Forage cactus (*Opuntia ficus-indica* (L.) Miller) f. Cactaceae as an alternative for ruminant feeding

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Summary

The objective of this review was to compile information regarding cacti as an alternative to ruminant feeding. Forage cactus adapts well to soils with low nutrient content, as long as the soil is not acidic, in addition to being tolerant to long periods of drought, since their metabolism is based on crassulacean acids (CAM), thus favoring the use of water and providing high dry mass productivity. Studies have been developed to include cactus in the diet of ruminants, in an attempt to improve consumption by avoiding the occurrence of metabolic disorders in animals. In addition, forage cactus contributes to the intake of colloidal water due to its composition of around 90% water. For forage cactus to be used to feed ruminants, it must be associated with some source of neutral detergent fiber, leading to greater chewing and, consequently, longer rumination time, to guarantee the normal functioning of the rumen, demonstrating improvement in water consumption, digestibility, and animal performance.

Keywords: consumption, alternative food, concentrate, *Opuntia* genus.

Palma forrageira (*Opuntia ficus-indica* (L.) Miller) f. Cactaceae como alternativa para alimentação de ruminantes

Resumo

O objetivo desta revisão foi compilar informações a respeito da palma forrageira como alternativa na alimentação de ruminantes. A palma forrageira adapta-se bem a solos com baixo teor de nutrientes, desde que o solo não seja ácido, além de ser tolerante a longos períodos de seca, pois seu metabolismo é baseado em ácidos crassuláceos (CAM), favorecendo assim o uso de água e proporcionando alta produtividade de massa seca. Estudos têm sido desenvolvidos para incluir a palma forrageira na dieta de ruminantes, na tentativa de melhorar o consumo evitando a ocorrência de distúrbios metabólicos nos animais. Além disso, a palma forrageira contribui para a ingestão de água coloidal devido à sua composição em torno de 90% de água. Para que a palma forrageira possa ser utilizada na alimentação de ruminantes, ela deve estar associada a alguma fonte de fibra em detergente neutro, levando a maior mastigação e, consequentemente, maior tempo de ruminação, a fim de garantir o funcionamento normal do rúmen, demonstrando melhora no consumo de água, digestibilidade e desempenho animal.

Palavras-chave: consumo, alimentação alternativa, concentrado, gênero *Opuntia*.

1. Introduction

The territorial extension of Brazil allows for great climatic diversity in the country, with most of the Brazilian territory being located within the tropical climate. For the agricultural production system, this factor is decisive for production, since forage plants are the main source of food for ruminant animals (Pacheco; Pissarra, 2023). In the Northeast region, food production requires special care about forage, the use of cultivars more adapted to soil and climate conditions is more recommended, which consists of high temperatures and low rainfall (Alves et al., 2020).

In the Brazilian semi-arid region, a widely used alternative is cactus, being one of the main forages that make up the ruminant diet. It belongs to the division: Embryophyta, Sub-division: Angiospermae, Class: Dicotyledoneae, Subclass: Archiclamidea, the main genera used are *Opuntia* and *Nopalea*, there is a very large diversity of known species, and each one has a different bromatological composition, but in general, specimens of the genus *Nopalea* have a higher nutrient availability than *Opuntias* (Pessoa et al., 2020; Dubeux et al., 2021; Ihaddaden et al., 2022; Alves; Santos, 2024). A characteristic of the palm is its adaptation to soils with low nutrient content, in addition to tolerance to long periods of drought. This mechanism is directly linked to the fact that the palm is a plant that is part of the acid metabolism of crassulaceans, enabling the capture and storage of CO_2 during the night and thus keeping their stomachs closed during the day, which favors better use of water, in addition to providing high productivity of dry mass, with annual production of approximately 55 tons of dry matter/ha/year (Santos et al., 2011).

Despite having low dry matter content (5 – 15%), neutral detergent fiber, and crude protein, the palm contains an excellent source of energy, becoming rich in non-fibrous carbohydrates (59.6%) and total digestible nutrients (78.1%), in addition to having high dry matter digestibility (68.5%) (Santos et al., 2017; Monteiro et al., 2018; Inácio et al., 2020).

This forage can be included in the diet for ruminants in different ways, such as dehydrated bran, grazed or chopped and fed in the trough. Due to its chemical composition similar to corn and its adaptation to different climates, the forage cactus can be used as an alternative to this grain, reducing dietary costs and dependence on traditional foods that are also used in human nutrition (Alves et al., 2023). This review aims to corroborate the use of cacti as an alternative feed for ruminants.

2. Material and Methods

2.1 type of search

In this study in question, a systematic bibliographic review was used as a research method, seeking results from published scientific research to provide greater familiarity with the topic addressed. The survey of scientific production on the proposed topic was carried out through databases available electronically on websites such as Scientific Library Online (SciELO), Scopus, Capes journal portal, Web of Science, and Google Scholar.

2.2 Selection

The selection looked for articles in periodicals between the years 2010 and 2024, however, some works published before this period were considered because they deal with the aforementioned topic. Next, an exploratory reading of the content found was carried out, obtaining a global view of the material of interest. The selected articles were in Portuguese and English and submitted for full reading and analysis. Articles, books, and theses with themes not associated with the research were used as exclusion criteria.

3. Bibliographic review

3.1 Characteristics of forage palm

Forage cactus was introduced into Brazil at the end of the 19th century, from seeds purchased in Texas – USA, originating in Mexico (Lopes et al., 2012). Initially, the palm did not have its forage recognition, as it arrived in Brazil with the aim of producing a natural dye which served as a host for the insect that is responsible for producing the natural dye (Carmine Cochineal – *Dactylopius opuntiae*). However, the cultivation of palm for forage purposes only began in the 20th century, when Brazil was historically affected by a major drought in 1915.

This forage plant belongs to the Division: Embryophyta, Sub-division: Angiospermea, Class: Dicotyledoneae, Sub-class: Archiclamideae, Order: *Opuntia*, and Family: Cactaceae. *Opuntia* is a xerophyte plant (that means it is able to survive in conditions poor in liquid water) that contains 200 to 300 species (Shoukat et al., 2023). In this family, there are 178 genera, with around 2,000 known species. However, in the genera *Opuntia* and *Nopalea*, the palm species most used as forage are present (Silva; Santos, 2006). The varieties most used in food are the species *Opuntia ficus-indica*, with the cultivars Gigante and Redonda as examples, and the other species *Nopalea cochenillifera*, with the cultivar Miúda or Doce (Santana et al., 2020).

The chemical composition of the different genera of cactus pear are shown in (Table 1). The nutritional difference between the genera *Nopalea* and *Opuntia* is evident, with *Nopalea* being the most nutritious. This is due to the fact that *Nopalea* cultivars have smaller clades compared to the *Opuntia* genus, which means that the proportion of nutrients is higher due to their size.

Table 1. Chemical composition of the different palm genera.

Authors	Gender	DM (%)	CP (% DM)	CNF (% DM)	NDF (% DM)
Inácio et al. (2020)	*Opuntia*	9,07	4,38	58,55	23,32
	Nopalea	15,6	3,93	65,98	21,71
Monteiro et al. (2018)	*Nopalea*	15	3,5	57,4	25,7
Bezerra et al. (2023)	*Nopalea*	10	5,86	47,75	25,97
Thakuria et al (2020)	*Opuntia*	11,4	5,45	-	26,43
Rezende et al. (2020)	*Opuntia*	10,7	3,6	5,41	27,5

Note: DM = Dry Matter. CP = Crude protein. CNF = Non-fibrous carbohydrates. NDF = Neutral detergent fiber. Source: Monteiro (2018), Thakuria (2020), Rezende (2020), Inécio (2020), and Bezerra (2023).

It is recommended that palm harvesting begins at 1.5 years, in ideal conditions, and, in less favorable conditions, at 2 years or more. This plant is considered a xerophyte, adapting to the adverse conditions of the Semiarid region. It presents a metabolism characterized by the photosynthetic process called crassulacean acid metabolism (CAM), where the stomata open mainly at night when the temperature is lower. Therefore, this behavior causes less water loss through transpiration (Taiz et al., 2017).

According to Abbas et al. (2022) and Espinosa-Solares et al. (2022), *Opuntia ficus-indica*, widely recognized as prickly pear or nopal cactus, is native to Mexico and it is distributed in many areas of the world because of its socioeconomic, agronomic, and ecological benefits, besides its large amounts of functional, nutraceutical, and biological activities. Is a plant with a crassulacean acid metabolism (CAM) that has received increased attention due to its high water and nutrient use efficiency, making it an energy crop (Yang et al., 2015). The giant palm (*Opuntia ficus indica*), also known as azeda or grande, is a developed plant and has a branched stem, conveying an erect appearance and vertical growth with little branching. The rackets weigh around 1 kg, are around 50 cm long, have an oval-elliptical or sub-oval shape, and have a matte green color. The flowers are considered hermaphrodite, medium in size, and bright yellow. Its fruit is an ovoid, large, yellow berry, which may turn purple when ripe.

The species *Nopalea cochenillifera* (L.), also known as sweet or small palm, has a small size and a branched stem, the rackets weigh around 350 g, the length is 25 cm, their shape is oval (apex wider than the base) to The color is an intense bright green. The flowers are red and its fruit is a purple berry. When compared to the giant palm, it has a higher nutritional value and is more appreciated by animals, as they are more palatable (Silva; Santos, 2006), It presents greater demands on soil fertility, greater susceptibility to scale insects, and resistance to carmine mealybug (Dutra et al., 2020). About the productivity of the small or sweet palm, its nutritional value is superior, when compared to other cultivars, such as the round and the giant.

The morphophysiological mechanism of cactus allows it to tolerate long periods of water stress (Júnior et al., 2021). With this, the plant uses the development of the root system, with a survival mechanism and carbohydrate reserve. As for the restoration of water in the soil to regularity, the system undergoes a transformation using reserve carbohydrates for root development, allowing the restoration of its flow of nutrients and, consequently, accelerated growth of the system (Campos et al., 2021; Bezerra et al., 2024).

One of the factors that assume great importance in the net photosynthesis rate of plants is light, because when the degree of radiation decreases the net photosynthesis rate also decreases until it reaches negative values. Therefore, the forage cactus has difficulty intercepting incident light, resulting in low initial growth, due to the low photosynthetic area. Thus, dense planting allows greater light interception by increasing the cladode area index, resulting in greater productivity (Sales, 2013).

3.2 Factors that affect cactus production

The morphogenic characteristics of forage plants can be determined by the genotype, but they are strongly influenced by the environment, and cultural management, in addition to the soil to which they are subjected (Diniz et al., 2017). Soils that have a high clay content, as they contain textures and structures that provide greater water accumulation, providing an environment suitable for the development of pathogens that can cause secondary injuries, such as rot and consequently senescence.

Silva et al. (2012) evaluated doses of 200 kg ha^{-1} of nitrogen associated with 50 kg ha^{-1} of phosphorus (P_2O_5) and observed an increase in production of around 37% of cactus pear. Almeida et al. (2012) demonstrated that the practice of nitrogen fertilization guarantees a significant increase in productivity, regardless of the cultivar, showing positive responses to nitrogen fertilization in conjunction with other nutrients.

Phosphorus is of fundamental importance in the metabolic process of plants, as it plays important roles in energy transfer to the cell, respiration, and photosynthesis. When limitations occur in the availability of phosphorus at the beginning of the vegetative cycle, they can cause restrictions in the development of plants, and as a result, they may not recover later, even if adequate levels of phosphorus are re-established in the soil. The supply of this element in the initial stages of plant growth is of fundamental importance, as it directly participates in the root growth process (Souza et al., 2013).

Dubeux Junior et al. (2006) evaluated different doses of Nitrogen fertilization in the plot, where 0, 75, 150, 225, and 300 kg ha^{-1} year of Nitrogen were used, associated with doses of 0 to 33 kg ha^{-1} year of Phosphorus, in a population varying between 5,000 and 40,000 plants ha^{-1}. As a result, they observed that the plots that obtained the highest densities were those fertilized with nitrogen, at doses of 225 and 300 kg ha^{-1} and Phosphorus, producing more cladodes.

Potassium, which is present in plants, plays an extremely important role in the process of osmotic regulation of plant cells, in addition to playing an important role in enzymatic reactions, the metabolism of carbohydrates and proteins, the translocation of sugars and starches, in the relationship between water-plant, and cell division (Hasanuzzaman et al., 2018).

Palm spacing, as a management strategy, is of paramount importance in the establishment of palm trees. Planting spacing is used with plants and rows of 1 m, however, its cultivation in dense systems (1 x 0,5 or 1 x 0,25 m) is becoming quite widespread, as it allows the productive increase of forage cactus in potential regions for its cultivation, increasing land use efficiency (Candido et al., 2013).

For the formation of the area, it is recommended to choose lighter soils, i.e. (clayey-sandy), thus avoiding areas with rocks, due to the difficulty of cleaning, increasing implementation and maintenance costs. It is also recommended to avoid areas subject to flooding, as the accumulation of water causes the rackets to rot. Therefore, it is recommended to plant two months before the start of the rainy season (Lima et al., 2010).

Ramos et al. (2015), evaluating the vegetative growth of *O. ficus indica* at different spacings, observed that the density of plants promoted a positive correlation with the total productivity of green stuff and dry matter, increasing 40,56 kg ha^{-1} MV at a spacing of 2 x 1 m, for 130,06 mg ha^{-1} green stuff at 1 x 0,5 m spacing.

3.3 Use of forage cactus in feeding ruminants

Several factors, such as variety, plant age, and cladode order can influence the chemical composition of cactus pear. In general, forage cactus can be used as an alternative energy supplement for ruminant diets (Abididi et al., 2009). In general, this forage must be supplied with a source of roughage to increase the amount of fiber in the food, as palm has an average of 26% neutral detergent fiber. With an increase in the proportion of fiber in the diet, there is greater chewing and, consequently, greater rumination, to guarantee the functioning of the rumen, avoiding nutritional disorders (Ferreira et al., 2009; Pinto et al., 2011).

According to Melo (2006), forage cactus contains a high content of non-fibrous carbohydrates (CNF) and a low concentration of neutral detergent fiber (NDF) and acid detergent fiber (ADF), when compared to bulky foods, thus it can be a determining factor in its use in animal feed. Since the former are readily available sources of energy for the microbial process to occur, they also play an important role in the maintenance of the rumen. For rumen function and animal health to occur, the minimum NDF recommended by the NRC (2001) is 25% of dry matter, of which 19% must come from forage. However, the physically effective fiber (peNDF) content alone has no longer justified the appearance of diarrhea in ruminants, since they consumed diets with a high palm content. Cordova-Torres et al (2017) replaced 70% of Tifton hay with cactus in the sheep diet and did not observe digestive problems.

Abidia et al. (2009), evaluating the supplementation of sheep and goats with cactus or barley associated with a roughage source (hay), reported that the total water intake of animals that consumed diets containing cactus decreased by 1/3 water intake. Moura et al. (2020) studied the replacement of maniçoba hay with cactus pear (0, 200, 400, and 600 g kg DM^{-1}) in diets for confined sheep and reported that the inclusion of cactus in the diets increased the animals' use of ingesting water, as drinking water reduced from 2,696 g day^{-1} to 365 g day^{-1}.

3.4 Ways to use cactus forage

Forage cactus can be consumed by both humans and animals, since its use is innumerable, ranging from fresh consumption to the production of bran, waste, and industrial by-products, making up around 80% of the animals' diet, mainly in dry periods (Soares et al., 2012). Oliveira et al. (2007) evaluated the production and composition of milk in Dutch cows, where the diets completely replaced corn and partially Tifton grass hay with forage cactus, and did not observe influences of the inclusion of cactus on total milk production and corrected for 3.5% for fat content and milk fat production. Fatty acids, capric, lauric, linolenic and arachidic were not influenced by palm levels in the diet.

Costa et al. (2009) evaluated the effect of increasing levels of cactus in the diets of dairy goats, using Tifton 85 hay as roughage in a ratio of 50:50, and cactus replacing corn in pains of 7, 14, 21, and 28% in DM, concluded that replacing corn with cactus associated with a source of fiber does not alter milk production. Ramos et al. (2015) analyzed the use of sorghum silage, maniçoba hay, and two proportions of concentrates (10 and 15% DM) in cactus-based feeds. As a result, they observed that the consumption of crude protein, neutral detergent fiber, and total digestible nitrogen differed in terms of forage, where they found lower consumption for diets containing *maniçoba* hay. Thus, the use of sorghum silage appears to be a viable alternative to be added to palm-based diets.

Wanderley et al. (2012) evaluated the consumption and digestibility of lactating cows fed silage (sunflower and sorghum) and hay (leucene, pigeon pea, and elephant grass) associated with cactus and observed that cows whose diets contained approximately 60% cactus and 35% of forage, represented by silage and hay, the amount of concentrate used was minimal. This factor is of great importance since the feed brings greater value to the feeding costs of dairy cows.

Gusha (2015) evaluated the supplementation of sheep with palm silage and the addition of legumes, in a proportion of 70/30 respectively. This combination increased the silage's fiber content, soluble carbohydrates, and protein content, where the animals received silage with greater microbial synthesis, greater digestibility, and higher concentrations of VFA'S than the control treatment, composed of hay and concentrates.

Offering palm to ruminants can be combined with doses of urea in order to increase the digestibility of dietary fiber. Hernandes (2012), evaluated 20 goats fed with and without palm silage, plus urea, molasses, corn silage, and triticale hay. Animals that were fed palm silage achieved a weight gain of 140 g day^{-1}, animals fed the control diet, which did not contain palm, achieved gains of 60 g day^{-1}. Therefore, cactus silage, associated with other foods that balance the diet, provided an increase in weight gain compared to traditional diets.

Regarding the enrichment of cactus pear associated with urea, Siqueira et al. (2017) evaluated the replacement of Tifton hay with cactus with 2% urea and Ammonium sulfate at levels (0, 147, 2294, and 558 g kg^{-1}) in the diet of crossbred steers. A quadratic effect was observed in DM consumption with a maximum value of 8.89 kg at the replacement level of 339 g day^{-1}. However, there was a linear increase in the ruminal digestibility of DM and CP, in addition to the DM degradation rate.

Sá (2012) evaluated the performance and digestibility of palm meal in lactating cows with inclusion levels of 0, 3.7, 7.4, 11.2, and 15.1% of dry matter in the total diet. It was observed that nutrient digestibility, milk composition and feed efficiency were not influenced by palm meal levels. Therefore, the feed efficiency results show the feasibility of using palm flour as an energy feed in the diet of lactating cows.

5. Conclusions

Palm is one of the main forage crops that feed animals in the Brazilian semi-arid region, mainly because it can withstand long periods of drought. The use of this species is recommended for feeding ruminants, as it is rich in energy, has high digestibility and provides a significant increase in animal productivity, whether for body mass gain or milk production.

Composed of around 90% water, cactus is a viable alternative to meet part of the water needs of animals in regions with low rainfall levels. Furthermore, it is possible to replace corn with cactus without causing losses in animal productivity. Its supply must be associated with a properly effective source of fiber, so as not to cause metabolic disorders in the animals.

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7. Authors' Contributions

Ingridy de Carvalho Dutra: article writing and submission. *Aureliano José Vieira Pires*: Scientific corrections. *Brenda Emilly Ferreira dos Santos*: search for articles and grammar reviews. *Nadjane Vieira da Silva*: search for articles and grammar reviews. *Luanna Pereira Pio*: search for articles and grammar reviews. *Priscila Coelho Galvão*: search for articles and grammar reviews. *Mateus Pereira Sousa*: search for articles and grammar reviews. *Natan Teles Cruz*: scientific corrections.

8. Conflicts of interest

There are no conflicts of interest.

9. Ethical approval

Not, applicable.

10. References

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