Enhancing the Nutritional Content of Cactus Prickly Pear Plant Residues for Ruminant Nutrition

Maen Taher Idell[1], Fayiq Alghamdi[2]

[1]Al Baha University. College of Science. Department of Biology. Kingdom of Saudi Arabia
Email: *mtidell[at]bu.edu.sa*

[2]Al Baha University. College of Science. Department of Biology. Kingdom of Saudi Arabia
Email: *fsaeed[at]bu.edu.sa*

Abstract: ***This study aimed to highlight the nutritional value of prickly pear waste (Opuntia ficus - indica) treated with chemicals as animal feed. A quantity of prickly pear waste cut into approximately 2 cm pieces was treated after determining its nutritional content through laboratory analyses and observing improvements after the planned chemical treatment. Additionally, an experiment on feed palatability was conducted by feeding the treated feed to ruminants, testing both positive and negative effects across different replications and treatments. The daily consumption of chemically treated filler feeds was compared with untreated feeds in terms of quantity and the nutritional elements acquired through treatment. Weight gain and feed conversion efficiency were also assessed. Results indicated improvements in nutritional value, palatability, and daily consumption rate for treated feeds.***

Keywords: Cactus Prickly Pear, Ruminant, Nutrition

1. Introduction

The agricultural sector is the backbone of food security, with the livestock component playing an essential role within it. Studies have shown that using prickly pear (Opuntia ficus - indica) as feed for broiler chickens can enhance growth performance and productivity (M., Hornick, J. L., Besseboua, O., & Ayad, A., 2023). In the Kingdom, sheep hold a prominent position among livestock, contributing approximately 75% of the total meat production. Food security for any community depends on its major crops, natural pastures, and, subsequently, its animal resources—particularly small ruminants grazing on natural pastures, which help meet the demand for animal protein.

The Al - Baha region, with its two main divisions—Al - Sarawat and Al - Tehamah—has a large population of livestock, predominantly sheep and goats. These animals are traditionally raised using inherited methods that do not include modern or semi - modern practices for breeding, feeding, or animal care. Consequently, local livestock farming has long relied on government subsidies for concentrated feed, which enables livestock owners to maintain modest profits despite high local meat prices compared to imported options. This reliance is crucial; any investment in the animal production sector without government support would be unsustainable, as feed expenses make up over 70% of total production costs. In Al - Baha, extensive or semi - intensive grazing is the predominant livestock - rearing style, which makes the availability and richness of natural pastures a key factor in sustaining livestock and minimizing production costs.

2. Research Problem

The issue addressed by this study is the scarcity of filler feeds in a region with a substantial livestock population. These feeds are generally low in nutritional value despite their significance in the diets of ruminants (e. g., sheep, cows, and goats). Improving the nutritional value of such feeds can help bridge the gap caused by their scarcity and low quality. For example, urea ($CO(NH_2)_2$), which contains 45% nitrogen, has been widely used in agriculture as an inexpensive nitrogen fertilizer. Leveraging prickly pear residues provides the potential for a non - traditional, locally available, low - cost filler feed that fulfills the function of a filler and could be gradually incorporated into the diet of small ruminants.

The objective of the Study:
The study aims to improve the nutritional value of filler feeds derived from prickly pear plant residues, such as discarded pads and fruit - processing waste, through chemical treatments designed to enhance protein content. This treatment facilitates ammonia penetration and distribution within the filler feed, creating nitrogenous compounds that can be utilized by rumen bacteria in ruminants.

Significance of the Study:
The importance of this study lies in its potential to increase the nutritional value of filler feeds by introducing additional nitrogenous chains. These nitrogen compounds can be used by the bacteria present in the rumen to produce protein, thereby providing the animals with enhanced nutritional value through chemically treated filler feeds.

Prickly Pear as Feed for Ruminants:
Prickly pear (Opuntia ficus - indica) has the largest cultivation area in Mexico, where it covers approximately 3 million hectares. In these regions, animals graze on prickly pear plants without any specific treatments, which helps control the spread of this invasive plant and meets the animals' feeding needs. Pasture restoration is a practice that involves reusing natural systems in conjunction with agriculture to achieve greater sustainability and maximize ecosystem utilization. Although it can be challenging to return farmland to its original natural state, achieving a balanced and economically viable ecosystem is possible through certain agricultural practices, such as crop diversification, integrated pest management, and natural pest control methods.

Since the early 1930s, North African countries, particularly Tunisia, have systematically developed fodder farming based on research conducted by Griffith and colleagues in Texas, USA. The Tunisian government invited Griffith to help mitigate the effects of drought on livestock by using prickly pear as animal feed. This approach succeeded in alleviating drought impacts by providing substantial amounts of feed for animals (United Nations, 2021).

Animal Nutrition:
Prickly pear (locally known as "barshoumi") has become a staple feed in dry regions, not only for its fruit but also for its significant benefits as livestock feed. Table 1 shows the distribution of prickly pear cultivation worldwide.

Country	Cultivated Area (hectares)
Brazil	600
Other South American Countries	75
Mexico	3, 230, 000
Other North American Countries	16
Tunisia	600
Algeria	150
Morocco	150
Italy	70
Total	**3, 230, 000**

Source: World Soil Resources Map, FAO/EC/ISRIC

It is known that animal feed relies on the by - products of agricultural crops, including the residues of prickly pear, which are widely used in several countries. These by - products are considered poor in nutritional content and contribute only a small part to the animal's dietary intake. However, since livestock such as sheep, cattle, and goats are ruminants, they require a certain amount of feed to feel full before the actual digestion process begins. The rumen plays a crucial role in digesting these cellulose - poor materials with the help of anaerobic bacteria that live in the rumen, which can convert complex carbohydrates into simple sugars that are beneficial. These bacteria also synthesize the necessary proteins for growth and building, relying on nitrogenous compounds available in the feed. Therefore, any process that enriches these feed materials, especially with nitrogen, will have a significant and positive impact on the animals. It will provide a source for bacteria to synthesize organic materials, particularly proteins, which means a considerable reduction in the cost of concentrated feed, which is typically made from grains, oilseed cakes, and bran. This process enhances the feed's ability to produce proteins, carbohydrates, and fats through the rumen efficiently.

Given the severe shortage of roughage, the importance of using non - traditional animal feeds and agricultural residues becomes apparent, despite their low nutritional value. This impacts their digestibility negatively (Gupta, L., and Murdia, P. C.2006). Nevertheless, these residues are very important for ruminants' nutrition and cannot be neglected. They help the animal feel full, affect saliva production, and increase the volume of rumen fluid, which supports the process of rumination and fermentation by the microorganisms present in the rumen. To increase the amount of intake, efforts must be made to improve the nutritional value and digestibility of these feed materials through various methods, such as chemical treatments or using dietary supplements to enhance the rumen's environment, thus increasing microbial activity.

According to Downing, J. A., J. Joss, and Scaramuzzi, R. J. (1997), adding molasses as an energy source and urea as a protein synthesis source led to an increase in the intake of both treated and untreated roughage with sodium hydroxide in Awassi lambs.

Hence, the improvement in treated roughage is due to enhanced digestibility, either from the chemical treatment outside the animal or from improved microbial efficiency inside the rumen, providing a direct source of energy and nitrogen. The aim of this study is to examine the improvement in the nutritional content of prickly pear residues treated with urea at different levels.

Biological treatment of lignocellulosic materials (such as wood and agricultural residues) is cheaper than chemical and natural treatments. However, the drawback is contamination of the roughage with unwanted microorganisms, as biological treatment relies primarily on the use of specific microorganisms that have high metabolic efficiency for lignin degradation. These microorganisms, however, have a limited ability to break down cellulose and hemicellulose. Additionally, these microorganisms are capable of:

1) Synthesizing high - protein content from essential amino acids required by ruminants, known as Single Cell Protein (SCP), by growing on cellulose - based materials.
2) Converting cheap nitrogen sources, such as urea, into proteins used for their growth.
3) Growing rapidly in the environment (agricultural residues), preferably in non - sterile conditions.
4) Producing a product that is free from toxins or disease - causing agents.

In China, urea treatment of agricultural residues has been widely promoted for ruminant feeding (Tingshuang et al., 1993; Tingshuang and Zhenhai, 1996). The process of mixing prickly pear residues with urea fertilizer is an effective technique for livestock breeders, as it improves the nutritional value of ruminant feed, transforming it from just a material to satisfy cows' hunger into an important feed that increases weight gain and milk production while being economically beneficial since it is inexpensive.

The process begins by dissolving urea fertilizer in water, spraying it onto the residues, and mixing it well. The mixture is then covered with plastic and isolated from air for a period ranging from 20 to 45 days, depending on the temperature. After that, it is ventilated for one day with light stirring. The mixture is stored like silage and gradually introduced to the livestock along with traditional roughage. After ten days, it can be provided as a complete feed. The optimal mixing ratio requires 4 kg of urea fertilizer for every 100 kg of prickly pear residues, along with a suitable amount of water depending on the moisture content of the residues.

The treated product is fit for animal consumption after 7 to 8 weeks in winter or 4 to 5 weeks in summer.

Urea Solution Treatment: Urea is a natural source of ammonia, used both as a fertilizer and as a source of non - protein nitrogen (NPN) in ruminant diets, known as "small farmer's ammonia. " The urea molecule breaks down, aided by the urease enzyme secreted by naturally occurring bacteria in the roughage, into two ammonia molecules:

Urea + Water → Ammonia + Carbon dioxide NH2 C = O + H2O → 2NH3 + CO2

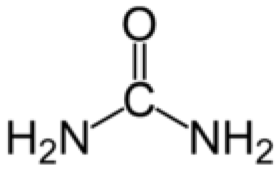
Advantages of Urea Treatment:
1) Suitable for small farmers handling limited quantities of residues.
2) Urea is easy to handle, transport, and widely available.
3) An effective method for improving the nutritional value of roughage when ammonia or ammonia solutions are not available.
4) Safer and more economical than using ammonia gas or solutions.

For this treatment, a urea solution is prepared by dissolving 4 kg of urea in 50 liters of water, which is enough to treat 100 kg of residues. The treatment is applied on the ground in mounds or layers, with each layer sprayed with the urea solution, compacted before the next layer is added, and covered with plastic to prevent ammonia loss. Ammonia begins to release within 12 - 24 hours, and the reaction continues for approximately two weeks in summer and three weeks in winter. After the reaction period, the mixture is opened for ventilation for two to three days before it can be fed to ruminants, gradually increasing the intake over a transition period of two weeks. Urea treatment can also be applied to prickly pear residues in pits, but this method is costly due to the labor required for excavation.

Recent research has focused on adding lime solution and salt along with urea treatment to reduce costs, particularly following the rise in urea prices. Furthermore, animal urine has been used effectively in treating roughage, where 1 liter of urine is added to 1 kg of hay or straw in mounds, covered tightly for 20 days, then opened for ventilation before use.
In industrial processes, urea decomposes at temperatures above 133°C, and when mixed with other feed ingredients, it decomposes at 175°C in pelletizing machines.

Benefits of Ammonia or Urea Treatment:
1) Increased digestibility of organic matter by about 20%.
2) Approximately 1% nitrogen is incorporated into the material during treatment, raising crude protein content by 250–300%.
3) Improved palatability of the treated material, increasing intake by 15–20%, reducing the need for concentrated feed, and lowering production costs. It is estimated that one ton of treated residues saves about a quarter ton of concentrated feed.
4) Enhanced animal performance, reflected in increased growth, fattening, and milk yield.
5) Complete safety when gradually introducing treated material into the animal's diet.

Urea is one of the most widely used synthetic substances in ruminant feeding. It is produced by combining ammonia and carbon dioxide under high pressure and temperature.



Urea is of no value to non - ruminant animals like pigs and poultry, nor to calves or lambs whose rumens are not fully developed. Only large ruminants can benefit from it, as the microorganisms in their rumen break down urea into ammonia and carbon dioxide. If the rumen environment is favorable for microbial activity, ammonia from urea breakdown or the feed protein is used to form the amino acids necessary for microbial growth and bodybuilding.

Advantages of Urea Use:
1) Low cost.
2) Allows the use of cheaper energy sources regardless of their protein content.
3) Enables the creation of concentrated feeds with low fiber content, ensuring the nutritional needs of high - yielding dairy cattle are met.
4) Increases microbial activity in the rumen, speeding up feed digestion and allowing animals to consume more feed.

Research Management:
The comparison is made with the control or witness group, which will not be exposed to any treatment (based on the null hypothesis, which states that there are no significant differences between the studied treatments) until statistical analysis of the results confirms or denies these differences and determines their significance level.

Conducted analyses:
- Raw protein
- Ether extract
- Ash content
- NDF - ADF analysis using the Van Soest method

Statistical analysis:
The statistical analysis of the samples was conducted using the SAS method. The obtained data were statistically processed using the F - test to assess the significance level. Correlation and determination coefficients, simple and multiple regression equations, and general trend equations were used to provide the required scientific reliability for the results. According to (Sendecon and Cochran).

The following mathematical model was used to study the impact of various factors:
Y = a + bx1 + cx2 + dx3 + e
Y = affected factor
a = constant
x = influencing factors
e = experimental error

Paper ID: SR25110141025 DOI: https://dx.doi.org/10.21275/SR25110141025

Task Table:

Task No.	Duration (Months)	Time (Month) 1	2	3	4	5	6	7	8	9	10	11	12
1	Preparing materials, devices, and means	×											
2	Chemical analysis of nutritional value before treatment		×										
3	Practical application and chemical treatment with repetitions			×	×	×	×						
4	Chemical analysis of nutritional value after treatment							×	×				
5	Analyzing results, making recommendations, and printing the research									×	×		

Samples were obtained from prickly pear plant residues, including discarded leaves and by - products of fruit processing. The chemical composition percentages were determined before chemical treatment with urea. The treatment was applied as follows:

Table 1: Chemical Composition Based on Dry Matter

No.	Treated Feed Material	DM (Dry Matter %)	CP (Crude Protein %)	ADF (Crude Fiber %)	Nitrogen - Free Extract %	Crude Fat %	Ash %
1	Prickly Pear Waste	11.4	5.5	20.2	24.45	1.60	7.55
2	Prickly Pear Waste After Urea Treatment	8.92	8.25	16.50	26.60	2.00	8.50
3	Concentrated Feed	88.00	17.00	4.00	75.00	4.10	4.00

3. Results and Discussion

It can be observed from Table 1 that the crude protein content in the urea - treated feed improved by 150% (from 5.5% to 8.25%), while the crude fiber content decreased by 32% (from 20.2% to 16.50%). Both Gupta & Murdia (2006) in their experiment using urea treatment at different concentrations, and the study on corn stalks used for fattening beef cattle, reported similar improvements in crude protein percentages and reductions in crude fiber content after urea treatment.

Table 2: Average Dry Matter and Crude Protein Consumption ± Standard Error (grams/head/day)

Parameter	Prickly Pear Waste	Prickly Pear Waste After Urea Treatment
DM (Dry Matter)	450±12.2	550±18.1
CP (Crude Protein)	14.6±0.39	39.8±1.31

It can be observed from Table 2 that there was an increase in dry matter consumption after treatment. This can be attributed to improved palatability and increased animal acceptance (which is a good indicator of the effectiveness and importance of chemical treatment with urea for improving the nutritional value of feed, as well as enhancing its palatability). Consumption increased by 22%, and the difference was statistically significant ($P<0.05$). This finding aligns with studies by Narayan et al., 2004, and Trishna et al., 2012, which reported increased feed intake in calves fed urea - treated corn stalks at various concentrations with a statistically significant difference ($P<0.05$).
It was also observed from the results that the treated feed group consumed about 100 grams more per day per head compared to the control group.

Table 3: Comparison of Weights in Research and Control Groups Before and After Feeding with Urea - Treated Roughage

Group	Average Starting Weight (kg) ± Standard Error	Average Daily Weight Gain (g) ± Standard Error	Average Ending Weight (kg) ± Standard Error
Research Group	13.6 ±0.8	85±8.6	19±1.2
Control Group	13.6 ±0.8	55±4.1	17.12±0.62

- Research Group: Fed with feed treated with a 46% nitrogen urea solution at a rate of 50 L solution per 100 kg dry feed.
- Control Group: Fed with untreated roughage.

Table 4: Comparison of Average Weights in Research and Control Groups Before and After Feeding with Urea - Treated Roughage

Treatment Groups		Significant Effects
Research Group	Control Group	**

It can be observed from Tables 3 and 4 that the research group (fed with urea - treated roughage) gained a daily weight increase of 85±8.6 grams, compared to the control group which gained a daily increase of 55±4.1 grams. The difference was very significant ($P<0.1$).

Table 5: Feed Conversion Efficiency for Research Groups Fed Chemically Treated Diets Compared to the Control Group

Group	Feed Conversion Efficiency	Significant Effects
Research Group	6.76±0.34	**
Control Group	8.24±0.22	

It can be observed from Table 5 that there was a very significant ($P<0.1$) difference in feed conversion efficiency between the treated and control groups, which emphasizes the effectiveness of chemical treatment of low - nutrient roughages to produce higher nutritional value feeds, improve their palatability, and consequently increase feed intake and weight gain, leading to better overall animal performance. The weight gain achieved by the treated groups was statistically very significant.

4. Recommendations and Suggestions

1) The use of chemical treatment with 46% urea in the form of an aqueous solution for treating prickly pear waste in an anaerobic environment for 30 days has significantly improved the nutritional value of roughage, enhanced palatability, increased daily feed intake, improved daily weight gain, and increased feed conversion efficiency with confirmed and high statistical significance.

2) It is recommended to apply the chemical treatment described in this study for feeding animals intended for fattening to obtain meat. This will have positive effects on the economics of raising and fattening small ruminants, which constitute a significant proportion of the overall livestock population.

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