three weeks can effectively reduce both labour and transportation costs.

In certain circumstances, producing silage from cladodes can be advantageous, especially when their availability is concentrated within a short period. This situation occurs during pruning in fruit production plantations or when wet agro-industrial by-products cannot be stored for long periods and need to be utilized efficiently. To obtain high-quality silage, proper lactic fermentation is essential, requiring adequate moisture levels (30–40%) and sugar content in a completely anaerobic environment (Dubeux et al., 2017). Cladodes contain sufficient carbohydrates for effective lactic fermentation;

however, their high-water content (85 – 92%) necessitates careful mixing with other materials (e.g., chopped straw). The ideal proportion may vary, but it is recommended to mix around 30–50% dry matter with *Opuntia* to reduce moisture content and ensure proper fermentation. The addition of dry material enhances fermentation and prevents issues such as excessive moisture in the silage, which could lead to spoilage losses.

In the case of cladode dehydration, this is a costly process as it requires cutting and drying. Since cladodes maintain their nutritional value for an extended period after harvest, preservation techniques such as ensiling or drying should only be used if they provide economic benefits (Dubeux et al., 2021).

Nutritive value

Species of *Opuntia* spp. have traditionally been used as fodder in various semi-arid and arid regions worldwide. In these areas, farmers burn the spines to enable sheep, goats, and cattle to consume the cladodes during periods of drought. The spines on the cladodes can cause injuries to the digestive system and must therefore be removed (Guevara et al., 2009). Considering the costs associated with burning the spines and the risk of injuries to animals, it is preferable to use spineless varieties of *O. ficus-indica* for animal feed.

The composition of *O. ficus-indica* cladodes depends on the season, the age of the plant, the order of the cladodes (position), the cultivar, fertilization, planting density, and environmental factors (Dubeux et al., 2021). Additionally, the cultivation site and the physiological state of the cladode tissue can influence its mineral content (Pastorelli et al., 2022).

The cactus pear offers considerable palatability, as well as a high mucilage and moisture content, making it a potential source of drinking water for animals (Nefzaoui and Ben Salem, 2001). In general, the cladodes of *O. ficus-indica* contain low levels of dry matter (10–15%), crude protein (4–6%), and neutral detergent fibre (NDF; 20 – 31%) (Azócar, 2001; Nefzaoui and Ben Salem, 2001; Costa et al., 2012b). Conversely, they are an excellent energy source, being rich in non-fibrous carbohydrates (NFC; 61.7%) and having a high coefficient of dry matter digestibility (Wanderley et al., 2002). Factors such as soil moisture and mineral content significantly influence the concentration of ash and minerals in the cladodes (Pastorelli et al., 2022).

Compared to conventional feeds, the cladodes of *O. ficus-indica* have a high ash content (Sawyer et al., 2001). Depending on the species and cultivar, the ash content ranges from 100 to 250 g kg⁻¹ DM, frequently exceeding 200 g kg⁻¹ DM. Their mineral composition is very low in sodium (Na), low in phosphorus (P), moderate in magnesium (Mg),

but high in potassium (K) and calcium (Ca) (Retamal et al., 1987; Galizzi et al., 2004).

According to Dubeux et al. (2015), the nutritional value of *O. ficus-indica* typically falls within the following ranges: 40–70 g kg⁻¹ for CP, 250–300 g kg⁻¹ for NDF, 180–200 g kg⁻¹ for acid detergent fibre (ADF), 650–700 g kg⁻¹ for total digestible nutrients (TDN), and 500–550 g kg⁻¹ for NFC. In another study, Rodrigues et al. (2016) reported that DM values ranged from 12.85 to 14.58%, metabolizable energy (ME) from 11.16 to 11.38 MJ kg⁻¹ DM, CP from 68.01 to 82.52 g kg⁻¹ DM, NDF from 164.67 to 198.99 g kg⁻¹ DM, ADF from 95.49 to 114.35 g kg⁻¹ DM, NFC from 612.38 to 665.58 g kg⁻¹ DM, and ash from 80.12 to 97.55 g kg⁻¹ DM.

Differences in DM content can be explained by variations in the age of the cladodes, harvest season, and genotypic differences. DM content tends to increase with the age of the cladode (Tegegne, 2001). Under normal conditions, the high-water content of the cladodes would be a disadvantage due to the high transportation costs of this forage. However, during drought periods in arid regions, the high moisture content of the cladodes becomes an advantage, as it significantly reduces the water requirements of animals (Feller et al., 2006). Water intake in dairy goats is significantly reduced when cactus pear is included in their diet (Costa et al., 2009). Nefzaoui and Ben Salem (1998) demonstrated that voluntary water intake drops to zero when sheep consume approximately 300 g of cladode dry matter per day.

Given that cladodes have low levels of crude protein, fibre, phosphorus, and sodium, they must be combined with other feeds to complete the daily diet (Nefzaoui and Ben Salem, 2001). Specifically regarding crude protein, nitrogen fertilization can increase its content by up to 10% (Gonzalez, 1989). Ca, followed by K, is the most abundant mineral in cladodes, but the availability of Ca for ruminal microflora and the host animal is compromised by the high oxalate content and the extremely elevated Ca-P ratio. Oxalates are insoluble and therefore non-toxic; however, they form complexes with Ca and Mg, making them unavailable to ruminal microflora and the host animal (Dubeux et al., 2017).

Animals fed exclusively on cactus pear may experience weight loss, reduced fat content in milk, and digestive disorders such as diarrhoea and bloating (Tegegne et al., 2007). Therefore, cactus pear should be combined with fibre sources to increase dry matter levels in the diet and maintain normal rumen conditions, preventing undesirable effects. According to Tegegne et al. (2007), cactus pear can replace up to 60% of hay and significantly contribute to meeting the water requirements of sheep. *Opuntia ficus-indica* can serve as a supplement to low-quality forage, such as straw, and the combination of both, along with a protein source, can be a

viable alternative for the nutrition of small ruminants in arid and semi-arid regions (Dubeux et al., 2017).

In summary, considering the information obtained on the chemical composition of cladodes, we can conclude that: i) cactus pear cannot be used as the sole feed source; ii) it must be supplemented with crude protein and fibre source; and iii) it is rich in soluble carbohydrates, making it necessary to avoid adding molasses and to limit the inclusion of grains or other sources of sugar/starch in the diet (Dubeux et al., 2015).

Formulation of diets for small ruminants

The cactus pear is a perennial plant that can be used as a valuable resource in animal feeding, particularly in situations where natural pasture production is insufficient. The partial replacement of forage and imported raw materials with *Opuntia* can reduce production costs and contribute to sustainability in arid and semi-arid regions. Its inclusion in animal diets can thus have a positive impact by reducing costly feed imports and water consumption, leading to a smaller carbon footprint and a positive environmental effect (Pastorelli et al., 2022).

When grazing, sheep consume less *Opuntia* than goats, as goats are less selective. However, when *Opuntia* is provided after being harvested and flame-treated (to remove spines when necessary), consumption can reach between 3 and 5 kg day⁻¹ (García et al., 2001).

According to Neves et al. (2010), in Brazil, *Opuntia* is distributed in the feeder after being chopped, without being mixed with any other feed. When used, compound feed is provided to the animals during milking. However, according to the same authors, the best way to supply *Opuntia* to ruminants is by mixing it with other forages (silage, hay, straw) and compound feed (concentrate). This approach ensures an adequate intake of nutrients without compromising rumen ecosystem function, milk production, or composition, thereby improving animal performance.

To maximize the use of cladodes in the feeding of small ruminants, they can be incorporated into the diet, provided they are combined with forage that has a higher dry matter content than the cladodes, along with compound feed. In this context, several factors must be considered to ensure adequate feed intake and the proper functioning of the rumen ecosystem. The DM content of the diet should exceed 40%, the NDF content should be above 35% DM (with 75% of the NDF coming from forages), the ADF content should be over 19% DM, the NFC content should remain below 36% DM, and the EE content should be under 5% DM (as excessive fat negatively affects the rumen microbial population). Additionally, the average particle size of the feed should exceed

1.5 cm to stimulate rumination and saliva production (ARC, 1980; AFRC, 1993; NRC, 2007).

Some authors (NRC, 2001) suggest that when the dietary dry matter content falls below 40%, the dry matter intake (DMI) decreases. Furthermore, when the diet contains NDF levels below 35% and NFC levels exceeding 36% of the total DM intake, the risk of metabolic diseases increases. This situation can result in both productive and economic problems for the production system.

This section explores the potential use of *O. ficus-indica* in the feeding of lactating sheep and goats, as well as in fattening lambs. For these small ruminants, three dietary regime examples were formulated.

Diet for an Assaf sheep breed

The first practical example refers to an Assaf sheep weighing 70 kg live weight (LW), at the beginning of lactation, producing 1.56 kg of milk per day with a fat content of 7%. The DMI for a sheep with these characteristics is 1.98 kg per day. The daily nutritional requirements are: ME \geq 19.79 MJ, CP \geq 292.0 g, EE \leq 99.0 g, NDF \geq 693.0 g, and NFC \leq 712.8 g (ARC, 1980; AFRC, 1993; NRC, 2007) (Table 1). The diet should meet the following DM nutrient concentrations: ME \geq 10.0 MJ kg⁻¹ DM, CP \geq 147.5 g kg⁻¹ DM, EE \leq 50.0 g kg⁻¹ DM, NDF \geq 350.0 g kg⁻¹ DM, and NFC \leq 360.0 g kg⁻¹ DM (Table 1).

Table 2 presents the chemical composition of three feed used in the formulation of a diet for lactating sheep: cactus pear cladodes, mixed grass-legume hay, and concentrate.

The three feedstuffs whose chemical composition is pre-

sented in Table 2 allow for the formulation of a diet for Assaf sheep. Comparing the nutrient concentrations of the diet (Table 1) with the nutritional composition of the cladodes (Table 2) reveals that including 1.0 kg DM of *O. ficus-indica* in the diet of lactating ewes meets at least 56.0% and 53.6% of their CP and NDF requirements, respectively. On the other hand, it exceeds their ME and NFC requirements by 12.8% and 76.9%, respectively. This forage is particularly valuable in terms of energy and non-fibrous carbohydrates. Its main limitation, however, is its low dry matter content.

Table 3 shows the amounts of DM matter and fresh feed that must be provided to the animal daily to meet its nutritional requirements. This feeding diet is designed to meet the needs of a 70-kg ewe at the beginning of lactation, producing 1.56 kg of milk per day with 7% fat content. The daily amounts of fresh feed required per ewe are as follows: 2.48 kg of *O. ficus-indica* cladodes, 0.75 kg of mixed hay, and 1.03 kg of concentrate. The quantity of *O. ficus-indica* represents 58.3% of the total fresh feed provided. This feeding diet, with 46.5% dry matter, includes *O. ficus-indica* and mixed hay at levels of 0.35 and 0.70 kg DM day⁻¹, respectively. These amounts result in a forage-to-concentrate ratio of 53:47, offering a nutritionally advantageous solution for maintaining rumen pH at appropriate levels without negatively affecting milk production.

Diet for a fattening lamb

The second practical example describes feeding regime for a fattening lamb with 20 kg of live weight (LW) and an average daily weight gain (DWG) of 100 g day⁻¹. The daily

Table 1. Daily nutrient requirements and concentrations for a feeding diet (kg DM⁻¹) to meet the needs of a sheep with a dry matter intake of 1.98 kg/day

DMI (kg day ⁻¹)	CP (g day ⁻¹)	EE (g day ⁻¹)	NDF (g day ⁻¹)	NFC (g day ⁻¹)	ME (MJ day ⁻¹)
1.98	\geq 292.0	\leq 99.0	\geq 693.8	\leq 712.8	\geq 19.79
Nutrient concentration of the dietary regime	\geq 147.5 g kg ⁻¹ DM	\leq 50.0 g kg ⁻¹ DM	\geq 350.0 g kg ⁻¹ DM	\leq 360.0 g kg ⁻¹ DM	\geq 10.0 MJ kg ⁻¹ DM

CP – Crude protein; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

Table 2. Chemical composition of the feed ingredients used in the formulation of the proposed diet for lactating sheep

	<i>Opuntia ficus-indica</i> ^(a)	Mixed grass-legume hay ^(a)	Concentrate ^(a)
DM (%)	14.10	93.98	90.00
CP (g kg ⁻¹ DM)	82.52	96.40	210.60
EE (g kg ⁻¹ DM)	14.43	22.00	49.00
NDF (g kg ⁻¹ DM)	186.05	653.50	257.50
NFC (g kg ⁻¹ DM)	636.87	181.00	356.10
ME (MJ kg ⁻¹ DM)	11.27	7.65	12.50

^(a)Data from the Animal Nutrition and Feeding Laboratory of ESACB. CP – Crude protein; DM – Dry matter; EE – Ether extract; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

nutritional requirements for a lamb with these characteristics are as follows: DMI = 0.59 kg DM, ME \geq 5.9 MJ, CP \geq 73 g, EE \leq 29.5 g, NDF \geq 236.0 g and NFC \leq 212.4 g (ARC, 1980; AFRC, 1993; NRC, 2007). Considering the daily requirements, the feeding regime should contain \geq 123.7 g CP kg⁻¹ DM, \leq 50.0 g EE kg⁻¹ DM, \geq 400.0 g NDF kg⁻¹ DM, \leq 360.0 g NFC kg⁻¹ DM, and 10.0 MJ kg⁻¹ DM of ME (Table 4).

Table 5 presents the chemical composition of the feedstuffs used to formulate a diet for fattening lambs: cladodes of *O. ficus-indica*, oat hay, and a specific concentrate.

When comparing the nutritional value of *O. ficus-indica* cladodes with the required nutrient concentrations in the diet, it becomes evident that their inclusion alone meets only 66.7% and 46.5% of the CP and NDF requirements, respec-

Table 3. Proposed diet for lactating Assaf sheep using *Opuntia ficus-indica* cladodes, mixed hay, and concentrate – chemical composition and nutritional value

Feed ingredients	DM (kg day ⁻¹)	FF (kg day ⁻¹)	DM (%)	FF (%)	CP (g day ⁻¹)	EE (g day ⁻¹)	NDF (g day ⁻¹)	NFC (g day ⁻¹)	ME (MJ day ⁻¹)
<i>O. ficus-indica</i>	0.35	2.48	17.68	58.27	28.88	5.05	65.12	222.90	3.94
Mixed grass-legume hay	0.70	0.75	35.35	17.48	67.48	15.40	457.45	126.77	5.36
Concentrate	0.93	1.03	46.97	24.25	195.86	45.57	239.48	292.00	11.63
Total daily intake	1.98	4.26	100.00	100.00	292.22	66.02	762.05	680.77	20.93

CP – Crude Protein; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; FF – Fresh feed; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

Table 4. Daily requirements and nutrient concentrations in the feeding diet (kg DM⁻¹) to meet the daily needs of a fattening lamb with a dry matter intake of 0.59 kg day⁻¹

DMI (kg day ⁻¹)	CP (g day ⁻¹)	EE (g day ⁻¹)	NDF (g day ⁻¹)	NFC (g day ⁻¹)	ME (MJ day ⁻¹)
0.59	\geq 73.0	\leq 29.5	\geq 236.0	\leq 212.4	\geq 5.9
Nutrient concentration of the dietary regime	\geq 123.7 g kg ⁻¹ DM	\leq 50.0 g kg ⁻¹ DM	\geq 400.0 g kg ⁻¹ DM	\leq 360.0 g kg ⁻¹ DM	\geq 10.0 MJ kg ⁻¹ DM

CP – Crude protein; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

Table 5. Chemical composition of the feedstuffs used in the formulation of the feeding diet for fattening lambs.

	<i>O. ficus-indica</i> ^(a)	Oat hay ^(b)	Concentrate ^(a)
DM (%)	14.10	90.00	89.45
CP (g kg ⁻¹ DM)	82.52	100.00	228.10
EE (g kg ⁻¹ DM)	14.43	23.00	49.00
NDF (g kg ⁻¹ DM)	186.05	630.00	257.50
NFC (g kg ⁻¹ DM)	636.87	167.00	465.40
ME (MJ kg ⁻¹ DM)	11.27	8.37	12.50

^(a)Data from the Animal Nutrition Laboratory and Feeding of ESACB. ^(b)NRC (2007); CP – Crude protein; DM – Dry matter; EE – Ether extract; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

Table 6. Proposed diet for fattening lambs (20 kg live weight) using cladodes of *O. ficus-indica* – chemical composition and nutritional value

Feed ingredients	DM (kg day ⁻¹)	FF (kg day ⁻¹)	DM (%)	FF (%)	CP (g day ⁻¹)	EE (g day ⁻¹)	NDF (g day ⁻¹)	NFC (g day ⁻¹)	ME (MJ day ⁻¹)
<i>O. ficus-indica</i> ^(a)	0.22	1.56	37.29	79.10	18.15	3.17	40.93	140.10	2.47
Oat hay ^(b)	0.25	0.28	42.37	14.10	25.00	5.75	157.50	41.75	2.09
Concentrate ^(a)	0.12	0.13	20.34	6.80	27.37	5.88	30.90	55.85	1.50
Total daily intake	0.59	1.97	100.00	100.00	70.52	14.80	229.33	237.70	6.06

CP – Crude Protein; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; FF – Fresh feed; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

tively. However, they exceed the ME and NFC requirements by 12.7% and 76.9%, respectively.

For fattening lambs, the amount of *O. ficus-indica* to be provided to each animal daily was set at 0.22 kg DM per day, which corresponds to 79.1% of the total amount of fresh feed provided to the animal (37.29% of the DMI) (Table 6). A similar value was used by Llorente et al. (2011).

The amounts of fresh feed to be provided daily per lamb would be as follows: 1.56 kg of *O. ficus-indica* cladodes, 0.28 kg of oat hay, 0.13 kg of concentrate. The amount of *O. ficus-indica* corresponds to 79.1% of the total feed. In this diet for lambs, the amounts of *O. ficus-indica* and oat hay, set at 0.22 and 0.25 kg DM day⁻¹, respectively, allow for a forage-to-concentrate ratio of 57:43, which promotes rumination and maintains an appropriate ruminal pH.

Diet for a Saanen goat breed

The third practical example refers to a 50 kg LW Saanen goat at the beginning of lactation, producing 3.8 kg of milk per day with a 4.0% fat content. The DMI of a goat with these characteristics is 2.29 kg DM day⁻¹, and its daily nutritional requirements are as follows: ME ≥ 22.9 MJ, CP ≥ 361.0 g, EE ≤ 114.5 g, NDF ≥ 916.0 g and NFC ≤ 824.4 g (ARC, 1980; AFRC, 1993; NRC, 2007) (Table 8). The diet must have the following nutrient concentrations: ME ≥ 10.0 MJ kg⁻¹ DM, CP ≥ 157.6 g kg⁻¹ DM, EE ≤ 50.0 g kg⁻¹ DM, NDF ≥ 400.0 g kg⁻¹ DM, and NFC ≤ 360 g kg⁻¹ DM (Table 7).

Considering the three feeds whose chemical composition is presented in Table 2, it is possible to formulate a diet for

Saanen goats. Comparing the nutrient concentrations in the diet (Table 7) with the nutritional composition of the cladodes (Table 2), reveals that incorporating cactus pear cladodes into the diet of lactating goats meets at least 52.4% and 53.5% of the CP and NDF requirements, respectively. Additionally, it exceeds the ME and NFC requirements by 12.7% and 76.9%, respectively.

Table 8 presents the values in dry matter (kg DM day⁻¹) and fresh feed (kg FF day⁻¹) for the three selected feeds used in formulating a dairy goat diet.

With the diet presented in Table 8, the nutritional needs of a 50 kg live weight goat at the beginning of lactation, producing 3.8 kg of milk per day with a 4% fat content, can be met. The daily amounts of fresh feed per goat are as follows: 2.27 kg of *O. ficus-indica* cladodes, 0.75 kg of mixed hay, and 1.41 kg of compound feed. *Opuntia ficus-indica* accounts for 51.3% of the total fresh feed provided.

In this diet, with 51.7% DM, the amounts of *O. ficus-indica* and mixed hay, set at 0.32 kg DM per day and 0.70 kg DM per day, respectively, result in a forage-to-concentrate ratio of 45:55. This ratio supports proper rumen fermentation without compromising milk production.

As observed in the three feeding regime proposed in this section, the inclusion of concentrate in the diet, in terms of dry matter intake, ranged from 55% in goats to 43% in lambs. This variation is primarily due to one of the main limitations of using cactus pear cladodes as ruminant feed — their low crude protein content. To reduce the need for protein concentrates when incorporating cactus pear into diets, several au-

Table 7. Daily requirements and nutrient concentration of the feeding diet (kg DM⁻¹) considering a dry matter intake of 2.29 kg per day for lactating goats

DMI (kg day ⁻¹)	CP (g day ⁻¹)	EE (g day ⁻¹)	NDF (g day ⁻¹)	NFC (g day ⁻¹)	ME (MJ day ⁻¹)
2.29	≥ 361.0	≤ 114.5	≥ 916.0	≤ 824.4	≥ 22.9
Nutrient concentration of the dietary regime	≥ 157.6 g kg ⁻¹ DM	≤ 50.0 g kg ⁻¹ DM	≥ 400.0 g kg ⁻¹ DM	≤ 360.0 g kg ⁻¹ DM	≥ 10.0 MJ kg ⁻¹ DM

CP – Crude protein; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

Table 8. Proposed diet for Saanen breed goats in lactation using *Opuntia ficus-indica* cladodes, mixed hay, and concentrate – chemical composition and nutritional value

Feed ingredients	DM (kg day ⁻¹)	FF (kg day ⁻¹)	DM (%)	FF (%)	CP (g day ⁻¹)	EE (g day ⁻¹)	NDF (g day ⁻¹)	NFC (g day ⁻¹)	ME (MJ day ⁻¹)
<i>O. ficus-indica</i>	0.32	2.27	13.97	51.28	26.41	4.62	59.54	203.80	3.61
Mixed grass-legume hay	0.70	0.75	30.57	16.83	67.48	15.40	457.45	126.70	5.36
Concentrate	1.27	1.41	55.46	31.89	267.46	62.23	327.03	452.25	15.87
Total daily intake	2.29	4.43	100.00	100.00	361.35	82.25	844.01	782.75	24.84

CP – Crude Protein; DM – Dry matter; DMI – Dry matter intake; EE – Ether extract; FF – Fresh feed; ME – Metabolizable energy; NDF – Neutral detergent fibre; NFC – Non-fibrous carbohydrates.

Source: Authors' own elaboration

thors have explored the use of non-protein nitrogen sources in diets based on cactus pear cladodes, aiming to lower costs and increase daily crude protein intake (Cavalcanti et al., 2008; De Lira et al., 2013; Reyes et al., 2020).

Based on the literature reviewed and the results of the proposed feeding regime, it can be concluded that cactus pear cladodes are a viable feed option for small ruminants. When used as forage, they can be a very interesting feed option, especially for the driest period of the year.

Impact of cactus pear use on meat and milk production and quality

Albuquerque et al. (2020) recommend the inclusion of cactus pear silage at up to 42% in goat diets during periods of water scarcity in semi-arid and arid regions. This inclusion improves feed intake, rumination efficiency, and body water retention, while simultaneously reducing drinking water consumption without negatively affecting animal performance or health.

In a study conducted by Reyes et al. (2020), ewes in the final stage of gestation were subjected to dietary diets consisting of alfalfa hay, *Opuntia*, or *Opuntia* enriched with a non-protein nitrogen source (pre-treated with urea and ammonium sulphate). Although the birth weight of lambs did not differ between treatments, offspring fed with *Opuntia* enriched with non-protein nitrogen grew faster, reaching a higher weaning weight. However, ewes in the control group produced more milk than those in the other treatments. The authors concluded that feeding ewes with *Opuntia* (enriched or not with non-protein nitrogen) during the last third of gestation is a viable alternative to alfalfa hay and can reduce production costs under extensive conditions in arid and semi-arid regions.

Cavalcanti et al. (2008) evaluated the incorporation of urea up to 0.8% of DM in dietary regimes where 50% of the DM came from cactus pear, while De Lira et al. (2013) mentioned the possibility of including urea up to 1.2% in diets based on *O. ficus-indica*.

Souza et al. (2020) evaluated the effect of cactus pear silage and intermittent water supply on carcass characteristics and meat quality of lambs. The authors recommend replacing Tifton hay (*Cynodon* spp.) with 42% cactus pear silage, as this results in higher slaughter weight, greater ribeye area, improved physical and chemical parameters of the *Longissimus lumborum* muscle, and a reduction in saturated fatty acids (C18:0 and C21:0), which is considered beneficial for health.

The combination of *Atriplex nummularia* Lindl., and cactus pear cladodes in goat diets can help reduce the need for concentrated feeds. A daily weight gain of 145.9 g day⁻¹

was recorded with a diet containing 8.4% *Atriplex* hay and 74.9% cactus pear (Tosto et al., 2021). This combination is satisfactory for small farmers, as it can reduce the use of more expensive concentrated feeds. However, diets containing 31.2% *Atriplex* hay and 37% cactus pear resulted in the highest body weight gains (216.9 g day⁻¹) and carcass yield.

In the Mediterranean region, olive cake and cactus pear are two alternative resources that can be used in ruminant feeding. Otmani et al. (2021) studied the inclusion of olive cake and cladodes in the diets of goat kids and concluded that, in general, this inclusion had no negative impact on growth, carcass characteristics, meat quality, or fatty acid profile. Furthermore, the inclusion of olive cake and cladodes in the diets of lactating goats, at proportions of up to 20% and 30%, showed no negative effects on milk production or its chemical composition.

The replacement of barley with *O. ficus-indica* cladodes in the diet of small ruminants (lambs and goat kids) had no significant effects on feed intake, digestibility, nitrogen balance, or intramuscular fatty acid composition of the meat (Abidi et al., 2009). However, daily weight gain was lower in the diet with prickly pear compared to the barley diet, with the difference being less pronounced in sheep than in goats. Nevertheless, the cost-benefit ratio favours supplementation with prickly pear.

Cactus pear can replace up to 100% of corn in the diets of Santa Inês sheep raised in confinement, resulting in a reduction in the lipid content of the meat (Costa et al., 2012b). These changes occur without compromising the yield of tissue components in the hip and leg or altering the physical and sensory characteristics of the meat. In another study, Costa et al. (2017) found that the use of cactus pear in the diet of Santa Inês sheep affected the lipid profile of the fat, leading to a decrease in saturated fatty acids and an increase in mono- and polyunsaturated fatty acids. According to the same authors, the fatty acid profile adds economic and nutritional value to the meat and meat products, thus benefiting sheep producers.

In situations of water scarcity, intermittent water supply for up to 48 hours and diets containing up to 42% cactus pear silage can be adopted for feeding stalled goats without affecting carcass characteristics or meat quality. However, the inclusion of cactus pear silage in the diet reduced the levels of C22:0, some branched-chain fatty acids, C20:1, and C13:0-C18:1 fatty acids (Cruz et al., 2023).

In lactating Alpine goats, the replacement of cornmeal with cactus pear cladodes reduced the ether extract of the diet and influenced the physicochemical characteristics of goat milk, leading to a decrease in fat, total solids, and saturated fatty acids, while increasing the amount of monounsaturated

fatty acids. The authors recommend the use of cactus pear, combined with a vegetable fat source (Costa et al., 2010).

In a study conducted by Mahouachi et al. (2012), it was concluded that, in dairy goats, the use of *O. ficus-indica* as a staple feed, along with a moderate amount of concentrate and oat hay, can generate milk production comparable to that of grazing animals. Additionally, the area required for cactus pear production represents only one-tenth of that needed for pasture, making it a viable solution for small ruminant farmers with limited grazing land. It was observed that the milk fat content was significantly higher in the control group than in the group fed cactus pear. Goat kids raised on a cactus pear-based diet and those in the control group showed similar growth rates. However, carcass fat was significantly lower in the group fed *O. ficus-indica* cladodes compared to the control group. The inclusion of cactus pear in the diet was associated with higher levels of CLA (conjugated linoleic acid) C18:2 *cis-9, trans-11*, rumenic acid, and a higher proportion of polyunsaturated fatty acids compared to the control group.

Morshedy et al. (2020) evaluated the use of dried cactus pear fruit peel, an agricultural by-product rich in phytochemicals, as a dietary supplement for lactating Barki sheep. Two doses were tested: 5 and 10 g per head per day. The results indicated that supplementation with 5 g of cactus pear peel improved milk production and composition in ewes. Supplementation with both doses enhanced serum lipid profile, kidney function, hormonal status, and antioxidant presence in the meat of suckling lambs. Additionally, supplementation improved nutrient digestibility and rumen fermentation parameters in the ewes.

In summary, the inclusion of cactus pear in small ruminant diets, when combined with fibre and crude protein sources, is a particularly important alternative during periods of feed scarcity, as it helps reduce feeding costs without compromising meat and milk production or quality.

Conclusions

Climate change is expected to profoundly impact certain regions, particularly the Mediterranean, characterized by long, dry, and hot summers. This makes the search for drought-tolerant forage species essential to ensure sustainable animal production and protect natural grazing systems from degradation. Perennial crops with higher productivity per unit area are required to address these challenges. The cactus pear is a multifunctional species known for its high drought tolerance, significant biomass yield, and excellent palatability, making it a promising candidate for sustainable forage production.

The cladodes of *O. ficus-indica* are characterized by low levels of dry matter, crude protein, and neutral detergent fibre. However, they are rich in non-fibrous carbohydrates and metabolizable energy. Given the importance of dry matter, crude protein and neutral detergent fibre in ruminant nutrition, *O. ficus-indica* cladodes can be used to feed small ruminants, provided they are supplemented with dry forage and a protein-rich feed source to fully meet their nutritional requirements.

By partially replacing imported feed, the cactus pear can help reduce farm operating costs and enhance sustainability in arid and semi-arid regions. Additionally, the area required to produce forage from *O. ficus-indica* represents only one-tenth of that needed for pasture production, making it a viable solution for small ruminant farmers with limited grazing land. As forage, this species is particularly useful for small ruminants during the driest periods of the year when the quality and quantity of available feed decline.

In regions where *O. ficus-indica* is primarily cultivated for fruit production, the cladodes resulting from pruning serve as an important by-product for animal feed, reducing the need for other forages. Furthermore, its agro-industrial residues are valuable raw materials that could serve as a starting point for creating circular economies enabling the development of new materials, products, and services.

Acknowledgments

The present study was funded by the DesirMED project – Demonstration and Mainstreaming of Nature-Based Solutions for Climate-Resilient Transformation in the Mediterranean, under Grant Agreement No. 101112972 | desirmed.eu.

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Received: February, 20, 2025; Approved: March, 25, 2025; Published: June, 2026