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Theme

EWE DIET BASED ON A CACTUS-ATRIPLEX MIXTURE: IMPACT ON DIGESTIBILITY, FEEDING LEVELS, BLOOD GLUCOSE, BLOOD UREA, AND LAMB WEIGHT GAIN

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Experimental Part

List of Abbreviations

ADF: Acid Detergent Fiber

ADG: Average Daily Gain

AL: albumin

ALT: Alanine aminotransferase

AOAC: Association of Official Agricultural Chemists

AST: Aspartate aminotransferase

Ca: calcium

CF: crude fiber

CIHEAM: International Center for Advanced Mediterranean Agronomic Studies.

CP: crude proteins

Crea: creatinine

DCF: digestibility of crude fiber content

DCP: digestibility of crude protein content

DDM: digestibility of dry matter content

dE: Digestibility of energy

DE: Digestible Energy

DM: dry matter

DMI: Dry Matter Intake

DOM: digestibility of organic matter content

Fat: Fat Content.

FG: Total Foggy Days per Year,

FL: Feed Level

FOM: Fermentable organic matter content

FUL: Forage Unit for lactation

GE: Gross Energy

Glu: Serum glucose

GR: Total Hail Days per Year.

INRA: National Institute of Agricultural Research

K: Potassium

ME: Metabolisable energy

Mg: Magnesium

mNM: microbial nitrogenous matter

MODI: digestible organic matter intake

MPI: Microbial proteins reaching the intestine

MR: Maintenance Requirements

NDF: Neutral Detergent Fiber

NE: Net Energy

OM: organic matter

OMI: Organic Matter Intake

P: phosphorus

$P^{0.75}$: metabolizable weight

PDI: protein digestible in the small intestine

PDIE: protein digestible in the small intestine (PDI) permitted by nitrogen (N) provide by food.

PDIN: protein digestible in the small intestine (PDI) permitted by energy (E) provided by food.

PP: Annual Total Precipitation of Rain and/or Meltwater (mm),

RA: Total Rainy Days per Year,

SN: Total Snowy Days per Year,

T: Annual Mean Temperature (°C),

TC: Total cholesterol

TG: Triglyceride

TM: Annual Mean Maximum Temperature (°C),

Tm: Annual Mean Minimum Temperature (°C),

TN: Total Days with Tornadoes or Funnel Clouds per Year,

TNM: Total Nitrogenous Matter

TP: Total protein

TS: Total Stormy Days per Year,

V: Annual Mean Wind Speed (km/h),

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Abstract

This study examines the viability of incorporating Opuntia ficus-indica and Atriplex halimus as alternative forage for Barbarine ewes in Algeria's arid and semi-arid regions, with a focus on ewes in late pregnancy. Thirty-six Barbarine ewes were assigned to nine feeding diets: the control group (D1) received 0.5 kg barley and 1.8 kg barley straw, while experimental groups D2 to D6 were fed barley straw ad libitum with varying combinations of Opuntia and Atriplex (100% Opuntia, 75% Opuntia + 25% Atriplex, 50% Opuntia + 50% Atriplex, 25% Opuntia + 75% Atriplex, and 100% Atriplex). Groups D7, D8, and D9 were fed exclusively with barley straw, Atriplex, and Opuntia, respectively. The results showed that dry matter intake (DMI) and digestibility were notably higher in groups with mixed Opuntia and Atriplex diets (D3, D4, and D5), compared to groups fed solely Atriplex (D8) or barley straw (D7). Organic matter (OM) and crude fiber digestibility also improved significantly in groups with combined feed, while those fed 100% Opuntia or Atriplex showed reduced digestibility. Blood metabolite analysis revealed that glucose levels decreased significantly in D8, while cholesterol levels dropped significantly in D7 and D9 but increased in D8. Triglycerides decreased in D2, D3, D4, D5, D7, and D9, but increased in D8. Total protein and albumin were slightly reduced in D1, D3, D4, and D5, with blood urea and creatinine levels significantly lower in D7 and D9. Aspartate transferase (AST) and alanine transferase (ALT) enzymes showed significant reductions in D7 and D9 and an increase in D8. Plasma calcium and phosphorus also decreased significantly in D7, D8, and D9. For milk composition, ewes in D5 had the highest fat content, showing a significant increase over the control group, while protein content was highest in D5 as well. Additionally, lambs in the D5 group exhibited significant weight gain, indicating enhanced milk quality and nutritional sufficiency in these feeding regimes. The study concludes that mixed diets of Opuntia ficus-indica and Atriplex halimus, with barley straw ad libitum, offer a sustainable alternative for Barbarine pregnant ewes. These results indicate that such diets could improve digestibility, blood parameters, and milk production and lambs weight gain without adverse health effects, presenting an effective solution for livestock feeding in resource-limited, arid environments.

Keywords: Atriplex Halimus, Barbarine Ewes, Blood Metabolites, Opuntia Ficus Indica, Milk Composition, Dry Matter Intake, Digestibility, Arid Environments

Résumé

Cette étude examine la viabilité de l'intégration d'*Opuntia ficus-indica* et d'*Atriplex halimus* comme aliments fourragers alternatifs pour les brebis Barbarine, en fin de gestation, dans les régions arides et semi-arides d'Algérie. Trente-six brebis Barbarine ont été réparties en neuf régimes alimentaires : le groupe témoin (D1) a reçu 0,5 kg d'orge et 1,8 kg de paille d'orge, tandis que les groupes expérimentaux D2 à D6 ont été nourris à volonté avec de la paille d'orge, combinée à différentes proportions d'*Opuntia* et d'*Atriplex* (100 % *Opuntia*, 75 % *Opuntia* + 25 % *Atriplex*, 50 % *Opuntia* + 50 % *Atriplex*, 25 % *Opuntia* + 75 % *Atriplex* et 100 % *Atriplex*). Les groupes D7, D8 et D9 ont été nourris exclusivement avec de la paille d'orge, de l'*Atriplex* et de l'*Opuntia*, respectivement. Les résultats ont montré que la consommation de matière sèche (DMI) et la digestibilité étaient significativement plus élevées dans les groupes recevant des régimes mixtes *Opuntia* et *Atriplex* (D3, D4 et D5) comparativement aux groupes nourris uniquement avec de l'*Atriplex* (D8) ou de la paille d'orge (D7). La digestibilité de la matière organique (MO) et des fibres brutes s'est également améliorée de manière significative dans les groupes recevant des régimes combinés, tandis que les régimes 100 % *Opuntia* ou *Atriplex* ont montré une digestibilité réduite. L'analyse des métabolites sanguins a révélé une diminution significative du glucose dans le groupe D8, tandis que les niveaux de cholestérol ont diminué de manière significative dans les groupes D7 et D9, mais augmenté dans D8. Les triglycérides ont diminué dans les groupes D2, D3, D4, D5, D7 et D9, mais augmenté dans D8. Les niveaux de protéines totales et d'albumine étaient légèrement réduits dans les groupes D1, D3, D4 et D5, tandis que les niveaux d'urée sanguine et de créatinine étaient significativement plus faibles dans D7 et D9. Les enzymes aspartate transférase (AST) et alanine transférase (ALT) ont montré des réductions significatives dans D7 et D9 et une augmentation dans D8. Les niveaux plasmatiques de calcium et de phosphore ont également diminué significativement dans les groupes D7, D8 et D9. Pour la composition du lait, les brebis du groupe D5 ont présenté la plus forte teneur en matières grasses, avec une augmentation significative par rapport au groupe témoin, tandis que la teneur en protéines était également la plus élevée dans le groupe D5. De plus, les agneaux du groupe D5 ont montré un gain de poids significatif, indiquant une meilleure qualité nutritionnelle et suffisance du lait dans ces régimes alimentaires. L'étude conclut que les régimes mixtes d'*Opuntia ficus-indica* et d'*Atriplex halimus*, avec un complément de la paille d'orge, offrent une alternative durable pour les brebis Barbarine en gestation. Ces résultats montrent que ces régimes

pourraient améliorer la digestibilité, les paramètres sanguins, la production de lait et le gain de poids des agneaux sans effets négatifs sur la santé et même remplacer l'orge en grain, offrant ainsi une solution efficace pour l'alimentation animale dans les environnements arides et limités en ressources alimentaires.

Mots-clés : Atriplex *halimus*, Opuntia *ficus-indica*, brebis barbarine, gestation, digestibilité, paramètres sanguins, croissance , lait, aridité.

ملخص

تبحث هذه الدراسة في دمج نبات الصبار والقطف كمصادر علف بديلة للنعاج البربرية في المناطق القاحلة وشبه القاحلة في الجزائر، مع التركيز على النعاج الحوامل في أواخر الحمل. تم توزيع ستة وثلاثين نعجة بربرية على تسعة أنظمة إلى R2 تلقت 0.5 كجم شعير و1.8 كجم قش شعير، بينما تم تغذية المجموعات التجريبية من (R1) تغذية: المجموعة الضابطة بقش الشعير حسب الحاجة مع مجموعات مختلفة من الصبار والقطف (100% صبار، 75% صبار + 25% قطف، R6 حصريًا R9 و R8 و R7 50% صبار + 50% قطف، 25% صبار + 75% قطف ، و100% قطف). تم تغذية المجموعات وقابلية الهضم كانت أعلى بشكل (DMI) بقش الشعير و القطف والصبار على التوالي. أظهرت النتائج أن مدخول المادة الجافة أو (R8) ، مقارنة بالمجموعات التي تم تغذيتها بالقطف فقط(R5 و R4 و R3) ملحوظ في المجموعات التي تم تغذيتها بالقطف والألياف الخام بشكل ملحوظ في المجموعات التي تم (OM) كما تحسنت قابلية هضم المادة العضوية .(R7) قش الشعير تغذيتها بعلف مشترك، بينما أظهرت المجموعات التي تم تغذيتها بالصبار أو القطف بنسبة 100% قابلية هضم منخفضة. كشف ، بينما انخفضت مستويات R8 تحليل الأيضات في الدم أن مستويات الجلوكوز انخفضت بشكل ملحوظ في المجموعة R2 وانخفضت الدهون الثلاثية في .R8 ولكنها زادت في المجموعة R9 و R7 الكوليسترول بشكل ملحوظ في المجموعتين R4و R3و R1 وانخفض البروتين الكلي والألبومين انخفاضًا طفيفًا في .R8 ، ولكنها زادت فيR9و R7و R5و R4و R3و R9 وR7 . ، وانخفضت مستويات اليوريا والكرياتينين في الدم انخفاضًا ملحوظًا R5و R9و R7 انخفاضًا كبيرًا في (ALT) والألانين ترانسفيراز (AST) أظهرت إنزيمات الأسبارتات ترانسفيراز بالنسبة لتكوين الحليب، كان .R9 و R8 و R7 كما انخفض الكالسيوم والفوسفور في البلازما بشكل ملحوظ في .R8 وزيادة في ، حيث أظهرت زيادة كبيرة عن المجموعة الضابطة، بينما كان R4 أعلى محتوى دهني في المجموعة R4 لدى النعاج في زيادة في الوزن، مما R4 أيضًا. بالإضافة إلى ذلك، أظهرت الحملان في مجموعة R4 محتوى البروتين أعلى في المجموعة يشير إلى تحسين جودة الحليب والكفاية الغذائية في أنظمة التغذية هذه. خلصت الدراسة إلى أن الوجبات الغذائية المختلطة من اللبخ الهندي الأوبونتيا واللبخ الهندي وأتريبلكس هاليموس، مع قش الشعير حسب الطلب، توفر بديلاً مستدامًا ومعززًا لصحة النعاج الحوامل من نوع بارباري. تشير هذه النتائج إلى أن مثل هذه الوجبات الغذائية يمكن أن تحسن من قابلية الهضم، .وبارامترات الدم، وإنتاج الحليب دون آثار صحية ضارة، مما يمثل حلاً فعالاً لتغذية الماشية في البيئات القاحلة محدودة الموارد

الكلمات المفتاحية: القطف، النعاج البربرية، نواتج الدم الأيض، الصبار، الحليب، كمية المادة الجافة، قابلية الهضم، البيئات القاحلة

GENERAL INTRODUCTION

General Introduction

Semi-arid regions cover approximately 15% of the world's land surface and are home to communities reliant on small ruminants for economic and nutritional sustenance. In Algeria, livestock farming is a cornerstone of rural livelihoods and contributes significantly to the agricultural economy. As of 2020, Algeria's total livestock population reached 38.1 million head, reflecting a 4% increase from 2019. Sheep dominate this population, accounting for 81% of all livestock, with a national count of 30.9 million, of which 62.4% are ewes. The number of ewes alone reached 19.3 million in 2020, marking a 4.3% increase compared to 2019 (ONS, 2023). This growth highlights the importance of sheep farming for meat, wool, and milk production, yet also underscores the mounting challenges of sustaining this sector in the face of chronic forage deficits and environmental degradation.

Algeria's forage resources are insufficient to meet the growing feed demand, creating a significant constraint for the livestock sector. Of the country's total land area of 238 million hectares, only 43.5 million hectares are utilized for agriculture, with 36 million hectares dedicated to forage production. This area includes steppe rangelands (85.2%), fallow land (11.7%), forage crops (2.8%), and permanent grasslands (0.4%) (MADR, 2016). Despite some growth in forage cultivation, the sector's productivity remains critically low. In 2016, forage production yielded only 153.82 forage units (UF) per hectare, meeting just 45% of the national demand of 13.3 billion UF, resulting in a deficit of 7.3 billion UF (Ladjali & Tayeb Bey, 2016; Merdjane & Yakhlef, 2016). This represents a significant increase from previous deficits reported in 2006 (-3.3 billion UF) and 1997–2001 (-2.34 billion UF) (Bouzida, 2008; Alfa & Bello, 2004).

The reliance on expensive imported feed supplements, such as barley, has become a necessity to sustain livestock productivity. Between 2011 and 2017, Algeria imported over 3.1 million tonnes of forage at a cost exceeding $1 billion (MADR, 2017). This dependence poses economic vulnerabilities, particularly in years of low rainfall, when barley imports compete with human food needs. At the same time, environmental degradation continues to exacerbate forage scarcity. The Algerian steppe, which spans over 20 million hectares, has faced severe degradation due to overgrazing, plowing for cereal cultivation, and recurrent droughts. These pressures have reduced the steppe's ability to support livestock, with current grazing demands exceeding sustainable limits by a factor of 12 (Nedjraoui & Bedrani, 2008).

To address these challenges, it is essential to identify and incorporate sustainable, locally available feed alternatives. Among these, *Opuntia ficus-indica* (cactus) and *Atriplex halimus* have shown promise as viable options for supplementing traditional diets in arid and semi-arid regions. Cactus cladodes are particularly valuable for their high water content and energy-rich composition, making them a crucial resource during periods of drought. Similarly, *Atriplex halimus* is notable for its high crude protein and fiber content, supporting both maintenance and production requirements in small ruminants. These plants have been cultivated increasingly in Algeria, especially in the wilayas of Tébessa and Biskra, where marginal lands have been converted for this purpose. Their integration into livestock diets aligns with global sustainability goals and offers a potential solution to Algeria's forage crisis.

This study focuses on the inclusion of *Opuntia ficus-indica* and *Atriplex halimus* in the diets of pregnant Barbarine ewes, a breed well-suited to Algeria's semi-arid

conditions. We hypothesize that varying proportions of these plants in the diet will meet nutritional needs without adversely affecting physiological health, as measured by blood biochemical parameters. Specifically, the research examines diets ranging from 100% cactus or *Atriplex* to mixed proportions of the two, with barley straw serving as roughage. By evaluating the digestibility, energy efficiency, and biochemical impacts of these diets, the study aims to provide practical insights into their use as alternative feed resources.

The objectives of this research are as follows:

1. To assess the physiological and biochemical impacts of incorporating *Opuntia ficus-indica* and *Atriplex halimus* into the diets of pregnant ewes and of the weight of their offspring.
2. To evaluate the digestibility, feeding level of these diets under semi-arid conditions.
3. To propose sustainable feeding strategies that mitigate forage deficits, reduce dependency on imports, and enhance livestock resilience in Algeria.

By addressing these objectives, this study seeks to contribute to the development of sustainable livestock systems in Algeria and other semi-arid regions. The findings have implications for policymakers, farmers, and environmental stakeholders, offering a pathway to alleviate forage shortages, protect vulnerable ecosystems, and support the long-term productivity of small ruminants.

Part I
Theoretical Background

Introduction

This chapter provides the theoretical foundation for the current study. It is crucial in contextualising the hypothesis tested during the experimental phase. The argument presented in the first chapter centres around the potential use of Atriplex and Opuntia ficus-indica as a sustainable forage crop and resolution to concentrates. It begins by providing an overview on the plant sources used during the study, namely, Opuntia ficus-indica and Atriplex halimus. Then, it moves to discuss the situation of forage resources in Algeria.

I.1.1 Plant Sources

This section presents the plant sources used in the experimental phase.

I.1.1.1 Opuntia ficus-indica

I.1.1.1.1 Origin

According to CABI, Opuntia ficus-indica has been grown in Mesoamerica since pre-Columbian times, making determining the plant's specific origin impossible. However, there appears to be agreement among ethnobotanists that the Opuntia genus and its cultivation are indigenous to Mexico (Bursać Kovačević et al., 2020; Griffith, 2004; Guerrero-Beltrán & Ochoa-Velasco, 2018). The Cactaceae family; which contain about 130 genera and about 1500 species of cactuses, where the Opuntia genus belongs, is distributed in America from western and southern Canada to the Patagonia (Bursać Kovačević et al., 2020; Butera et al., 2002; Guerrero-Beltrán & Ochoa-Velasco, 2018; Kaur, 2012). It was first introduced into Spain and later, in the 16th century, to North and South Africa. It spread rapidly throughout the Mediterranean basin and became naturalized there, becoming a characteristic element of the landscape (Erre et al., 2009; Neffar, 2012).

Opuntia cactus cultivation is primarily concentrated in the western Mediterranean region, encompassing southern Spain, Portugal, and North Africa (Tunisia, Algeria, and Morocco) (Bensalem et al., 2002; Arba, 2009). For instance, the cultivated area in the WANA region (West Asia and North Africa) is estimated to be around 900,000 hectares (Nefzaoui & Bensalem, 1998). In countries like Italy, Spain, Mexico, and Israel, cactus cultivation is practiced intensively and modernly, with research and development programs focused on fruit and forage production, as well as industrial applications (Mulas & Mulas, 2004). In contrast, in Australia and South Africa (Dean & Milton, 2000; Orwa et al., 2009), this plant, particularly the Opuntia ficus-indica variety, is considered a weed due to its ease of propagation.

In Algeria, cacti have long been used by farmers as hedges around their fields. Since 1961, a significant collection of cacti has been established by the forestry service, along with several experimental plots. The first plantations of spineless cacti for forage were carried out in Zériba near Bouira. The main collection of Opuntia is located in the Lesser Atlas Mountains (Bois de Boulogne), the second collection is located at the forestry and DRS nursery in Chebli. A small collection is also found in the city of Bois in Algiers. As for the experimental plots, there is one in Ain Oussera, the second is located in the Benhar arboretum a few kilometers from Ain Oussera. The third experimental plot, which belongs to INRA, is located in Tadmit (Khouri 1970 as cited in Louacini, 2014).

On an important note, O. ficus-indica is not invasive in Mexico, where it was originally found; which is referenced for two reasons according to Zimmermann and Granata (2002), one is that the plant is frequently consumed by humans and animals; second, it is constantly attacked by a wide range of specialised natural enemies and illnesses.

I.1.1.1.2 Description

Cactus is classified as tropical or subtropical plant and is commonly dispersed in arid and semi -arid climates of the Mediterranean and Central America, to which it presents a high morpho-physiological adaptation capacity to their extreme environmental conditions (Aruwa et al., 2018; Butera et al., 2002; Griffith, 2004; Kiesling, 1998; Lallouche et al., 2015; Stintzing & Carle, 2005;).

Opuntia ficus-indica is a perennial shrub that grows slowly and reaches a height of three to five metres. They can usually be found growing in semi-arid and arid conditions, withstanding poor soil conditions, high temperatures and low water availability (Kluge & Ting, 2012; Gallegos-Vazquez et al., 2012; Omar et al., 2021). Additionally, many countries' agricultural economies still rely heavily on Opuntia which were domesticated long ago in arid and semi-arid areas and are still a crucial crop (Griffith, 2004). Its unique organization features cladodes, commonly known as "pads." These cladodes are modified stems with a flattened shape, measuring 30 to 40 cm in length. They replace leaves in their photosynthetic function and have a surface dotted with alveoli (Schweizer, 1997; Stintzing et al., 2005; Feugang et al., 2006). The thick and succulent paddle-like parts of this cactus are named cladodes. They are spiny or spineless, O blong with variable widths, and possess a waxy, water-proof epidermis with a photosynthesis capacity and asexual reproduction (Heuzé & Tran, 2017).

I.1.1.1.3 Opuntia species and varieties

Opuntia argentina: bright green tree-like cactus. Flat, oblong segments 12 cm long. Yellow flowers. Up to 15 m high with a spread of 3 m.

Opuntia ficus-indica: prickly pear. Large segments (40 cm long and 25 cm wide). Yellow flowers. Height 5 m for as much spread.

Opuntia ficus-indica var. inermis: prickly pear without prickles. Smooth green/blue segments.

Opuntia microdasys: bushy cactus with flattened, oval segments bearing white, yellow or brown glochids depending on the variety. Bright yellow flowers tinged with red. Height 40 cm with as much spread.

Opuntia imbricata: cylindrical segments 10 to 40 cm long, bright green to bluish green. Red or purple flowers in summer. Up to 3 m high with a spread of 1.5 m.

Opuntia robusta: large bluish-green segments with white, brown or yellow prickles. Yellow flowers in June. 2 metres in all directions.

Figure 1: *The Plant of Cactus Ficus Indica*

Note. From Figuier de Barbarie, Opuntia ficus-indica, by I. Makoto, 2018 (https://www.gerbeaud.com/jardin/fiches/figuier-barbarie-opuntia,1822.html). Copyright 2024 by I. Makoto/gerbeaud

I.1.1.1.4 Roots of Opuntia

O. ficus-indica roots often have mean depths of about 15 cm, which allows them to react quickly to mild rains. For example, it can grow new roots in a dry soil in just 24 hours after being wet (Kausch, 1965). Since roots only make up around 12% of the overall plant biomass in O. ficus-indica, its numerous water-conserving techniques necessitate a modest root system (Nobel, 1988). Usually staying within 30 cm of soil depth, its horizontal root system rarely reaches far into the ground. One of its unusual traits is that when it rains, it grows a lot of extra roots, or "rain roots," which hydrates the cactus more than the soil (Naorem, 2021).

The roots exhibit unique xeromorphic adaptations that enable the plant to withstand prolonged periods of drought. The roots contribute to drought tolerance through several mechanisms:

- Reduced root surface area and decreased permeability: These adaptations minimize water loss.
- Rapid absorption of small amounts of water: The development of rain roots following precipitation allows for quick uptake of moisture. These roots can rapidly emerge and recede depending on soil moisture conditions.
- Decreased shoot transpiration: The high negative water potential in the roots reduces water loss from aerial parts.

Figure 2: *Roots of Opuntia ficus-indica*

Note. From "Cladode planting methods improves the initial growth and production of cactus pear (Opuntia ficus-indica (L.) Mill.)" by A.H. Bakali, C. Alem, L. L. Ichir and E. Mzouri, 2016, Journal of AAB Bioflux, 8(3), p. 111-128 (https://www.researchgate.net/publication/310800167).

These characteristics, indicative of drought-resistant water-saving plants, result in high hydraulic resistance, which in turn diminishes water flow to the shoots (Assifer. 2019). This compound serves as a water storage reservoir (Saenz et al., 2004), slowing down transpirational losses (Neffar, 2012). The plant has a shallow root system, and this enables it to accumulate elements (Chiteva & Wairagu, 2013). Furthermore, O. inermis root has been evaluated for its antioxidant and anti-ulcerogenic activities (Alimi et., 2010).

Opuntia species are characterized by superficial, fleshy roots that exhibit a horizontal, lateral, and fasciculated growth pattern. In extremely arid environments, secondary fleshy roots can develop from the primary roots, penetrating deep into the soil to access moisture from lower strata [49]. The root system of Opuntia is typically found within the top 30 cm of soil, with a horizontal spread that can reach up to 8 meters [39]. A study has revealed that the root system of Opuntia ficus indica constitutes only 11% of its total biomass [50] (Hadjkouider, 2008)

I.1.1.1.5 Cladodes

Opuntia plants have rectangular, thick, succulent sections called cladodes that range in width and are either spiny or spineless. These parts can reach lengths of 70 to 80 cm. Their asexual reproduction and photosynthesis are both possible, and they have a waxy, water-repellent skin. The areoles may have barbs and small bristles called glochidia (Heuzé & Tran, 2017). Numerous investigations have demonstrated that the composition of Opuntia cladode compounds varies depending on the species, post-harvest handling, growing environment, and age of the plant (Astello-García et al., 2015; Contreras-Padilla et al., 2011; Guevara-Figueroa et al., 2010). However, other research has shown that identical flavonol profiles among cladode cultivars from various areas can be utilised for taxonomic identification and categorisation of Opuntia cultivars and products (Moussa-Ayoub et al., 2014).

Figure 3: *Cladode of Opuntia ficus-indica*

I.1.1.1.6 Uses of Cladodes

Previous research has extensively documented the various uses of cladodes on Opuntia. According to Giraldo-Silva (2023), Cladodes are rich in fibers such pectin, lignin, cellulose and hemicellulose and can be used as animal feed, fodder or for human consumption. Others have also contended that they are consumed mainly as staple food, but according to Mexican popular

medicine, some diseases like diabetes mellitus, blood glucose levels, hyper-lipidemy, obesity and gastrointestinal disorders can be alleviated by eating this vegetable (Corrales-Garcia et al. 2004).

Cladodes from cactus plant are used in folk medicine for their antioxidant and anti-ulcerogenic properties. They have been investigated as potential treatments for gastritis, hyperglycemia, ateriosclerosis, diabetes, and prostatic hypertrophy. Cladodes are also used in the food industry for gelling properties and as a source of fibre and colour (Alimi, 2010)

I.1.1.1.7 Areole

Oval in shape, the areolae are located 2 mm below the skin's surface. New roots, blooms, or cladodes will grow out of the areoles' meristematic tissue in the correct environmental circumstances. The areoles of O. ficus-indica are organised in a helical arrangement and grow spines rather than leaves, as is the case with other plants. The areoles form at the base of the podarium (nipple) when the cladode is young. A tiny, transient subulate structure that swiftly dries out and falls off is present in the podarium. In Figure 4, this transient form is analogous to a leaf. As the stem ages, the podarium disappears and becomes less noticeable in the early phases of cladode growth.

Figure 4: *Areole in the young cladode.*

Note from "Crop Ecology Cultivation and Uses of Cactus Pear", by P. Inglese & A. Nefzaoui, p. 25, 2018.

The short apical meristem's base is where the areola starts, and from there, spines grow quickly from the basal meristem (Mauseth, 1984). The number of spines varies, but typically there are one or two long central spines and another shorter lateral spine.

In comparison to the other spines, the long central spines develop longer and have thicker walls due to their production by more robust primordia (Gibson & Nobel, 1986) and elongated cells with lignified cell walls. Glochids appear while they grow.

I.1.1.1.8 Flower of Opuntia

Although opuntia flowers can be found in a variety of colours, their colours gradually change from white to yellow to red, orange, pink, peach, or cream as they bloom. According to Heuzé and Tran (2017), flowers are big, bisexual, auxillary, and have spirally organised tepals. Following fruit separation, the Opuntia ficus-indica flowers are typically discarded as by-products (Benayad et al., 2014; Yeddes et al., 2014). The primary pigments in cactus flowers are phenolics and betalain. The betaxanthins and betacyanins that are produced by the binding of various amino/imino groups to the betalamic acid core of betalains (Aruwa et al,. 2018). Opuntia flower infusions have been shown to have diuretic properties both in vitro and in vivo, and this activity has been related to their potassium content (Galati et al., 2002). Interestingly, studies on the polyphenolic profile of Moroccan O. ficus-indica flowers revealed that the flowers might be employed as an initial ingredient in the production of nutraceuticals or infusions (Hossain et al., 2011; Benayad et al., 2014).

Areoles give rise to cactus blooms. Myrtillo-cactus geometrizans typically produces a single flower from each areole, however occasionally many flowers might emerge from a single areole. The only genus that produces a real inflorescence—a collection of individual blooms

grouped on a stem—is Pereskia, which includes P. grandifolia. Neoraimondia areoles have the ability to continuously produce flowers from a single areole, giving rise to a unique short-shoot structure. Few cacti actually generate terminal blooms from the tip of the shoot, though flowers might appear on quite various portions of the stem. Remember that the areole is actually a small stem from which flowers are often formed. However, several species have dimorphic or two-parted areoles, with one part producing spines and the other producing flowers.

Figure 5: *Flower of Opuntia ficus-indica*

Note. From Cabi Website (Opuntia ficus-indica (prickly pear) | CABI Compendium (cabidigitallibrary.org))

Because of its diuretic properties, flowers are commonly used as infusions. Opuntia flower is beneficial in many areas, including traditional medicine, because of its depurative properties, which include being a diuretic and relaxing the renal excretory system (Giraldo-Silva, 2023).

I.1.1.1.9 Fruits of Opuntia

The O. ficus-indica fruit is a fleshy berry that develops from an inferior ovary buried in the stem tissues of the container. The peel shares the cladode's morphology and begins in the receptacle:

- Thin hypodermis with a thick cortex;
- Plenty of mucilage cells but no crystals;
- Epidermis with transient leaves and perfects areoles; the glochids are more persistent than in the cladodes.

Trichomes that begin in the funiculi's epidermal cells and the funicular envelope proliferate to generate the pulp (Pimienta Barrios and Engelman, 1985). The quantity of fertilised ovules and the number of rejected seeds determine the size of the fruit (Archibald, 1935; Pimienta Barrios, 1990; Barbera et al., 1994). It is still unknown why seeds fail to germinate.

Figure 6: *Fruits of Opuntia*

Cactus fruit and stem are used in various products, including jam, pickles, squash, wine, body lotions, shampoos, and creams. They also have medicinal properties, such as anti-inflammatory, hypoglycemic, inhibitive, and neuroprotective effects. Cactus pear juice is a popular natural food substitute due to the trend towards better diets and increased availability of nutritional components. Juices from fruits and vegetables are beneficial for human health, and are enjoyed at home, in vegetarian restaurants, or at health food stores. However, commercial products are not developed due to specific technological issues related to manufacturing. Cactus pear juice is also used in traditional folk medicine and is used to treat diabetes, burns, bronchial asthma, and indigestion due to its antioxidant properties.

I.1.1.1.10 Grains of Opuntia

The pollen grain contains a thick exterior wall known as the exine, which serves a protective role. The humidity level affects its volume (Eames, 1961). Thin and readily able to adjust to size variations is the inner layer, or intine. Since the wall can be extremely thick and complicated in structure, and the outer layer is carved with protruding ridges, spines, and granules, the patterns of the exine are of significant taxonomic and evolutionary relevance. As to Scheinvar's (1995) description, the pollen grains of Opuntia are spheroidal, reticulate, and polycollate. They possess 18 colpi, making them akin to those of O. fusicaulis. One can witness the pollen tubes a full day following anthesis, and a substantial quantity of pollen grains.

The germinated pollen tubes are visible on the glandular epidermal surface of the broad stigma canal following anthesis. 48 hours after anthesis, the ovules progressively begin to fertilise, a process that lasts for ten days. This kind of fertilisation is referred to as "progamyc" by Rosas and Pimienta Barrios (1986). The variety determines the average number of fertilised ovules per flower (Rosas and Pimienta Barrios, 1986). In O. ficus-indica, 18.4 to 30.1% of the pollen grains placed on the stigma germinate to create pollen tubes. In this species, tubes can

form up to 397 and grow on the inner style duct's glandular epidermis. The majority of tubes begin at the stigma and extend towards the style's base. About 48 hours after pollination, the pollen tubes reach the base of the style, and 72 hours later, the ovule is fertilised. 48% of the ovules become fertilised after 4 days (Rosas and Pimienta Barrios, 1986). In Opuntia, nucleolar polyembryony is frequent. This describes how a single seed can grow into two or three plants.

I.1.1.1.11 Taxonomy and vernacular names

According to CABI digital library (2018), variation of names within Opuntia plant is common. The common scientific name is Opuntia ficus-indica (L.) Mill as it is also known as prickly pear. There are many other scientific names for the plant such as: Cactus compressus Salisb, Cactus ficus-indica L and Cactus opuntia L. to name only a few. The plant has few vernaculars. For example, in English it is barbary fig, cactus pear, Indian fig, smooth mountain prickly pear, sweet prickly pear. In Spanish: chumba, chumbera, higo chumbo, nopal and tuna. In French: cactus raquette, figuier de barbarie, figuier d'Inde, nopal and raquette. In Arabic: Sabbar, Teen Chawki, Hindi.

Numerous authors have developed classifications for the genus Opuntia. This plant was categorised by Linnaei (1753) in the Species Plantarum plants compendium as Cactus opuntia and C. ficus-indica. In 1768, Philip Miller identified the plant as Opuntia ficus-indica (Griffith, 2004). Nevertheless, due to the existence of several species within the Opuntia genus in Mexico, America, and other parts of the world, classifications have had to alter over time (Guerrero-Beltran & Ochoa-Velasco, 2018). In reviewing the literature, few classifications exist, and the most detailed one is the latest classification by USDA (2016) as mentioned in Guerrero-Beltran & Ochoa-Velasco (2018):

Kingdom: Plantae

Subkingdom: Tracheobionta

Superdivision: Spermatophyta

Division: Magnoliophyta

Class: Magnoliopsida

Subclass: Caryophyllidae

Order: Caryophyllales

Family: Cactaceae

Subfamily: Opuntioideae

Tribe: Opuntieae

Genus: Opuntia

Species (edible): there exist various names (INE, 1994;): ficus-indica, albicarpa, megacantha, undulata, among others. (Guerrero-Beltrán, J. Á., & Ochoa-Velasco, 2018)

I.1.1.1.12 Ecological importance of Opuntia

Opuntia has the power to halt the advance of the desert and protect wildlife (Barringer et al, 1996). Opuntia cultivation provides the land it colonises with a powerful canopy, shading the soil surface (Monjauze and Lehouérou, 1965). Cacti can be used to combat water and wind erosion. The prickly pear is very often used as a defensive hedge in its native region and even for ornamental use in ornamental gardens (Chriyaa, 2000). The desert cactus Opuntia Ficus indica, which tolerates drought and protects soils against erosion, is still used in Tunisia, Algeria and Morocco to slow down and direct the movement of sand, increase plant cover and prevent the destruction of terraces built to reduce run-off (I.F.A.D, 2000).

I.1.1.1.13 Economic Importance of Opuntia

Livestock forage production is the second most important economic use of cacti worldwide. It is also the second most important use of cacti in Morocco (arba, 2009). cacti have long been used as livestock feed in arid areas, and their production in these areas is more

profitable than that of certain other forage species such as maize and sorghum (Russel, 1986). A number of countries, including Mexico, the USA, Brazil, Peru and Chile, produce large quantities of cactus snowshoe as livestock feed (Nobel et al., 1987). Cactus snowshoe is valued by livestock for its high water, fibre, protein and mineral content (Nefzaoui and Ben Salem, 2000; Lehouérou, 2002).

I.1.1.2 Atriplex halimus

It is a xerohalophytic shrub widely distributed in the arid and semi-arid regions of the Mediterranean Basin, extending to Saudi Arabia, at altitudes below 900 meters. It grows on a variety of soil types, ranging from fine to coarse textures, with varying degrees of salinity. There are two subspecies of *Atriplex halimus*: *halimus*, a diploid (2n = 2x = 18), which is found in less saline semi-arid regions, and *schweinfurthii*, a tetraploid (2n = 4x = 36), which occupies saline arid regions (Tadjani, 2022). Commonly known as sea purslane, *Atriplex* is one of the most widespread shrubs along the Atlantic coastline and the Mediterranean coast. Resistant to salt spray and drought, it forms protective hedges in seaside gardens. The genus *Atriplex* is the largest and most diverse within the Chenopodiaceae family (Amaranthaceae), distributed across temperate and subtropical regions, with a few species also found in polar areas, albeit in very limited numbers (Kharoubi & Halim, 2023).

I.1.1.2.1 Origins

The origin of *Atriplex halimus* remains uncertain and has been the subject of debate among researchers. According to Belarbi (2018), the precise origins of this species are not well-documented. Some authors, such as Osman and Ghassali (1997), suggest that it may have originated in Australia before spreading to arid and semi-arid regions worldwide. Conversely, others, including Kinet et al. (1998), propose that *Atriplex halimus* is native to North Africa, where it is particularly abundant. This ambiguity highlights the need for further research to

clarify the evolutionary and geographical history of this species. *Atriplex halimus* is a widely distributed species found across various regions of the world. Its range spans from Alaska to Patagonia, Brittany to Siberia, and Norway to South Africa (Franclet & Le Houérou, 1971). It is native to North Africa and the Near East, extending as far south as Iran. In Europe, it occurs predominantly in Mediterranean regions, including Bulgaria and Algeria, as well as the Hoggar Massif (Choukr, 1995; Castroviejo et al., 1990).

Figure 7: *Geographic Repartition of Atriplex*

Note from Évaluation in vitro des activités biologiques d'Atriplex Halimus L., by D. Merikhifa & T. Tennah p. 6, 2022.

In Algeria, *Atriplex halimus* is spontaneous and widespread in arid and semi-arid bioclimatic zones, as well as in the Sahara, particularly in the Béchar region (Castroviejo et al., 1990). Quézel and Santa (1962) documented 13 native *Atriplex* species in Algeria, including five

perennial and eight annual species. Le Houérou (1992) later added two naturalized species to this list: the perennial *A. semibaccata* R. Br. and the annual *A. inflata* F.V. Muell. The species thrives in areas such as Tiaret, Tébessa, M'Sila, Saïda, Djelfa, Boussaâda, Biskra, and Batna, demonstrating its adaptability to diverse environmental conditions.

I.1.1.2.2 Description

Atriplex halimus is a perennial and spontaneous species that can grow as a ground cover or adopt a shrub-like form, particularly in arid and semi-arid climates (Ozenda, 1983). It is native to North Africa, where it is highly abundant (Kinet, 1988), and has spread to Mediterranean coastal areas of Europe as well as gypsiferous-saline inland regions in Spain. This shrub typically reaches a height of 50 to 200 cm (Quézel & Santa, 1962).

The species is known by various common names, including sea purslane, sea orache, Mediterranean saltbush, shrubby orache, and in Arabic as *G'atef* or *Raghl*. The *Atriplex* genus encompasses numerous species, such as *Atriplex nummularia*, *Atriplex lentiformis*, *Atriplex amnicola*, and *Atriplex canescens*. These species are notable for their high protein content, which enhances their ecological and nutritional value (Guettoche, 2021).

By thriving in diverse environments, including Mediterranean coastal zones and saline soils, *Atriplex halimus* demonstrates significant adaptability. Its ability to establish itself in challenging conditions makes it an important species for ecological restoration and sustainable agriculture.

I.1.1.2.2.1 Flower of Atriplex

According to Talamali et al. (2001), two types of flowers are distinguished based on the presence or absence of a perianth. The first type, characterized by five tepals, features yellow, actinomorphic flowers connected at their base and equipped with five well-developed stamens.

This type also has a more or less developed tissue puff on the axis, and anatomical studies reveal whether this tissue puff contains an ovule.

The second type lacks a perianth and includes green, actinomorphic flowers with two symmetrical, triangular bracteoles. Its gynoecium is superior, consisting of a unilocular, uniovular ovary with two stigmas. Some flowers of this type also possess fertile stamens.

In male flowers, there are 5 petals and 5 stamens, whereas female flowers lack a perianth. The gynoecium in female flowers consists of an ovary topped with 2 styles and enclosed by two opposing, triangular bracteoles (Kinet et al., 1998).

Figure 8: Flower of Atriplex

Note From Variabilité des Caractères morphologiques des populations naturelles d'Atriplex subsp. halimus et subsp. Schweinfurthii Cas Mostaganem Oran, by A.A. Abbou & F. Zagharia p. 8, 2018.

Flowers can be unisexual, monoecious, or dioecious, with some occasionally being hermaphroditic. Male flowers do not have bracteoles and feature a perianth with 4-5 tepals and

3-5 stamens. Female flowers have two bracteoles and either no perianth or a perianth with 2-4 hyaline segments. The ovary is unilocular and uniovular, with 2 filiform styles. The fruit is membranous, compressed between the two bracteoles of the female or hermaphroditic flower (perianth or fruit valves). The seed is lenticular, black, and vertically oriented (except in hermaphroditic flowers, where it is horizontal) (Quezel & Santa, 1962).

I.1.1.2.2.2 Root System of *Atriplex halimus*

The root system of *Atriplex halimus* is highly developed, enabling the plant to efficiently access soil water reserves, a key adaptation for survival in arid environments. The primary root typically measures 50 to 90 cm in length, with sparse secondary roots of similar or sometimes greater length. These secondary roots give rise to numerous fine, short tertiary roots (Le Houérou, 1992). The primary root is initially spread obliquely before penetrating vertically into the soil, with its depth varying depending on soil type and the plant's age. In some cases, the root length can reach three to five times the height of the stem and is composed of whitish rootlets (Maire, 1962). This robust root architecture highlights the species' exceptional ability to adapt to drought, as root growth is a critical indicator of drought tolerance (Douib, 2013).

Figure 9: Roots of Atriplex halimus

Note from Réponse antioxidative d'Atriplex halimus vis-à-vis l'exposition aux métaux lourds, by S. Tedjani p.9, 2022.

I.1.1.2.2.3 Stem of *Atriplex halimus*

The stem of *Atriplex halimus* is highly polymorphic, exhibiting diverse forms such as upright, erect, or interwoven growth patterns. The branches bear elongated clusters of grains (Gougue, 2005). The main stem is woody, erect, and highly branched, with the branches initially upright before spreading. These branches are rounded or angular, whitish in color, and often taper to varying degrees (Maire, 1962). This structural variability reflects the plant's adaptability to different environmental conditions.

I.1.1.2.2.4 Leaves of Atriplex halimus

The leaves of *Atriplex halimus* are alternate, distinctly petiolate, and somewhat fleshy, a characteristic that aids in water conservation in arid environments. They are covered with whitish vesicular hairs (trichomes) that give them a glossy appearance. Leaf shapes vary, being primarily oval but sometimes oval-rhomboid, triangular, or hastate, with margins that are entire or slightly sinuate-dentate. Leaf size typically ranges from 2 to 5 cm in length and 0.5 to 1 cm in width, with a general ratio of two times the length to the width (Maalem, 2002; Quézel & Santa, 1962).

Figure 10: *Leaves of Atriplex halimus*

Note from Réponse antioxidative d'Atriplex halimus vis-à-vis l'exposition aux métaux lourds, by S. Tedjani p.9, 2022.

The leaves are sometimes lanceolate, with more or less acute or acuminate tips, and are trinerved at the base. The prominent midrib is slightly raised on the underside and terminates freely within the leaf network. Larger leaves can reach up to 4.5 cm in length (Maire, 1962).

I.1.1.2.2.5 Grains of *Atriplex halimus*

The seeds of *Atriplex halimus* are enclosed within a membranous pericarp, measuring approximately 2 mm in diameter. They are flattened and can be arranged either vertically or horizontally, depending on the genus, which serves as an important taxonomic characteristic for distinguishing between genera (Quézel & Santa, 1962). The seeds are typically reddish-brown to dark brown, sometimes appearing black, with a lateral compression ranging from 0.9 to 1.1 mm (Franclet & Le Houérou, 1971; Quézel & Santa, 1962; Maâlem, 2002).

Figure 11: *Grains of Atriplex halimus*

Note From Variabilité des Caractères morphologiques des populations naturelles d'Atriplex subsp. halimus et subsp. Schweinfurthii Cas Mostaganem Oran, by A.A. Abbou & F. Zagharia p. 10, 2018.

Their lenticular shape and dull surface are consistent across specimens, with their arrangement being a defining feature for taxonomic differentiation (Nègre, 1961). Notably, the seeds of *Atriplex halimus* exhibit a remarkable ability to germinate under highly saline conditions, though germination is also a stage of heightened sensitivity to salt stress (Zid, 1977; Castroviejo et al., 1990). This duality underscores their ecological significance and adaptability in arid and saline environments.

I.1.1.2.3 Taxonomy

According to Singh (2004), the classification of the studied subspecies is as follows:

Kingdom: Plantae

Phylum: Spermaphyta

Subphylum: Angiospermae

Division: Magnoliophyta

Class: Magnoliopsida

Subclass: Caryophyllidae

Order: Caryophyllales

Family: Chenopodiaceae

Genus: Atriplex

Species: halimus L.

Atriplex halimus is known by various vernacular names, including:

- In French: *Arroche halime* or *Pourpier de mer*.
- In Algeria: *G'ttaf* or *L'egttef* (Kadi et al., 2016).
- In Morocco: *Chenane* (Medjekal & Bousseboua, 2016).
- In English: *Saltbush* (Medjekal & Bousseboua, 2016).

I.1.1.2.4 Chemical Composition of *Atriplex halimus*

The chemical composition of *Atriplex halimus* varies depending on factors such as climate, plant age, and season, reflecting its adaptability to diverse environmental conditions. Organically, the plant is rich in proteins, fibers, vitamins A, C, and D, as well as secondary metabolites like saponins, alkaloids, and flavonoids. On a dry matter basis, *Atriplex halimus* contains 34.2% dry matter, 15.1% total nitrogenous material (relative to dry matter), and 15.4% crude cellulose (relative to dry matter). Mineral composition further highlights its nutritional value, with the plant exhibiting significant mineral content critical for ecological and agricultural applications (Guettoche, 2021).

I.1.1.2.5 The importance of Atriplex halimus

I.1.1.2.5.1 Forage Value of *Atriplex halimus*

Atriplex halimus serves as an essential source of minerals, vitamins, and proteins for livestock, making it a valuable forage reserve during the summer and autumn seasons when other forage species are scarce (El-Shatnawi & Mohawesh, 2000). This shrub addresses the seasonal forage deficit that arises before the spring growth of herbaceous forage plants (Kessler, 1990). Experimental studies have demonstrated that livestock can endure prolonged periods of food scarcity caused by drought due to the availability of *Atriplex halimus* (Le Houérou, 1980). Notably, well-managed stands of *Atriplex halimus* can yield up to five tons of dry matter per hectare annually, even on degraded or saline soils unsuitable for conventional crops (Dutuit et al., 1991). Its evergreen foliage, rich in protein, is particularly valued during extended summer droughts when herbaceous species have disappeared, providing a critical forage resource for sheep and other livestock (Abu-Zanat, 1995). Additionally, its adaptability to arid conditions underscores its significance in sustainable agricultural systems.

I.1.1.2.5.2 Economic Importance of *Atriplex halimus*

Numerous studies have highlighted the economic benefits of integrating *Atriplex* shrubs into agricultural systems. During summer and autumn, livestock can graze on barley stubble and *Atriplex* shrubs, providing a valuable forage source in periods of scarcity (Mulas & Mulas, 2004). Additionally, *Atriplex halimus* is particularly valued for its persistent, protein-rich foliage, which is highly appreciated by livestock during extended summer droughts. A well-managed stand of *Atriplex halimus* can produce up to five tons of dry matter per hectare annually on degraded or saline soils unsuitable for other crops, demonstrating its significant economic potential (Chalbi, 1991). Furthermore, its woody structure serves as an important energy

resource (Abbad et al., 2004b), underscoring its multifunctional role in agro-pastoral systems and its adaptability to marginal environments.

I.1.1.2.5.3 Ecological Importance of *Atriplex halimus*

Atriplex halimus plays a significant role in ecological restoration and environmental protection, particularly in arid and semi-arid Mediterranean regions. Its deep and extensive root system enhances soil fertility, combats desertification, and mitigates soil erosion by stabilizing degraded lands (Mulas & Mulas, 2004; Abbad et al., 2004b). The roots also create a favorable microclimate that supports the growth and productivity of other forage species such as oats and alfalfa (El Mzouri et al., 2000). Additionally, certain *Atriplex* species, like *Atriplex canescens*, form symbiotic associations with mycorrhizal fungi that enhance phosphorus absorption and improve drought tolerance (Barrow & Osuna, 2002; Barrow et al., 2004).

In regions facing desertification, caused primarily by the loss of vegetation in steppe and woodland areas, forage shrub plantations, including *Atriplex halimus,* provide an effective solution (Osmond et al, 1980). These plants offer dense vegetative cover that protects the soil from climatic aggressions such as rain, wind, and hail (Chalbi, 1991). With rapid growth, minimal care requirements during initial stages, and early usability, *Atriplex halimus* contributes significantly to the reforestation and stabilization of arid and semi-arid ecosystems (Lutts et al., 2004). Moreover, its ability to enhance soil aggregation and water retention makes it an indispensable resource for sustainable land management in vulnerable environments.

I.1.1.2.5.4 Medicinal Importance of *Atriplex halimus*

Atriplex halimus is a nutritionally rich plant, containing high levels of protein (Franclet & Le Houérou, 1971), vitamins C, A, and D, as well as essential minerals (Benrebiha, 1987). It has long been used in traditional medicine for its therapeutic properties (Dutuit et al., 1991), including its application in managing diabetes. In Western Sahara, the ashes of *A. halimus,*

dissolved in water, are traditionally used to treat gastric acidity, while its seeds are consumed as an emetic (Bellakhdar, 1997). The plant is also valued for its medicinal applications in alleviating colic, diarrhea, spasms, and rheumatism, as well as serving as an antiseptic, vasodilator, and respiratory stimulant (Chahma, 2006).

In traditional medicine, *Atriplex halimus* is renowned for its hypoglycemic and hypolipidemic properties (Yaniv et al., 1987; Mirsky & Nitsa, 2001). It has been employed in treating urinary inflammations, cystitis, and urinary stones (Belouad, 2001; Emam, 2011). In Western Sahara, its ashes are believed to potentiate insulin effects (Shani et al., 1972; Mertz et al., 1973; McKell et al., 1994; Mirsky & Nitsa, 2001). Additionally, the seeds, when raw and crushed, are ingested as an emetic, while the roots, used as toothbrush-like sticks, aid in oral and dental care. The leaves are traditionally used to treat heart diseases and diabetes (Bellakhdar, 1997; Said et al., 2000). Moreover, Saharan communities attribute the plant with the ability to cure *debbab*, a severe camel disease caused by trypanosomes transmitted by horseflies.

I.1.2 Forage Resources

I.1.2.1 Forage

The availability and diversity of feed resources are fundamental to the nutrition of livestock, ensuring optimal animal production (Salhi, 2013). The term "forage" refers to all woody and herbaceous plant materials consumed by herbivores. These plants belong to various botanical families, particularly the Poaceae (grasses), Leguminosae (legumes), Asteraceae, and Chenopodiaceae (CPAR, 2006). Forage crops are primarily drawn from two main botanical families: grasses (Poaceae), which are herbaceous, and legumes (Leguminosae), which include both herbaceous and woody species (Klein et al., 2014). These families exhibit different biological characteristics and technical requirements (César et al., 2004).

Forage plants are diverse and were initially identified in natural environments due to their palatability to livestock. Over time, they have been genetically selected for various desirable traits (Klein et al., 2014). Among these, forage legumes are particularly cost-effective compared to grasses. Their ability to fix atmospheric nitrogen reduces the need for nitrogen fertilization, although they require higher levels of phosphorus (César et al., 2004). This ecological and economic efficiency underscores the importance of legumes in sustainable livestock nutrition.

I.1.2.2 Forage Plants

Forage plants are species cultivated for their aerial parts, which are harvested or grazed to feed livestock (Bélanger et al., 2013). These plants include both annual and perennial crops, primarily from two botanical families: grasses (comprising 50% to 90% of permanent pastures) and legumes (accounting for 40% of permanent pastures). Other botanical families contribute only a small proportion to forage crops. This composition highlights the dominance of grasses and legumes in supporting livestock nutrition and pasture ecosystems.

I.1.2.3 Situation of Forages Worldwide

Globally, 3 to 4 billion hectares—approximately 80% of agricultural land—are dedicated to livestock farming, reflecting the rising demand for animal products (Klein et al., 2014). The vast extent of land allocated to livestock underpins the critical role of forage crops in agricultural systems. Forage production is vital for sustainable development in warm regions, acting as a key driver of productivity in livestock systems and an essential component of agroecological practices that integrate plant and animal production (Klein et al., 2014).

In Morocco, forage crops contribute only 14% to the country's forage balance and occupy a mere 3% of the total utilized agricultural area (UAA), which is predominantly used for cereal cultivation (60%), despite the significant role of livestock in the national economy (DE-MADR, 2003). Similarly, in Europe, the share of forage legumes has drastically declined since the 1950s

due to the intensification of livestock farming reliant on imported soy, European agricultural policies favoring cereal production, and adverse climatic and pest conditions. By 2006, legumes accounted for only 3.3% of agricultural land in Europe compared to over 30% in the United States (Voisin et al., 2013).

In the Mediterranean Basin, forage legumes such as vetch (*Vicia sativa L.*) are among the most important winter annual forages. According to FAOSTAT (2013), global production of vetch seeds is approximately 734,566 tonnes, with an average yield of 1,500 kg/ha. Turkey and Spain are leading producers, cultivating 90,000 ha and 75,000 ha, respectively, and producing 114,200 tonnes and 67,000 tonnes. A secondary group of producers includes Albania, Greece, Italy, and Morocco, with a total cultivated area of 60,000–100,000 ha and outputs ranging from 2,000 to 9,000 tonnes. These statistics underscore the economic and ecological significance of forage crops in global agriculture.

I.1.2.4 Forage Situation in Algeria

The forage sector in Algeria is characterized by a reliance on natural pastures, steppe rangelands, and cultivated forages, reflecting the country's pastoral and agricultural traditions. Forage resources cover an estimated 39 million hectares, encompassing natural pastures, steppe rangelands, forest grazing areas, and cultivated forages, which collectively support livestock nutrition (Adem & Ferrah, 2002). However, the forage supply is dominated by cereal stubble, grazed fallow vegetation, and rangelands, accounting for 97.7% of the total forage area, while cultivated forages constitute only 1.95% and natural forages 0.51% (Khaldoun et al., 2001). This extensive production system primarily provides forage units (UF) from cereal zones (52%) and steppe rangelands (44%), underscoring the limited intensification of forage production (Adem & Ferrah, 2002).

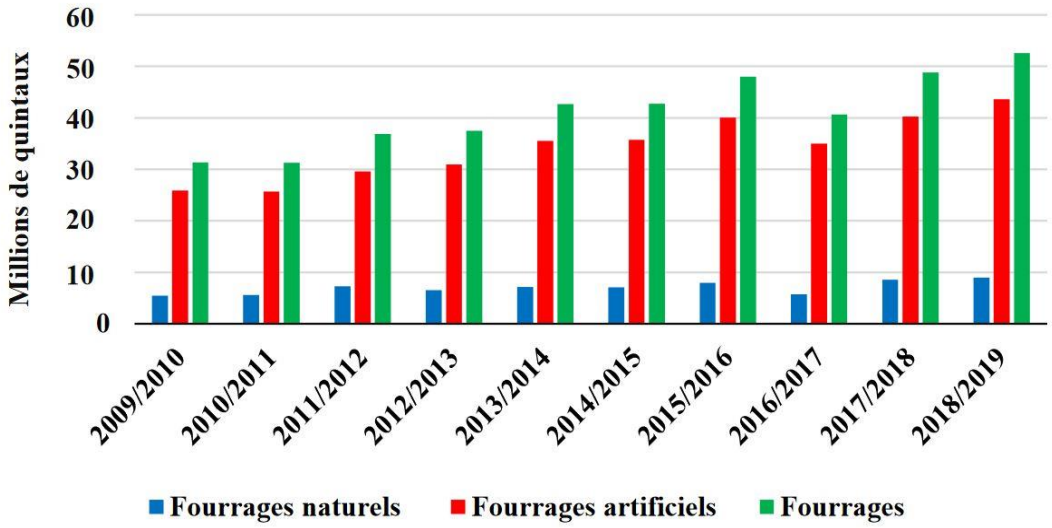


Figure 12: *Evolution of fodder crop production in Algeria*

Note from Valorisation de certaines légumineuses fourragères à graines dans l'alimentation animale, by S. Mahmah, p. 10, 2023.

Despite Algeria's natural and climatic suitability for forage cultivation, the sector faces significant constraints. Cultivated forage areas have expanded significantly, growing from 450,178 hectares in the 2000s to 997,121 hectares during 2010–2019, marking a 121% increase. Artificial forages (dry and green) dominate, covering 75% of the total forage area, with natural forages accounting for only 25% (MADR, 2020). Artificial forage production has risen from 25.9 million quintals in 2010 to 43 million quintals in 2019, representing a 68.5% increase and contributing 83% of the total forage supply. In contrast, natural forage production, which includes natural pastures and mown fallows, represents 17% of the total, having increased by 64.3% over the same period, from 5.4 million quintals in 2009/2010 to 8.9 million quintals in 2018/2019 (MADR, 2020).

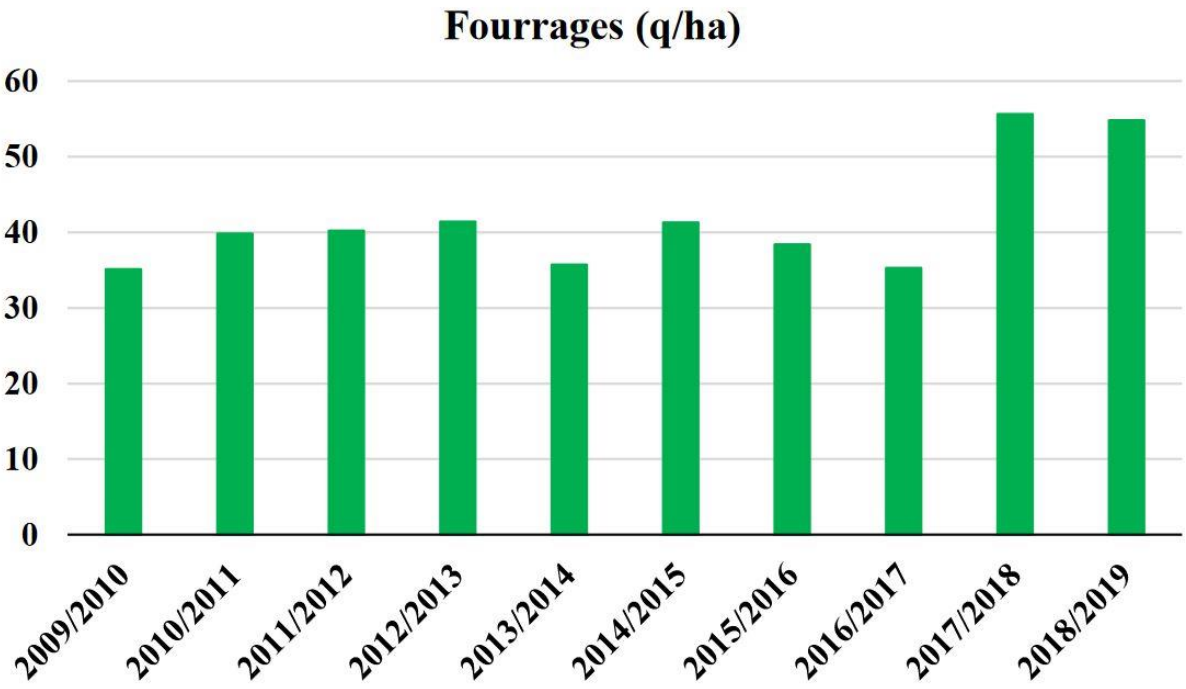


Figure 13: *Evolution of forage crop yields (q/ha) in Algeria*

Note from Valorisation de certaines légumineuses fourragères à graines dans l'alimentation animale, by S. Mahmah, p. 10, 2023.

However, overall forage production has fluctuated, with recent declines from 52.6 million quintals in 2018/2019 to 46.1 million quintals in 2020/2021, reflecting a 9.2% reduction (ONS, 2023). These variations highlight the challenges in achieving consistent production levels amidst climatic and systemic constraints. The forage sector remains a cornerstone of Algeria's agricultural system, but the underfeeding of livestock and the limited share of forage crops in agricultural land use emphasize the need for further investment and intensification in forage cultivation to meet rising demands (Senoussi, 2010).

I.1.2.5 Agro-Climatic Zones of Algeria

The diversity of Algeria's environment necessitates the definition of distinct agro-climatic zones. Although the boundaries between these zones are not strictly defined, three main zones can be identified:

- **High-precipitation zone (> 600 mm/year):** This zone is bordered by the Mediterranean Sea to the north and by a line connecting Algiers, Bouira, and Souk-Ahras towards the Tunisian border. The terrain is generally mountainous, with a variety of landforms ranging from gentle hills to steep mountains.
- **Cereal-growing zone (350-600 mm/year):** This narrow and discontinuous band stretches from east to west. At its widest point, it spans approximately 150 km. This zone is characterized by cereal cultivation.
- **Steppe zone (150-350 mm/year):** Covering approximately 20 million hectares, this vast zone traverses Algeria between the cereal-growing belt to the north and the Sahara Desert to the south. It is characterized by vegetation adapted to arid conditions, including esparto grass, wormwood, and saltbush (Hamrit S, 1995).

I.1.2.6 Algerian Steppe Rangelands

Algerian steppes cover more than 20 million hectares, characterized by low, stunted vegetation subjected to intense human exploitation. The primary use of these steppes is extensive sheep farming, supplemented by sporadic cereal cultivation (Nedjraoui and Bedrani 2008; Nedjimi and Guit, 2012). For centuries, nomadic tribes have relied on these steppes for transhumant pastoralism of small ruminants. Steppe regions serve as a buffer between coastal and Saharan Algeria, mitigating negative climatic influences.

Over the past three decades, these ecosystems have experienced severe degradation affecting all components: flora, vegetation cover, soil, fauna, and habitats (Daoudi et al., 2013).

According to Bencherif (2011), the collective and regulated exploitation of rangelands has been replaced by competitive family-based management. To meet the growing demand for mutton, driven by population growth, herders have increased their flocks, expanded mechanized forage cultivation, and overgrazed rangelands, leading to degradation. Furthermore, Senoussi (2011) reported that plowing has expanded, and rangelands are systematically cleared, exacerbating desertification and weakening the steppe ecosystem. Consequently, rangelands have been significantly reduced by recurrent droughts, increasing anthropogenic pressure such as overgrazing, and the expansion of cereal cultivation onto unsuitable lands (Nedjraoui and Bedrani, 2008; Kanoun et al., 2007; Khaldi and Dahane, 2011). Numerous studies on vegetation have highlighted the pastoral and forage potential of Algerian steppes, which are dominated by four major vegetation types (Djebaili, 1978; URBT, 1974-1991; Nedjraoui, 1981; Aidoud, 1989; LeHouerou, 1998, 2000).

I.1.2.7 Forage Deficit in Algeria and the Need for Alternative Diets Ruminants

Algeria faces a chronic forage deficit that severely impacts livestock productivity and necessitates the exploration of alternative feed solutions. Of the country's total land area (238 million hectares), only 43.5 million hectares are used for agriculture, with 36 million hectares allocated to forage production. This includes 85.2% for steppe rangelands and pastures, 11.7% for fallow land, 2.8% for forage crops, and only 0.4% for permanent grasslands (MADR, 2016). Despite increases in forage cultivation alongside herd expansion, the sector remains unable to meet animal feed demands (MADR, 2017).

A forage deficit of -7.3 billion UF was recorded in 2016, meeting only 45% of the total demand of 13.3 billion UF, with a low yield of 153.82 UF/ha (Ladjali & Tayeb Bey, 2016; Merdjane & Yakhlef, 2016). This marks a significant increase from the deficits reported in 2006 (-3.3 billion UF) and 1997–2001 (-2.34 billion UF) (Bouzida, 2008; Alfa & Bello, 2004). The

deficit forces reliance on expensive imported concentrates and feedstuffs, with forage imports reaching over 3.1 million tonnes, valued at $1 billion, between 2011 and 2017 (MADR, 2017). This dependency underscores the need to enhance domestic forage availability to sustain ruminant meat production (Rami et al., 2021).

These challenges highlight the urgency of integrating alternative forage plants into sheep diets to mitigate the deficit, reduce reliance on imports, and support sustainable livestock production.

I.2.1 Livestock Farming Systems

The concept of livestock farming systems has evolved significantly over the years, reflecting the complexity and diversity of agricultural practices. Lhoste (1984) defines a livestock farming system as "the set of techniques and practices implemented by a community to exploit plant resources through animals in a given space, under conditions compatible with its objectives and environmental constraints." This definition is applicable across various scales, from individual farms to rural communities and even larger territorial frameworks.

Since the 1980s, the concept has been expanded to better understand the social and ecological dynamics of livestock farming as a human activity. These developments have sought to formalize the rationale, practices, and real-world dynamics of livestock farming, particularly in situations that deviate from optimal management due to environmental or socio-economic factors. Livestock systems are inherently shaped by their natural environment, where sustainability depends on the careful management of natural resources and the preservation of the ecosystem (Dedieu et al., 2008).

Modern livestock systems face dual challenges: they must intensify production to meet growing demands while ensuring ecological sustainability by protecting air, water, and biodiversity. Dedieu et al. (2008) emphasize the need for adaptable systems capable of enduring in an increasingly uncertain future while addressing changes in traditional family farming structures. Thewis et al. (2005) provide a more specific definition, describing livestock farming systems as a dynamic interplay of elements organized by humans to transform resources through domestic animals into diverse products such as milk, meat, leather, labor, and fertilizer.

I.2.2 General Situation of Livestock

In 2020, the total number of livestock (all breeds) is 38.1 million head compared to 36.8 million head in 2019, showing a 4% increase. It should be noted that the predominance of these breeds is the sheep breed with 81% of the national total. The Goats come in second place with a share of 12.9%, followed by cattle with 4.6%. For camels and horses, they represent only 1.1% and 0.4% of the overall number.

The number of sheep per breed, which represents 81% of the national population, reached 30.9 million in 2020, an increase of 5% compared to its level of 2019. It is important to note that 62.4% of the total sheep are ewes. The number reached 19.3 million head in 2020 compared to 18.5 million head in 2019, an increase of 4.3%.

In Algeria, there are only a few classifications of sheep races, but a widespread one is the classification presented by Chellig (1992). This classification divides the sheep into two groups consisting of 8 races, which were created after observing the evolution of the number of sheep:

- The principal races are: Ouled-Djellal, Hamra, Rembi and Taâdmit;
- The secondary breeds are: D'man, Sidaou, Berbère and Barbarine.

That said, according to Afri-Bouzebda *et al*. (2018), this classification is no longer up-to-date and incomplete although it is based upon certain phenotypic criteria as a number of scholars (See Sagne,1950; Trouette, 1929; Chellig, 1992). They state that the local sheep population is represented by 12 varieties, including the Ouled Djellal, Rembi, Hamra, Berbère, Barbarine, D'man, Sidaou, Taâdmit, Tazeg Zawt, Srandi and Darâa. Some of these breeds are relatively obscure, such as the Ifilène and Tazeg Zawt, while others are endangered, including the D'man, and there are even some, such as the Berbère, Barbarine, Tâadmit and Rembi, that are at risk of becoming extinct (Afri-Bouzebda *et al*., 2018)

The Ouled Djellal breed is indigenous to the steppe and high plains. According to the latest figures, the total number of sheep in this breed is approximately 12 million, which represents 63% of the national population (Feliachi et al, 2003). The reproductive performance of the Ouled Djellal breed is no better than that of other Algerian breeds. However, the breed's hardiness in different conditions and its productivity in terms of weight explain its rapid spread throughout the country, with the exception of the southern region, where it is replacing certain breeds in their native habitat.

The Rembi sheep breed is situated in a transitional zone, situated between the Ouled Djellal breed, which is found in the eastern regions of the country, and the Hamra breed, which is prevalent in the western regions. The sheep in question, with a red or brownish head and a buff-coloured coat, has a total population of approximately two million, representing 11% of the total sheep population (Feliachi et al, 2003). The breed is particularly well-suited to the Ouarsenis and Tiaret mountain regions. These sheep are notable for their resilience and productivity, making them a valuable asset for utilising marginal mountain pastures. In terms of numerical and weight productivity, this breed is the most productive of the steppe breeds (Lafri, 2011).

The Hamra or Beni Ghil breed is believed to have originated in eastern Morocco. Despite exhibiting favourable conformation and meat quality, the population is in constant decline. Indeed, it was estimated at over 2.5 million head in the 1980s; the current figure is only around 0.5 million. The reduction in its numbers has resulted in the Hamra being classified as an endangered breed (Feliachi et al, 2003). Its range extends from the Chott Ech-Chergui in the east to the Saharan Atlas in the south-east and Morocco in the west. It is also found in the Tlemcen and Saida mountains to the north.

I.2.2 The Barbarine Breed

The Barbarine breed has its origins on the Tunisian border, in the eastern erg (Oued Souf). The breed is genetically linked to the Tunisian Barbarin, which in turn shares ancestry with the Middle Eastern Barbarin and the Asian Barbarin; however, it diverges in having a more substantial half-tail, which is comparatively less pronounced than that of the Tunisian Barbarin (Chellig, 1992).

I.2.2.1 Morphological Characteristics

The breed is notable for the volume of its tail, which varies in fullness depending on its geographical origin and serves an important functional role in storing fat reserves.

From the nape of the neck to the sacrum, the skin is lined with an adipose mantle that is sometimes several centimetres thick and extends laterally over the shoulders, thorax and flanks.

This breed is notably well adapted to the sandy desert and the extreme heat of summer. They are able to move with ease in the sand due to the width of their hooves. The breed is capable of tolerating and even thriving in saline environments, exhibiting remarkable digestive capabilities. It is able to rapidly gain weight by utilising the dunes of the Eastern Erg (Chellig, 1992).

Additionally, Laoun and Rahal (2007) describes the white colour of the body, with the exception of the head and legs, which may be brown or black. The horns are developed in males and absent in females. The body is generally compact, the neck and legs are short, the chest is broad and deep, and the fleece covers the entire body, with the exception of the head and legs.

The Barbarine sheep is a medium-sized animal, with males typically reaching heights of 60-80 cm and females of 55-70 cm. Body weight exhibits considerable variation

contingent on nutritional conditions, with rams ranging 45-85 kg and ewes 28-65 kg (Atti et al., 2004).

Figure 14: ewe of Barabrine (Djaout et al., 2015a)

I.2.3 Nutrition of Ewes

Feed is a major budget item. It accounts for 45-55% of operating costs. Controlling it affects breeding and production performance (growth, development, fat cover, etc.) as well as economic results.

I.2.3.1 Rationing

The aim of rationing is to meet the needs of animals at a given time, considering their weight, physiological condition and level of production. According to Dudouet (2003), there are several critical periods in sheep: end of pregnancy, lactation, desiccation, growth and fattening (Dudouet, 2003). Rationing a flock of sheep consists of assessing the animals' needs and establishing a feed ration to meet them: using, as a priority, fodder produced on the farm and then purchased (Toussaint, 2001). In order to achieve maximum zootechnical

productivity while respecting the animal's biological integrity (Paragon, 1995), these feeds must be supplied at the right time, in the desired quantity and quality (Petit et al., 1994). The efficiency of feed intake varies according to species, age, individual physiological state and pathological disorders (Deghnouche, 2011). Daily requirements for each nutrient are calculated using a factorial method, by summing the respective requirements that may arise in the corresponding production situation. In the case of ewes, these may correspond to: Maintenance, Growth, Weight change, Pregnancy, Lactation and Milking.

I.2.3.2 Maintenance

Under current intensive farming conditions, domestic ruminants are very rarely in maintenance; they are in production for most of their lives. The traditional distinction between maintenance and production costs is artificial from a nutritional point of view, since these costs do not correspond to different metabolisms. As maintenance costs represent a large proportion of the total costs over the lifetime of the animal, it is useful to estimate them correctly. The lower the production level of the animal, the higher this percentage will be; for example, for energy, it is between 60 and 80 % for sheep (Laoucini, 2014).

I.2.3.3 Gestation

Gestation requirements are practically negligible until the last third (100 days). From this point onwards, requirements increase rapidly, reaching higher or lower values depending on the number of fetuses (prolificacy). Therefore, the values shown in Table 1, which correspond to fetal or lamb weights at parturition, should be used in relation to the average number of lambs and their expected birth weights. This last phase of gestation is the most delicate from a nutritional point of view.

The increase in requirements is normally linked to a reduction in the ewe's ingestion capacity, which is more or less dependent on the nature of the ration (INRA, 1988; Thériez *et al.*, 1987; Bocquier and Caja, 1993a, b; Prió *et al.*, 1993). For this reason, and

during this stage, it is advisable to select the feed and nutrient concentration of the gestation ration. Underfeeding at the end of gestation can have undesirable effects (light lambs, onset of gestation toxemia, reduced colostrum production, etc.). For all these reasons, and to provide a safety margin for gestation rations, the recommended intakes in Table 1 should always be considered as minimums.

I.2.3.4 Lactation

During lactation, the ewe quantitatively reaches the highest stage of her entire production cycle. Milk production is high, depending on the number and vigor of lambs suckled. For most Mediterranean breeds, this production can vary from 1 to 3 l/d per ewe (Caja ef a/., 1992; Gargouri el a/., 1993), during the first month after lambing, and can be maintained at 0.7 to 1.5 I/d (Torre, 1991) throughout lamb fattening (3-4 months). Normally, it is estimated that 0.5 to 0.6 liters of milk are required for every 100 g of lamb growth (INRA, 1988; Torre, 1991). In the case of hardy Mediterranean ewes, such as the "Manchega", average milk production according to estimates by Caja *et al.* (1992) and Gargouri et a/. (1993), with 1.2 to 1.5 lambs per ewe, is between 1.4 and 1.7 l/d, allowing an average lamb growth rate of 150 to 250 g/d. In practice, this implies total milk production of 40 to 70 liters over 5 weeks of suckling.

The high requirements due to the quantities of milk produced during lactation, peaking between the second and third weeks after lambing, are partially mitigated by a parallel decrease in fat and protein content following the increase in milk quantity. For this reason, the data in Table 1 should be used for the first and second (or later) months of breastfeeding respectively.

Despite this, nutritional deficiencies during lactation are inevitable. However, the pathological risks for the ewe are more limited than those at the end of gestation. In this

case, the ewe adapts her intake capacity to milk production and draws on her body reserves, thus tolerating the existence of limited deficits (maximum 80% of maintenance requirements according to INRA, 1988), which corresponds to 0.5 UFL/d for a 50-60 kg ewe.

Table 1. Food requirements for Sheep

Situation productive	Energy (UFL/d)	Protein (g PDI/d)	Ca (g/d)	P (g/d)
Maintenance	0,033[1]	2,22[1]	0,19[1]	0,05[2]
Lamb growth (/100 g DWG[3])	0,26	22,0	1,40	0,40
Weight increase (/100 g DWG)	0,56	22,0	-	
Weight loss (/100 g DWG)	-0,25	-22,0	-	
Gestation (/kg lamb born)				
-6 to -5 weeks	0,015	5	0,50	0,12
-4 to -3 weeks	0,04	10	0,80	0,20
-2 at lambing	0,08	13	1,35	0,33
Breastfeeding 0-6 weeks (/liter milk)[4]	0,61-0,64	75-88	6,0	1,5
Milking (/Iiter)[5,6]	0,5-1,03	69-120	6,4-7,0	2,5-2,8

[1]/kg PV ^{0,75} (Metabolic weight $40^{0,75} = 15,9$; $50^{0,75} = 18,8$; $60^{0,75} = 21.6$; $70^{0,75} = 24.2$; $80^{0,75} = 26.8$)
[2]/kg PV
[3]DWG = Daily Weight Gain
[4]1 kg DWG of lamb = 5 to 6 liters of milk
[5]UFL/liter = 0.0066 x TB (g/l) + 0.241 (Molina *et al.*, 1991)
[6]g PDI/liter = 1.74 x MAT (g/I)

I.2.4 Parameters of energy metabolism

I.2.4.1 Glucose

Glucose is a simple carbohydrate which provides sheep with energy. It belongs to the family of carbohydrates that are found in the diet of ruminants. Its concentration in the blood

is under the control of the insulin-glucagon pair (Iglesias, 2023). In ruminants, carbohydrates are hydrolysed by microbial enzymes into simple sugars and subsequently fermented into volatile fatty acids, leading to the formation of gases and energy (Benyattou, 2017).

Table 2: Physiological norms for blood sugar levels in sheep

	blood glucose (mg/dl)	References
Hay standards	40.7 ± 7.1	Haddad, 1981
Bibliographic standards	61 ± 10 (ewes) 49 ± 1.8 (adult) 72.5 ± 3.25 55 ± 5	Smith et al., 1978 (a) Tollesrud et al., 1971(a) Yakup et al., 1999 Ndoutamia and Ganda, 2005

(a) quoted by Haddad 1981

I.2.4.2 Cholesterol

Cholesterol is a lipid that belongs to the sterol family and plays a central role in a wide range of biochemical processes. Cholesterol plays an essential role in the structure of cell membranes. It is also a precursor of steroid hormones and bile acids. Cholesterol can be synthesised by liver through a highly metabolically regulated mechanism, and can be eliminated via bile, either as cholesterol or converted to bile acids (Marshall et al., 2005).

It circulates in the blood via lipoproteins called HDL, LDL, VLDL and chylomicrons. High or low cholesterol levels in the blood lead to several diseases (Guesmia, 2008).

Table 3: Physiological norms for cholesterol levels in sheep

	cholesterol (mg/dl)	References
Hay standards	46.5 ± 9.1	Haddad 1981

Bibliographic standards	57 ± 8 (ewes)	Smith et al., 1978 (a)
	63 ± 8.2 (adult)	Popof 1979 (a)
	60 à 150	Sommer, 1984 (b)
	65 à 116	Ndoutamia and Ganda,2005

a : quoted by Haddad (1981)

b : quoted by Schmid et al. (1986) as cited in Louacini (2014).

I.2.4.3 Triglycerides

Triglycerides are composed of fatty acids and glycerol. They are stored in adipose tissue and serve as a source of energy. Additionally, they facilitate the transportation of vitamins A, D, E and K in the blood (Batouri, 2019). Plasma triglycerides have a dual origin, exogenous (dietary fats) and endogenous (hepatic synthesis). Like cholesterol, they are transported to the body's cells by the lipoproteins in the blood. A number of diseases, such as certain liver dysfunctions (cirrhosis, hepatitis, biliary obstruction), may be associated with a high level of lipoproteins.

I.2.4.4 Total protein

Proteins are macromolecular organic compounds. They are widely distributed throughout the body. They act as structural and transport elements.

They are into two fractions, albumin and globulin.

Their determination is useful to detect:

- Hyperproteinemia due to haemoconcentration, dehydration or increased dietary protein concentration.

- Hypo-proteinemia due to haemodilution caused by a failure in protein synthesis, excessive losses (haemorrhage) or excessive protein catabolism.

I.2.4.5 Urea

Urea is the end product of the microbial breakdown of nitrogenous substances. It is synthesised from ammonia in the liver. In monogastric animals, urea is completely excreted in the urine. However, in ruminants it is either excreted in the urine and therefore lost, or reabsorbed into the rumen via the saliva and, to a lesser extent, the rumen wall, where it is converted back into ammonia and can be used for bacterial growth. When the ration is low in protein, a lot of urea is recycled in the rumen and little nitrogen is produced. On the other hand, when the protein content of the ration is increased, less urea is recycled and the loss of nitrogen in the urine is greater (Meziane, 2001)

Table 4: Physiological standards for blood urea in sheep

	Uremia (mg/dl)	References
Standards	43 ± 8	Haddad. O ,1981
Bibliographic standards	28 ± 4 36.2 ± 10.5 20 -30	Smith et al, 1978(a) Popof .M ,1979 (a) Brugére-Picoux ,2002

(a) quoted by Haddad (1981)

I.2.4.6 Creatinine

Creatinine is the result of the breakdown of creatine, a component of muscle that can be converted to ATP, a source of energy for cells. Creatinine production depends on changes in muscle mass and is virtually independent of dietary protein intake. It is virtually independent of dietary protein intake (Meziane, 2001). It is excreted by the kidneys, which makes it a very good marker of the function of the kidneys.

I.2.4.7 Calcium

Calcium is the most abundant mineral in the body and its main role is in the formation of the skeleton. the formation of the skeleton, which in addition to its role in supporting the

muscles and protecting the organs and tissues, also contains calcium. it also plays an essential role as a mineral reservoir.

For example, 99% of the body's calcium is found in the bones in the form of hydroxyapatite. Despite its small amount, extra-osseous calcium plays a number of essential roles in the animal body. It serves as an intracellular messenger and plays a crucial role in various physiological processes, including neuromuscular transmission, muscle and heart contraction, and the blood clotting process by facilitating the conversion of prothrombin into active thrombin. Additionally, calcium is essential for triggering the immune response, supporting milk production (Meschy, 2010), maintaining the integrity of cell membranes, and functioning as a cofactor in enzymatic systems (Ammerman and Goodrich, 1983).

I.2.4.8 Phosphorus

In the animal body, 80% of P is found in bone, and unlike Ca, soft tissues are richer in P, notably the liver, fat, brain and muscle (Jean-Blain, 2002). Phosphorus is an essential element involved not only in bone development, growth and productivity, but also in most metabolic processes in the animal body.

Phosphorus plays a vital role in the formation and maintenance of bone, acting as an essential reservoir when the body's phosphorus needs exceed dietary intake (Suttle, 2010; Karn, 2001). It is crucial for the transfer of genetic information, as it is a key component of DNA and RNA, which are necessary for cell growth and differentiation. Phosphorus also contributes to the fluidity and integrity of cell membranes, the myelination of nerves, and is involved in glyconeogenesis, fatty acid transport, amino acid and protein synthesis, and the activity of the sodium/potassium ion pump, helping maintain acid-base balance (Suttle, 2010). As a component of ATP, phosphorus is universally involved in energy transfer mechanisms. In ruminants, phosphorus must be in soluble form to be utilized by

microorganisms in the rumen, particularly cellulolytic bacteria, with deficiencies leading to reduced cellulolytic activity (Meschy & Ramirez-Perez, 2005).

I.2.5 Sheep milk production

Dairy production is a strategic sector in Algerian agricultural policy, especially for its role as a supplier of animal protein in the face of rapid population growth, as well as for its role in generating employment and wealth (Ouakli and Yakhlef, 2003).

Milk production is mainly ensured by the bovine sector, where around 80% of milk production is bovine (Kacimi ElHassani, 2013). Programmes to intensify the various forms of livestock production, particularly milk production through the importation of heifers with high production potential, have failed to meet national needs. In fact, Algeria is considered a major consumer of milk and milk by-products, due to food traditions.

This demand cannot be met by national milk production. This reached about 03 billion litres in 2011, an increase of 84% compared to 2000, the year the National Agricultural Development Plan (NADP) was launched. Milk consumption has increased rapidly, from 54 litres per capita per year in 1970 to 112 litres per capita per year in 1990, and now stands at 120 litres per capita (Kacimi El Hassani, 2013).

I.2.5.1 Chemical composition

Sheep's milk is characterised by its lipid content. On average, it is twice as high as that of goat's milk. This milk is pearly white and more viscous. It has a discreet odour, known as "oozing". when harvested under the right conditions.

I.2.5.1.1 Protein

The high serum protein content of ewe's milk is mainly due to the high levels of beta-lactoglobulin and immunoglobulins (Daviau et al, 2000).

Goat's and sheep's milk coagulate faster and produce firmer curds than cow's milk. They are therefore widely used in cheese production (Badis et al., 2004).

The average protein content of sheep's milk (5.8%) is higher than that of goat's milk (4.6%) or cow's milk (3.3%). Protein content varies considerably between species and is influenced by breed, stage of lactation, diet, climate, season and udder health (Haenlein et al., 2006). Sheep milk contains approximately 0.4-0.8% nitrogen, which is distributed in fractions of varying importance in dairy technology and human nutrition. The protein content of sheep's milk is approximately 95% total nitrogen and 5% non-protein nitrogen (Anifantakis et al., 1987). The main proteins in ewe's and goat's milk are more or less the same as in cow's milk. Milk proteins are formed in two distinct phases. One is the unstable micellar phase, composed of casein micelles in suspension, which gives milk its opaque white appearance. The other is a soluble phase consisting of whey proteins.

Caseins precipitate at pH 4.6 at room temperature, whereas whey proteins (β-lactoglobulin, α-lactalbumin and serum albumin) remain soluble under the same conditions (Accolas et al., 1977; Anifantakis, 1987).

I.2.5.1.2 Caseins

From a nutritional point of view, caseins are a relatively inexpensive source of amino acids (AA), especially essential amino acids not synthesised by the body, dietary calcium and phosphorus for newborns (Pelmus et al., 2012). The processing of caseins into cheese is one of the most important technological transformations in the agri-food industry (Hinrichs, 2004). Caseins are currently in great demand both for their functional properties and for the biological activities of the peptides that make up their composition (Pelmus et al., 2012).

Sheep milk is richer in casein than goat milk (Pelmus et al., 2012). It ranges from

3.38% (Rassu et al., 2007) to 7.75% (Potocnik et al., 2011), with a mean of 4.50% (Pelmus et al., 2012).

Caseins in sheep's milk represent 74.1% (Pelmus et al., 2012) to 83% (Park et al., 2007) of the proteins present. As in the reference milk, they comprise several proteins, including the caseins αs1, αs2, β and κ.

I.2.5.1.3 Fat

Ewe's milk is known for its high fat content. This varies greatly depending on a number of factors. Some are feed related (quality and quantity of feed), other factors are non-nutritional (genetics, stage of lactation, parity, season, etc.) (Perea et al., 2000; Gargouri, 2005). The lipid content varies between 4.96 (Kuchtik et al, 2008) and 9.60% (Simos et al, 2011). These values are much higher than those reported for cow's milk (2.8-4.8%).

Milk fat is mainly composed of triglycerides (98%). Diglycerides, monoglycerides and free fatty acids are naturally present in small quantities, but their proportion may increase in the event of an accident. Fatty acids are naturally present in small amounts, but their levels may increase during lipolysis (Vignolles et al., 2007). Many other compounds are present, but at much lower levels (phospholipids, cholesterol, vitamins) (Amitot et al., 2002).

I.2.6 Factors influencing birth weight in livestock production

According to the review conducted by Assan (2013), there are many factors that influence the birth weight in livestock production. They include:

- Genetic Factors: Heritability estimates for body weight traits vary among sheep breeds. Genetic selection can lead to improvements in body weight over generations.

- Environmental Factors

1. Nutrition: The quality and quantity of feed significantly affect growth rates and body weight. Maternal nutrition during pregnancy is particularly crucial.

2. Management Practices: Variations in management, such as feeding strategies and health care, can influence body weight.

3. Climatic Conditions: Weather conditions, including temperature and humidity, can impact feed intake and overall growth.

- Physiological Factors

1. Age and Parity of the Dam: The age of the ewe can affect the birth weight of lambs, with older ewes generally producing heavier lambs due to better milking capacity.

2. Litter Size: Larger litter sizes often result in lower individual birth weights due to competition for nutrients in utero.

- Seasonal Variations: Seasonal changes can affect the availability and quality of feed, which in turn influences body weight 6.

- Health Status: The overall health of the sheep, including the presence of diseases or parasites, can significantly impact growth and body weight.

I.2.7 Apparent and real digestibilities of DM constituents

I.2.7.1 Apparent digestibility

The apparent digestibility of a constituent (X) of the DM (organic matter, nitrogenous matter, crude fibre, etc.), DX, is equal to the quantity of constituent X ingested, minus the quantity of X excreted in the faeces and divided by the quantity of X ingested, this

relationship can be written as follows:

$$D(X) = I . Xi - F . Xf / I . Xi$$

The X content of I and F respectively, The relationship can also be written as:

$$D(X) = 1 - F\,Xf / I\,Xi = 1 - indMS.\,Xf / Xi$$

I.2.7.2 Digestibility

But faeces can be divided into 2 fractions: F = Fa + Fm

The fraction of dietary origin: Fa and of metabolic origin: Fm

$$Dr(DM) = I - Fa/I$$

Real digestibility (Dr) is then equal, for dry matter for example, to :

Whereas apparent digestibility (DMS) is equal to : D (M S = I - (F a + F m) / I which can also be written :

$$D(MS) = DrMS - Fm/I$$

Apparent digestibility D is therefore equal to Dr minus the metabolic (non-food) fraction of dry matter (Fm). If Fm is n u l , which is practically the case for parietal constituents D(X) = Dr (X).

I.2.7.3 Methods for measuring digestibility in vivo

The digestibility of the same feed measured on the same animals varies according to a number of factors (feed level, nitrogen and certain mineral content, presentation methods, length of experimental periods and number of animals, etc.) obtain reliable, repeatable and comparable results. Before examining this method, which differs according to the type of feed studied (conventional fodder, straw and poor fodder; concentrates and certain rich by-products), it is worth recalling certain general rules or precautions necessary for correct measurement.

General conditions necessary for the validity of measurements

- A pre-experimental period of adaptation to the diet of sufficient length, minimum one week, but which can be extended in certain cases to 2 or 3 weeks (Cammell 1977, Wainman 1977) in the event of a major change of diet or with poor forages. There are 3 reasons for this:
  - the composition of the faeces must correspond only to the diet studied. Due to very slow transit, complete excretion of undigested feed residues from wall-rich forage can take up to 10 days (Blaxter et al 1956).
  - in the case of ad libitum diets, the quantity ingested only stabilises after 9 to 12 days (Blaxter et al 1961).

Proper rumen function, characterised by normal cellulolytic and/or amylolytic activity of the rumen flora. This requires :

- the animal receives the minimum amount of forage in normal form necessary for a sufficiently long rumination period and abundant salivary secretion, so that the pH of the rumen remains above 6.5
- and that nitrogen or certain minerals are not the limiting factors in rumen activity.

- A sufficiently long experimental period and a sufficient number of animals.

Discontinuous faecal excretion, which is responsible for so-called start-of-period and end-of-period errors, and differences in digestive capacity from one animal to another mean that measurements have to be taken over a minimum number of days (varying from 5 to 14 days, depending on the author, and most often 10) and on a minimum number of animals (varying from 3 to 8, depending on the author, and most often 4). In fact, these numbers vary according to the type of feed studied, the feeding method (in terms of quantity, quality, etc.)

and the number of animals fed or at will) and, above all, the accuracy required for the measurement. This accuracy depends, of course, on both the number of days and the number of animals.

The digestibility of the same feed measured on the same animals varies with a number of factors (feed level, nitrogen and certain mineral content, presentation methods, length of experimental and experimental periods, number of animals, etc.), hence the need to standardise the measurement method in order to obtain reliable, repeatable and comparable results.

I.2.7.4 Digestibility of food

I.2.7.4.1 Digestibility of forages

Ruminant faeces contain little or no intracellular constituents (soluble carbohydrates, starch, nitrogen, lipids, etc.) of dietary origin because the actual digestibility of these constituents is total or very high. Soluble carbohydrates (simple sugars and fructosans) are fully digestible (Jarrige, 1988). Their apparent or real digestibility is therefore 1.0.

Starch is practically absent from the vegetative organs of forages in temperate countries and is only found in the seeds of cereals used at an immature stage (maize silage). Seed starch is also highly digestible: 0.99 ± 0.012 in the 51 measurements on sheep and cattle summarised by Jarrige (1988), but mainly on animals fed close to maintenance and receiving the grains in their ration in ground form.

The apparent digestibility of nitrogen is highly variable and depends essentially on the TNM content. It generally rises from 0.81 to 0.41 when the TNM content of green fodder falls from 250 to 60 g/kg DM. Forage lipids are made up of 35 to 50% pigments and esterified lipids, which are an essential source of fatty acids in green grass after hydrolysis in the rumen, have an apparent digestibility of 0.85 or more (Bauchart, 1981). Chlorophylls are

virtually indigestible and are found in the faeces, as are the lipids contained in the waxes of the plant cuticle.

Van Soest's neutral detergent solubilises almost all intracellular constituents.

The D(OM) of forages therefore decreases when their non-digestible wall content increases, i.e. when their wall content and the lignification of these walls (although lignification alone may not explain the indigestibility of the walls) increase. These two parameters depend on both the morphological composition and the age of the forage.

The leaves of legumes and the blades of grasses are much richer than stems in intracellular constituents and poorer in parietal constituents. The difference increases with the age of the plant, since the composition of legume leaves and, to a lesser extent, grass blades, changes much less rapidly than that of stems, in which parietal constituents increase rapidly to the detriment of intracellular constituents. The result is that:

The nitrogen content varies, as does the proportion of leaves or leaf blades. The same is true of the content of minerals, vitamins and lipids, but not of soluble carbohydrates, at least in grasses where they are made up of fructans which accumulate preferably at the base of the stems.

I.2.7.4.2 Digestibility of concentrated feed and rich by-products

Concentrated feeds and highly digestible by-products generally cannot be fed to animals on their own, as they do not induce sufficient salivary secretion, ferment too quickly in the rumen and do not contain enough fibre for the rumen to function properly. They must be combined with forage, generally hay.

I.2.7.5 Calculation of the energy and nitrogen value

I.2.7.5.1 Energy value

I.2.7.5.1.1 Gross energy fodder and concentrates

For fodder in its fresh or dry state**,** gross energy was estimated on the basis of the close relationship observed between the gross energy content determined using a calorimeter bomb (Y in Kcal/ kg of organic matter so as to eliminate the influence of ash content) and the nitrogen content (X = N x 6.25 in g per kg of organic matter) for 166 fodders of various origins (INRA, 1978 and INRA, 1988):

$$Y = 4\,531 + + 1.735\,X \pm 38$$

- △= +82; green fodder from alfalfa and lowland permanent grassland; hay from lowland or mountain permanent grassland.

- △= -11; green fodder from red clover, sainfoin, permanent grassland of whole plants of immature cereals (maize, wheat, barley, oats, rye); hay from artificial or temporary grassland (alfalfa, Italian ryegrass, etc.).

At the same nitrogen content, the gross energy of cereal plants, natural meadow grass, legumes and especially alfalfa is higher than that of grasses. These differences are probably due to the fact that these plants are richer in lipids than grasses.

For concentrated feeds, gross energy was calculated from the chemical composition using the formula and corrections proposed by Schiemann et al. (1971) reported by (INRA, 1978 and INRA, 1988). Gross energy content is expressed in Kcal/kg of dry matter.

$$GE\ Kcal/\ Kg\ DM = 5.72TNM + 9.50\ Fat + 4.79CF + 4.17ENA + \Delta$$

The Δ values are +31 for barley, - 113 for faba bean

I.2.7.6 Digestibility of energy (d.E) and digestible energy (ED):

I.2.7.6.1. Forages

The digestibility of organic matter (d OM) had been measured but not that of energy (d E). The latter was estimated from the digestibility of organic matter using the relationship established by (INRA, 1978 and INRA, 1988) on 81_t forage samples (59 green forages of grasses and legumes, 17 hays of permanent grassland, grasses and alfalfa and 5 straws):

R = 0.996 n = 81

$$d\,E = 1.0087\,d\,OM - 0.0377 \pm 0.007$$

Digestible energy content (DE in Kcal/kg of dry matter)

$$DE = GE\,(1.0087d\,OM - 0.0377).$$

The digestibility and energy value of hay can be predicted from its chemical composition using the charts presented at the end of the book (INRA, 1978) for a number of types of hay.)

- Prediction based on chemical composition

CFØ = Crude Fiber content
TNMØ= Nitrogen content
dOM =- Digestibility of organic matter
FULØ = FUL per kg of organic matter
FUVØ = FUV per kg of organic matter

} In g per kg of organic matter

- **Nitrogen and crude fibre content**

For CBØ =	Average	minimum	maximum
	304	190	400

The forecasting equations are as follows:

dOM = 0.516 + 0.001007 TNMØ 0.00000085 $CFØ^2$

= 0.485 + 0.001007 TNMØ + A(dOM)

with Δ(dMO) = 0.031 - 0.00000085 $CFØ^2$; SR = ± 0.03; R = 0.877

FULØ = 0.632 + 0.001911 MATØ - 0.00000188 $CFØ^2$

= 0.564 + 0.001911 TNMØ + Δ (FULØ)

with Δ (UFL0) = 0.068 - 0.00000188CBØ ;SR : = ± 0.06;

R=0.882

FUVØ = 0.519 + 0.002168 TNMØ - 0.00000219$CFØ^2$

= 0.440 + 0.002168 TNMØ + Δ(FUVØ)

with Δ (UFVØ) = 0.079 - 0.00000219 CB02 ; SR = ± 0.07 ; R = 0.87

Concentrated Feed:

We have adopted relationships taken from the work of Nehring et al (1963), reported by (INRA.1978 and INRA, 1988)

- cereals : d E = d OM - 0.013
- cake : d E = d OM - 0.020
- other foods: d E = d OM- 0.015.

Equations for predicting the digestibility of organic matter in concentrated feed based on the content of parietal constituents (INRA, 1978 and 1988).

I.2.7.6.2 Cereals:

DOM = 91.7 - 1.48 CF (N = 5, R = 0.95, S_R = 2.11)

I.2.7.6.3 Pulses:

DOM = 89.7 - 0.21 CF (N = 4, R = 0.64, S_R = 2.48)

(1) Acronyms :

- CF = Crude fibre (g/KG MS)
- TF = True fibre (g/KG DM)
- LI = Lignin (g/KG MS)

I.2.7.7 Metabolisable energy (ME)

The metabolizable energy content (in Kcal/kg of dry matter) is calculated as follows:

$\frac{EM}{ED}$ Calculated on the basis of the relationship established by Vermorel and Bouvier (INRA, 1988)

$$EM = E\Delta \times \frac{EM}{ED}$$

Where CF and TNM are respectively the crude fibre and nitrogen contents of the feed in g/kg dry matter and FL is the feed level:

$$FL = \frac{\text{Quantity of digestible organic matter ingested (g/kg } P^{0.75})}{23}$$

23 being the quantity of digestible organic matter to be supplied per kg $P^{0.75}$ to cover the sheep's maintenance energy requirements (INRA, 1988).

The feed level chosen to estimate the ME of the feeds is 1.7 because it corresponds on average to that observed during measurements of the digestibility of green fodder on sheep and avoids introducing corrections for the feed level of growing and fattening animals.

- Green fodder: While the average feed level is 1.7, it has varied from 1.1 to 2.7. However, the digestibility of green fodder decreases little when the feeding level is increased (INRA.1978) and this decrease is entirely, or almost entirely, offset by the reduction in energy losses in the form of methane and in the urine when digestibility is greater than 0.60.
- Hay, straw, etc. Feeding levels observed during measurements on straw and hay are 1.7 taken as a reference. With these feeds, particularly those with the lowest digestibility, the decrease in digestibility with an increase in feed level is much greater than for green fodder (INRA, 1978) and is not entirely offset by the increase in the EM/ED ratio. The metabolizable energy content of poorly digestible hay and straw therefore decreases as the feed intake level increases.

I.2.7.8 Net Energy (NE)

Net energy (NE) was calculated from the gross energy content (GE) of the feed, the energy digestibility coefficient (d E), the ratio of digestible energy content (DE) to metabolizable energy content (ME) and the yield.

(k) the use of metabolizable energy for milk production or the whole of the milk production process

$$NE = GE \times dE$$

"Maintenance + meat production

Net energy (NE) is the product of metabolisable energy and efficiency k

NE = ME x k

The efficiency (k) with which ME is used depends on the concentration (q) of metabolizable energy in the feed or ration: q = ME/GE

The net energy for lacatation (NEL) is therefore equal to :

NEL (Mcal/kg DM) = ME- (Mcal/kg DM) X kl

With kl = 0.463 + 0.24 q where NEL = EM X (0.463 + 0.24 q).

The energy value of the feed given is expressed in milk fodder units (FUL) obtained by dividing their NEL content by 1.700, the NEL content of the reference barley:

$$FUL = NEL/1700$$

This value is given per kg of dry matter.

- Net energy for maintenance and meat production (ENEV) is calculated for a production level of 1.5 :

ENEV (Mcal/kg DM)= ME (Mcal/kg MS) x kmf 1.5

$$kmf = \frac{km \times kf \times NP}{kf \times km(NP - 1)}$$

$$FUV = ENEV/1800$$

I.2.8 Expression of Ingestibility and Filling Value

The forage chosen to have a FVL (Filling Value per Unit of Live Weight) of 1 is young grass harvested at the "pasture" stage. It has an organic matter digestibility of approximately 0.80 and is ingested at a rate of 75 g of dry matter per kg $P^{0.75}$ by the "standard" sheep. When a limited amount of concentrate feed (10%) is added, the forage-to-concentrate substitution rate is 1:1 on a dry matter basis.

The FVL (Filling Value per Unit of Live Weight) of a forage or feed is expressed by the ratio:

VEF= 75/Quantity ingested by the sheep of the forage or feed in g DM/kg $P^{0.75}$

VEG = 90/Quantity ingested by the heifer of the forage or feed in g DM/kg $P^{0.75}$

VEL = 140/Quantity ingested by the dairy cow of the forage or feed in g DM/kg $P^{0.75}$

The calculated filling values of feed are used to determine the ingestion capacities of sheep, heifers, and dairy cows.

I.2.9 Sustainable Development

According to FAO, the livestock sector plays a key role in addressing many of the Sustainable Development Goals, particularly when it comes to supporting livelihoods, generating income, and contributing to healthy diets and resilience in the face of climate change. Livestock production is associated with externalities such as climate change, land degradation and biodiversity loss. This calls on Member States to put in place a framework and policies conducive to mitigating the effects of climate change, while pursuing the Sustainable Development Goals (SDGs) of the 2030 Agenda. This study contributes to the call of FAO to study and evaluate various technical and methods to support science- and evidence-based policies and to facilitate intergovernmental and multi-stakeholder dialogue.

On a global scale, it is estimated that food systems are responsible for around 30 per cent of greenhouse gas emissions, 70 per cent of freshwater withdrawals, 40 per cent of land use, as well as major disruptions to nutrient cycles in ecosystems (Clark et al., 2019). As a food group, animal

products exert more pressure on the environment pressure on the environment than other food groups, in terms of greenhouse gas emissions, but also in terms of impacts on biodiversity, nutrient flows (such as nitrogen) and the use of fresh water, largely through the use of cultivated land for animal feed (Springmann et al., 2018). However, animal products and animal production can have multiple interactions with climate and the wider environment, depending on the farming method, scale and production system. Sustainable livestock production and mixed systems can be an integral part of Sustainable livestock production and mixed systems can be an integral part of solutions to combat climate change and help achieve not only Sustainable Development Goal (SDG) 2 (Zero Hunger), but also SDGs 12 (Responsible Consumption and Production) and 13 (Action on Climate Change).

All over the world, ecosystems are being damaged by food production, and man's contribution to climate change. Livestock farming, which accounts for 14.5% of man-made greenhouse gas emissions, also has other environmental impacts, on biodiversity, the use of fresh water and the disruption of nutrient flows. However, these deleterious effects depend to a large extent on production systems, agricultural practices and supply chain management, where there are opportunities to mitigate these effects (Gerber et al., 2013).

Livestock feed production is directly correlated with greenhouse gas emissions, accounting for between 72% and 78% of total agricultural emissions (Gerber et al., 2013). Ruminant enteric fermentation processes, low feed efficiency and manure-related emissions are the main causes (Godfray et al., 2018). However, it is important to distinguish between different production systems, animal types and activities (Herrero et al., 2013; 2016). It should also be noted that the global estimates often cited are developed using models and data based on OECD production systems. Tropical countries need their own data and models to properly estimate baseline greenhouse gas

emissions from their own livestock production systems, as well as to monitor their progress towards their mitigation commitments under the United Nations Framework Convention on Climate Change. Research to date shows significant variation in emissions (Ndung'u et al., 2018).

I.2.10 Conclusion

This chapter has outlined the theoretical underpinnings of livestock farming systems, with particular focus on ewe nutrition and sustainability in Algeria's semi-arid regions. The Barbarine breed, uniquely suited to these challenging environments, exemplifies the need for innovative approaches that address forage scarcity, maintain productivity, and preserve ecological balance. By exploring the interplay of nutritional strategies, physiological requirements, and environmental constraints, this chapter sets the stage for a practical examination of sustainable feeding solutions.

The next chapter transitions from theory to experimentation, investigating the incorporation of *Opuntia ficus-indica* and *Atriplex halimus* into the diets of pregnant Barbarine ewes. Through five experiments, this study evaluates intake, digestibility, physiological responses, and offspring weight under nine dietary regimens.

EXPERIMENTAL PART

II. Materials and Methods

II.1. Geographical Location of Study Regions

II.1.1. Geographic Situation of Region 1

The wilaya of Tebessa covers an area of 13,878 km2 and occupies a strategic position in the far east of Algeria. It is characterised by its location on the border of the eastern plateaux of the country. It is a crossroads city where the desert meets Tunisia. Geographically, it lies between 34° 15'N and 36° 00'N latitude and 7° 15'E and 8° 30'E longitude. It is bordered as follows: 1. to the north by the wilaya of Souk Ahras; 2. to the south by the wilaya of El Oued; 3. to the east by Tunisia; 4. to the west by the wilayas of Oum El Bouaghi and Khenchela (Boumachrouk, 2020).

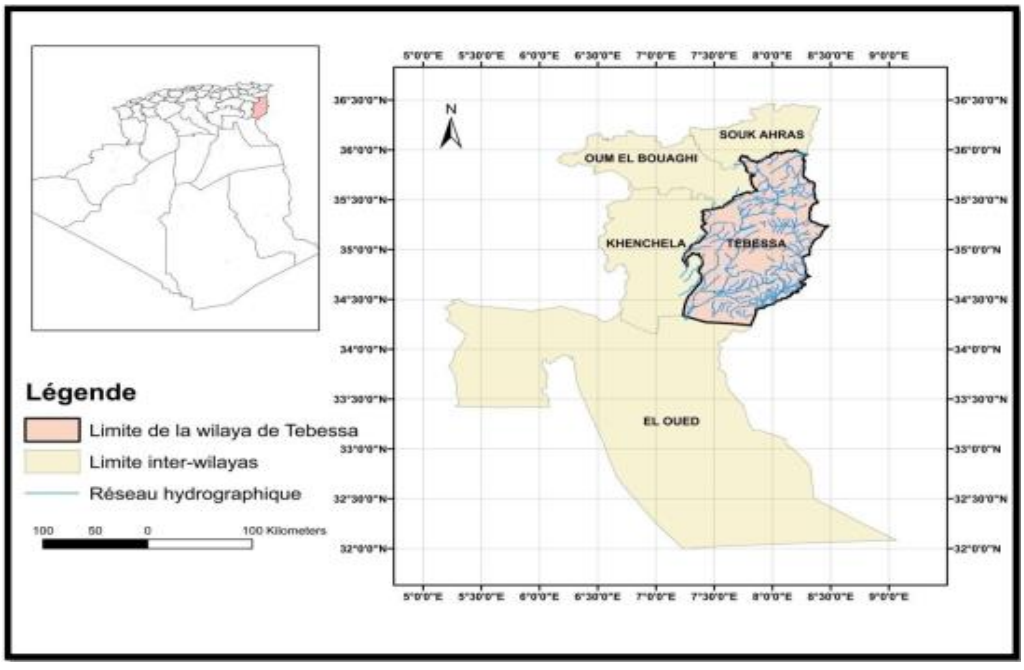


Figure 15: Geographic Map of Tebessa.

Note. from Evolution des Extremes Pluviometriques dans un Contexte de Changement Climatique dans une Zone Semi Aride (Cas de la Wilaya de Tebessa), by R. Boumachrouk, 2020, http://dspace.univ-khenchela.dz:4000/handle/123456789/2721

Our first study region where the plant of Opuntia ficus-indica was sourced is Bedjene commune. Bedjene is located in the high plains of eastern Algeria on the Algerian-Tunisian border and covers an area of 132 km². On Figure 18, Bedjene region is situated in the semi-arid bioclimatic stage. It is located between the following coordinates 35° 25' N, 7° 28' E at an altitude of 1093 m. The area is bounded as follows Gourigueur to the north, El Ogla to the south, El Mazeraa to the east and the Wilaya of Khenchela to the west. The Bedjen region is made up of different types of relief that vary in time and space and can be divided into three groups: mountains, hills and plains. It is characterised by the beauty of its nature and fresh springs such as the Boussaid spring, mainly based on agriculture and livestock farming due to the diversity of its vegetation cover.

In the Bedjene region, the vegetation cover consists of forests, scrubland and reforestation. The study area is a mountainous area and is a plot of natural vegetation (Chaouaf & Brakni, 2016). Figure 16 shows the location of Bedjene in Tebessa.

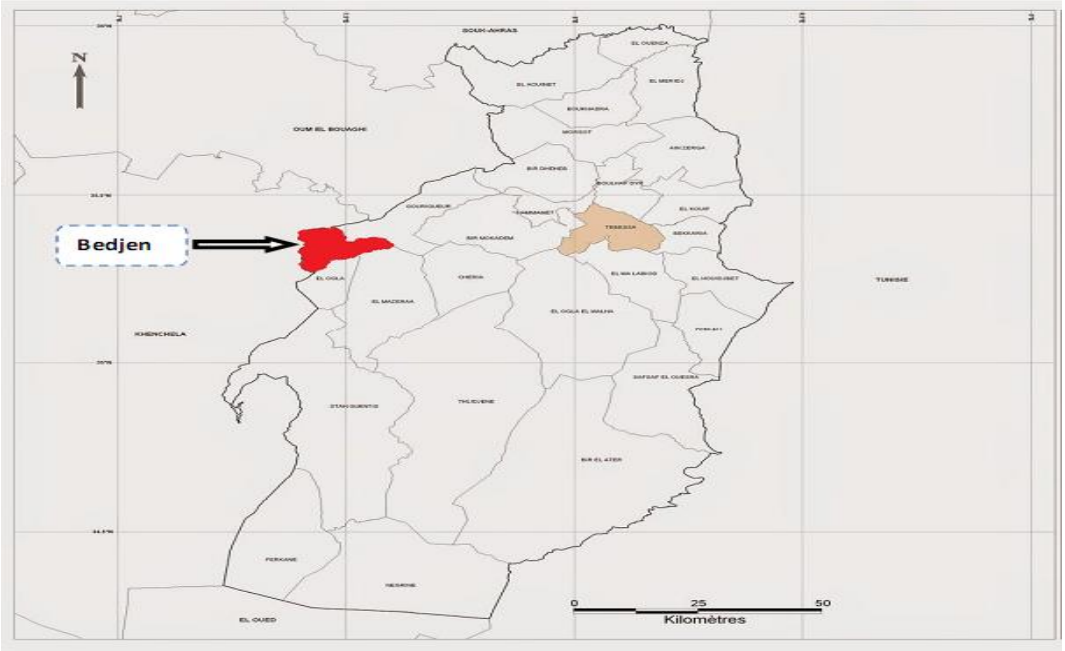


Figure 16: Administrative map of Tebessa showcasing Bedjene commune.

Note. from Analyse du choix floral des Hyménoptères Apoïdes dans la commune de Bedjen (tébessa), by Z. Chaouaf & W. Brakini, 2016, http//localhost:8080/jspui/handle/123456789/1239

II.1.2 Geographic Situation of Region 2

The wilaya of Biskra is in the south-eastern part of the country. Situated on the slopes of the Aurès massif, which forms a natural border with the north, it covers an area estimated at 21509.80 km2 and comprises 33 communes and 12 departments, bordered to the north by the wilayas of Batna, to the north-west by the wilayas of Msila, to the south-west by the wilayas of Djelfa, to the south by the wilayas of El-Oued and to the north-east by the wilayas of Khenchela (Guerguet, 2020).

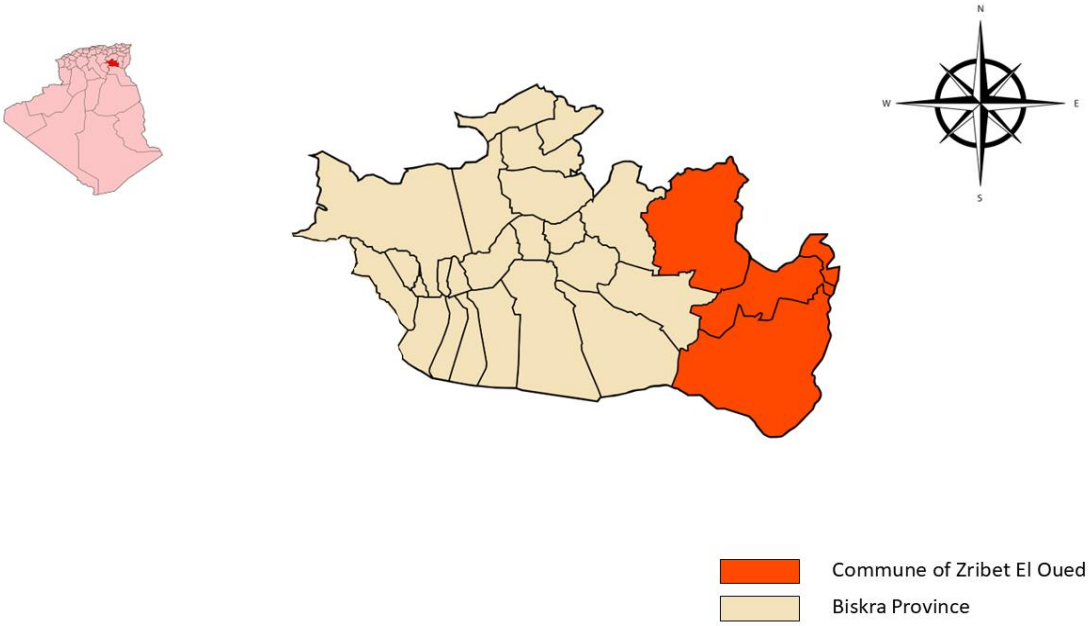


Figure 17: Geographic Map of Biskra showcasing Zribet El Oued.

The plant Atriplex halimus was sourced from the natural fields in the region of Zribet El Oued, which is located 80 km east of the capital of the wilaya of Biskra and covers an area of 2916.9 km2. This region is considered one of the main agricultural production areas of the Biskra wilaya and is bordered to the north by Batna, to the north-east by the commune of Khanguet Sidi Nadji, to the north-west by the commune of M'Mziraa, to the south by the commune of El Feidh, to the west by the commune of Ain Naga and to the east by the wilaya of El Khenchela (Bettaybi, 2019).

II.1.3 Bioclimatic Context of Study Regions

According to Isferalda (2023), the Emberger rainfall quotient “Q” specific to the Mediterranean climate makes it possible to locate the bioclimatic stage of the study area. This quotient considers the annual precipitation and the average minimum temperatures of the coldest month and the average maximum temperatures of the hottest month.

$$Q = 3{,}43 \times \frac{P}{M - m}$$

R is the average monthly rainfall (mm)

M is the maximum average temperature (degree Celsius)

m is the minimum average temperature of the coldest month (degrees Celsius).

For the Biskra region, the rainfall quotient (Q) is 14.41. By transferring this value to the Emberger climagram and the temperature of the coldest month, the Biskra region is in the Saharan bioclimatic stage with a moderate winter (See Figure 4)

According to ANDI (2013), the wilaya of Tebessa is characterised by four bioclimatic stages:

1. Subhumid (400 to 500 mm/year), which is very limited in extent and covers only a few islands confined to the summits of a few reliefs (Djebel-Serdies and Djebel-Bouroumane).

2. Semi-arid (300 to 400 mm/year), represented by the cool and cold sub-stages, covering the entire northern part of the wilaya.

3. The subarid (200 to 300 mm/year) covers the steppe plateaus of Oum-Ali - Saf-Saf-El-Ouesra - Thlidjene and Bir El-Ater.

4. The Arid or Mild Sahara (less than 200 mm/year) begins and extends beyond the Saharan Atlas and includes the Negrine and Ferkane plateaux.

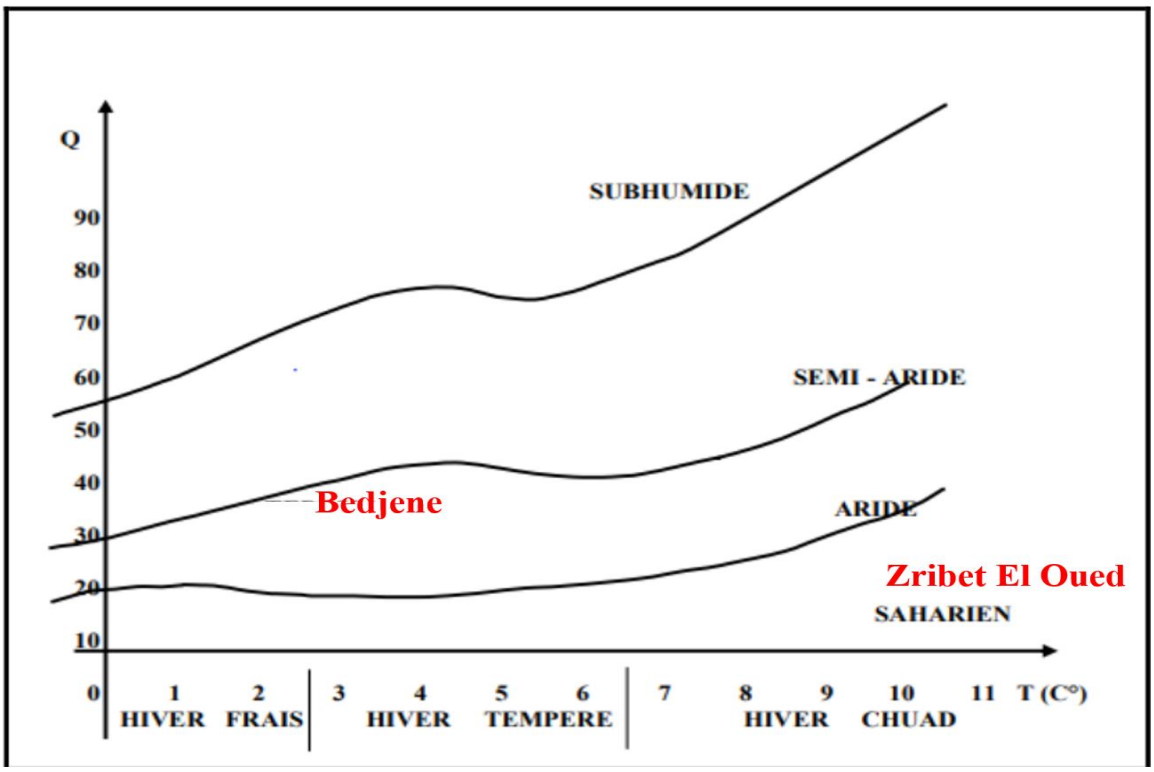


Figure 18: Bioclimatic location of the Study Regions on the Climagram

II.1.4 Historical Analysis of Climate Data of Study Regions

II.1.4.1 Region 1

Table 5. presents climate data from 2012 to 2022 of the first region of the study.

Table 5: Climate Data of Tebessa

Year	T	TM	Tm	PP	V	RA	SN	TS	FG	TN	GR
2012	17	24.5	9.6	346.70	11.9	54	8	44	3	0	0
2013	-	-	-	-	-	-	-	-	-	-	-
2014	17.3	24.7	9.9	282.96	12.8	60	2	44	1	0	0
2015	-	-	-	-	-	61	6	36	3	0	0
2016	17.2	24.4	9.8	278.34	10.5	63	3	31	3	0	0
2017	16.7	23.6	9.4	302.00	12	61	2	22	9	0	0

2018	**16.5**	**22.9**	**9.7**	**391.36**	**12.2**	**63**	**1**	**45**	**4**	**0**	**0**
2019	**16**	**22.5**	**8.9**	**478.78**	**11.9**	**80**	**7**	**44**	**3**	**0**	**0**
2020	**16.6**	**23.7**	**9.2**	**370.79**	**11.4**	**64**	**0**	**39**	**9**	**0**	**1**
2021	**17.9**	**24.8**	**10.2**	**192.02**	**11.9**	**53**	**0**	**34**	**5**	**0**	**2**
2022	**17.5**	**24.8**	**9.8**	**352.35**	**11.4**	**57**	**0**	**39**	**2**	**0**	**1**

T: Annual Mean Temperature (°C), **TM**: Annual Mean Maximum Temperature (°C), **Tm** Annual Mean Minimum Temperature (°C), **PP:** Annual Total Precipitation of Rain and/or Meltwater (mm), **V:** Annual Mean Wind Speed (km/h), **RA:** Total Rainy Days per Year, **SN:** Total Snowy Days per Year, **TS:** Total Stormy Days per Year, **FG:** Total Foggy Days per Year, **TN:** Total Days with Tornadoes or Funnel Clouds per Year, **GR:** Total Hail Days per Year.

Note from. https://fr.tutiempo.net/climat/ws-604750.html

The table above show the climate data recorded over the period 2012 and 2022 of Tebessa and it shows that the annual mean temperature across the years is somehow stable, while the annual mean maximum temperature is rising over the last few years. Figure 19 shows this:

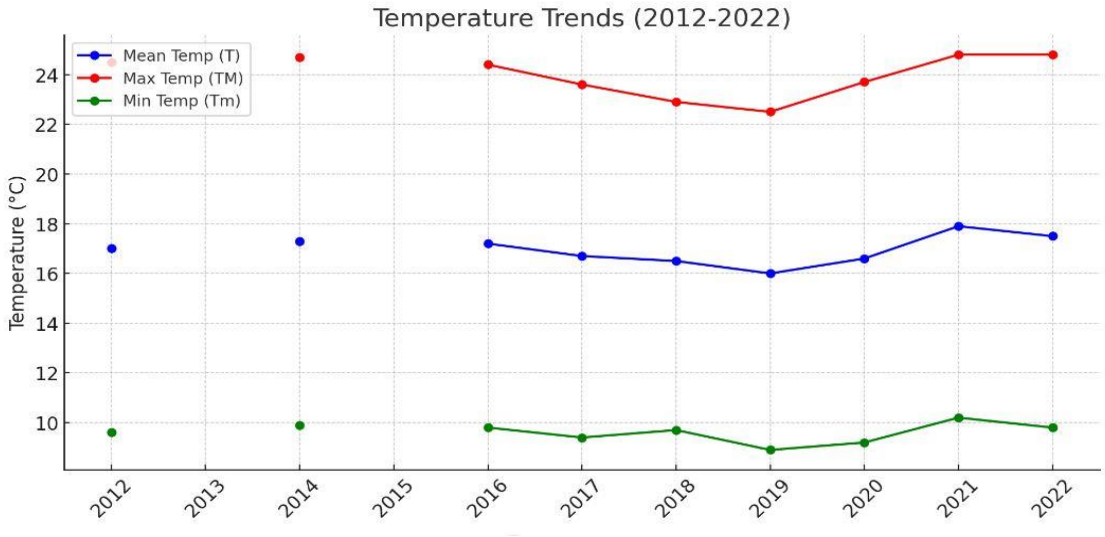


Figure 19: Temperature trends in Tebessa from 2012 to 2022.

The Annual Total Precipitation of Rain records shows that there is notable variability in annual precipitation from 2012 to 2022, with no consistent increasing or decreasing trend. The

data also shows that 2021 stands out as a potential drought year with the lowest recorded value (~192 mm), significantly below other years, but 2019 has the highest precipitation (~479 mm), indicating a stark contrast to 2021. It can be concluded that the unpredictable rainfall distribution may exacerbate drought risk in years with insufficient precipitation. These trends are visually represented in figure 20.

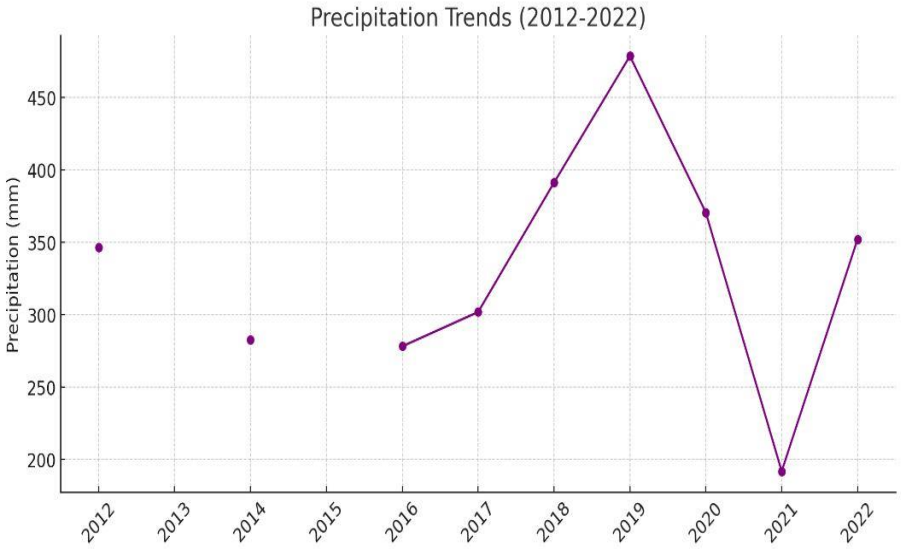


Figure 20: Precipitation trends in Tebessa from 2012 to 2022

II.1.4.2 Region 2

Table 6. presents the climate data of Biskra from 2012 to 2022.

Table 6: Climate Data of Biskra

Année	T	TM	Tm	PP	V	RA	SN	TS	FG	TN	GR
2012	23.4	29.5	17.2	125.98	11.9	32	0	10	0	1	0
2013	22.9	28.8	17	204.49	-	35	0	22	0	0	0
2014	23.6	29.6	17.4	63.76	8.3	30	0	13	0	0	0
2015	23	29	16.8	109.72	13.5	32	0	20	0	0	0
2016	23.5	29.4	17.5	140.97	14.4	38	0	21	0	0	1

2017	23.1	28.9	17	49.25	13.8	26	0	11	0	0	0
2018	22.8	28.1	17.4	-	15.7	39	0	19	0	0	0
2019	23.2	28.6	17.3	96.24	15.5	34	0	13	0	0	0
2020	23.4	29	17.7	81.00	13.6	28	0	13	0	0	0
2021	24.2	29.7	18.3	50.27	13.4	25	0	10	1	0	1
2022	24.2	30.2	18.3	41.91	12.3	20	0	13	0	0	0

T: Annual Mean Temperature (°C), **TM**: Annual Mean Maximum Temperature (°C), **Tm** Annual Mean Minimum Temperature (°C), **PP:** Annual Total Precipitation of Rain and/or Meltwater (mm), **V:** Annual Mean Wind Speed (km/h), **RA:** Total Rainy Days per Year, **SN:** Total Snowy Days per Year, **TS:** Total Stormy Days per Year, **FG:** Total Foggy Days per Year, **TN:** Total Days with Tornadoes or Funnel Clouds per Year, **GR:** Total Hail Days per Year.

Note from. https://fr.tutiempo.net/climat/ws-604750.html

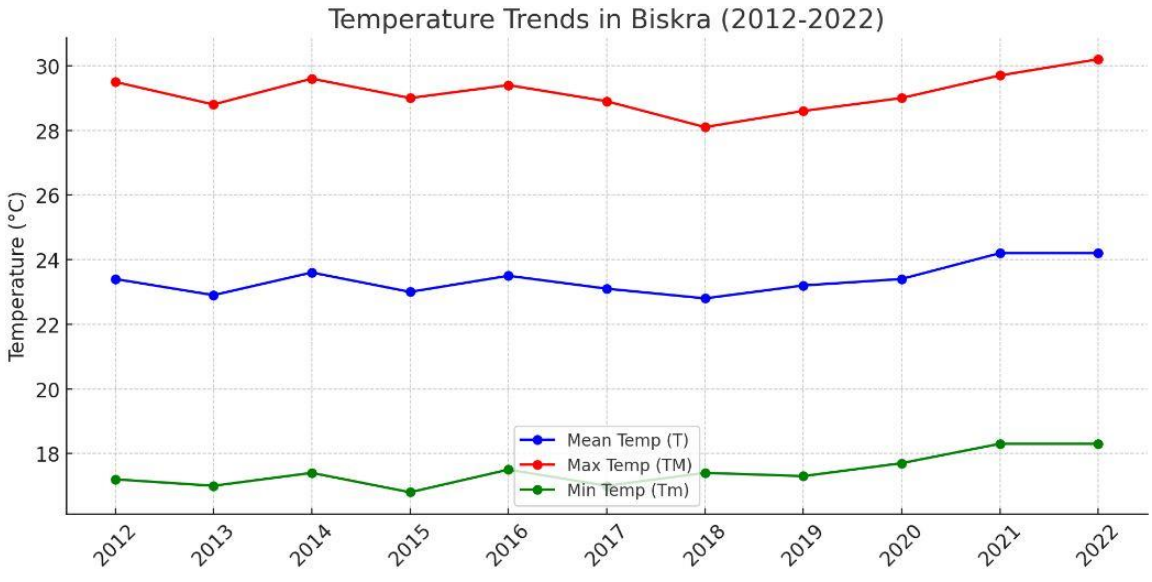


Figure 21: Temperature trends in Biskra from 2012 to 2022.

Figure 21. shows that the temperature is on the rise in all its categories including: the annual mean (T), maximum (TM), and minimum (Tm), especially in 2021 and 2022.

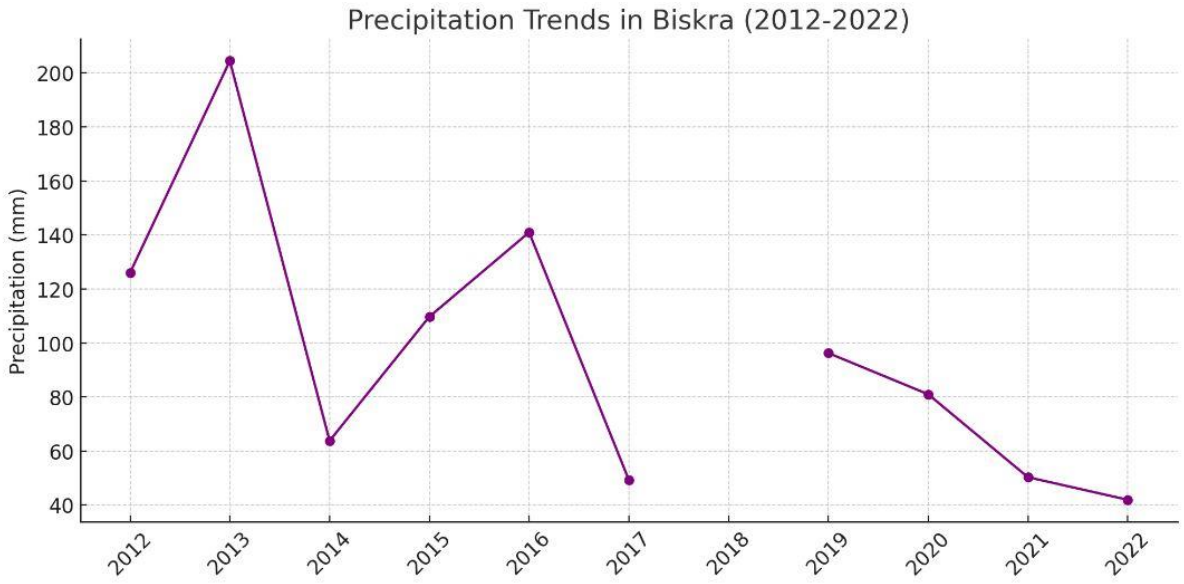


Figure 22: Precipitation trends in Biskra from 2012 to 2022

Precipitation (PP) demonstrates significant variability, with extremely low values in 2021 (~50 mm) and 2022 (~42 mm), indicative of potential drought conditions. Both figures 7 and 8 indicate that the climate of the Biskra region is characterized by two distinct periods: a cooler and wetter phase extending from mid-November to the end of February, and a hotter and drier phase from the end of March to mid-November.

II.2 Plant material

In this study, 4 raw materials were analysed with a view to their incorporation into different maintenance rations for ewes. These were:

1. Cladodes of Opuntia ficus indica: these were collected from the Bedjene region (Wilaya of Tebessa). The samples were taken in March 2022 and stored at -5°C.

2. Atriplex halimus: these were collected for Zribet El Oued (Wilaya de Biskra). The plants were gathered in the early stages of April 2022, when they were in the flowering stage. Atriplex was similarly kept at -5 C.
3. Barley straw: A local by-product of the experimental farm of the private farm where the study was conducted. Barley straw is known of having low nutritional value, except for oat straw, which is rich in carbohydrates and nitrogen (Lamand, 1986, as cited in Louacini, 2014).
4. Grains of barley: a local product of the experimental farm, considered to be an energy-rich, but low in nitrogen, it forms the basis of feed mixtures for concentrated feeds. Carbohydrates account for around 80% of the dry matter in the seeds and consist mainly of starch located in the caryopsis, where it is the main source of energy. Cellulose is mainly concentrated in the glumellae (50 to 60%), the grain envelopes and the cell walls of the aleurone layer represent 5 to 8% of dry matter on average (Louacini, 2014)

II.3 Animal Material

Thirty-six pregnant Babarine ewes, also known as Oued Souf sheep or "Guebliya" (El Bouyahiaoui, 2017), are a prevalent breed in the El-Oued region in the east of Algeria. They have an initial live body weight of 57 + 4.6 kg. The ewes received vaccinations against common illnesses and parasites. The ewes were divided into nine lots, four of which were randomly selected, and placed in separate digestibility boxes.

Before the start of the experiments, 70 were subjected to vaginal sponge heat synchronisation (FGA = 20 mg; Intervet, France; and PMSG = 300 UI). Each ewe was restrained by a worker. After disinfecting the applicator with an antiseptic solution (Betadine), the sponge

was placed into the applicator with the bevelled end first, compressing it with the fingers. The other end of the string remained outside the tube (See photo 2 and 3 in Appendix E)

Following disinfection of the perineal region, the applicator containing the sponge was gently inserted into the vaginal canal of the ewe, tilting and rotating it slightly. It was carefully directed towards the roof of the vagina using a rotational and forward thrusting motion. The applicator tube was then withdrawn by 2-3 cm to release the sponge by pressing on the plunger. The sponges were left in place for 14 days, before they were introduced to the males. Each male with five ewes. After breeding and a period of observation, ewes with twin pregnancies or those that failed to conceive were excluded, resulting in a final study group of 36 single-bearing ewes.

II.4. Storage and Sampling of Raw Materials

An important first step in the analysis of the plant material included in the study is sampling. The sample under analysis ought to be typical of the entire stock for which data is being sought. In order to do this, sampling was done in multiple phases:

1. Dispersed sampling across the volume (based on the Z pattern for cladodes at a distance of one kilometre and the cone pattern for concentrations).
2. Gathering, combining, and creating a fresh sample from the original
3. A backup sample is collected and forwarded to the lab for preservation.
4. Storage: After sampling, the samples were kept in a way that guarantees their properties will not change until the analysis is performed.
5. Grinding: the secondary sample is crushed using a grid with openings of between 0.8 and 1 mm in diameter. In the case of straw, an initial coarse crushing was carried out (5 to 10 mm diameter mesh), followed by a fine crushing.

6. Sample for analysis: the weight of the sample varied between 1 and 10 g depending on the component to be analysed. Samples were placed in sample boxes and stored for analysis in a clean, airy place. Sampling is reliable if the sampling error is only slightly scattered around the mean.

(a): Barley Grain (b): Cladodes of Opuntia ficus-indica

(c): Barley Straw (d): Atriplex

Figure 23: Preparation of Samples of Raw Materials

II.5. Analysis of Chemical Parameters of Experimental Feed Samples

II.5.1 Measuring Dry matter (DM) Content

The DM content was determined on the basis of a 10-gram test sample, after a stay of 24 hours in an oven at 103° ± 2° C, until a constant weight was obtained.

By weighing the sample of fresh material DM1 before placing it in an oven heated to 103°C. In this process, the water contained in the food evaporates and only the dry matter remains. The sample is then weighed again to obtain the weight of the dry matter DM2. The degree of moisture is the difference between the first and second weight (Chesworth, Guerin, 1996).

The results are expressed by the following formula:

DM = $(DM1 - DM2)/DM1 \times 100$

DM1: initial mass, in grams, of the test sample

DM2: mass, in grams, of the dry test sample.

II.5.2 Determination of ash (MM) and organic matter (OM)

The ash content was determined from a test sample of 1 g dry matter by calcination in a muffle furnace at 550 °C for 8 hours. The minerals (Ca, P, K, Mg) were determined by atomic absorption spectrometry (AAS) at FATILAB2 (El Oued). Organic matter content was calculated as the difference between 100% and the ash content.

Results were expressed as follows:

- **Organic Matter (MO):** MO = MS – MM
- **Ash (MM):** MM = (P3-P1)/P2 x 100 where:
- P1: tare of crucibles

- P2: initial mass of the sample
- P3: final mass of the sample and crucibles post-calcination

II.5.3 Kjeldahl Method for Protein Determination (AOAC, 2005)

Kjeldahl method involves the mineralization of organic matter present in the sample. Organic nitrogen is converted into mineral nitrogen in the form of ammonia under the oxidative action of boiling sulfuric acid on the organic matter and in the presence of a catalyst. The nitrogen is then in the form of ammonium sulfate ($(NH_4)_2SO_4$; an excess of sodium hydroxide solution neutralizes the sulfuric acid and releases ammonia (NH_3) which is carried over by steam during distillation; it can then be titrated in the presence of a colour indicator.

II.5.3.1 Reagents

- Concentrated sulfuric acid (95%) (H_2SO_4)
- 40% sodium hydroxide (NaOH)
- 0.1 N hydrochloric acid (HCl)
- Catalyst (80 g potassium sulfate + 20 g copper sulfate + 2 g selenium)
- Receiving solution (per liter of solution): Dissolve 40 g of boric acid in a small amount of distilled water, then add 10 mL of RB dye solution (200 mg methylene blue and 100 mg methyl red in 100 mL of 95% alcohol), and bring the total volume to 1000 mL.

II.5.3.2 Apparatus

250 mL flask, digestion block, heating apparatus, distillation apparatus, 20 mL burette for titration.

II.5.3.3 Procedure

- **Mineralization**

1. Weigh 1 g of the sample (depending on the nitrogen content of the sample) and place it in a 250 mL flask, ensuring that the particles do not adhere to the walls.
2. Add 2 g of catalyst and 20 mL of concentrated sulfuric acid (95%).
3. Place the flask on the digestion block and heat until the liquid is decolorized, or a clear light blue colour is obtained, for approximately 4 hours.
4. Allow to cool for 30 minutes, then slowly and carefully add 100 mL of distilled water while stirring and cooling under a water stream to completely dissolve the sulfates.

- **Distillation and Titration**

1. Transfer 20 mL of the content from the flask to the distillation apparatus. Collect the distillate in a beaker containing 20 mL of the color indicator.
2. Slowly pour 20 mL of sodium hydroxide solution (density = 1.33) into the flask of the distillation apparatus.
3. Start the apparatus and allow the distillation to continue until at least 100 mL of distillate is collected.
4. Once the distillation is complete, rapidly titrate the ammonia in the boric acid solution, to which a few drops of methyl red have been added, with 0.1 N sulfuric acid solution. The colour should change from light blue to pink.

The results of the crude protein can be obtained following this equation:

Total Nitrogen (TN) % = (mL HCl x N*HCI* x 1.40071) / sample weight x F

- **Sample weight:** This is the weight of the original sample that was analysed.
- **N:** This represents the normality of the hydrochloric acid solution, which indicates its concentration.
- **F = 6.25** is the standard conversion factor for fodder.
- **F = 5.70** is the standard conversion factor for grains.
- **F = 6.38** is the standard conversion factor for milk.

II.5.4 Crude fibre (CF) determination

Crude fiber content in the experimental feed samples (Opuntia ficus indica, Atriplex, barley straw, and barley grain) was determined using the Weende method. This involved boiling 1 g of each plant material in 50 mL of 0.25 N sulfuric acid followed by boiling in 50 mL of 0.31 N sodium hydroxide for 1 hour. The resulting residue was dried at 105°C for 8 hours and then incinerated at 550°C for 3 hours.

The results are expressed using the following equation:

$$CF\ (\%): = (P1 - P2/\ \text{sample weight}) \times 100$$

- **P1:** The oven-dry weight represents the weight in grams of the crude fiber before incineration.
- **P2:** The weight after incineration represents the weight of the ash remaining from the crude fiber.

II.5.5 Determination of Fat Content

Lipids provide approximately 2.25 times the energy density of carbohydrates. Nonetheless, the primary energy source in forages and concentrates is carbohydrates. Lipids, along with other organic solvent-soluble substances such as phospholipids, steroids, waxes, and fat-soluble vitamins, constitute lipidic matter. Quantitative analysis of this matter is typically

achieved through ether extraction. Crude fat, synonymous with ether extract, is determined by Soxhlet extraction using petroleum ether (as per AOAC, 1990) or other hexane-based solvents.

Figure 24: Soxhlet Machine

The principle of extracting fat through Soxhlet machine is that a desiccated and pulverized sample is subjected to extraction with diethyl ether, which solubilizes fats, oils, pigments, and other lipid-soluble compounds. Subsequent evaporation of the ether yields a residue, termed ether extract or crude fat. To prevent co-extraction of hydrophilic substances like carbohydrates, urea, lactic acid, and glycerol, both the ether and sample must be anhydrous. The percentage of ether extract is calculated using the following formula:

$\%Fat = ((P2 – P1) / PE \times DM_a) \times 100$

where: P1 = weight of the empty flask (g)

P2 = weight of the flask post-oven drying at 105°C (g)

PE = sample weight (g)

DM_a = %DMa/100"

II.5.6 Determination of neutral and acid fibres

Acid Detergent Fiber (ADF) and Neutral Detergent Fiber (NDF) are important measures used in animal feed. Both calculations are based on the digestibility of the plant material in an animal's diet. Researchers use these calculations to determine the quantity of feed an animal needs and the amount of energy the animal will receive from that feed. These two fiber calculations are used together to determine the quantity and energy content of a feed. Fibers low in cellulose, lignin, and hemicellulose generally take up less space in the stomach and can provide greater amounts of energy to the animal. Fibers high in these materials take up more space and produce less energy for the animal. Fiber analysis methods are based on successive chemical treatments of the sample to solubilize non-fiber components, resulting in a residue that determines the fiber content (ADF, NDF). This gravimetric technique relies on the extraction of soluble components from cell walls using neutral (for NDF) or acidic (for ADF) detergent solutions, and weighing the remaining residue after drying.

The cell walls (NDF: Neutral Detergent Fiber) are the residue of extraction with dodecyl sulphate in a neutral medium for 1 hour.

- Lignocellulose (ADF: Acid Detergent Fiber) is the residue of hydrolysis for 1 hour with 0.5 M H2SO4, combined with the detergent cetyltrimethylammonium bromide (CTAB).

The lignocellulosic residue is not polluted with starch but may contain nitrogenous constituents and tannins.

To calculate the results for both acids, we followed the following equations:

Neutral Detergent Fiber (NDF) content is calculated as follows:

$$\% NDF = ((P1-P2)/ PE \times DM_a) \times 100$$

Where: **P1**: Weight of the crucible after drying at 105°C (g); **P2:** Weight of the crucible after ashing (g); **PE:** Sample weight (g) **DM_a:** % DM/ 100

Acid Detergent Fiber (ADF) content is calculated as follows:

$$\% ADF = ((P1-P2)/ PE \times DM_a) \times 100$$

Where: **P1:** Weight of the crucible after drying at 105°C (g); **P2:** Weight of the crucible after ashing (g); **PE:** Sample weight (g); **DM_a:** % Dry matter of the sample / 100

II.5.7 Determination of Minerals

The minerals (Ca, P, K, Mg) were determined by atomic absorption spectrometry (AAS) at FATILAB2 (El Oued). Atomic Absorption Spectrometry (AAS) is a technique first described by Walsh in 1955. It studies the absorption of light by free atoms. It is one of the main techniques of spectroscopy or atomic spectrometry in the UV-visible range used in chemical analysis.

It can be used to measure over seventy chemical elements (metals and non-metals) from the Mendeleev table. It has a wide range of applications, as concentrations are less than mg/L (ppm).

The principle of this method is that it is essentially used to measure metals in solution. This method of elemental analysis requires the measurement to be made using an analyte (element to be measured) that has been converted to the state of free atoms. The sample is heated to a temperature of 2,000 to 3,000 degrees so that the chemical combinations in which the elements are involved are destroyed.

Atomic absorption spectrometry is based on the theory of quantifying the energy of the atom. The energy of the atom varies as one of its electrons moves from one electron orbit to

another: E = h orbit to another: E = h. ν, where h is Planck's constant and ν is the frequency of the photon absorbed or emitted. In general, only the outer electrons of the atom are involved.

II.6 The Nutritional Value of Feed

For determining the nutritional value, a sequential approach was adopted, focusing on the estimation of organic matter digestibility (d(OM)) and/or chemical composition. The calculation of FUL and PDI values followed the sequence of equations proposed by INRA (1978, 1988) specific to each feed group. This nutritional value allowed us to assess the contribution of each feed to meeting the nutritional requirements of the ewe.

For the energy value of straw, the approach primarily involved estimating d(OM) and chemical composition. FUL values were calculated sequentially based on estimates of gross energy, digestible energy, metabolizable energy, and finally, net energy. As for concentrates, such as maize grains and wheat bran, the estimation of FUL values relied solely on chemical composition.

The energy value and organic matter digestibility of oat hay were predicted based solely on its chemical composition.

II.6.1 Principle of Determining PDI Values of Feed (INRA, 1988, 2004)

The prediction of the PDI content of feed requires consideration of four parameters:

- Total nitrogenous matter content (TNM);
- Theoretical degradability of nitrogenous matter in nylon bags (TD);
- True digestibility of dietary proteins in the small intestine (rd);

- Fermentable organic matter content (FOM), which itself depends on the digestible organic matter content (DOM), fat content (Fat), and the content of non-degradable nitrogenous matter in the rumen (TNM × (1 - TD)).

II.6.1.1 Calculation of PDIA Value

The theoretical degradability (TD) tends to overestimate the actual degradation of nitrogenous matter. At the entry of the intestine, dietary-origin intestinal proteins (PDIA) are estimated to be 1.11 times those calculated based on TD:

$$PDIA=1.11\times TNM\times(1-TD)\times rd$$

The values for TD and rd are published by INRA (2004 edition).

II.6.1.2 Calculation of PDIM Value

Microbial proteins reaching the intestine (MPI) represent 80% of microbial nitrogenous matter (mNM). Their digestibility averages 0.8, leading to the equation:

$$\mathbf{MPI=0.8\times mNM}$$

$$\mathbf{PDIM=0.8\times 0.8\times mNM= 0.64mNM}$$

Two methods are available for estimating the quantity of microbial nitrogenous matter:

1. If the estimation considers the limiting factor of degradable nitrogenous matter, the quantity of digestible proteins in the intestine of microbial origin permitted by nitrogen (N) is derived from the quantity of nitrogenous matter permitted by nitrogen, MAMN:

   PDIMN = 0,64 MAMN

   Microorganisms can capture up to 90% of degradable dietary nitrogen:

   MAMN = TNM [1 -1.11(1 – TD)]0,9

PDIMN= 0,64 TNM [1 -1.11(1 – TD)]0,9

PDIMN= 0,64 TNM (TD – 0,10)

2. If the estimation accounts for the limiting factor of fermentable energy, the quantity of digestible proteins in the intestine of microbial origin permitted by energy (E), PDIME, is derived from the quantity of nitrogenous matter permitted by energy, MAME:

   PDIME = 0.64 MAME

   Microorganisms produce approximately 145 g of MAm per kilogram of FOM:

   MAME = 0,145MOF

   PDIME = 0,8 x 0,8 x0, 145 FOM

   PDIME = 0,093 FOM if FOM is expressed in kilogrammes;

   PDIME = 93 FOM if FOM is expressed in grammes;

   PDIN = PDIA + PDIMN

   PDIE = PDIA + PDIME

II.7. Ingestibility and Digestibility

The experiment involved nine groups, each consisting of four Barbarine ewes with an average live weight of 57 ± 4.6 kg, aged between 4 and 6 years. The ewes were fed nine different predetermined diets:

- Diet 1 (control): 500g Barley grain + 1550g barley straw.
- Diet 2: 5500g cactus (100%) + barley straw ad libitum.
- Diet 3: 4125g (75%) cactus + 650g Atriplex (25%) + barley straw ad libitum.
- Diet 4: 2750g cactus (50%) + 1300g Atriplex (50%) + barley straw ad libitum.

- Diet 5: 1375g cactus (25%) +1950g Atriplex (75%) + barley straw ad libitum.
- Diet 6: 2600g Atriplex (100%) + barley straw ad libitum.
- Diet 7: 1800g barley straw (100%)
- Diet 8: 2600g Atriplex (100%)
- Diet 9: 5500g cactus (100%)

The research was carried out on a private farm situated in Bayadha commune, within El-Oued province, Algeria. This region is located approximately 700 kilometers southeast of Algiers, the nation's capital, and 80 kilometers from the Tunisian border. The experimental protocol involving animals was ethically reviewed and approved by the Laboratory of Agro-biotechnology and Nutrition in Semi-arid Zones, as well as the scientific committee of the Faculty of Natural and Life Sciences at Tiaret University, Algeria. The experiment was conducted in two periods, twenty-nine days each (between 25 April- 21 June 2022), following a crossover design. The experiment was carried out in the second half of ewes' pregnancy. During the second period, we implemented dietary changes: D1 versus D5, D2 versus D4, and D3 versus D6. It is worth noting that we deliberately terminated the experiment for ewes receiving diets D7, D8, and D9 to prevent potential negative effects of these diets on the pregnant ewes.

During the experimental phase, the following procedures were performed: Nutrient value prediction, quantity of feed distributed for gestation, quantity of feed consumed, quantity of fecal matter excreted, fecal matter storage at -18°C, sampling of feed and feces, chemical analyses of samples in the laboratory, Calculation of in vivo digestibility of DM, OM, CF, CP and blood sampling.

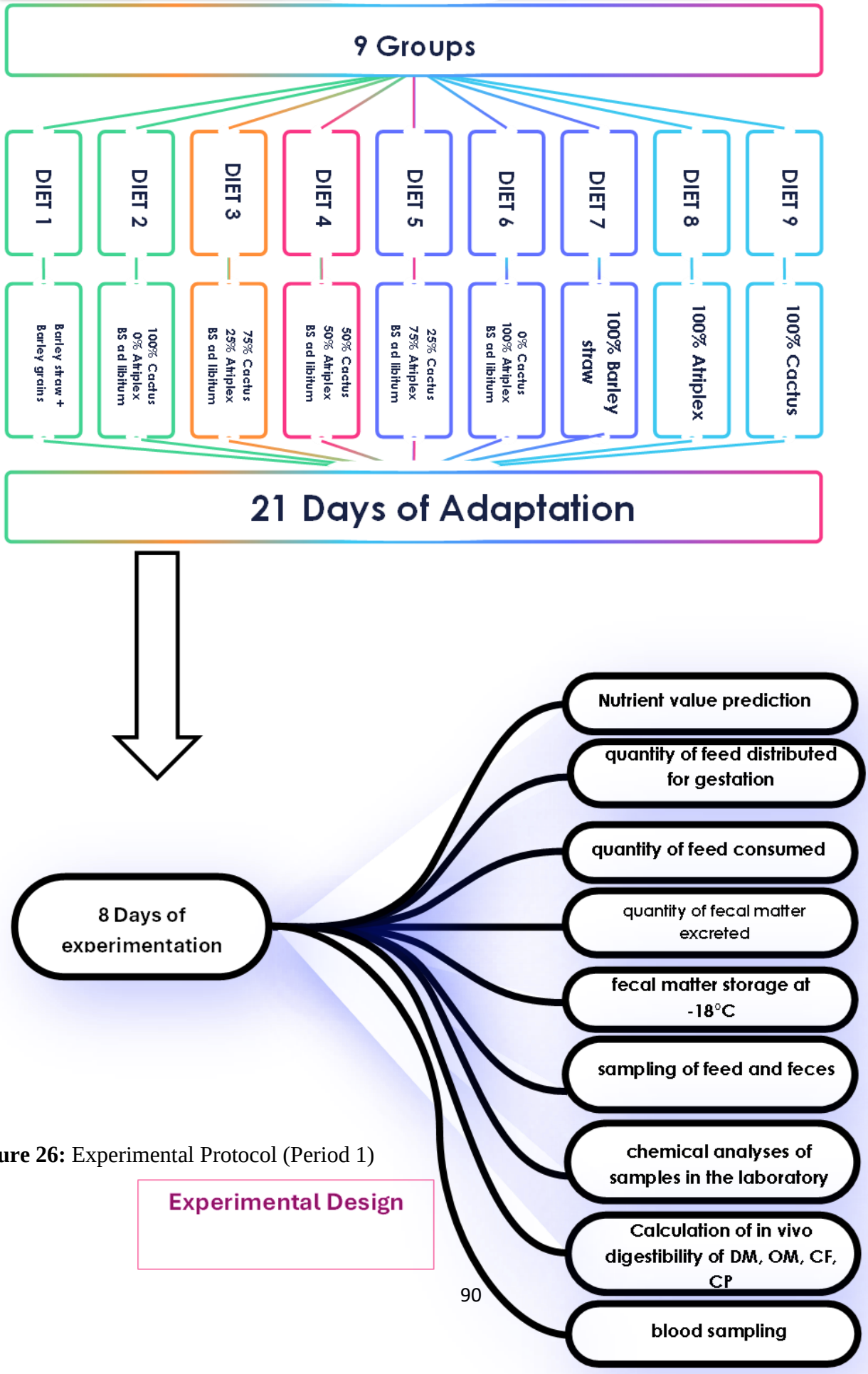
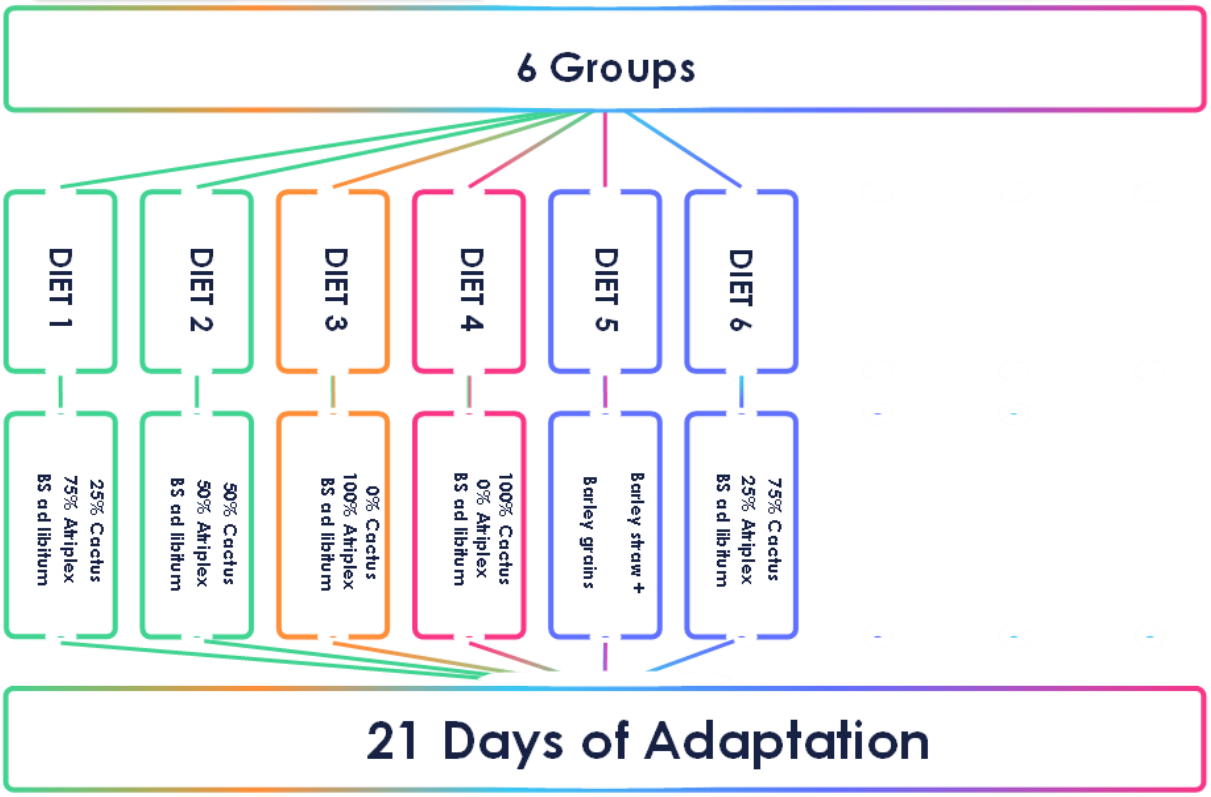


Figure 26: Experimental Protocol (Period 1)

Experimental Design



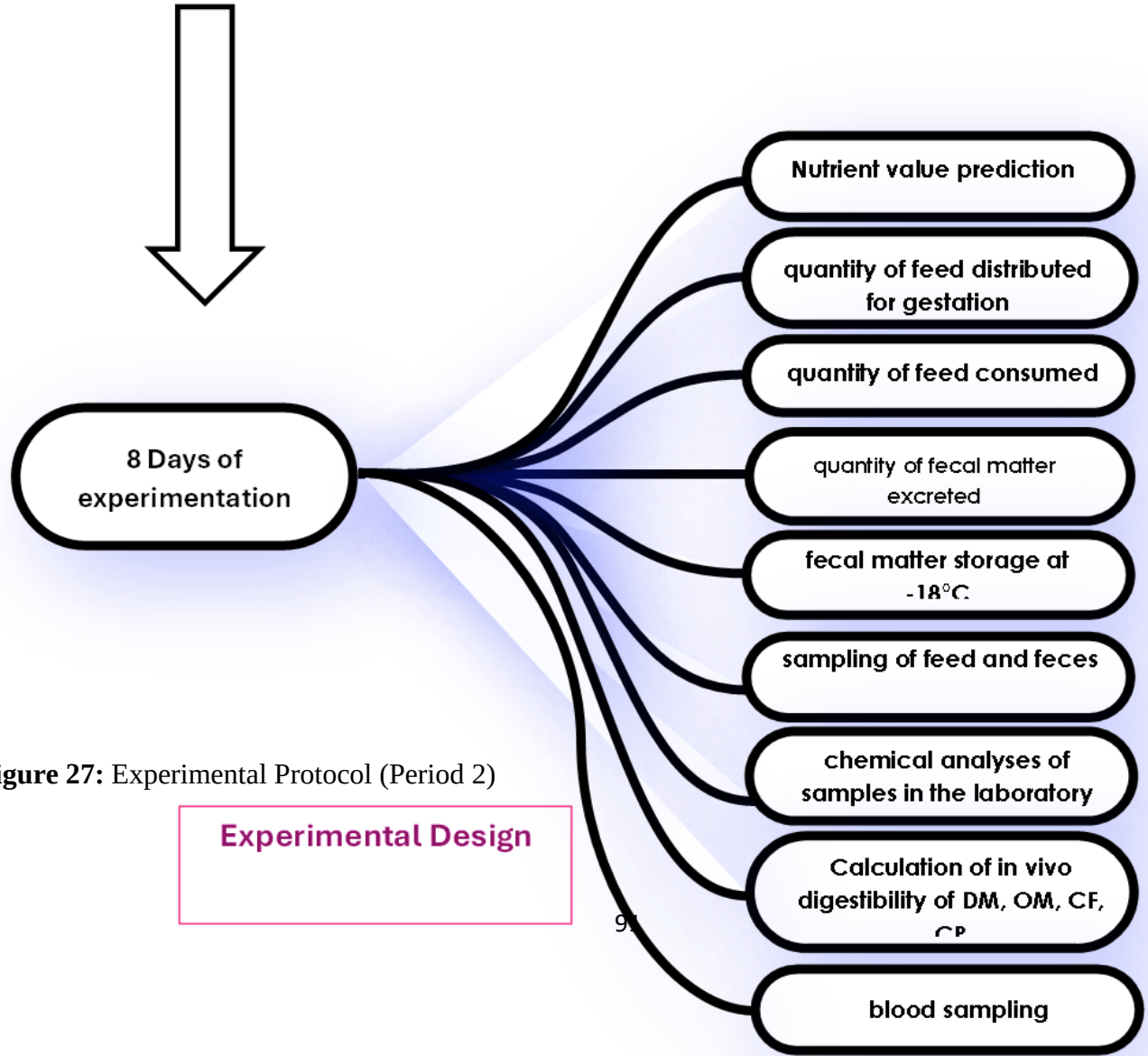


Figure 27: Experimental Protocol (Period 2)

Experimental Design

The previous diet of the animals was soft barley wheat straw supplemented with concentrate for sheep fattening because the animals were close to herds of sheep on fattening feed. The sheep received different feeds to meet their gestation requirements. The main raw materials, namely: Atriplex, Opuntia, barley grain and barley straw underwent chemical characterisation to predict their energy and nitrogen values, allowing for the calculation of feed distribution**. (Refer to Experiment 1).**

II.7.1 Metabolism Cage

These are individual cages, measuring 1.02 m in length, 1 m in width, and 1 m in height, designed at the private farm where the experiment took place. The flat cement floor facilitated the collection of fecal matter, ensuring accurate measurement of feed intake and fecal output, which is crucial for determining nutrient digestibility. The cages were equipped with manually filled feed troughs for roughage (Atriplex, Opuntia and straw), a plastic bucket for water, and a second bucket for concentrate (barley grain).

II.7.2 Experimental Procedure

Diet 1 was considered a classic ration for sheep. The quantities consumed of each diet were determined by daily weighing of the amounts distributed and refused. Each morning, refusals were weighed and partially dried in an oven. After establishing the dry matter content, they were stored in plastic bags labeled with the date and animal number and kept until the end of the experiment. Two meals per day were distributed:

Diet 1: barley straw was given in the morning at the same time (8.00am) [First meal] and the concentrate was given in the afternoon at the same time (15.00pm) [Second meal].

Diet 2, 3, 4, 5 and 6: ewes in these experimental groups were given ad libitum access to barley straw. Their experimental feed was divided into two meals one at 8.00 am and the second at 15.00 pm.

Diet 7 received only barley straw.

Diet 8 received only Atriplex.

Diet 9 received only Opuntia.

The cladodes of Opuntia were presented to the animal in a square shape, 3-4 cm in size, and fresh. Atriplex, straw and barley grains were presented in their natural physical form.

II.7.3. Validity of Measures

Our study followed the validity measures employed by Louacini (2014). This work is an extension to his work which explored the impact of cladodes of Opuntia on Rembi ewes.

II.7.3.1 Adaptation or Pre-experimental Period

This is an adaptation period to the diet of sufficient duration (8 days), but can be extended to 2 or 3 weeks in certain cases, according to Cammel (1977) and Wainman (1977), especially in cases of significant changes in diets, poor quality forages, or the introduction of a new feed. In our case, the adaptation period to the diet lasted 21 days. There are two reasons for this: (1) the rumen flora must adapt to the diet being studied, although this adaptation seems to be very rapid (5 days) in the case of animals fed at the maintenance level (Potter and Dehoryti, 1973); and the composition of the feces must correspond only to the diet being studied; in our situation (2) there is a significant change in the diet compared to a classic diet (straw + cereals).

II.7.3.2 Experimental Period

The discontinuous nature of fecal excretion, leading to errors at the beginning and end of the period, and the differences in digestive capacity between animals, necessitate a minimum measurement period (varying from 5 to 14 days depending on the authors, and most often 10 days) conducted on a minimum number of animals (varying from 3 to 8 depending on the authors and most often 4 animals). In fact, these numbers vary depending on the type of feed studied, the feeding mode (limited or ad libitum), and especially the desired precision of the measurement. This precision depends, of course, on both the number of days and the number of animals.

Feeders were filled daily with weighed feed. Any remaining uneaten feed outside the feeder was returned to the feeder if it was free of any contamination. The first collection took place the following morning, and the last on the 9th morning at the same time.

Feces were placed in their entirety in an identified plastic bag for each animal, by cage, and stored at -18°C. The feces collected each day were added to the same bag of feces collected on previous days. At the end of the collection period, the total was weighed. The dry matter of the feed, refusals, and feces was determined by oven drying, while that of organic matter was determined by calcination in a furnace at 550°C for 5 hours.

In our case, the general conditions necessary for the validity of the measurements were respected.

II.7.4 Measurement of Digestibility

Digestibility is the ability of a feed to be degraded through an animal's digestive tract. It represents the amount of a given feed that is digested. It is, in fact, assessed by the difference between the amount of nutrient ingested (total weight of feed ingested x concentrations of that

nutrient in the feed) and the amount of nutrient excreted in the feces that escapes digestion (total weight of feces excreted x the concentrations of that nutrient in the feces) over a determined period, in our experiment: 8 days.

For each nutrient, we calculated the quantity ingested (I) and excreted (E), knowing that: E = (concentration of nutrient in feces in g/kg of DM) x (total quantity of feces excreted in g of DM)

I: (concentration of the nutrient concentration in the feed in g/kg of dry matter) x (total amount of feed consumed in g of dry matter).

Apparent Digestibility: expressed as a coefficient (CUDa or D), it is calculated as follows:

$$(I-E)/ I \times 100$$

Digestibility was assessed using the apparent digestive utilization coefficient (CUDa), commonly referred to as digestibility (D) of a nutrient. This coefficient represents the proportion of the nutrient consumed that is digested. To perform this measurement, the ewes were placed in specialized enclosures known as metabolism cages.

II.7.5 Experimental Procedure and Data Recording

Sheep were housed in metabolic cages to allow for precise measurement of feed intake and fecal output. The following data were recorded for each animal:

1. Date
2. Live weight: Weekly measurements to monitor animal growth or weight changes on a scale of 300kg (See Photo 1 in Appendix E).
3. Feed offered: The daily amount of feed provided (See Photo 4,5 & 6 in Appendix E)
4. Feed intake: Calculated as the difference between feed offered and feed refused.
5. Temperature: Ambient temperature was recorded to assess any environmental effects.

6. Animal care and enclosure hygiene were maintained by two technicians.
7. Daily fecal output was weighed for each animal, using the fresh weight.
8. Water offered: the daily amount of water provided.
9. Water Refused: the daily amount of water left.

II.8. Energy and Nitrogen Feeding Levels (FL)

The feeding levels were calculated based on the intake of digestible organic matter (MODI) expressed in grams per kilogram of metabolic weight (g / kg $P^{0.75}$).

II.8.1. Energy Feeding Level (Energy FL)

The energy feeding level was determined using the formula:

Energy FL= Quantity of MODI (g/kg $P^{0}.^{75}$)/26

Here, the value "26" represents the quantity of digestible organic matter (MOD) required per kilogram of metabolic weight ($P^{0}.^{75}$) to meet the maintenance energy needs of reproductive ewes.

II.8.2. Nitrogen Feeding Level (Nitrogen FL)

The nitrogen feeding level was calculated as follows:

Nitrogen FL = Quantity of PDI (g/kg $P^{0}.^{75}$)/2.64. The value "2.64" denotes the amount of digestible protein in the intestine (PDI) necessary to meet the maintenance nitrogen needs of ewes.

II.8.3 Calculations of FUL and PDI Provided by the Diet

The amounts of energy (FUL) and nitrogen (PDI) supplied by the diet were calculated using the following formulas:

1. **Maintenance Requirements**:

Energy (FUL):

Maintenance FUL Requirements=$P^{0.75}$×0.033 FUL

Nitrogen (PDI):

Maintenance PDI Requirements (g)=$P^{0.75}$×2.64

2. **Total Intake**:

Total FUL Intake:

Total FUL Intake=$P^{0.75}$×0.033 FUL×FL

Total PDI Intake (g):

Total PDI Intake=$P^{0.75}$×2.64×FL

FUL Available for Production = ($P^{0.75}$ × 0.033 FUL× FL) − ($P^{0.75}$×0.033 FUL).

PDI Available for Production = ($P^{0.75}$×2.64× FL) − ($P^{0.75}$×2.64)

MODI Calculation

MODI (digestible organic matter intake) is derived as follows: MODI=Total OM Intake× D (OM)

Energy FL = MODI g/kg $p^{0.75}$ / 26

Nitrogen FL = PDI g/kg $p^{0.75}$ /2.64

II.9. Blood Sample Collection and Analysis

During both periods, the researcher took four blood samples (5 ml): two samples per period and diet were taken. Through the jugular vein, blood samples were drawn into sterile heparin tubes. Blood was centrifuged at 300 rounds per minute for ten minutes in the laboratory of the polyclinic (Bilal Bachir). For further examination, plasma samples were stored in microtubes at -20 C. Commercial kits (spinreact kits, Spain) were used to analyse the concentrations of serum glucose (Glu), total cholesterol (TC), total protein (TP), triglyceride (TG), urea, creatinine (Crea), albumin (AL), aspartate aminotransferase (AST), alanine aminotransferase (ALT), calcium (Ca), and phosphorus (P). Beckman Coulter Diagnostic was used to read the results.

Prior to introducing the diets, 36 samples per biochemical parameter were collected from each of the nine experimental groups. An additional 36 samples per parameter were collected at the termination of the first experimental period (period 1). Following a 7-day adaptation period, a second experimental period commenced. Due to the exclusion of ewes in groups 7, 8 and 9, 24 samples 24 samples per parameter were collected at the start of the second period and 24 samples were collected at the end of the experiment. Thus, a total of 120 samples per parameter were collected over the 58-day experimental period.

II.10. Milk Sample Collection

After the lambs were separated from their mothers thirteen hours prior to milking, the milk production was collected at 7:00 a.m. by competent workers using manual milking. The ewes were milked one day before entering experimental period 3; each ewe was milked, and 24 samples of milk (50 mL) were collected in plastic containers that had been sterilised. During the last couple of days of the experiment, 24 samples of milk were collected from the ewes. The samples were immediately analysed for total protein using the Kjeldahl method (See section 5.3 for the protocol followed for measuring the protein level in milk. and fat using the Gerber method (See Figure 13).

Figure 28: Milk Composition Analysis

II.10.1 Butyrometric Determination of Milk Fat

The butyrometric method, a sulfuric acid-based procedure for determining milk fat content, was pioneered by Dr. N. Gerber in 1892 and has been officially recognized since 1935. Despite advancements in automated analytical techniques, the Gerber method remains prevalent due to its simplicity and cost-effectiveness. It eliminates the need for intricate instrument calibration and is suitable for a wide range of milk types. However, the method's reliance on concentrated sulfuric acid necessitates strict safety protocols for handling and disposal.

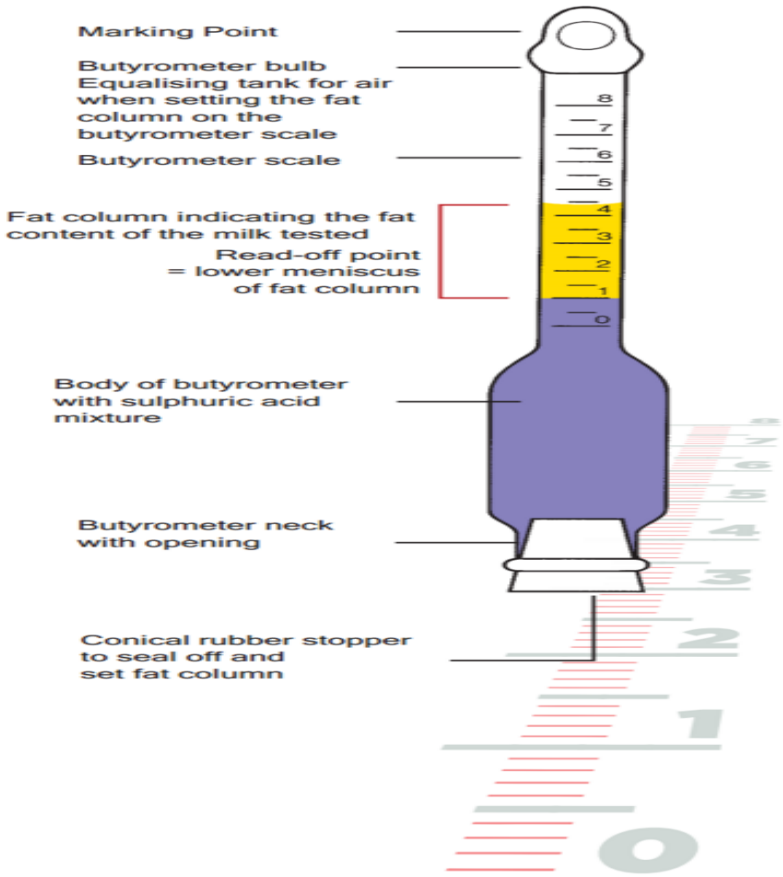


Figure 29: Butyrometric Determination of Lipids

Milk fat globules, ranging from 0.1 to 10 micrometers in diameter, are emulsified within the milk. These globules are stabilized by a protective membrane comprising phospholipids,

proteins, and hydration water. To isolate the fat, concentrated sulfuric acid is added to the milk sample within a specialized vessel known as a butyrometer. The acid's oxidative and hydrolytic properties disrupt the protective membrane, releasing the fat globules. The exothermic reactions accompanying these processes elevate the temperature within the butyrometer. Subsequent centrifugation, facilitated by the addition of amyl alcohol, separates the liberated fat from the acidified serum. The percentage of milk fat is then directly read from the butyrometer scale.

II.11 The Weight of Offspring

To assess the impact of the alternative diets composed of Atriplex and Opuntia on lamb growth, newborn lambs were monitored for a period of 21 days. Ewes were allowed a one-week post-partum recovery period before the initiation of lamb weight measurements. Subsequently, the lambs were weighed daily for 21 consecutive days, beginning on day 7 post-partum. Average daily gain was calculated for this 21-day period to evaluate the growth rate of the lambs under the different dietary treatments.

II.12 Statistical Analysis

IBM SPSS Statistics software was used to handle the data from the chemical analyses. The software calculated the mean, standard deviation, and one-way analysis of variance (ANOVA). According to Duncan (1955), the significant differences were established at $P<0.05$.

III. Results and Discussion

III.1. Experiment 1: Chemical Composition and Nutritional Value of Experimental Feed

III.1.1 Chemical Composition of Experimental Feed

Table 7 shows the results of the chemical composition of the experimental feeds. The results show that the cladodes of Opuntia have a lower dry matter content (14.63%) than Atriplex halimus, barley grain, and barley straw (42.43%, 92.28%, and 91.24, respectively). This lower DM content in Opuntia might be explained by its high-water content, which can exceed 90% (Nefzaoui and Bensalem, 2002; Louacini et al. 2012). Opuntia and Atriplex have higher levels of ash (24.69% and 19.26%, respectively) than barley grain and straw (3.5% and 5.4%, respectively). This is consistent with earlier studies that found high salt content in Atriplex (Ben Salem et al. 2002; Shawket et al. 2015). Researchers have reported that the high level of ash may encourage ruminants to drink more water, which could have an impact on rumen functions (Shawket et al. 2015; Kewan, 2021).

Table 7: The Chemical Composition of the Experimental Feeds (in % DM)

	Opuntia ***Ficus Indica***	***Atriplex Halimus***	**Barley grain**	**Barley straw**
DM	14.63±1.5	42.43±1.51	92.28±1.27	91.24±0.41
OM	75.31±1.1	80.74±1.3	96.5±0.15	94.6±0.7
Ash	24.69±0.9	19.26±1.17	3.5±0.4	5.4±0.23

CP	4.91±1.4	12.87±1.2	9.8±0.7	3.2±0.81
CF	13.37±1.35	27.21±1.08	6.83±1.02	48.07±1.75
Fat	1.70± 0.45	2.4 ± 0.24	1.82 ± 0.2	/
NDF	30.33±2.9	50.29±0.85	25.9±0.8	67.8±2.6
ADF	15.2±1.9	35.43±1.34	6.8±0.57	45.4±3.59
Ca	6.81±0.57	1.44±0.6	0.1±0.28	0.2±0.37
P	0.35±0.66	0.25±0.2	0.4±0.76	0.12±0.9
Mg	0.49±0.12	0.98±0.56	0.2±0.14	0.11±0.48
K	2.91±0.21	0.38±0.13	0.6±0.93	1.20±0.11

Each value is the mean of four observations. ±: Standard deviation. DM: dry matter, OM: organic matter, CP: crude proteins, CF: crude fiber. Fat: Fat Content. NDF: neutral detergent fiber. ADF: acid detergent fiber. Ca: calcium. P: phosphorus. Mg: Magnesium. K: Potassium.

The crude protein (CP) in Opuntia falls between 3 and 6%, which is in line with what Nefzaoui and Bensalem (2002) found, but it is higher in Atriplex (12.87%). Previous studies have shown that Atriplex's high protein content does not explain the nutritional value that they provide as protein supplements, especially since roughly 66% of its total nitrogen is soluble and digestible in the rumen (Kaitho et al. 1998a; Ben Salem et al. 2002; Kewan, 2021). Opuntia has lower CF, NDF, and ADF values (13.37%, 30.33%, and 15.2%, respectively) than Atriplex (12.87%, 27.21%, and 50.29%, respectively) (Ben Salem et al. 2002c). Fat content in Opuntia exhibited lower value (1.70%) than of the values of fat in Atriplex and barley grain (3.80%, 1.82% respectively)

The NDF and ADF values reported in the current study show that they are higher than the norms reported in other fodder shrubs by Ben Salem et al. (2010), which were 30-45% and 15- 29%, respectively (Kewan, 2021). This can be explained by the type of soil, the age of the plant and the botanic composition. It is noticeable that Opuntia is high in Ca (6.81%) compared to Atriplex (1.44%). Our finding agrees with those reported in previous work (Ben Salem et al. 2004).

III.1.2 Nutritional Value

A sequential approach was adopted to assess nutritional value, focusing on the estimation of digestibility of organic matter and/or chemical composition. The INRA equations (1978, 1988 and 2007) for each feed category were used to calculate the nutritional values in PDI and FUL. This nutritional value was used to assess the contribution of each feed to meeting the ewe's nutritional requirements.

Table 8: Equations for Predicting Feed Nutrient Values

Aliments	Equations	Reference	R^2	SR	Expression
Barley Straw	GE = 4531+1,735TNM+ Δ. Δ : terme correctif paille =±11	INRA, 1988	0.945	-	Kcal/Kg OM
	DE= GE × dE	Ibid	0.96	-	Kcal
	dE=1,0087dOM-0,0377	Ibid	0.99	-	Kcal
	ME/DE= 0,8417-9,9×10^{-5} CF - 1,96×10^{-4} TNM+0,0221NA	Ibid	0.90	-	
	EN=ME-Q Q = ME/GE	Ibid		-	Kcal

	Km= 0,287Q + 0,554	Ibid		-	Rendement
	FUL= ME*km/1720	ibid		-	UFL/KgDM
Barley Grain	FUL=121,8+ 0,11TNM- 1,81 CF+1,26MG (Fat, CF, TNM en %)	INRA, 1978	0.96	±0.05	100kg(OM)
	PDIN = PDIA + PDIMN **PDIE = PDIA + PDIME**	INRA, 1988, 2004	0.97	±12.9	g/kg(OM)
Opuntia	FUL=0,632+191.10^{-5} TNMg/kg(OM)-188.10^{-8} CF /kg(OM)^2	INRA, 1978	0.882	± 0.06	kg(OM)
	PDIN = PDIA + PDIMN **PDIE = PDIA + PDIME**	INRA, 1988, 2004			kg(DM)
Atriplex	FUL= (0,84+ (0,00133 × TNMo)-(0,000832×CFo))	Jarrige, 1980			kg(DM)
	PDIN = PDIA + PDIMN **PDIE = PDIA + PDIME**	INRA, 1988, 2004			kg(DM)

For estimating the energetic value of barley straw, the approach primarily involved determining organic matter digestibility and chemical composition. The FUL values were calculated sequentially from estimates of gross energy, digestible energy, metabolizable energy, and net energy. For concentrates such as barley grain, FUL estimation relied solely on chemical composition.

For Opuntia , we used equations for green lucerne, given its crude fiber content of less than 20%. According to Bentlidja (1987) and Araba et al. (2009), the energy value of Opuntia is comparable to that of first-cut green lucerne. For Atriplex, we used the equation of Jerrige (1980) to calculate FUL value (See table 8).

Table 9: Nutritional Value (kg of Dry Matter)

	Barley Straw	**Barley Grain**	**Opuntia**	**Atriplex**
FUL	0.45 ± 0.04	1.08 ± 0.09	0.63 ± 0.05	0.83 ±0.03
PDIN	27 ± 8	27 ± 8	38±10.8	120 ± 17
PDIE	49 ±6	96 ±2.5	64±2	98± 9
Retenue	27 ± 8	64± 8	38±10.8	98± 9

The nutritional values of each feed incorporated in this study are shown in table 9. For Opuntia, the nutritional values are as follows: 0.63 ± 0.05 forage units (FUL) per kg of dry matter (DM). According to the FAO (1989), this value falls within the range of 0.6 to 0.7 FUL/kg DM. CIHEAM (1990) reported an FUL value of 0.71. Additionally, Bencherchali et Houmani, 2017, reported a FUL value of 0,72. The values of PDIN and PDIE are 38±10.8 and 64±2 for Opuntia. These results are similar to those reported in a

number of previous works by Zirmi-Zembri and Kadi (2016) which were (39 -64) PDIN et (35 à 65) PDIE. Our result showed a slightly lower PDIN than previous studies which is not surprising given that the crude protein was lower in the cladodes on Opuntia (See table 7).

For Atriplex halimus, the nutritional values are as follows: 0.8344±0.03 forage units (FUL) per kg of dry matter (DM). Our results are comparable with those found by Benkuider (2018) who reported an energy value of Atriplex halimus at 0,85FUL. However, Le Houérou (2004) and Ouasseltia (1990) reported a feed unit (FUL) value for A.halimus of 0.56 UF/kg DM and 0.25 to 0.30 UF/kg DM, respectively; these values are significantly lower than our results. This might be due to the season when the Atriplex was collected. In our study, the Atriplex was collected during spring which is the same period as Benkuider (2018). The values of PDIN and PDIE are 120±17 and 98±9 respectively. The PDIN value reported in our study is closer to the results of PDIN in Atriplex halimus that was reported at 139.05 g/Kg in Benkuider (2018). Radjef, (2010) recorded a value of PDIN at 91,88 g/Kg.

A PDIE value of 98±9 of Atriplex was revealed in our study, which is close to the PDIE value obtained from A. halimus in winter (96,78), which also reports the highest value in spring (105.57) (Benkuider, 2018).

Barley Straw had FUL values of 0.45±0.04 FUL/kg DM. Our results are compatible with the result of Louacini (2014). Additionally, values of 27 ± 8 PDIN and 49 ±6 PDIE were recorded for barley straw. Our results are slightly higher but closer to the values reported by INRA (2010), which recorded 24 PDIN and 46 PDIE.

Barley grain had 1.08±0.09 FUL/kg DM. This result concurs with the results of Louacini (2014). For the value of PDIN, barley grain recorded 27 ± 8 and 96 ±2.5PDIE.

III.1.3. Conclusion

Significant differences between the various plants were shown by the chemical composition analysis of the experimental feed. Opuntia has a distinct nutritional profile because to its high ash, calcium, and low dry matter content, especially when compared to barley grain, straw, and Atriplex halimus. Even while Opuntia had less crude protein than Atriplex, its digestible nutrients and forage units (FUL) make it a good substitute for other fodder sources for animals, particularly in areas with limited water supplies. These results highlight Opuntia 's potential as a beneficial supplement to animal diets, especially when combined with higher-protein feeds such as Atriplex. Additionally, Atriplex's greater protein concentration makes it a useful supplement for ruminant systems' diet balancing. The significance of region-specific feed methods is underscored by these findings, which also call for more research into their combined application for the best possible animal nutrition.

III.2. Experiment 2: Ingestibility and Digestibility

III.2.1. Choice of the Diets

Following up on Louacini (2014), the proposed diets were not isoenergetic or isonitrogenous and did not meet the criteria for a balanced ration (Table 4). The aim of this study was to explore an alternative feeding strategy to the traditional system, which typically relies on barley grain and straw. This research was conducted under conditions

of scarcity exacerbated by the ongoing conflict between Russia and Ukraine, which has disrupted the global barley supply and affected its availability for animal feed, further intensifying pressure on food resources for human consumption. Moreover, if we had proposed a diet consisting entirely of Barley straw (diet 7), Atriplex halimus (Diet 8) or Opuntia cladodes (diet 9), it would undoubtedly have been unbalanced. However, in order to calculate the differential digestibilities of Opuntia, Atriplex and straw, it was necessary to set up diets containing 100% straw, 100% Atriplex and 100% Opuntia, which would clarify the effect of the addition of Atriplex and Opuntia in the different diets studied. In addition, it would make it possible to evaluate and clarify the following question: is the incorporation of Atripex and Opuntia in proportions of 25, 50 and 75% in the diets studied capable of causing digestive disorders?

Table 10: *Quantity of dry matter distributed and consumed (g/animal/day). Chemical composition by diet.*

	Rationed Feed								
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**
Barley Straw	1414,2	ad libitum	ad libitum	ad libitum	ad libitum	ad libitum	1660,32 (100%)	(0%)	(0%)
Barley Grain	461,5	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)	(0%)
Opuntia	(0%)	804,65 (100%)	603,49 (75%)	402,32 (50%)	201,16 (25%)	(0%)	(0%)	(0%)	804,65 (100%)
Atriplex	(0%)	(0%)	275,21g (25%)	551,59 (50%)	827,38 (75%)	1103,18 (100%)	(0%)	1103,18 (100%)	(0%)
Total DM distributed	1875.70	804,65	878.70	953.91	1028.54	1103,18	1660,32	1103,18	804,65
	Ingested Ration								
Total Ingested DM	1078,81±88,95	1069,09±100,86	1083,21±98,97	1146,33±106,08	1129,78±103,10	949,16±36,73	729,95±36,67	655,56±34,58	582,28±20,51
OM	1030,80±84,99	908,73±85,73	899,06±82,15	951,46±88,04	937,73±85,58	835,27±32,31	686,16±34,45	524,45±27,66	436,71±15,38
CF	291,28±24,01	331,31±31,05	314,14±28,70	332,44±30,76	327,64±29,90	351,19±13,59	350,38±17,59	177,00±9,33	75,70±2,66
CP	64,73±5,33	42,76±4,03	75,82±6,92	80,24±7,42	79,08±7,21	75,93±2,93	21,90±1,09	85,22±4,49	17,47±0,60

III.2.2. Ingestibility

Concerning DM, diet 4 had the highest total ingested DM (1146.33 g), followed by diet 5 with a record of 1129,78±103,10, then diet 3 and 2. The control (Diet 1) performed well (1078.81 g), though lower than the experimental diets 4 and 5, emphasizing that diversity in forage may enhance nutrient intake. Diets 7 (barley straw only), 8 (Atriplex only), and 9 (Opuntia only) showed the lowest total DM intake, suggesting that monotonic diets are less preferred or less digestible. Total ingested DM in diet 6 decreased slightly compared to the control group. Louacini (2014) that did not find a positive correlation between Opuntia intake and increased straw consumption. However, Bensalem et al. (1996) reported that combining Opuntia and straw increased straw intake. In our study, the results show that combining Opuntia and Atriplex with straw increase the total ingested DM of the diet as in diets 3, 4, and 5.

For the OM, the control diet (1030.80 g OM) outperformed all experimental diets except Diet 4, suggesting barley grain and straw provide a high OM intake. Diets 8 and 9 (monotonic Atriplex and Opuntia) showed significant OM reductions, aligning with the lower total DM intake in these diets. Diet 6, rich in atriplex, showed the highest CF ingestion (351.19 g), emphasizing its contribution to dietary fiber. Monotonic diets (Diet 9: Opuntia and Diet 8: Atriplex) recorded significantly lower CF values, particularly Opuntia -only (75.70 g), highlighting limited fiber contribution. Atriplex-based diets (Diets 4-6) consistently showed higher CP ingestion, with Diet 8 reaching 85.22 g, showcasing Atriplex's protein-rich profile. Monotonic barley straw (Diet 7) and Opuntia (Diet 9) diets had minimal CP values (21.90 g and 17.47 g, respectively), unsuitable for high-protein dietary needs.

Mixed diets, particularly Diet 4, showed the highest DM and OM intake. This is consistent with research emphasizing the benefits of combining *Opuntia ficus-indica* with *Atriplex*, which provides a balance between energy, protein, and digestibility (Ben Salem et al., 2002).

III.2.3 Digestibility

Table 11. shows the results of the *in vivo* digestibility of the dry matter (DM), organic matter (OM), crude fiber (CF) and crude protein (CP).

Tableau 11: *Digestibility of various constituents expressed as a percentage of dry matter (DM), n=8 (diets in cross over D1 vs D5; D2 vs D4; D3 vs D6) and n=4 (diets 7, 8 & 9)*

Diet	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
D(DM)	70,75±3,52^{d}	53,78±2,54^{b}	71,44±1,58^{d}	72,37±1,84^{d}	64,12±3,41^{c}	55,16±1,88^{b}	44,51±1,74^{a}	42,68±1,69^{a}	62,48±2,01^{c}
D(OM)	72,45±3,11^{e}	56,30±3,44^{b}	67,47±8,19^{d}	74,27±2,54^{e}	66,34±3,05^{cd}	62,10±1,65^{c}	52,35±1,58^{b}	46,92±2,28^{a}	62,61±2,03^{c}
D(CF)	60.99±7,96^{d}	51,10±6,36^{c}	69,38±4,66^{e}	72,87±6,69^{e}	62,17±3,73^{d}	49,80±3,64^{bc}	44,67±1,83^{b}	33,68±0,73^{a}	82,64±1,27^{f}
D(CP)	79,96±5,31^{e}	64,38±5,15^{c}	89,06±2,55^{f}	89,06±1,19^{f}	85,33±1,80^{f}	49,18±1,58^{b}	45,26±2,49^{a}	50,86±1,46^{b}	69,48±4,77^{d}

III.2.3.1. Determination of the Digestibility of the DM

Based on our results, we observed an improvement in dry matter digestibility (DDM) for all diets compared to a diet consisting solely of straw (diet 7) and compared to a diet consisting solely of Atriplex (diet 8). Diet 1 (control), a conventional sheep ration, exhibited a higher DDM (70.75 ± 3.52) than diets 2, 5, 6 and 9 (straw + Opuntia), (straw + Atriplex + Opuntia), (straw + Atriplex and (Opuntia solely). Lower digestibility of dry matter (DDM) in diet 9 can be attributed to an insufficient fiber intake. Despite this, the digestibility of of the DM of the control group D1 was not significantly different from the D (DM) reported in the diets 3 and 4, but it showed significant difference from the diets 2, 5, 6, 7, 8 and 9.

Diet 1, a conventional ration for sheep, exhibited good digestibility of its components. Indeed, Jarrige (1988) reported that the addition of concentrates to a ration improves its digestibility (Louacini, 2014). Compared to diets solely based on straw or Atriplex, the dry matter digestibility (DDM) of D1, D3, D4 and D5 increased significantly and by approximately: 27, 28, 29, and 21 points, respectively (Table 11). Consequently, the inclusion of Opuntia and Atriplex enhanced DDM, particularly in diets 3 and 4. The work of Degu and Solomon (2009) in Ethiopia and Abidi et al. (2009) in Tunisia found an in vivo digestibility of 60-65% for dry matter in diets composed of Opuntia and cereal straw. Our results align with these previous findings.

Findings from previous research show that Atriplex can have a detrimental impact on digestibility (Salem et al. 2010). Other studies, however, indicate that Atriplex had no influence on the digestibility of the nutrient (Al-Owaimer et al. 2008, 2011). The current study's findings showed that DM was more digestible in diets 3 and 4, but less digestible

in diet 5 compared to the control group which may be explained by the nutritional differences between barley straw, Opuntia and Atriplex. Our findings also concur with Ben Salem et al (2010) that Atriplex impact the DM digestibility negatively as shown in diet 8 which showed the least digestibility of dry matter.

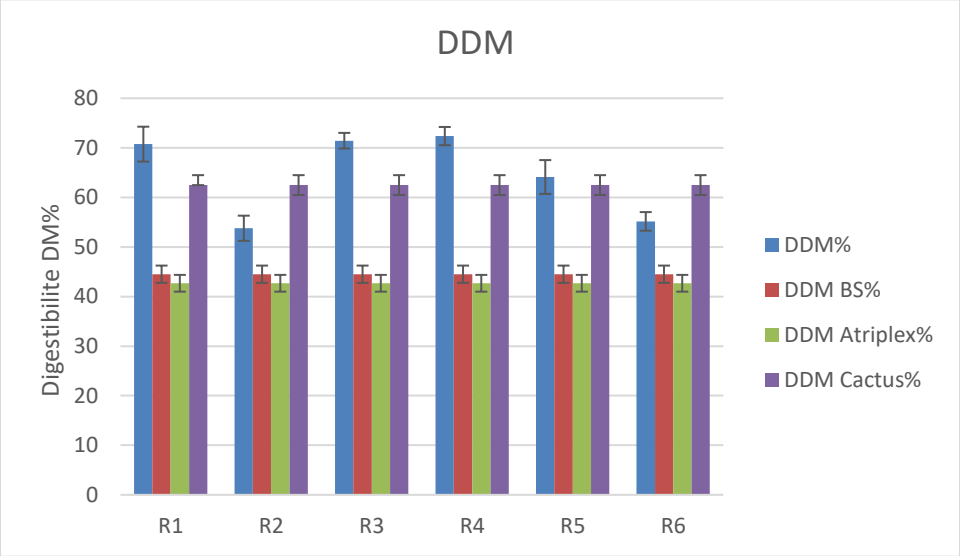


Figure 30: Digestibility of Dry Matter compared with Diets 7, 8 and 9.

III.2.3.2 Determination of the Digestibility of the OM

Similar to dry matter (DM), the organic matter digestibility (DOM) of Diet 4 (straw + Opuntia + Atriplex) improved to almost 75%, compared to the control group D1 (72.45 ± 3.11), but the difference was not significant. Similarly, organic matter (OM) digestibility was significantly higher in diets, D3 (67.47 ± 8.19) D5 (66.34 ± 3.05), D6 (62.10 ± 1.65), and D9 (62.61 ± 2.03) compared to diets D2 (54.88 ± 3.49), D7 (52.35 ± 1.58). D8 was significantly lower than all recorded D (OM) of all diets with a result: 46.92 ± 2.28. Our results concur with those of Chehma et al. (2003) who found an in vivo D (OM) of barley straw to be around 53.46%, an increase of 10 points compared to the INRA (1988) value of straw at 40%. Compared to the digestibility of organic matter in

diet 7 (solely straw) and diet 8 (solely Atriplex), D1, D3, D4 and D5 increased by 23, 18, 25 and 17 points, respectively. Our DOM results are similar to those of Chehma et al. (2003) when it comes to barley straw only diet. However, the work of H. Yakhlef and S. Triki (2007) showed that the in vivo OMD reached values of 54.4% and 62.4% for baled or pre-chopped straw, compared to 48.3% for untreated straw. Our results are consistent with these previous findings.

Our results also show that the organic matter digestibility decreased significantly in diet 3 and 5 (Opuntia + Atriplex +Straw) compared to the control group. This might be attributed to the incorporation of Atriplex in diet 3 and its high amount in diet 5.

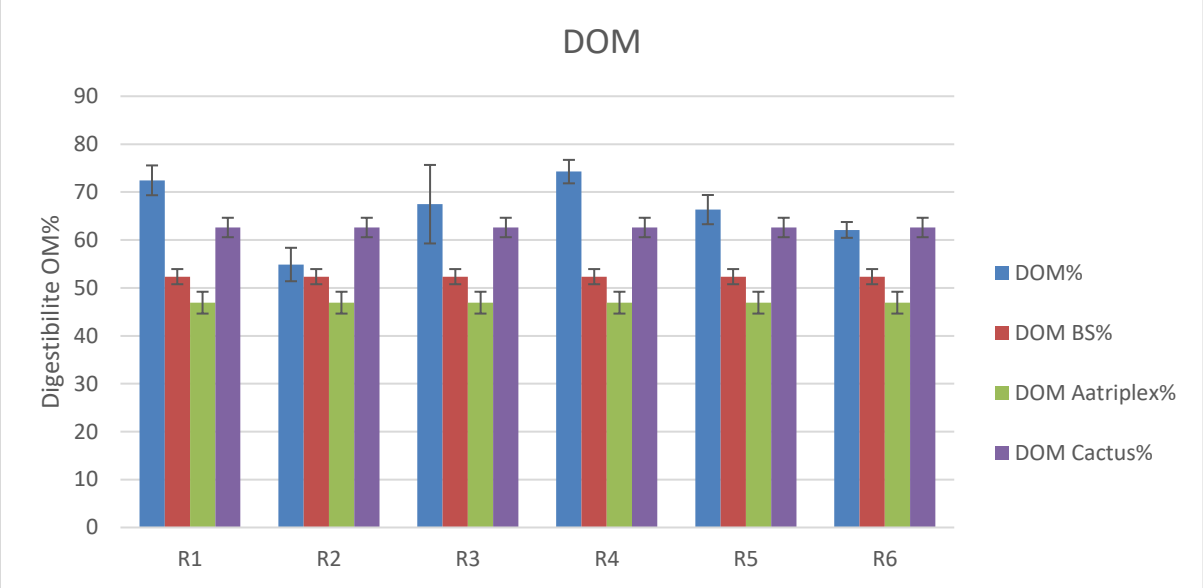


Figure 31: Digestibility of Organic Matter compared with Diets 7, 8 and 9.

III.2.3.3 Determination of the Digestibility of the CF

Crude fiber (CF) digestibility increased significantly in diets D3 (69.38 ± 4.66), D4 (72.87 ± 6.69) compared to D1 (60.99 ± 7.96). The digestibility of crude fiber also increased slightly in D5 but the difference was not significant (62.17 ± 3.73) compared to D1. Atriplex-based diet D8 (33.68 ± 0.73) and the straw-based diet D7 (44.67 ± 1.83)

showed the lowest CF digestibility and were significantly different from D1. Additionally, CF digestibility in diet 2 and 6 were significantly lower than the result recorded in D1. D9 recorded: 82.64 ± 1.27. Similar to Louacini (2015), one can explain that the low crude fiber (CF) digestibility of diet 2 can be attributed to the increased intake of Opuntia in the ration, which may have a depressive effect on cellulolytic rumen bacteria due to its high soluble carbohydrate content (Abidi et al., 2009). These results also highlight the protective effect of the lignocellulosic fraction, specifically crude fiber, on the degradation of organic matter (Louacini, 2014). Degu and Solomon (2009) in Ethiopia and Abidi et al. (2009) in Tunisia found an in vivo digestibility of 40-50% for CF in diets based on Opuntia and cereal straw. Additionally, when the level of Opuntia ficus indica inerme increases in the ration, the concentration of volatile fatty acids, the number of protozoa, and the concentration of ammonia in the rumen increase. Al-Owaimer et al found that the digestibility of crude fiber was significantly lower with diet containing Atriplex without date pits than control diet or diets containing Atriplex with date pits as energy source for Nejdi lambs. Our results are similar to these previous findings. In that, the digestibility of crude fiber in diets containing Atriplex without Opuntia (D6) were lower than control diet (D1) or diets containing Atriplex with Opuntia (D3, D4 and D5).

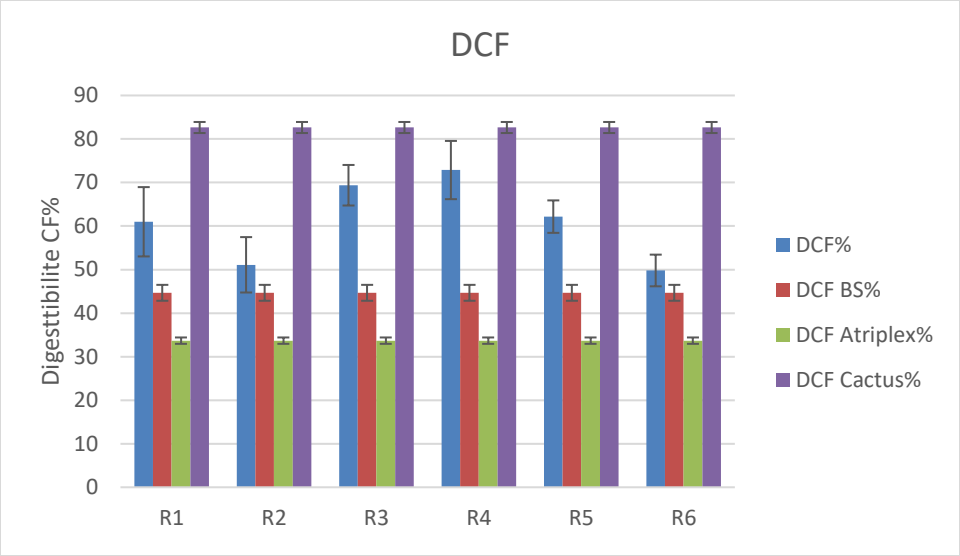


Figure 32: Digestibility of Crude Fiber compared with Diets 7, 8 and 9.

III.2.3.4 Determination of the Digestibility of the CP

In terms of the digestibility of crude protein (CP), our results shown that D3 (89.06 ± 2.55), D4 (89.06 ± 1.19), D5 (85.33 ± 1.80) were significantly higher than crude protein digestibility in diet of the control group D1 (79.96 ± 5.32). The increased CP digestibility of Diets 1, 3, 4 and 5 can be explained by the better availability of energy provided by barley grain in Diet 1, the inclusion of Opuntia in diet 2 (Louacini, 2014), the interaction between Atriplex and Opuntia in diet 3 and 5. Additionally, because of the high solubility of N in the Atriplex, which raises the digestible CP in the rumen, adding Atriplex might explain the improved the digestibility of protein in diet 3 and 5 (Salem et al. 2010; Aljamal et al. 2021).

Overall, Nobel (1988) and Nefzaoui et al. (1996) showed that in diets based on straw and Opuntia , in vivo crude protein digestibility ranged from 35 to 70%. Our results are within this range were D2 recorded a digestibility value for CP (64.38 ± 5.15). The

CP digestibility values were significantly lower in diets D6 (49.18 ± 1.58), D7 (45.26 ± 2.49), and D8 (50.86 ± 1.46).

As for diet 9, it recoded a value of CP digestibility as (69.48 ± 4.77) and although Diet 9 was highly digestible for all its studied components compared to D7 and D8 (Straw alone and Atriplex alone), it could not constitute a complete ration. It exhibited limitations such as weight loss and very rapid digestive transit due to its higher water content. A laxative effect appeared when the volume of cactus in the ration exceeded 60% of DM (Louacini, 2014). This problem can be easily resolved by introducing amounts of straw and Atriplex as evidenced in diet 3, 4 and 5.

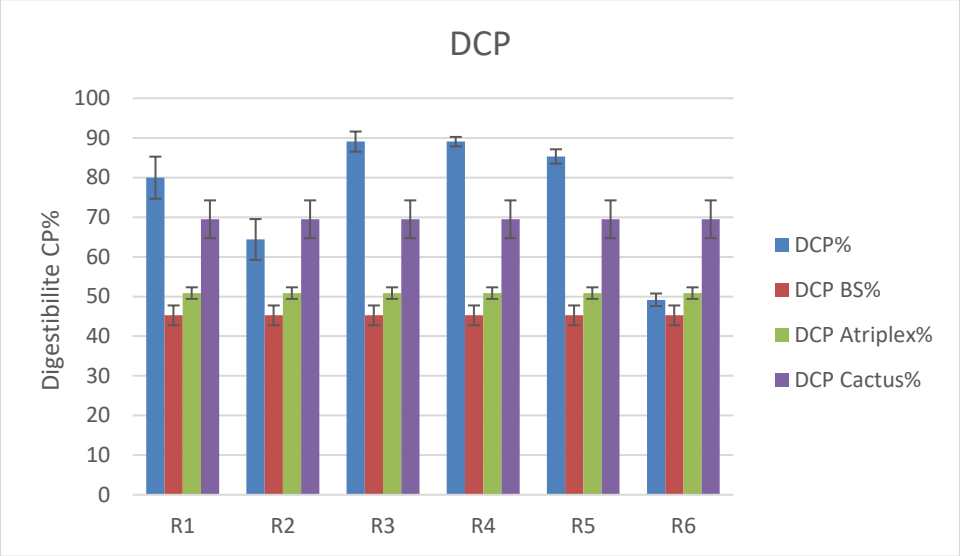


Figure 33: Digestibility of Crude Protein compared with Diets 7, 8 and 9.

III.3. Experiment 3: Feeding Level, Feed Intake and Average Daily Gain (ADG)

III.3.1. Calculation of Feeding Level

The feeding level was caculated based on the MODI (Digestible Organic Matter Ingested in g /kg $P^{0.75}$).

The energy feed level was calculated using the following formula: Amount of MODI (g/kg $P^{0.75}$) / 26. The value 26 represents the quantity of digestible organic matter (DOM) required per kilogram of metabolic weight ($P^{0.75}$) to cover the maintenance energy requirements of the breeding ewe.

Nitrogen feed level: quantity of PDI (g/ kg of $P^{0.75}$) /2.64. 2.64 being the quantity of PDI required to cover the ewe's maintenance needs.

The quantities of FUL and PDI provided by the ration are calculated as follows:

Maintenance requirements in FUL = $P^{0.75}$ x 0.033FUL

Maintenance requirements in g PDI = $P^{0.75}$ x2.64

Total FUL ingested = $P^{0.75}$ x 0.033FULxFL

Total PDI ingested in g = $P^{0.75}$ x2.64 x FL

FUL available for production = ($P^{0.75}$ x 0.033FULxFL) - ($P^{0.75}$ x 0.033FUL)

PDI available for production = ($P^{0.75}$ x2.64 x FL) - ($P^{0.75}$ x2.64)

For MODI = total OM ingested x D (OM)

FL of energy = MODI g/kg $p^{0.75}$ / 26

FL of nitrogene = PDI g/kg $p^{0.75}$ /2.64

Diet	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
P0.75	22.06±0.69	20,06±0,46	22.26±0.70	22.61±0.96	22.40±0.65	19.94±0.58	16.97±0.51	16.61±0.35	16.24±0.29
MR in FUL	0.72	0.66	0.73	0.74	0.73	0.65	0.56	0.54	0.53
intake DM	1078.81±88.95	1069.09±100,86	1083.21±98,97	1146,33±106,08	1129,78±103,10	949,16±36,73	729,95±36,67	655,56±34,58	582,28±20,51
intake OM	1030.80±84.99	909.73±85,73	899,06±82,15	951,46±88,04	937,73±85,58	835,27±32,31	686,16±34,45	524,45±27,66	436,71±15,38
DOM	72,45±3,11	54,88±3,49	67,47±8,19	74,27±2,54	66,34±3,05	62,10±1,65	52,35±1,58	46,92±2,28	62,61±2,03
MODIg / P0.75	35.38	24.86	27.27	31.23	27.77	26.04	21.16	14.80	16.84
energy FL = MODI / 26	1.30±0.15^{d}	0.98±0.11^{c}	1.05±0.21^{c}	1.21±0.14^{d}	1.06±0.09^{c}	0.99±0.05^{c}	0.78±0.05^{b}	0.56±0.06^{a}	0.64±0.04^{ab}
MR in PDI	58.2384	52.9584	58.2384	59.6904	59.136	52.6416	44.8008	43.8504	42.8736
Ingested TNM	65	43	76	80	79	76	22	85	17
DTNM	79,96±5,31	64,38±5,15	89,06±2,55	89,06±1,19	85,33±1,80	49,18±1,58	45,26±2,49	50,86±1,46	69,48±4,77
Ingested PDI	51.97	27.68	67.68	71.24	67.41	37.37	9.95	43.23	11.81
Nitrogen FL	0.89±0.12^{d}	0.52±0.08^{b}	1.15±0.14^{e}	1.20±0.14^{e}	1.14±0.11^{e}	0.71±0.03^{c}	0.21±0.01^{a}	0.99±0.05^{d}	0.28±0.01^{a}
FUL TOTALES	0.99	0.63	1.20	0.89	0.78	0.65	0.45	0.31	0.18
FUL productions	0.26	-0.02	0.47	0.15	0.05	0.001	-0.10	-0.23	-0.34
theoretical ADG	Positive	negative	positive	Positive	Positive	positive	negative	Negative	negative
measured ADG	78.51±16.98^{d}	33.88±4.04^{c}	81.19±14.42^{d}	104.19±9.59^{e}	89.09±9.08^{de}	26.11±11.87^{c}	-200.95±12.90^{a}	-180.25±39.77^{b}	-217.17±37.25^{a}
PDI TOTALES	51.97	14.47	77.95	85.04	76.84	26.53	10.05	42.62	3.25
PDI Production	-6.26	-38.48	19.72	25.35	17.70	-26.10	-33.79	-1.23	-39.61
theoretical ADG	negative	negative	positive	Positive	positive	Negative	negative	Negative	Negative
measured ADG	78.51±16.9	33.88±4.04^{c}	81.19±14.4	104.19±9.5	89.09±9.08^{d}	26.11±11.	-	-	-

	8[d]		2[d]	9[e]	[e]	87[c]	200.95±12.90[a]	180.25±39.77[b]	217.17±37.25[a]

A, b, c: Means with different letters in the same raw are significantly different (P<0.05)

Tableau 12: Feed Level, Dietary Intake, and Average Daily Gain

Monitoring of Live Weight Changes

Sheep were weighed fasted once a week throughout the trial to monitor changes in live weight and calculate average daily gain or loss.

III.3.2. Calculation of Gestation Requirements and Protein Digestible in the small Intestine (PDI)

Gestation requirements in FUL were calculated as follows: FUL = $P^{0.75}$ * 0.033. The factor 0.033 represents the quantity of FUL required per kilogram of metabolic weight to meet the gestation needs of an ewe.

Gestation requirements in PDI were calculated as follows: PDI = $P^{0.75}$ * 2.64. The factor 2.64 represents the quantity of PDI required per kilogram of metabolic weight to meet the gestation needs of an ewe.

The feeding level (FL) results allow for an assessment of whether this level is sufficient to meet the production requirements of the ewe. The dietary intakes enabled a comparison of the average daily gain (ADG) supported by the energy and nitrogen content of the ration.

III.3.2.1 Feeding Level: Control Group D1

The results of the feeding level for the control group are presented in the table above. R1 recorded an energy feeding level of 1.30 ± 0.15 and a nitrogen feeding level of 0.89± 0.12. This increase in FUL can be attributed to the high content of fermentable carbohydrates provided by barley grain (Louacini, 2014). Additionally, the control group diet (R1) recorded an average daily weight gain (ADG) of 78.51 g ± 16.98 g. On another hand, Jarrige (1980) asserts that the feeding level must equal 1 to satisfy maintenance requirements. However, from a nutritional perspective, there are no discrete maintenance

and production expenditures; these expenditures do not correspond to distinct metabolisms, making this maintenance condition challenging to achieve.

Our findings align with the reported ADG of 75g ± 22g in Louacini (2014), though our study focuses specifically on late-pregnancy ewes in an arid region. While both regimes meet maintenance requirements, the physiological demands of late pregnancy and the environmental constraints of aridity in our study highlight the additional challenges in ensuring nutritional adequacy compared to the cited conditions.

III.3.2.2 Feeding Level: D2

Diet 2 showed an energy feeding level of 0.98 ± 0.11, which is significantly lower than D1 and it also a surprising result given the increased proportion of water-soluble carbohydrates provided by Opuntia. This shows that the energetic concentration in barley grain in D1 is higher than that of Opuntia in this diet. Similarly, the nitrogen feeding level decreased significantly to approximately 0.52 ± 0.08 compared to D1. In this diet, we recorded a slight weight gain of 33.88±4.04. Since the feeding level of energy value is higher than nitrogen feeding level, it could be attributed to protein deficiency (Warren et al., 1990). Additionally, cereal straws such as barley straw are known for their low nutritive value and may restrict the DMI (Abu-Zanat & Tabbaa, 2005).

Degu and Solomon (2009) reported a weight gain of 20g using a diet of eragrostis straw and 172g of dry matter (DM) of Opuntia, whereas Tegegne et al. (2005) observed a weight loss of 27g on a diet of wheat straw and Opuntia, with each animal exhibiting its own unique average daily gain. Nefzaoui and Bensalem (1998) concluded that it is possible to meet maintenance energy requirements using diets based on Opuntia inerme with 300g of DM of straw. Louacini (2014) reported that the energy requirements of

maintenance were met for Rembi ewes on diet of Opuntia and barley straw. Our results fall within the range reported by Tegegne et al. (2005), Degu and Solomon (2009), and Nefzaoui and Bensalem (1998) and Louacini (2014) Although diet 2 did not yield a significant weight gain, it was able to meet maintenance energy requirements with 393 g of DM of straw and 425g of DM of Opuntia.

III.3.2.3 Feeding Level: D3, D4 and D5

Our results showed that the diets in treatment groups of D3, D4 and D5 are the most balanced diet in terms of energy and nitrogen, as shown by its energy feeding level: 1.05 ±0.22, 1.21 ±0.14, 1.06 ±0.09 respectively. For nitrogen feeding level, we recorded the following: 1.15±0.14, 1.20±0.14, 1.14±0.11 of R3, R4 and R5 respectively. The increase in protein is explained by the higher proportion of protein provided by the Atriplex in the ration. A measured ADG of around 81.19 g ±14.42g, 104.19 g ±9.59g and 89.09g ±9.08g for R3, R4 and R5 respectively. The increase in daily weight gain in diet 4 shows that it is the best optimal diet among the experimental groups and also compared to the control group.

The results of Tegegne et al. (2005) in Ethiopia showed a daily weight gain of 41.5g on a diet consisting of (untreated straw + Opuntia + wheat bran), while the results of Degu and Solomon (2009) showed a weight gain of 69g on a diet consisting of (eragrostis straw + 172g Opuntia and 145g cotton cake). Bensalem and Nefzaoui (1996) in Tunisia reported an average daily gain (ADG) of 55 g using a diet composed of 241 g of dry matter (DM) of Opuntia inerme, 308 g of DM of barley straw, 149 g of hay, and 8 g of urea. The results of Loucini (2014) results an ADG of approximately 93 g with a diet consisting of 485 g of DM of barley straw, 189 g of Opuntia , and 125 g of vetch. Our

results shows that diet 4 where the ewes gained 104.19 g (ADG) on a diet composed of (2750g cactus + 1300g Atriplex + barley straw ad libitum), followed by diet 5 with ADG of 86.09g on a diet composed of (Diet 5: 1375g cactus +1950g Atriplex + barley straw ad libitum), then diet 3 with an ADG of 81.19g with a diet composed of (4125g cactus + 650g Atriplex+ barley straw ad libitum).

III.3.2.4 Feeding Level: D6

D6 showed an energy feed level of 0.99± 0.05, which is not surprising given the increased proportion of protein provided by the Atriplex plant. Similarly, the nitrogen feeding level decreased significantly to approximately 0.71 ± 0.03, compared to D1. In this diet, we recorded a low weight gain with a slight increase of 26.11 g ± 11.87, but this was significantly lower than the weight gained in the control group. This goes to show that this diet rich in Atriplex almost covers the energy requirements of gestation, like diet 2. However, the control group diet 1 is still higher in terms of energy feed level, hence better cover the energy requirements of ewes in gestation. The ADG has tripled in diet 1 compared to diet 6. However, the decent level of CP in this rich Atriplex diet might have been enough to maintain the animals' requirements and keep a slight gain of weight (Freer et al., 1997).

III.3.2.5 Feeding Level: D7, D8 & D9

Our results showed that the diets of groups D7, D8, and D9 were the least balanced in terms of energy feeding level (EFL) and nitrogen feeding level (NFL), as demonstrated by their EFL values: 0.78 ± 0.05, 0.56± 0.06, 0.64± 0.04, respectively. For the nitrogen feeling level, we recorded the following values: 0.21 ± 0.01, 0.99 ± 0.05, 0.28 ± 0.01 for D7, D8, and D9, respectively. The increase in NFL in D8 can be

explained by the higher proportion of protein provided by Atriplex in the ration. A weight loss was measured in ewes fed these diets: -200.95 g ± 12.90 g, -180.25 g ± 39.77 g, -217.17 g ± 37.25 g for D7, D8, and D9, respectively.

Terblanche et al. (1971) investigated the impact of an exclusively Opuntia -based diet on Merino sheep weight loss and recorded a weight decrease of 620g per animal per week with a 10% dry matter (DM) inclusion rate. The findings from Louacini (2014) demonstrated the most significant weight loss with a 9.45% DM inclusion of Opuntia, which, along with the laxative effect, was likely due to an inadequate energy-to-protein ratio (Santana 1992). Nonetheless, the inclusion of Opuntia in a ration improves digestibility and can increase hay intake (Bensalem and Nefzaoui 1996). Conversely, its water content can be considered a positive factor as it helps to address water scarcity in arid regions. A diet containing 300g DM of Opuntia eliminates the need for additional water (Nefzaoui and Bensalem 1998). It is important to note that Louacini (2014) and our study were conducted in a specific arid context where the priority was to alleviate severe feed shortages.

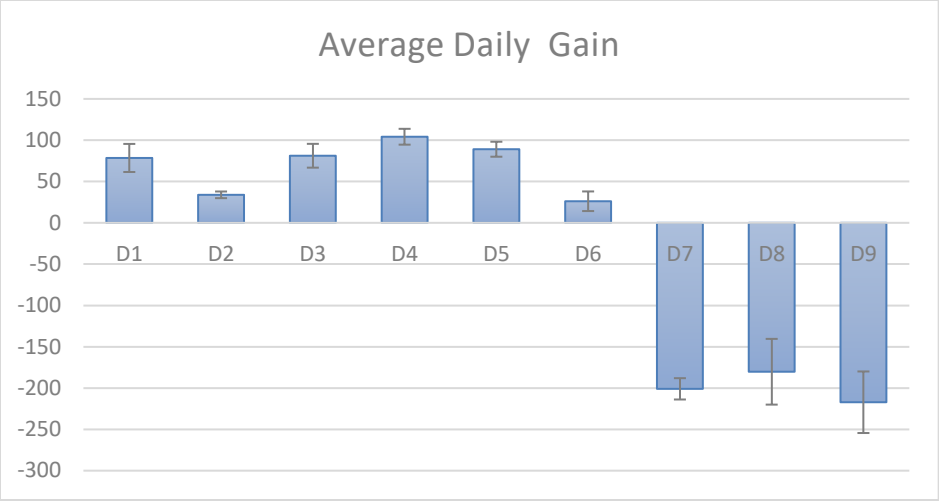


Figure 34: Average Daily Gain in g per diet.

III.3.3. Conclusion

Diet 4 demonstrated the highest effectiveness among the experimental groups, with an ADG of 104.19 g ± 9.59 g, surpassing both the control group (D1) and all other diets. Its superior performance can be attributed to the optimal balance of energy (1.21 ± 0.14) and nitrogen feeding levels (1.20 ± 0.14), driven by the inclusion of 2750 g cactus, 1300 g Atriplex, and ad libitum barley straw. Compared to the control diet, which achieved an ADG of 78.51 g ± 16.99 g with a high energy feeding level of 1.30 ± 0.15, Diet 4 offered a more balanced nutritional profile that better addressed the demands of late pregnancy. In contrast, diets with lower energy FL and nitrogen FL (e.g., Diet 2 and Diet 6) struggled to meet energy requirements, leading to minimal weight gain, emphasizing the critical role of a well-balanced ration such as Diet 4 in arid conditions.

III.4. Experiment 4: The Influence of Experimental Feed of Cladode and Atriplex on Blood Biochemical Parameters of Ewes

Table 13 shows blood parameters before and after introducing the experimental feeds.

Table 13: Blood metabolites Concentration for Ewes fed Cactus and Atriplex**.**

		D1	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**
Glu	Before	0.51^{+}-0.01^{a}	0.54^{+}-0.03^{a}	0.54+-0.04^{a}	0.52+-0.03^{a}	0.53+-0.03^{a}	0.55+-0.03^{a}	0.55+-0.05^{a}	0.53+-0.03^{a}	0.55+-0.05^{a}
	After	0.42^{+}-0.02^{b}	0.45^{+}-0.04^{b}	0.42^{+}-0.05^{b}	0.44^{+}-0.05^{b}	0.43^{+}-0.06^{b}	0.44^{+}-0.04^{b}	0.44^{+}-0.05^{b}	0.37^{+}-0.03^{c}	0.53^{+}-0.05^{a}
TC	Before	0.73^{+}-0.08^{a}	0.83^{+}-0.13^{a}	0.62^{+}-0.06^{a}	0.71^{+}-0.13^{a}	0.73^{+}-0.07^{a}	0.74^{+}-0.17^{a}	0.69^{+}-0.09^{a}	0.59^{+}-0.11^{a}	0.74^{+}-0.12^{a}
	After	0.67^{+}-0.15^{a}	0.70^{+}-0.13^{a}	0.60^{+}-0.08^{b}	0.61^{+}-0.10^{b}	0.63^{+}-0.13^{a}	0.73^{+}-0.13^{a}	0.39^{+}-0.05^{b}	0.91^{+}-0.08^{a}	0.20^{+}-0.08^{c}
TG	Before	0.30^{+}-0.73^{a}	0.32^{+}-0.75^{a}	0.29^{+}-0.79^{a}	0.30^{+}-0.78^{a}	0.32^{+}-0.92^{a}	0.30^{+}-0.79^{a}	0.35^{+}-0.85^{a}	0.35^{+}-0.83^{a}	0.34^{+}-0.38^{a}
	After	0.30^{+}-0.08^{b}	0.10^{+}-0.02^{c}	0.08^{+}-0.02^{c}	0.13^{+}-0.03^{c}	0.13^{+}-0.02^{c}	0.27^{+}-0.03^{b}	0.14^{+}-0.04^{c}	0.75^{+}-0.04^{a}	0.03^{+}-0.01^{c}
AL	Before	34.33^{+}-2.98^{a}	33.21^{+}-4.33^{a}	32.01^{+}-5.11^{a}	32.35^{+}-4.64^{a}	33.10^{+}-3.62^{a}	33.58^{+}-3.35^{a}	34.57+-3.56^{a}	31.07^{+}-3.12^{a}	34.57^{+}-3.56^{a}
	After	32.62^{+}-4.07^{b}	25.07^{+}-5.21^{c}	31.15^{+}-5.61^{b}	30.83^{+}-5.18^{b}	32.12^{+}-4.49^{b}	35.76^{+}-4.27^{b}	20.17^{+}-1.12^{c}	56.25^{+}-5.42^{a}	16.85^{+}-3.62^{c}
TP	Before	67.87^{+}-	76.8^{+}-	68.15^{+}-	70.3^{+}-	68.47^{+}-	72.32^{+}-	78.75^{+}-	70.02^{+}-	78.12^{+}-

		5.86^{a}	8.79^{a}	5.5^{a}	8.35^{a}	5.53^{a}	8.77^{a}	7.22^{a}	7.31^{a}	5.84^{a}
	After	64.36^{+}-5.82^{b}	70.23^{+}-7.97^{a}	65.20^{+}-3.93^{b}	69.18^{+}-6.70^{b}	66.50^{+}-6.05^{b}	80.65^{+}-8.11^{ab}	63.85^{+}-10.63^{b}	86.85^{+}-4.38^{a}	52.57^{+}-1.43^{b}
Urea	Before	0.35^{+}-0.06^{a}	0.35^{+}-0.06^{a}	0.35^{+}-0.06^{a}	0.35^{+}-0.05^{a}	0.35^{+}-0.05^{a}	0.35^{+}-0.05^{a}	0.37^{+}-0.06^{a}	0.35^{+}-0.07^{a}	0.37^{+}-0.05^{a}
	After	0.34^{+}-0.07^{a}	0.17^{+}-0.03^{ab}	0.27^{+}-0.10^{a}	0.30^{+}-0.06^{a}	0.28^{+}-0.08^{a}	0.26^{+}-0.09^{a}	0.28^{+}-0.08^{a}	0.15^{+}-0.02^{ab}	0.04^{+}-0.03^{b}
Crea	Before	11.97^{+}-1.13^{a}	11.45^{+}-2.25^{a}	10.30^{+}-2.02^{a}	10.09^{+}-2.44^{a}	10.31^{+}-2.44^{a}	9.65^{+}-1.72^{a}	12.42^{+}-2.41^{a}	11.08^{+}-1.48^{a}	10.65^{+}-2.49^{a}
	After	11.15^{+}-1.83^{ab}	13.10^{+}-2.56^{a}	11.33^{+}-1.86^{a}	11.83^{+}-2.31^{a}	11.48^{+}-1.94^{a}	11.02^{+}-2.40^{ab}	6.22^{+}-0.79^{b}	5.20^{+}-0.86^{b}	5.09^{+}-1.42^{b}
AST	Before	88.25^{+}-11.04^{a}	101^{+}-12.36^{a}	71.12^{+}-18.37^{a}	79.39^{+}-17.98^{a}	74^{+}-17.09^{a}	85.37^{+}-17.47^{a}	74.5^{+}-10.40^{a}	77^{+}-11.16^{a}	78^{+}-13.68^{a}
	After	78.62^{+}-7.28^{bc}	70.5^{+}-7.46^{bc}	75^{+}-15.74^{bc}	77.62^{+}-2.32^{bc}	102.37^{+}-8.80^{b}	134.5^{+}-30.31^{ab}	53.5^{+}-5.32^{c}	172^{+}-14^{a}	42.75^{+}-6.02^{c}
ALT	Before	10.62^{+}-3.24^{a}	11.37^{+}-3.7^{a}	8.75^{+}-2.12^{a}	12.62^{+}-7.2^{a}	9.62^{+}-2.66^{a}	9.12^{+}-2.85^{a}	9.5^{+}-2.08^{a}	11^{+}-2.16^{a}	10.5^{+}-1.29^{a}
	After	10.37^{+}-2.72^{b}	7.62^{+}-2.82^{b}	9.62^{+}-3.24^{b}	12.37^{+}-6.13^{b}	13.75^{+}-4.83^{ab}	13.87^{+}-4.29^{ab}	5.5^{+}-1.29^{b}	23.25^{+}-3.3^{a}	4^{+}-0.81^{b}
Ca	Before	104.12^{+}-6.17^{a}	96.96^{+}-12.47^{a}	94.86^{+}-10.44^{a}	102.67^{+}-12.10^{a}	95.26^{+}-15.45^{a}	93.63^{+}-12.60a	95.2^{+}-13.77^{a}	103.75^{+}-12.81^{a}	97.22^{+}-19.66^{a}
	After	100.15^{+}-	98.21^{+}-12.3^{ab}	93.93^{+}-14.43^{ab}	103.07^{+}-12.58^{a}	502.02^{+}-6.12^{a}	105.12^{+}-8.65^{a}	63.17^{+}-4.91^{b}	74.2^{+}-11.03^{b}	61.2^{+}-5.63^{b}

		10.59^{ab}								
P	Before	73.75^{+}-16.17^{a}	76.68^{+}-18.38^{a}	75.38^{+}-14.69^{a}	76.89^{+}-15.15^{a}	73.98^{+}-15.70^{a}	65.50^{+}-12.21^{a}	60.06^{+}-11.60^{a}	69^{+}-10.31^{a}	61.26^{+}-15.09^{a}
	After	70.69^{+}-15.26^{ab}	71.92^{+}-12.66^{ab}	78.21^{+}-18.43^{a}	75.36^{+}-13.44^{ab}	68.93^{+}-16.39^{ab}	63.69^{+}-12.46^{ab}	42.15^{+}-7.05^{b}	34.38^{+}-9.29^{b}	28.42^{+}-4.5^{b}

A, b, c: Means with different letters in the same raw are significantly different ($P<0.05$). Serum glucose (Glu), total cholesterol (TC), total protein (TP), triglyceride (TG), urea, creatinine (Crea), albumin (AL), Aspartate aminotransferase (AST), Alanine aminotransferase (ALT), calcium (Ca), phosphorus (P)

III.4.1 Blood Parameters of Energy Metabolism

The blood parameters of all the experimental groups' sheep are displayed in Table 13. The glucose readings are within Haddad's (1981) stated range (0.4 and 0.7 g/l) prior to the introduction of experimental diets. This could be accounted for by the effect of the concentrate consumed prior to the trials. Blood glucose levels in diets D1, D2, D3, D4, D5, D6, and D7 exhibit a modest reduction following the addition of experimental meals, although they still stay within the range. However, the animals provided D8 showed a considerable decrease in their glucose levels, while the animals fed D9 showed no change in their glucose levels. According to previous studies, plasma glucose is a vital sign of ruminants' contentment with their energy requirements and offers a quick evaluation of animals exposed to various stressors (Louacini et al. 2012 ; Bennett et al. 2017; El-Gindy et al. 2021). Reduced blood glucose levels in ewes fed from D1 to D7; possibly because of the strain of altering diets and the condition of the animals during the latter half of gestation. As noted by Andrade-Cetto and Wiedenfeld (2011), higher levels of Opuntia

in D9 protected plasma glucose stability, which may be related to the medicinal properties of Opuntia plants and their capacity to improve glycaemic management by inhibiting the hepatic glucose output. Our findings align with those of Louacini et al. (2012), who found no change in blood glucose concentrations when feeding 100% Opuntia to non-pregnant Rembi ewes. Increasing amounts of research on feeding goats varying amounts of cactus have shown similar outcomes diets (Lopes et al. 2017; Ben Salem et al. 2019; Albuquerque et al. 2020; Ravari et al. 2022).

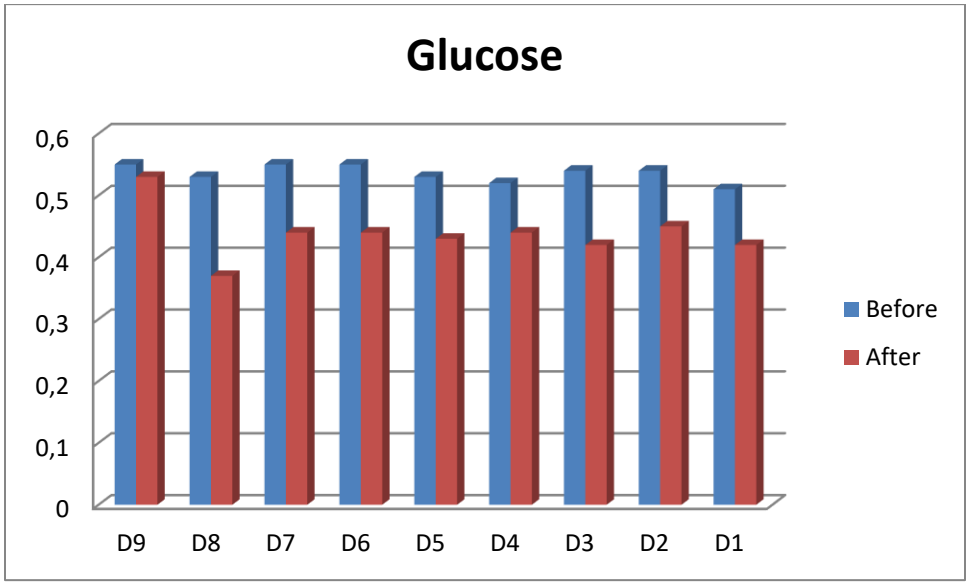


Figure 35: *Glucose before and after the introduction of experimental diets*

Furthermore, calves fed cactus cladodes at varying concentrations showed a comparable tendency (Inácio et al. 2020). The current outcome, however, is not the same as that of Cardoso et al. (2019), who found that feeding male Ines lambs with varying amounts of spineless cactus (Nopallea cochenillifera Salm Dyck) raised their blood glucose levels. El-Gindy et al. (2021) discovered that in Barki nursing sheep with low amounts of prickly pear cactus peels, blood glucose dramatically increased. Deldicque et al. (2013), who conducted their investigation on healthy male subjects, suggest that this

phenomenon may be attributed to the combination of leucine and the skin of the Opuntia ficus indica fruit, which accelerates the rate at which glucose emerges from the liver and intestine. Depending on the sampling time, different glucose concentrations have been recorded by other researchers. For instance, Rekik et al. (2010) found that in Barbarine ewes, plasma glucose levels rose two weeks prior to lambing and fell two weeks post the event. The variations in Opuntia concentrate, animal condition, and animal features can account for the variation in outcomes regarding sheep's plasma glucose in the reported research, including the present study.

The range was maintained by the glucose concentrations in D3, D4, D5, and D6 _containing Atriplex coupled with Opuntia and barley straw_. This outcome is consistent with that of Kewan (2021), who found that glucose concentrations were not impacted by feeding Barki sheep fresh Atriplex or silage Atriplex mixed with barley grain. Similar to this, other studies revealed that adding Atriplex with various concentrates—Opuntia , barley grain, and barley straw—did not alter plasma glucose levels in the diets of lambs and ewes (Otal et al. 2010; Alhanafi et al. 2019). Our findings, however, conflict with other research (Shawket et al. 2015; El-Saadany et al. 2016), which found higher levels of sanguine hyperglycemia in Barki sheep given Atriplex plants as opposed to those fed Barseem hay or control diets. However, in D8 (100% Atriplex diet), plasma glucose dropped significantly to 0.37 g/l. This might be attributed to a number of factors, including the fact that the ewes were in a late stage of pregnancy and in desperate need of high-energy feed; also, the Atriplex plant is a high-protein, low-energy feed.

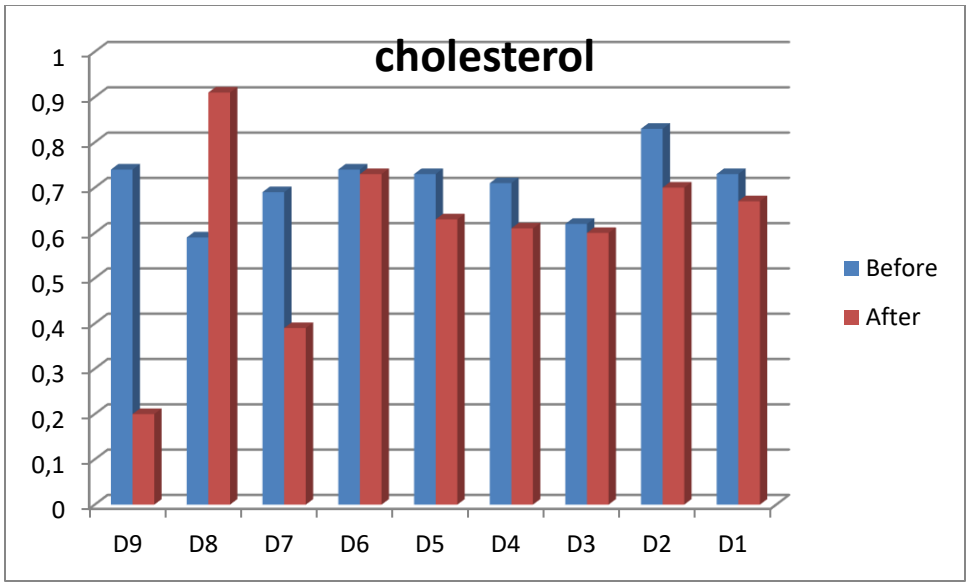


Figure 36: *Cholesterol before and after the introduction of experimental diets*

Before adding experimental feed, the amounts of triglycerides and cholesterol in the control and experimental groups fall within the reference range for sheep, which is (0.2-0.4 g/l) and (0.52-0.76 g/L), respectively, according to Brugere Picoux (2002). Following feedings of D1 (control), D2, D3, D4, D5, and D6, the serum cholesterol readings stayed within the range. However, animals in D7 and D9 showed a substantial ($P<0.05$) decline in mean values of 0.39 and 0.20 g/l, respectively (Table 2), but in D8, there was an insignificant increase (0.91 g/l). After implementing the experimental meals, the triglyceride levels in the D6 and D1 control groups were unchanged. They did, however, exhibit a significant increase ($P>0.05$) in D8 and a substantial drop ($P<0.05$) in D2, D3, D4, D5, D7, and D9. The lower cholesterol levels observed in diets high in Opuntia (D9) according to our findings are in line with the findings of Louacini et al. (2012), Alhanafi et al. (2018), and El-Gindy et al. (2021). This may be because pectin in Opuntia binds to bile acids and interferes with cholesterol synthesis (Jesch and Carr 2017; El-Gindy et al. 2021), which in turn promotes cholesterol catabolism (Louacini et

al., 2012). The outcome of the rise in cholesterol in D8 is consistent with the findings of Sabri et al. (2003), who investigated the effects of feeding Barki male sheep Atriplex lentiformise on an unlimited basis. Since both components have a substantial impact on cholesterol levels, we regretfully did not estimate the amounts of fat and carbohydrates in the Atriplex plant in this study ("Cholesterol", 2020). This could be a direction for future research that explains this finding. The combination of Atriplex and Opuntia, _despite their varying concentrations_, was found to have no negative effects on cholesterol levels.

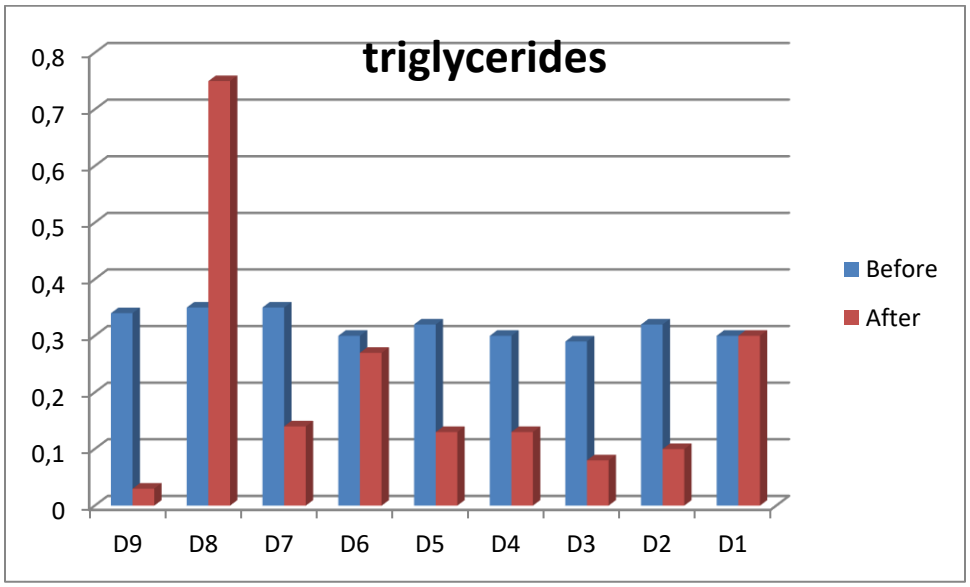


Figure 37: *Triglycerides before and after the introduction of experimental diets*

Our findings about the reduction in triglyceride levels in diets containing Opuntia are in line with earlier studies conducted in Wistar mice and published by Chilliard et al. (1998). Pectin's involvement with lipid absorption may be the cause of this (Van Bennekum, 2005, as referenced in Louacini, 2014). The current findings, however, are different from those of other researchers (Cardoso et al. 2018; Albuquerque et al. 2020; Ravari et al. 2022) who discovered no change in triglyceride levels following the

integration of Opuntia . Likewise, the findings of El-Saadani et al. (2016) and Alhanafi et al. (2019) are in line with the rise in triglycerides observed in the Atriplex-based diet (D8). This may be the result of inadequate nutrition during the crucial phase of late-stage pregnancy, which calls for a diet high in protein and energy. This could have had a detrimental effect on the liver's ability to synthesise triglycerides.

III.4.2 Blood Protein Metabolism Parameters

Table 13 shows the serum concentrations of albumin and total protein (TP) before and after treatments. After treatment, there was a small but substantial drop in the levels of TP and albumin for the ewes in treatment groups D1, D3, D4, D5, D6 for albumin only, and D7 for protein only. Given that the control group (D1) also had a minor decline, this could be explained by the influence of time. Therefore, serum TP and albumin were unaffected by the therapies started in these groups. The current study's findings about the decline in TP and Albumin for pregnant ewes near the end of the pregnancy are consistent with those of Rekik, El-Sherif and Assad (2001), Balikci et al. (2007), and Rekik et al. (2010). Because of the fetus's growth and, in particular, its use of amino acids for protein synthesis, blood protein concentrations fall during pregnancy (Jainudee and Hafez, 1994; Antunović et al. 2002; Piccione et al. 2009). The albumin levels of the treatment groups D2, D7 (25.07 g/l and 20.17 g/l, respectively), and D9 (52.57 g/l and 16.85 g/l) showed a substantial decline. This discovery aligns with El-Gindy et al.'s findings from 2021. We contend that this is a result of these treatment groups' (especially D2 and D9) Opuntia -based diets.

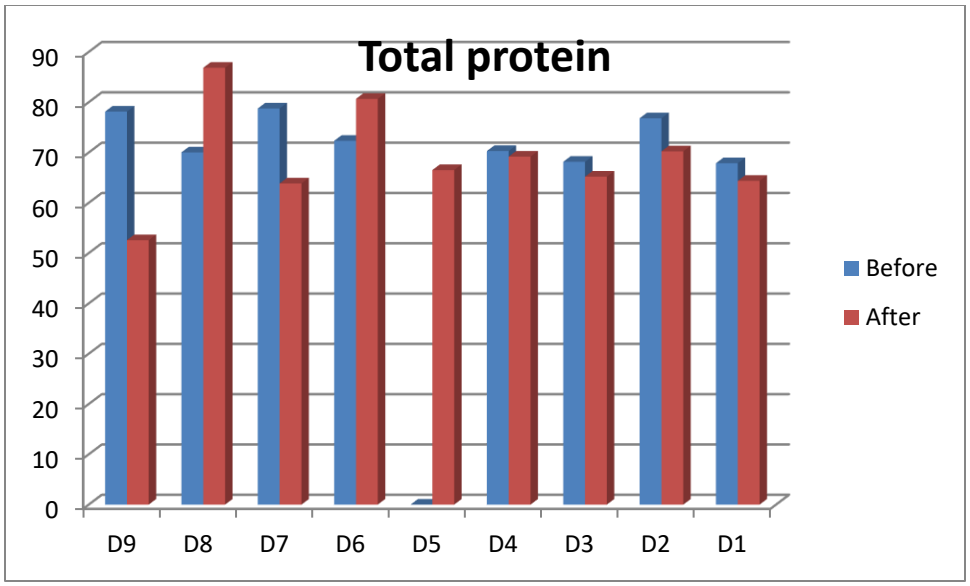


Figure 38: *Total protein before and after the introduction of experimental diets*

According to reports, Opuntia cladodes have relatively little protein (Ben Salem et al. 2019). This matches our findings about the chemical composition of the plant (Table 1). Mammary epithelial cells utilise almost 80% of the nutrients in blood in addition to producing colostrum (McManaman and Neville, 2003; Rekik et al. 2010).

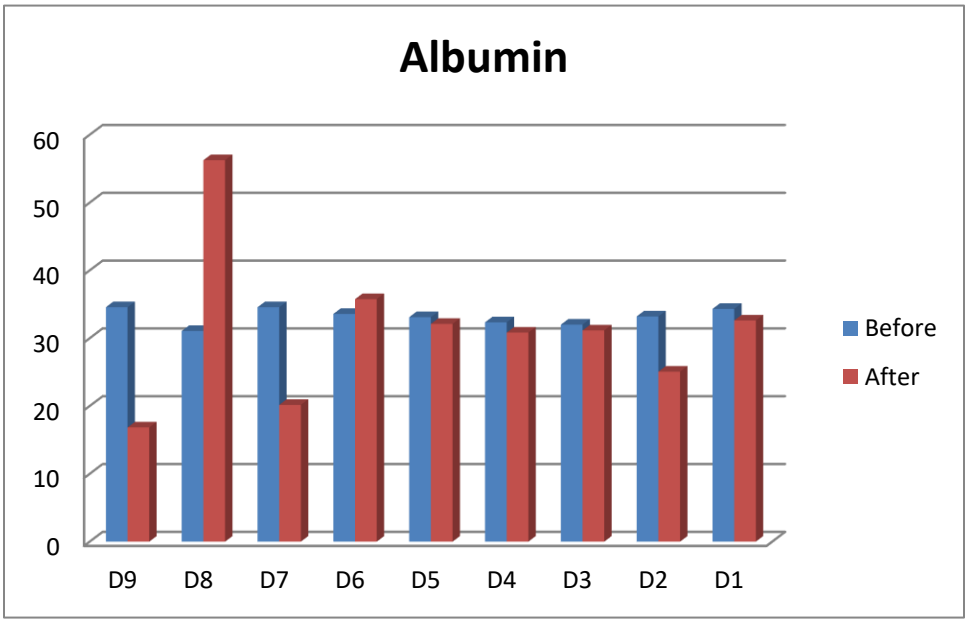


Figure 39: *Albumin before and after the introduction of experimental diets*

Conversely, treatment groups D6 and D8 for serum TP and D8 for albumin showed a significant increase ($P<0.05$) (Table 2). El-Saadani et al. (2016) found that several experimental diets, such as Atriplex halimus vs. Barseem Hay, showed a comparable pattern of a large increase in serum total protein. This may be explained by the fact that Atriplex has a high crude protein content (Table 1). El-Gohary et al. (2017) found that Barki lambs fed a combination of Acacia and Atriplex nummularia had significantly higher plasma albumin levels. The current outcome may be explained by albumin's ability to manage the body's fluid balance and respond to salt stress (Abdel-Bary, 1990). Our results, however, are not the same as those of Badawy et al. (2002), who found that the Al/Gl ratio was lower in Barki lambs fed Atriplex nummularia. Furthermore, Barki ram fed various Atriplex Lentiformis feeds demonstrated a significant decrease in TP in all groups, according to Sabri et al. (2003). In summary, blood parameters were unaffected by a balanced combination of Opuntia and Atriplex, but an extreme diet that included any of these plants showed negative consequences.

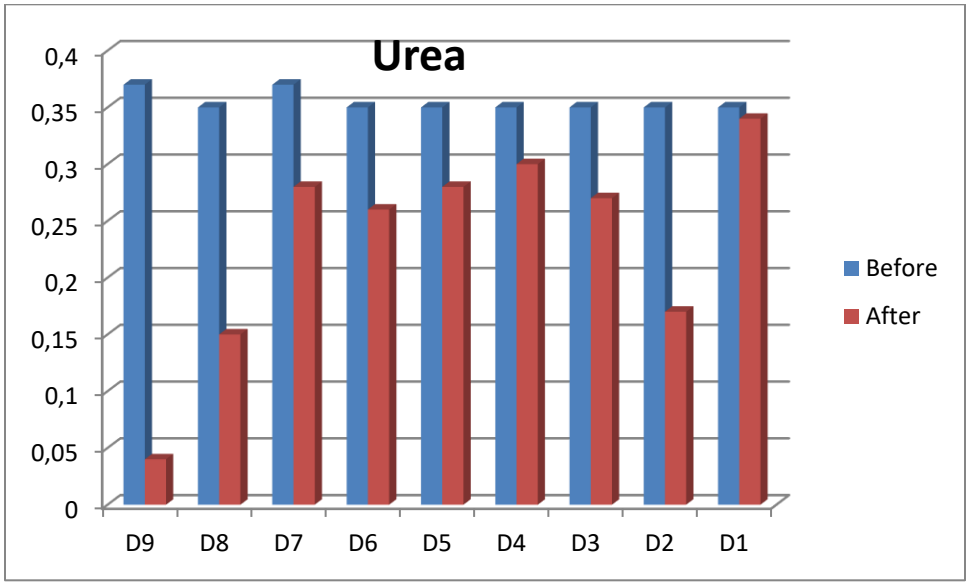


Figure 40: *Urea before and after the introduction of experimental diets*

After treatment, there was no difference in the concentrations of urea and creatinine in groups D3, D4, D5, D6; D7 in urea only, and D2 in creatinine only. Blood urea and creatinine levels in these groups were comparable to those of the control group (D1), suggesting that animals given a combination of Opuntia and Atriplex were fed on a normal diet. This is consistent with Alhanafi et al.'s (2019) findings. Animals fed the greatest doses of Opuntia (D2 and D9) had significantly lower blood urea concentrations, whereas animals fed barley straw and Opuntia (D2 and D9, respectively) had significantly lower creatinine levels. Our findings on blood urea are consistent with those of Cardoso et al. (2019); Louacini (2014); and Louacini et al. (2012). The low crude protein in Opuntia may be related to this (Nefzaoui and Ben Salem, 1998).

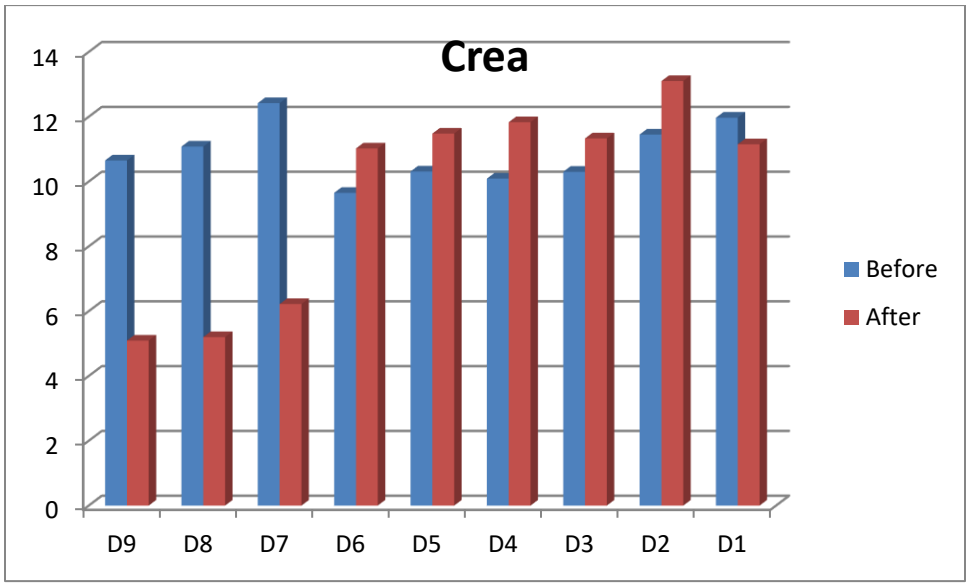


Figure 41: *Creatinine before and after the introduction of experimental diets*

Additionally, with a mean of 0.15 g/l, urea blood concentrations dropped dramatically in the Atriplex-based diet (D8) (table 2). This outcome is consistent with the

findings of Fayed et al. (2010), who observed elevated blood urea levels in Barki lambs fed Atriplex. A modest CP intake is reflected in the current outcome (Samanta et al. 2003). Conversely, the concentrations of creatinine in D7, D8, and D9 showed a considerable decrease, with averages of 6.22 g/l, 5.20 g/l, and 5.09 g/l, respectively. This finding could have two alternative interpretations: first, the less balanced diets in D7, D8, and D9 as opposed to the control and other experimental diets had a detrimental effect; second, the problems associated with the end of pregnancy in sheep. Our findings, however, are not consistent with those of others who discovered no variation in creatinine levels in goats fed spineless cactus (Cardoso et al. 2019). Increased creatinine concentrations were seen in Barki lambs fed a combination of Alfafa and Atriplex, according to Fayed et al. (2010).

III.4.3 Parameters of Enzyme Metabolism

Two crucial markers of liver function are the enzymes aspartate transferase (AST) and alanine transferase (ALT). Comparing the treatment groups D2, D3, D4, D5, and D6 for ALT only, to the control group D1, there was no difference in the concentrations of AST and ALT (Table 2). The results found are consistent with earlier research (Dey et al. 2015; Cardoso et al. 2019; El-Gindy et al. 2021) that fed lambs and nursing ewes with cactus. Alhanafi et al. (2019) also found comparable results, reporting that a combination of Atriplex and Opuntia did not change the levels of ALT and AST. Therefore, there are no negative effects on the hepatic tissue from these experimental therapies, which included a combination of Atriplex and Opuntia.

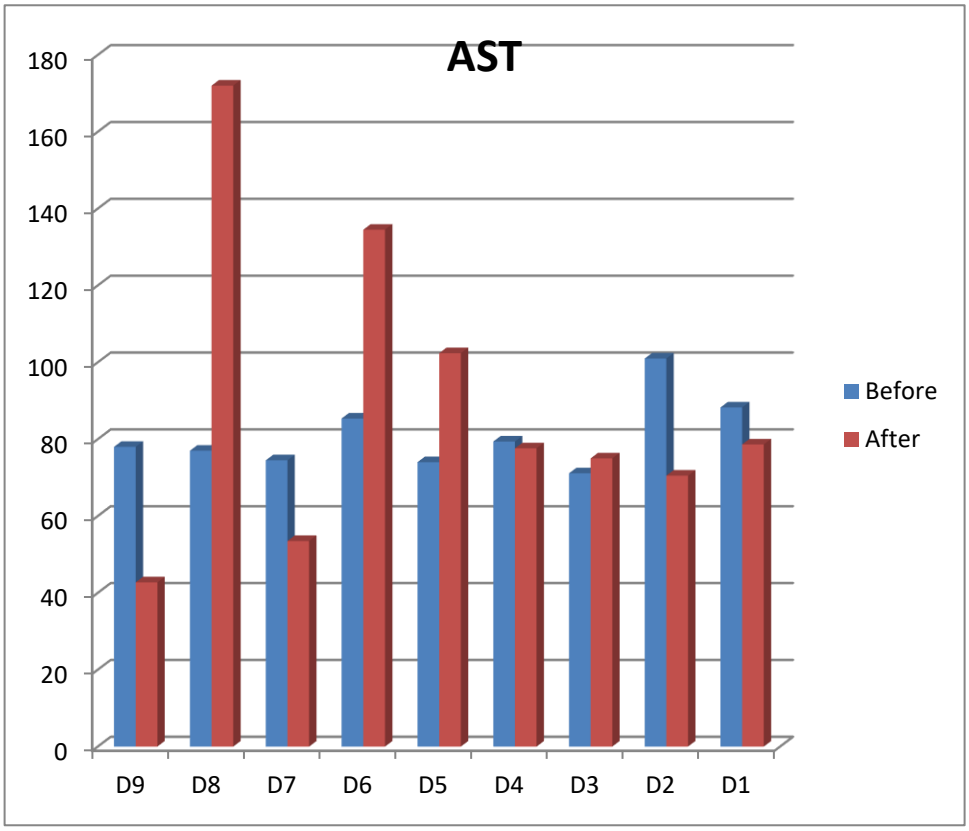


Figure 42: *Aspartate transferase before and after the introduction of experimental diets*

Following the treatment, the concentrations of AST and ALT in the groups D7 and D9 showed the lowest means, 53.5; 42.75 and 5.5; 4 UI/l, respectively. This is explained by the fact that neither group's diet was balanced and by the difficulties associated with the conclusion of the pregnancy. However, following the treatment in D8 and D6, the concentrations of AST and ALT increased significantly ($P<0.05$) for AST alone.

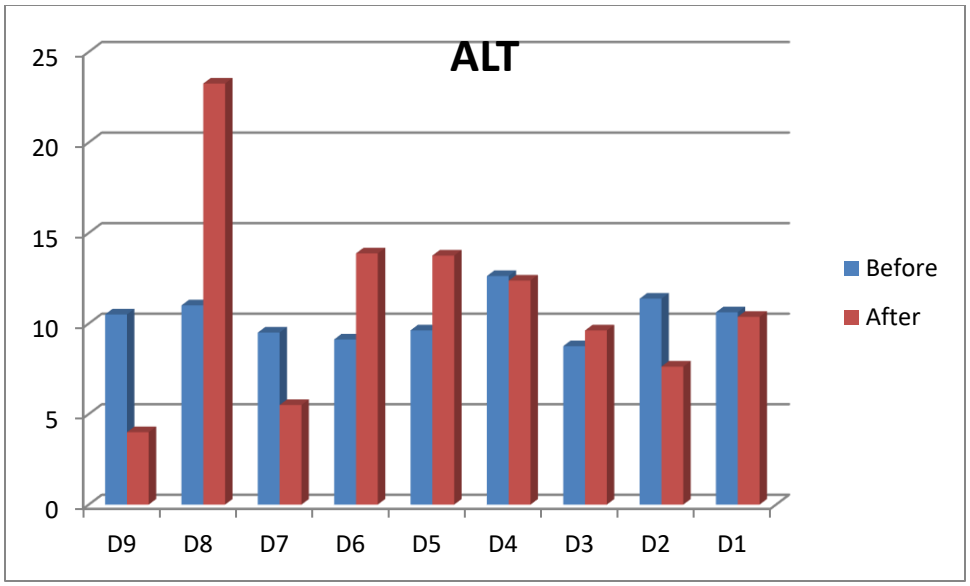


Figure 43: *Alanine transferase before and after the introduction of experimental diets*

Sabri et al. (2003) and Fayed et al. (2010) found similar outcomes, stating that giving Atriplex or a combination of Atriplex and Alfafa caused an increase in blood enzyme AST in Barki lambs compared to those fed a control diet. Additionally, a noteworthy rise in the two enzymes was noted by Eissa et al. (2022) in Barki pregnant ewes fed Accasia, Cassava, and Atriplex. This can be explained by Atriplex's high tannin and salt content.

III.4.4 Blood Mineral Metabolism Parameters

The D1, D2, D3, D4, D5, and D6 treatment groups did not significantly differ in terms of blood mineral concentrations. This is consistent with earlier studies (Alhanafi et al. 2018; Rekik et al. 2010). According to Klashing et al. (2005), plasma calcium concentrations increased quantitatively but stayed within the range (90–110) in the experimental groups D2, D4, D5, and D6 (Table 2). The small increase could be attributed to the high calcium concentration in the Opuntia plant, which was found to be

6.81% of DM in our study and previously reported (Ben Salem et al. 2004). Notably, previous studies have shown that high blood compositional Ca levels do not accurately reflect the condition of the oxalates present in Opuntia 's chemical makeup (Roque et al. 2007).

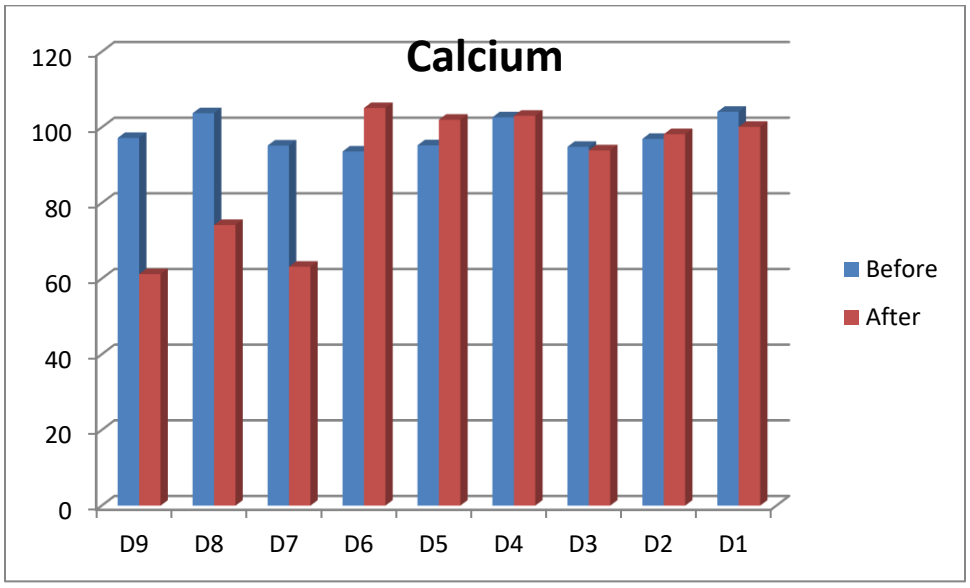


Figure 44: *Calcium before and after the introduction of experimental diets*

Plasma phosphorus (P) declined in the experimental groups D2, D3, D4, D5, and D6 as well as the control group numerically but not significantly. These results were in line with those of Rekik et al (2010). In the experimental groups D7, D8, and D9, there was a notable drop in Ca and P. The imbalanced nutrition in these groups and the crucial stage of late pregnancy may help to explain this.

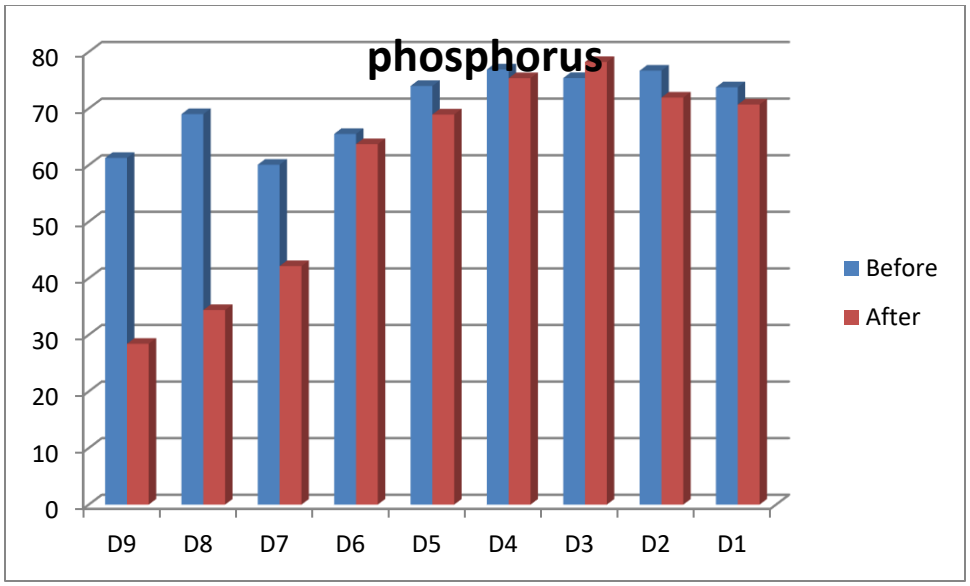


Figure 45: *Phosphorus before and after the introduction of experimental diets*

III.4.5 Conclusion

The experiment identifies D2, D3, D4, D5, and D6 as a combination of Opuntia ficus indica and Atriplex halimus that can be fed ad libitum to pregnant sheep to reduce feeding expenditures without compromising health or pregnancy. Furthermore, a diet that only contains barley straw, Atriplex, or cactus (D7, D8, and D9) puts the health of liver and kidneys of pregnant sheep at danger. Thus, when combined to the right degree, Atriplex and Opuntia plants can serve as a cost-effective substitute for the concentrate diets that Algerian sheep caretakers generally employ.

III.5 Experiment 5: Milk Composition

After the elimination of the three diets of D7, D8 and D9, this experiment stayed with the following treatment groups:

- Control Group D1: 0.45 kg of barley and 1.8kg of barley straw.
- D2: 100% cactus + Barley straw *ad libitum*

- D3: 75% cactus + 25%Atriplex + Barley straw *ad libitum*
- D4: 50% cactus + 50% Atriplex + Barley straw *ad libitum*
- D5: 25% cactus + 75% Atriplex + Barley straw *ad libitum*
- D6: 100% Atriplex + Barley Straw *ad libitum*

Table 14: *Milk Fat and Protein Content before and after the Supplementation of Treatment Groups*

		D1	D2	D3	D4	D5	D6
Fat	Before	7.07 ± 0.15^{c}	7.08 ± 0.33^{c}	7.52 ± 0.50^{ab}	7.77 ± 0.55^{ab}	7.22 ± 0.52^{ab}	7.82 ± 0.38^{a}
	After	7.45 ± 0.31^{c}	5.55 ± 0.40^{c}	8.4 ± 0.78^{c}	9.55 ± 0.51^{b}	10.65 ± 0.59^{a}	10.37 ± 0.75^{ab}
Protein	Before	4.3 ± 0.31^{a}	4.26 ± 0.15^{a}	4.08 ± 0.09^{a}	4.49 ± 0.24^{a}	4.5 ± 0.17^{a}	4.28 ± 0.43^{a}
	After	4.24 ± 0.21^{c}	2.82 ± 0.22^{c}	4.95 ± 0.12^{c}	5.47 ± 0.27^{b}	5.95 ± 0.12^{a}	5.62 ± 0.47^{ab}

The composition of the milk was measured both before and after the treatments are shown in the table above (Table 14). The results demonstrated that the various diets of the groups differed in terms of fat content; following experimental feed integration, D5 had the highest average fat percentage (10.65 ± 0.59^{a}) and D2 had the lowest mean with a record of 5.55 ± 0.40^{c}. Additionally, the study showed that, in comparison to the control group, the group receiving D5 showed a significant difference in fat % ($p = 0.062$), but no significant differences were seen for the other treatments ($p > 0.05$). Diets highest in Atriplex content also had the highest fat content (D5 and D6) in the current study.

These results are consistent with other studies that found that the introduction of Atriplex had a beneficial effect on milk fat content (Aljamal et al., 2021). According to a different study, cheese made on an Atriplex leaf diet was firmer than cheese made on other diets, which may indicate a change in the composition of milk fat (Abbeddou et al., 2011). On the other hand, some found a progressive rise in fat content in the milk of ewes fed Atriplex during the lactation period, without any noteworthy impact from dietary intervention (El-Saadany et al., 2016). In a similar vein, studies conducted on goats revealed that the type of roughage had no effect on the proportion of fat in their milk (Abdalla et al., 2013). In addition, our results, which showed that the Opuntia diet reduced the amount of fat in the milk D2, are consistent with earlier studies by other researchers that found that she-camels fed a high-energy diet had reduced amounts of milk fat (Al-Saiady et al., 2012). Furthermore, new studies have shown that low dry matter concentrations in cacti may alter the amount of dry matter that animals require, which may have an impact on the amount of protein in milk (Magalhães et al., 2021). The protein content of the control group was 4.25 on average, whereas diet Group D5 had the greatest mean protein content (5.95 ± 0.12^{a}), and the group who received the diet D2 had the lowest mean with a record of: 2.82 ± 0.22^{c}. This shows a non-significant decrease compared to the control group. The significance of dietary protein in affecting the protein content of milk has been extensively examined, with a focus on taking into account the quantity and origin of dietary protein when analysing the composition of milk (Jenkins & McGuire, 2006). Furthermore, it is well recognised that milk protein levels are directly impacted by the protein content of the diet (Kamoun et al., 1989). This emphasises how important dietary protein is and how it affects the composition of milk. Our results, which

show that the diet group D5 had the highest protein content, are consistent with earlier studies that found a positive correlation between protein intake and milk protein content (EL-Saadany & Omar, 2018). These studies looked at the impact of feeding Barki ewes halophytic plants and found that the milk of ewes fed specific plants had higher protein content, suggesting a possible relationship between dietary protein sources and milk protein content. Because Atriplex has a high protein content, it is therefore possible to deduce that adding it to the diet of the Barbarine ewes may have raised the protein level of the milk. Furthermore, our results support earlier research by demonstrating that milk protein decreases in D2, the plant with the greatest milk protein content in cactus. For instance, a recent study found that when prickly pear cactus peel was supplemented at a high dose as opposed to the treatment of a low dose, a drop in milk protein % was detected (El -Gindy et al., 2021). The observed significant reduction in milk protein content in the treatment with the greatest cactus content could be explained by the way phenolic chemicals interact with food proteins, perhaps obstructing certain amino acids (Jakobek, 2015; Gu et al., 2020).

III.5.1 Conclusion

The favourable outcomes we saw highlight the viability of adding these alternative forage choices to animal diets, particularly the notable increases in fat and protein content. This is significant not just for the immediate improvement of milk quality but also for the larger goals of resilience and sustainable development in the face of climate change, especially in semi-arid and arid areas. In order to increase their resistance to climate change, farmers in arid and semi-arid areas might profit practically from these discoveries. Farmers can mitigate the effects of drought and guarantee a

consistent revenue stream and food security by producing alternative fodders that are appropriate for these circumstances.

III.6. Experiment 6: The Average Dail Gain of Weight of Lambs.

III.6.1. Results and Discussion of ADG of Lambs

Table 15. shows the results of the Average Daily Gain (ADG) of the lambs during the experimental period 3.

Table 15: *The Average Daily Gain of Lambs during the Experimental period 3.*

	D1	**D2**	**D3**	**D4**	**D5**	**D6**
	180,50	95,65	179,65	188,90	192,56	102,89
	177,75	94,25	184,53	185,68	189,67	100,45
	189,00	103,50	180,42	182,75	190,23	109,50
	187,40	102,90	175,33	190,84	188,87	110,00
Mean	**183,66^{cd}**	**99,08^{a}**	**179,98^{c}**	**187,04^{de}**	**190,33^{e}**	**105,71^{b}**
Ecart	**5,40**	**4,80**	**3,76**	**3,57**	**1,57**	**4,77**

The daily weight gain of lambs during the lactation period ranged from a low of 99.08 ± 4.80 g/day to a high of 190.33 ± 1.57 g/day across the different dietary treatments. Lambs of ewes fed diet D5 exhibited the highest daily weight gain at 190.33 ± 1.57 g/day, which demonstrate a significant increase compared to the control group (D1). Lambs of ewes fed diets D4 followed, with daily weight gains of 187.04 ± 3.57 g/day, showcasing a slight increase, but was not statistically significant compared to the control group which recorded: 183.66 ± 5.40 g/day. However, the lambs in D3 recorded

an average daily gain of 179.98 ± 3.76 g/day, which shows a non-statistically significant difference compared to the control group. Despite this, all these records align with the findings of previous research on the Barabrine breed (Djemali et al., 1995b; Ben Gara, 2000; Rabhi, 2003). Conversely, lambs of ewes fed diets D6 and D2 showed the lowest ADG at 105.71 ± 4.77 g/day and 99.08 ± 4.80 g/day, respectively. The change in these ADG was statistically significant compared to ADG in D1. This lower growth rate can be attributed to the reduced feed intake in diets D2 and D6, as previously discussed. It is also well-established that increased feed intake leads to higher milk production, consequently resulting in greater lamb growth (Boudechiche et al., 2010). For D2, the lower ADG for the new-born lambs can also be explained by the composition of Opuntia since it represents the highest percentage of the diet. Opuntia as discussed in experiment 1 is high with water content and its dilution effect on nutrient concentration, which might lead to less benefit from the milk and eventually to lower ADG. For D3, the lower ADG compared to the control group, might have been because of the possible imbalances in nutrient composition or suboptimal feed conversion. For D6, the significant decrease in the ADG of the lambs is probably because of the imbalance of the diet.

III.6.2 Conclusion

Diet D5 exhibited the highest ADG at 190.33 ± 1.57 g/day, making it the most effective for lamb growth during the lactation period. However, Diet D4, with an ADG of 187.04 ± 3.57 g/day, demonstrated almost identical growth rates and highlights its potential as a balanced diet that closely matches D5 in performance. Both diets significantly outperformed the control group (183.66 ± 5.40 g/day), emphasizing their superior nutrient composition. In contrast, diets D2 (99.08 ± 4.80 g/day) and D6 (105.71

± 4.77 g/day) resulted in the lowest growth rates, attributed to reduced feed intake, high water content of Opuntia in D2, and dietary imbalances in D6. In experiment 1, diet 2 and 6 struggled to meet the energy requirements for gestation, which might be impacted the growth of lambs recording the lowest ADG. These results confirm the importance of balanced rations, such as D4 and D5, in maximizing lamb growth while maintaining nutritional adequacy.

GENERAL CONCLUSION

General Conclusion

This study evaluated the potential of *Opuntia ficus-indica* and *Atriplex halimus* as alternative feed resources for pregnant ewes and their offspring in arid regions. The findings indicate that *Opuntia* and *Atriplex* possess complementary attributes: *Opuntia* offers high moisture content (14.63% DM), energy (0.63 UFL/kg DM), and calcium (6.81%), while *Atriplex* is richer in protein (12.87% CP) and fiber (50.29% NDF). Combining these plants improved the digestibility of dry matter (DM), organic matter (OM), and crude protein (CP). An optimal digestibility of DM (72.37%) was recorded at a 50:50 inclusion ratio, surpassing both single-species diets and the conventional diet for sheep. This balance maximized nutrient absorption, meeting the maintenance and production requirements of pregnant ewes, as demonstrated by their net energy (NE) and nitrogen levels in diets D3, D4, and D5, which were 1.04–1.05 (NE) and 1.19–1.20 (nitrogen), effectively meeting the nutritional needs of ewes during late gestation.

Balanced diets maintained optimal body weight, while imbalanced diets (D2: 100% *Opuntia* and D6: 100% *Atriplex*) failed to provide adequate energy or protein, leading to reduced feed efficiency and serious nutritional deficits. Additionally, *Opuntia*'s high calcium and ash content make it especially valuable in arid regions where water is scarce, as it supplies hydration and essential minerals. However, D2 (100% *Opuntia*) resulted in low protein levels, and D6 (100% *Atriplex*) highlighted the need for energy-protein synergy due to nitrogen depressor effects.

Biochemical parameters showed that balanced diets (D3, D4, and D5) maintained stable glucose, protein, and enzyme levels, reflecting adequate nutrient availability. These diets successfully met the energy requirements of pregnant ewes. In contrast, imbalanced diets (D7, D8, and D9) caused significant metabolic disruptions, including reduced glucose and protein levels and elevated

hepatic stress markers. Milk quality results showed significant increases in fat and protein content with *Atriplex*-based diets, with D5 (25% *Opuntia*, 75% *Atriplex*) achieving the highest fat (10.65%) and protein (5.95%) levels, outperforming all other diets.

In conclusion, the results of this study have broad implications for sustainable livestock management in environments with limited water and feed resources, while maintaining cost-effective practices. However, the *Opuntia-Atriplex* combination is most promising at specific ratios, notably 50:50 and 25:75, due to:

- Its balanced energy and nitrogen supply.
- Improvements in digestibility.
- Equilibrium in net energy and nitrogen levels.
- Enhanced biochemical stability.
- No adverse effects on productive and reproductive potential.

Based on our findings, the following recommendations are proposed to support the sustainable development of arid regions:

1. Implement a national policy prioritizing the use of local phytogenetic bioresources.
2. Explore, through selection, molecular biology, and genetic engineering, the possibility of developing an *Opuntia* cultivar with higher protein content and an *Atriplex halimus* cultivar with reduced sodium chloride levels.
3. Reduce dependence on imported animal feed, aligning with national goals for sustainable agriculture and food security.

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APPENDICES

APPENDIX A

Summary table of intake: DM, OM, BC, MAI in g, per diet in cross over n =8

R 4	CP	79,94	92,75	70,63	83,86	84,06	76,85	83,09	70,77	**80,24**	**7,42**		
	CF	331,18	384,25	292,61	347,42	348,26	318,36	344,24	293,2	**332,44**	**30,76**		
	OM	947,86	1099,75	837,5	994,34	996,75	911,17	985,21	839,13	**951,46**	**88,04**		
	DM	1142	1325	1009	1198	1200,9	1097,8	1187	1011	**1146,33**	**106,08**		
R 3	CP	68,8	75,25	78,42	91	69,9	75,25	75,88	72,1	**75,82**	**6,92**		
	CF	285	311,8	324,9	377	289,62	311,75	314,36	298,7	**314,14**	**28,70**		
	OM	815,68	892,25	929,79	1079	828,9	892,25	899,72	854,9	**899,06**	**82,15**		
	DM	982,75	1075	1120,23	1300	998,7	1075	1084	1030	**1083,21**	**98,97**		
R 2	CP	40,03	48	49,28	40,76	39,02	40,36	44,82	39,84	**42,76**	**4,03**		
	CF	310,26	372	381	315,87	302,4	312,8	347,36	308,8	**331,31**	**31,05**		
	OM	850,72	1020	1047,2	866,11	829,13	857,65	952,43	846,6	**908,73**	**85,73**		
	DM	1000,85	1200	1232	1018,95	975,45	1009	1120,5	996	**1069,09**	**100,86**		
R 1	CR	67,08	69	72,06	59,88	66,9	59,16	57,06	66,7	**64,73**	**5,33**		
	C F	301,86	310,5	324,27	269,46	301,05	266,22	256,77	300,11	**291,28**	**24,01**		
	OM	1068,25	1098,83	1147,56	953,59	1065,38	942,12	908,68	1062,04	**1030,80**	**84,99**		
	DM	1118	1150	1201	998	1115	986	951	1111.5	**1078,81**	**88,95**		
		Period 1				Period 2				Mean	SD		

R 8	CP	88,24	85,93	78,67	88,05						**85,22**	**4,49**	
	CF	183,28	178,47	163,38	182,88						**177,00**	**9,33**	
	OM	543,04	528,8	484,1	541,86						**524,45**	**27,66**	
	DM	678,8	661	605,12	677,33						**655,56**	**34,58**	
R 7	CP	23,27	22,3	21,11	20,92						**21,90**	**1,09**	
	CF	372,38	356,7	337,7	334,75						**350,38**	**17,59**	
	OM	729,25	698,53	661,29	655,6						**686,16**	**34,45**	
	DM	775,8	743,12	703,5	697,4						**729,95**	**36,67**	
R 6	CP	77,76	71,76	74,13	79		73	76,23	80,16	75,42	**75,93**	**2,93**	
	CF	359,64	331,9	342,84	365,35		337,44	352,8	370,74	348,84	**351,19**	**13,59**	
	OM	855,36	789,36	815,4	868,9		802,6	839,08	881,76	829,7	**835,27**	**32,31**	
	DM	972	897	926,6	987,42		912	953,5	1002	942,8	**949,16**	**36,73**	
R 5	CP	75,81	78,54	77,86	75,36		87,15	92,54	75,02	70,39	**79,08**	**7,21**	
	CF	314,07	325,38	322,63	312,21		361,05	383,38	310,8	291,6	**327,64**	**29,90**	
	OM	898,9	931,26	923,38	893,58		1033,4	1097,26	889,5	834,57	**937,73**	**85,58**	
	DM	1083	1122	1112,5	1076,6		1245	1322	1071,7	1005,5	**1129,78**	**103,10**	
		Period 1					Period 2				Mean	SD	

R 9	CP	17,56	18,01	16,6	17,71						**17,47**	**0,60**	
	CF	76,08	78,05	71,9	76,77						**75,70**	**2,66**	
	O M	438,9	450,3	414,75	442,91						**436,71**	**15,38**	
	D M	585,2	600,4	553	590,55						**582,28**	**20,51**	
		Period 1					Period 2				Mean	SD	

Summary table of faecal matter excreted: DM, OM, BC, MAT, in g per diet in cross over

R 3	CP	6,23	8,95	8,23	8,67		11,46	9,14	6,76	6,53	**8,24**	**1,73**	
	CF B	90,29	88,72	91,5	106,52		116,51	85,76	81,78	102,63	**95,46**	**11,86**	
	OM	237,92	228,31	253,31	247,13		384,61	355,42	352,5	258,13	**289,66**	**63,08**	
	DM	297,4	289,95	305,20	347,14		300,82	295,74	282,11	311,18	**303,69**	**19,68**	
R 2	CP	15,27	17,92	13,8	16,76		16,69	13,06	13,6	13,77	**15,10**	**1,81**	
	CF	143,27	158,72	166,75	176,86		175,89	155,62	184,68	128,01	**161,22**	**18,91**	
	OM	389,23	394,24	471,6	387,9		368,17	421,69	388,8	342,26	**395,48**	**38,17**	
	DM	492,7	512,63	575,12	478,9		451,2	502,35	486,4	444,5	**492,97**	**40,63**	
R 1	CP	10,19	12,24	11,81	10,8		13,57	10,64	12,93	12,12	**11,78**	**1,17**	
	CF	121,33	120,67	114,68	99,2		135,83	82,82	120,93	124,48	**114,99**	**16,54**	
	OM	305,63	309,77	278	255,51		310,62	221,85	303,72	284,99	**283,76**	**31,48**	
	DM	351,7	360,2	347,5	300,6		357,45	295,8	349,5	327,57	**336,29**	**25,48**	
		Period 1					Period 2				Mean	SD	

R 6	CP	37,08	37,67	37,74	41,45		37,89	38,88	40,02	37,71	**38,55**	**1,48**	
	C F	164,8	169,74	177,6	169,2		166,29	168,48	195,75	197,6	**176,18**	**13,20**	
	OM	309,75	306,36	319,68	317,25		319,96	328,32	334,95	293,3	**316,19**	**13,03**	
	DM	412,56	414,27	443,5	422,8		420,91	432,26	435,26	418,9	**425,05**	**10,88**	
R 5	CP	10,58	12,57	12,90	9,1		13,83	12,32	9,67	11,68	**11,58**	**1,65**	
	C F	121,52	127,79	136,61	108,5		138,3	128,18	102,96	124,41	**123,53**	**12,43**	
	OM	286,16	297,49	347,14	276,5		373,41	394,4	258,96	297,83	**316,48**	**48,97**	
	DM	392,4	418,65	445,09	350,39		460,62	492,55	312,15	376,7	**406,06**	**59,88**	
R 4	CP	8,75	8,64	9,02	8,85		7,85	8,69	9,98	7,91	**8,71**	**0,66**	
	C F	101,5	118,8	90,21	97,35		97,34	93,31	97,88	90,83	**98,40**	**9,09**	
	OM	248,5	280,83	249,45	224,27		260,62	198,66	260,82	228,54	**243,96**	**25,77**	
	DM	349,62	360,45	290,75	294,9		314,17	301,25	322,39	292,80	**315,79**	**26,69**	
		Period 1					Period 2				MEAN	SD	

R9	CP	4,65	6,47	4,4	5,87						**5,34**	**0,98**	
	CF	13,50	12,72	13,65	12,58						**13,11**	**0,54**	
	OM	163,24	173,25	162,8	153,3						**163,14**	**8,14**	
	DM	211,5	231,42	220,19	209,85						**218,24**	**9,88**	
R8	CP	43,01	42,79	37,20	44,64						**41,91**	**3,24**	
	C F	121,21	116,7	108,81	122,76						**117,37**	**6,25**	
	OM	285,43	291,75	263,25	271,41						**277,96**	**12,97**	
	DM	390,72	388,65	350,95	371,8						**375,53**	**18,44**	
R7	CP	12,9	12,49	11,07	12,12						**12,14**	**0,78**	
	C F	206,4	189,41	183,36	197,96						**194,28**	**10,05**	
	OM	344,17	330,13	305,6	327,24						**326,78**	**15,94**	
	DM	430,22	402,6	382,4	404,16						**404,84**	**19,60**	
		Period 1					Period 2				Mean	SD	

Summary table of digestibility of DM, OM, BC and MAT cross-over diet

R 3	CP	90,94	88,1	89,5	90,47		83,60	87,85	91,09	90,94	**89,06**	**2,55**	
	C F	68,31	71,54	71,83	71,74		59,77	72,49	73,72	65,64	**69,38**	**4,66**	
	OM	70,83	74,41	72,75	77,09		53,59	60,54	60,82	69,80	**67,47**	**8,19**	
	DM	69,73	73,02	72,75	73,29		69,87	72,48	70,65	69,78	**71,44**	**1,58**	
R 2	CP	61,85	62,66	71,83	58,88		57,22	67,64	69,65	65,33	**64,38**	**5,15**	
	C F	53,82	57,33	56,23	44		41,83	50,24	46,83	58,54	**51,10**	**6,36**	
	OM	54,24	61,34	54,96	55,21		55,11	50,83	59,17	59,57	**54,88**	**3,49**	
	DM	50,77	57,28	53,31	53		53,74	50,21	56,59	55,37	**53,78**	**2,54**	
R 1	CP	84,8	82,26	83,62	68,1		79,71	82,08	77,33	81,82	**79,96**	**5,31**	
	C F	59,80	61,13	64,63	73,20		48,90	68,89	52,90	58,52	**60.99**	**7,96**	
	OM	71,38	71,80	75,77	73,20		70,84	76,45	66,57	73,65	**72,45**	**3,11**	
	DM	68,54	68,67	71,06	69,87		66,32	70	74,07	77,5	**70,75**	**3,52**	
		Period 1					Period 2				Mean	SD	

R6	CP	52,23	47,50	49,08	47,53		48,09	48,99	50,07	50,00	**49,18**	**1,58**	
	C F	54,17	48,88	48,19	53,68		50,72	52,24	47,20	43,35	**49,80**	**3,64**	
	OM	63,78	61,18	60,79	63,48		60,13	60,87	62,00	64,64	**62,10**	**1,65**	
	DM	57,55	53,81	52,13	57,18		53,84	54,66	56,56	55,56	**55,16**	**1,88**	
R5	CP	86,04	83,94	83,43	87,92		84,13	86,68	87,11	83,40	**85,33**	**1,80**	
	C F	61,30	60,72	57,65	65,24		61,69	66,56	66,87	57,33	**62,17**	**3,73**	
	OM	68,16	68,05	62,40	69,05		63,86	64,05	70,88	64,31	**66,34**	**3,05**	
	DM	63,76	62,68	59,99	67,45		63,00	62,74	70,87	62,54	**64,12**	**3,41**	
R4	CP	89,05	90,68	87,22	89,44		90,66	88,69	87,98	88,82	**89,06**	**1,19**	
	C F	69,35	69,08	69,17	71,97		72,04	70,69	71,56	89,17	**72,87**	**6,69**	
	OM	73,78	74,46	70,21	77,44		73,85	78,19	73,52	72,76	**74,27**	**2,54**	
	DM	69,38	72,79	71,18	75,38		73,83	72,55	72,83	71,03	**72,37**	**1,84**	
		Period 1					Period 2				Mean	SD	

R9	CP	73,51	64,07	73,49	66,85						**69,48**	**4,77**	
	C F	82,25	83,70	81,01	83,61						**82,64**	**1,27**	
	OM	62,80	61,52	60,74	65,38						**62,61**	**2,03**	
	DM	63,85	61,45	60,18	64,46						**62,48**	**2,01**	
R8	CP	51,23	50,2	52,71	49,30						**50,86**	**1,46**	
	C F	33,86	34,61	33,40	32,87						**33,68**	**0,73**	
	OM	47,43	44,75	45,62	49,91						**46,92**	**2,28**	
	DM	42,43	41,20	42	45,10						**42,68**	**1,69**	
R7	CP	44,56	44.97	47,56	42,06						**45,26**	**2,49**	
	C F	44,57	46,89	44,81	42,41						**44,67**	**1,83**	
	OM	52,83	52,73	53,78	50,08						**52,35**	**1,58**	
	DM	44.54	45,82	45,64	42,04						**44,51**	**1,74**	
		Period 1					Period 2				Mean	SD	

Appendix B

Metabolisable Weight

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Period 1	21,71	19,50	21,93	24,32	22,14	20,27	17,66	16,20	15,90
	21,95	20,38	22,94	21,34	21,74	19,14	16,70	16,70	16,35
	21,34	20,14	21,28	22,62	23,23	19,72	17,05	17,05	16,58
	21,09	19,50	21,69	22,49	22,62	19,36	16,49	16,49	16,14
Period 2	22,49	19,92	22,77	23,20	23,41	19,92			
	23,20	20,52	23,33	21,39	21,82	20,93			
	22,20	19,78	21,82	22,89	22,49	20,47			
	22,57	20,74	22,36	22,70	21,77	19,78			
Mean	**22,06**	**20,06**	**22.26**	**22,61**	**22,40**	**19,94**	**16,97**	**16,61**	**16,24**
SD	**0,69**	**0,46**	**0,70**	**0,96**	**0,65**	**0,58**	**0,51**	**0,35**	**0,29**

MODI

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Period 1	762,51	461,43	577,74	699,33	612,69	545,54	332,43	257,54	275,62
	788,95	625,66	663,92	818,87	633,72	482,93	368,33	236,63	277,02
	869,50	575,54	676,42	588,00	576,18	495,68	355,64	220,84	251,19
	698,02	478,17	831,80	770,01	617,01	551,57	328,32	270,44	289,57
Period 2	754,71	456,93	444,20	736,06	659,92	482,60			
	720,25	435,94	540,16	712,44	702,79	510,74			
	604,90	563,55	547,20	724,32	630,47	546,69			
	782,19	504,31	596,72	683,31	536,71	536,31			
Mean	**747,62**	**512,69**	**609,77**	**716,54**	**609,90**	**519,00**	**346,18**	**246,36**	**273,35**
SD	**77,09**	**67,81**	**115,90**	**67,30**	**22,40**	**29,44**	**19,04**	**21,99**	**16,04**

Energy Feeding Level

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Period 1	1,35	0,91	1,01	1,10	1,06	1,03	0,72	0,61	0,66
	1,38	1,18	1,11	1,47	1,12	0,97	0,84	0,54	0,65
	1,56	1,09	1,22	0,99	0,95	0,96	0,80	0,49	0,58
	1,27	0,94	1,47	1,31	1,04	1,09	0,76	0,63	0,69
Period 2	1,29	0,88	0,75	1,22	1,08	0,93			
	1,19	0,85	0,89	1,26	1,23	0,93			
	1,04	1,09	0,96	1,21	1,07	1,02			
	1,33	0,93	1,02	1,15	0,94	1,04			
Mean	**1,30**	**0.98**	**1,05**	**1,21**	**1,06**	**0,99**	**0,78**	**0,57**	**0,65**
SD	**0,15**	**0,12**	**0,22**	**0,14**	**0,09**	**0,05**	**0,05**	**0,06**	**0,05**

PDI

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Period 1	56,88	24,75	62,57	71,19	65,22	40,61	10,36	45,20	12,91
	56,76	30,08	66,30	84,11	65,93	34,09	10,03	43,14	11,54
	60,25	35,40	70,19	61,60	64,96	36,38	10,04	41,47	12,20
	40,77	23,99	82,33	75,00	66,26	37,55	8,80	43,41	11,88
Period 2	53,33	22,32	58,44	76,21	73,35	35,11			
	48,56	27,29	66,11	68,16	80,21	37,34			
	44,12	31,22	69,12	73,10	65,34	40,14			
	54,57	25,79	65,57	62,86	58,71	37,71			
Mean	**51,90**	**27,61**	**67,58**	**71,53**	**67,50**	**37,37**	**9,80**	**43,31**	**12,13**
SD	**6,79**	**4,35**	**7,00**	**7,37**	**6,47**	**2,24**	**0,69**	**1,53**	**0,58**

Nitrogen Feeding Level

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Period 1	0,99	0,48	1,08	1,11	1,12	0,76	0,22	1,06	0,31
	0,97	0,55	1,09	1,49	1,15	0,67	0,23	0,98	0,27
	1,07	0,67	1,25	1,03	1,06	0,70	0,22	0,92	0,28
	0,73	0,47	1,44	1,26	1,11	0,73	0,20	1,00	0,28
Period 2	0,90	0,42	0,97	1,24	1,19	0,68			
	0,79	0,50	1,07	1,21	1,39	0,68			
	0,75	0,60	1,20	1,21	1,10	0,74			
	0,92	0,47	1,11	1,05	1,02	0,72			
Mean	**0,89**	**0,52**	**1,15**	**1,20**	**1,14**	**0,71**	**0,21**	**0,99**	**0,29**
SD	**0,12**	**0,08**	**0,14**	**0,15**	**0,11**	**0,03**	**0,01**	**0,06**	**0,02**

ADG

	R1	R2	R3	R4	R5	R6	R7	R8	R9
Period 1	95,12	35,71	80,00	97,15	102,13	43,22	-215,28	-202,50	-189,71
	81,42	27,85	83,12	88,32	95,14	20,12	-185,14	-120,80	-196,10
	89,76	40,12	76,50	113,14	91,76	16,33	-197,06	-195,32	-211,54
	54,12	33,42	79,24	100,98	87,32	28,71	-206,34	-202,40	-271,33
Period 2	103,17	37,44	82,36	115,76	76,95	35,42			
	66,80	31,18	52,77	104,65	97,80	10,16			
	75,3	35,20	103,47	99,53	80,43	17,17			
	62,41	30,18	92,13	114,00	81,20	37,75			
Mean	**78,51**	**33,89**	**81,20**	**104,19**	**89,09**	**26,11**	**-200,96**	**-180,26**	**-217,17**
SD	**16,99**	**4,04**	**14,42**	**9,59**	**9,08**	**11.87**	**12,90**	**39,78**	**37,25**

ADG of Lambs

	R1	R2	R3	R4	R5	R6
	180,50	95,65	179,65	188,90	192,56	102,89
	177,75	94,25	184,53	185,68	189,67	100,45
	189,00	103,50	180,42	182,75	190,23	109,50
	187,40	102,90	175,33	190,84	188,87	110,00
Mean	**183,66**	**99,08**	**179,98**	**187,04**	**190,33**	**105,71**
SD	**5,40**	**4,80**	**3,76**	**3,57**	**1,57**	**4,77**

APPENDIX C

Published Article 1

The Impact of Alternative Fodder (Atriplex *Halimus* and Cactus *Ficus Indica*) on Barbarine Ewes's Milk Quality

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ABSTRACT

INTRODUCTION

The research is part of a broader investigation into the impact of various diets, specifically designed with Atriplex halimus and Opuntia Ficus Indica, on multiple factors concerning Barbarine ewes in a semi-arid area of southeastern Algeria. The goal was to assess whether these two plants could offer effec- tive sustainable solutions for addressing drought in the region. This experimental study aimed to inves- tigate the impact of alternative forage such as Opun- tia Ficus Indica and Atriplex halimus on milk com- position, specifically protein and fat content, in Bar- barine ewes within a semi-arid region of Southeast Algeria. A cohort of 24 Barbarine ewes in the lacta- tion phase was enrolled in the study. The subjects were stratified into six distinct groups, each contain- ing four animals, encompassing a control regimen and diets featuring Cactus Inerme, Atriplex halimus, and a combination of both. The control group's diet comprised 0.45 kg of barley and 1.8 kg of barley straw (Control). Contrarily, ewes in the experimental groups (T1 to T5) were provided with barley straw ad libitum along with the following compositions: 100% cactus (T1), 75% cactus + 25% Atriplex (T2),
50% cactus +50% Atriplex (T3), 25% cactus + 75% Atriplex (T4), and 100% Atriplex (T5). Analysis of the results indicated that the treatment group T4 ex- hibited the highest milk fat content, approaching sta- tistical significance in comparison to the control group, whereas treatment group T1 displayed the lowest mean. Moreover, protein content was notably higher in T4 and T5 than in T3 and T2, with treat- ment group T1 recording the lowest mean. These re- sults provide valuable insights into the effects of these specific substitute diets on the quality of milk in Barbarine ewes, especially within the context of the semi-arid environments in Algeria.

KEYWORDS:

Atriplex, Barbarine ewes, Cactus, Milk Quality, Semi-arid regions, Sustainable Development

Algeria has experienced a notable shift in rain- fall patterns since the 1970s, resulting in a steady de- cline in precipitation and the emergence of a drought crisis [1]. These adverse climatic conditions, exacer- bated by ongoing socio-cultural changes, pose a sub- stantial threat to livestock production and available animal feeding sources [2]. The impact is particu- larly pronounced in the steppe, semi-arid, and arid regions of Algeria, where recent demographic ex- pansion, escalating livestock numbers, and intensi- fied fodder cereal production have further strained the delicate balance of ecosystems [3,4,5,6].

Crucially, sheep and other livestock represent linchpins in the livelihoods of communities in these regions [6], underscoring the urgent need for sustain- able and alternative fodder sources. It has also been contended that achieving sustainability in Algeria faces formidable challenges due to the inadequate availability and production of forage and livestock feed. This inadequacy results from a lack of compre- hensive assessments of fodder resources, including considerations of diversity, quantities produced, and particularly their nutritional values [7] Furthermore, the dearth of technical expertise and the failure to implement effective strategies in animal feeding are identified as contributing factors. Of particular con- cern is the prevalent use of unbalanced rations heav- ily reliant on concentrated feed at the expense of coarse fodder [7]. To address these pressing chal- lenges, this study proposes the utilization of Cactus Inerme and Atriplex halimus as substitute forage, positing these alternatives as potential solutions.

In the semi-arid and arid steppe regions of Al- geria, traditional livestock breeding practices persist, with local communities predominantly raising goats and sheep [8]. This collaborative effort, often involv- ing women and children, contributes significantly to family income or local markets. The freely grazing animals, sustained by provided fodder and

cropped land after harvest, play multifaceted roles, including milk provision [9]. Extensive research on small ru- minant products, such as milk and meat, underscores their susceptibility to feeding systems [10]. Building on this knowledge, the current experimental study investigates the impact of alternative fodder, specif- ically Cactus Inerme and Atriplex halimus, on milk composition.

MATERIALS AND METHODS

Plant Material. The experiment took place in El-Oued province, Algeria. The Opuntia Ficus In- dica plant was obtained from a private farm in the Bedjene commune of Tebessa province, Algeria. The cactus was harvested at the end of March 2022 and stored in a cool chamber at -5°C. In contrast, Atriplex halimus plants were sourced from Zeribet El-Oued in the Biskra province, also within the same geographical area but under different administration. These plants were collected in early April 2022 dur- ing their flowering stage and similarly stored at -5°C. Additionally, local sources provided barley grains and barley straw for the experiment.

Animals, treatments and experiments. In this study, a total of 24 Barbarine ewes in the lactation period were used as test subjects. This breed pre- dominates in the Oued Souf region and eastern Al- geria, with an age range of 4-6 years old and has been vaccinated against common diseases and parasites. The ewes were randomly allocated into boxes, each containing four animals. The research involved six different treatment groups and the trial took place over a prolonged period of twenty-nine days, from July 10th to August 8th, 2022. The experimental an- imal protocol was approved by the Doctoral Scien- tific Committee of the University of Tiaret. The fol- lowing are the treatment groups:

- Control Group: 0.45 kg of barley and 1.8 kg of barley straw.
- Treatment group 1: 100% cactus (T1)
- Treatment group 2: 75% cactus + 25% Atriplex (T2)
- Treatment group 3: 50% cactus + 50% Atri- plex (T3)
- Treatment group 4: 25% cactus + 75% Atri- plex (T4)
- Treatment group 5: 100% Atriplex (T5).

Chemical Composition of Fodder. In an air oven set to 103°C for 24 h, the principal author dried representative samples from all plants/grains to de- termine dry matter (DM). Then, the samples were ground on a mill using a 0.8-1 mm screen. Following the AOAC 2000 method 942.05 [11], the ash content was determined by placing the DM in a muffle fur- nace at 550°C. Crude protein content was calculated by multiplying the total nitrogen by 6.25. Neutral Detergent Fibre (NDF) and Acid Detergent Fiber (ADF) values were determined following the method outlined by Van Soest and his colleagues [12]. Crude fiber content was analysed according to the Weende method (AFNOR NF V03-40, 1993). For total nitro- gen, the Kjeldahl method was used (AOAC 2005; method 954.01). Finally, the minerals calcium (Ca), phosphorus (P), potassium (K), and magnesium (Mg) were quantified using atomic absorption spec- trometry (AAS) at FATILAB in El Oued.

Milk Sampling and Composition. Milk pro- duction was collected at 7:00 a.m. through manual milking by skilled staff after lambs were separated from their mothers 13 hours before milking. Each ewe was milked before and after the experiment, and samples of milk (50 mL) were collected in sterilized plastic containers for immediate analysis of total protein using the Kjeldahl method [13] and fat using the Gerber method [14]. See FIGURE 1.

Statistical Analysis. Following chemical and milk analysis, data treatment and statistical analysis were conducted using IBM SPSS Statistics software. This software facilitated the calculation of

descrip- tive statistics, including the mean and standard devi- ation, for all measured parameters. Additionally, one-way analysis of variance (ANOVA) was em- ployed to assess the presence of statistically signifi- cant differences between the investigated groups. Following the recommendations of Duncan (1955), a p-value threshold of 0.05 was adopted to determine significance levels.

RESULTS AND DISCUSSION

Comparative Chemical Composition of Cac- tus and Atriplex. The following table (Table 1) demonstrates the findings of the chemical composi- tion of the different fodder employed in the experi- mental study.

Dry Matter (DM) and Ash. The present study revealed a significantly lower DM content in Opun- tia cladodes (14.63%) compared to Atriplex Halimus (42.43%), barley grain (92.28%), and barley straw (91.24%). This finding aligns with previous reports highlighting the high water content of Opuntia, which can reach up to 90% [15, 16]. Conversely, both Opuntia and Atriplex displayed significantly higher ash levels (24.69% and 19.26%, respectively) compared to barley grain and straw (3.5% and 5.4%, respectively). This finding agrees with previous studies reporting high salt content in Atriplex [17, 18]. Researchers have suggested that high ash levels may encourage ruminants to consume additional wa- ter, potentially impacting rumen function [19].

FIGURE 1

Milk Composition Analysis

TABLE 1

The Chemical Composition of the Experimental Feeds (in % DM)

	Atriplex Halimus	***Opuntia Ficus Indica***	**Barley straw**	**Barley grain**
DM	42.43±1.51	14.63±1.5	91.24±0.41	92.28±1.27
OM	80.74±1.3	75.31±1.1	94.6±0.7	96.5±0.15
Ash	19.26±1.17	24.69±0.9	5.4±0.23	3.5±0.4
CF	27.21±1.08	13.37±1.35	48.07±1.75	6.83±1.02
CP	12.87±1.2	4.91±1.4	3.2±0.81	9.8±0.7
K	0.38±0.13	2.91±0.21	1.20±0.11	0.6±0.93
Ca	1.44±0.6	6.81±0.57	0.2±0.37	0.1±0.28
P	0.25±0.2	0.35±0.66	0.12±0.9	0.4±0.76
Mg	0.98±0.56	0.49±0.12	0.11±0.48	0.2±0.14
NDF	50.29±0.85	30.33±2.9	67.8±2.6	25.9±0.8
ADF	35.43±1.34	15.2±1.9	45.4±3.59	6.8±0.57

Each value is the mean of four observations. ±: Standard deviation. DM: dry matter, OM: organic matter, CP: crude proteins, CF: crude fiber. NDF: neutral detergent fiber. ADF: acid detergent fiber. Ca: calcium. P: phosphorus. Mg: Magnesium. K: Potassium.

Crude Protein (CP). The CP content of Opun- tia (4.95%) lies within the range of 3-6% [16], while Atriplex exhibits a considerably higher level (12.87%). However, previous research suggests that the high protein content of Atriplex does not fully translate to its nutritive value as a protein supple- ment. This is because approximately 66% of its total nitrogen is soluble and readily degradable in the ru- men, potentially limiting its protein availability for absorption [20, 21]

Fiber Fractions. The present study found lower concentrations of crude fiber (CF), neutral de- tergent fiber (NDF), and acid detergent fiber (ADF) in Opuntia (13.37%, 30.33%, and 15.2%, respec- tively) compared to Atriplex (12.87%, 27.21%, and 50.29%, respectively). However, the NDF and ADF values for Atriplex are higher than the norm reported in other fodder shrubs [22], which ranged from 30- 45% and 15-29%, respectively [19]. These variations may be attributed to factors such as soil type, plant age, and botanical composition.

Mineral Content. It is noteworthy that Opun- tia exhibited a significantly higher calcium (Ca) con- tent (6.81%) compared to Atriplex (1.44%). This finding corroborates previous observations [23].

TABLE 2

Milk Fat and Protein Content before and after the Supplementation of Treatment Groups

		Control	T1	T2	T3	T4	T5
Fat	Before	7.07 ±0.15^{c}	7.08±0.33^{c}	7.52±0.50^{ab}	7.77±0.55^{ab}	7.22±0.52 ^{ab}	7.82±0.38 ^{a}
	After	7.45±0.31^{c}	5.55±0.40^{c}	8.4±0.78^{c}	9.55±0.51^{b}	10.65±0.59^{a}	10.37±0.75 ^{ab}
Protein	Before	4.3±0.31 ^{a}	4.26±0.15^{a}	4.08±0.09 ^{a}	4.49±0.24 ^{a}	4.5±0.17 ^{a}	4.28±0.43 ^{a}
	After	4.24±0.21^{c}	2.82±0.22^{c}	4.95±0.12^{c}	5.47±0.27 ^{b}	5.95±0.12 ^{a}	5.62±0.47 ^{ab}

Milk Composition. The table above (TABLE 2) shows the results of the milk composition meas- ured before and after the integration of the treat- ments.

The findings showed differences in fat content among the different treatment groups, with Treat- ment Group 4 (T4) having the highest average fat percentage (10.65) and Treatment Group 1 (T1) hav- ing the lowest mean after the integration of treat- ments. Furthermore, the analysis indicated that Treatment 4 (T4) displayed a slightly significant dif- ference in fat percentage when compared to the con- trol group ($p = 0.062$), while no significant differ- ences were observed for the other treatments ($p > 0.05$). In the present study, diets with the highest Atriplex content exhibited the highest fat content (T4 and T5). These findings align with previous research that observed a positive impact of Atriplex inclusion on milk fat content [24]. Another study reported that a diet incorporating Atriplex leaves resulted in firmer cheese compared to other diets, suggesting a potential alteration in milk fat composition [25]. However, others noted a gradual increase in fat con- tent in ewes' milk when fed Atriplex throughout the lactation period, with no significant effect observed due to dietary treatment [26]. Similarly, research on goats found that fat percentages in their milk re- mained unaffected by the type of roughage [27] On another note, our finding that the cactus treatment re- sulted in lower milk fat content (T1) is also in line with previous findings of other researchers who ob- served lower milk fat in she-camels who were fed a high-energy diet [28]. Additionally, recent research highlighted that the low concentrations of dry matter in cactus could compromise the dry matter require- ments of animals, potentially influencing milk pro- tein content [29].

In terms of protein content, the control group showed an average protein content of 4.25, while Treatment Group 4 (T4) displayed the highest mean protein content (5.95), and the lowest mean was noted in Treatment Group 1 (T1). The importance of dietary protein in influencing milk protein content has been widely discussed, emphasizing considera- tion for both the amount and source of dietary pro- tein regarding milk composition [30]. Additionally, the protein content of the diet is known to have a di- rect impact on milk protein levels [31] This

under- scores the significance of dietary protein as a critical factor impacting milk composition. In this regard, our finding that the highest protein content was observed in Treatment Group 4 (T4) aligns with previ- ous research suggesting a positive correlation be- tween protein intake and milk protein content [32], that investigated the effect of feeding Barki ewes with halophytic plants and observed higher protein content in the milk of ewes fed certain plants, indi- cating a potential link between dietary protein sources and milk protein content. Thus, it is feasible to infer that including Atriplex in the Barbarine ewes' diet, because of its high protein content, could poten- tially have increased the milk's protein content. On another note, our finding of the decrease in milk pro- tein in T1 which is the highest in Cactus is also con- sistent with previous studies. For example, a recent study reported a decrease in milk protein percentage was observed when prickly pear cactus peel was sup- plemented at a high dose compared to the treatment of a low dose [33]. The considerable decrease in milk protein content observed in the treatment containing the highest cactus may be attributed to the interaction of phenolic compounds with dietary proteins, poten- tially blocking certain amino acids [34, 35]

CONCLUSION

Our study highlights the significant potential of alternative forages such as Cactus Inerme and Atri- plex halimus in enhancing the milk composition of Barbarine ewes. The positive results we observed, especially the considerable increases in fat and pro- tein content, emphasize the feasibility of incorporat- ing these alternative forage options into livestock di- ets. This not only has implications for improving im- mediate milk quality but also holds broader signifi- cance for sustainable development and resilience in addressing climatic challenges, particularly in semi- arid regions. These findings offer practical benefits for farmers in arid and semi-arid regions to improve their resilience to climate change. By cultivating al- ternative fodders suited to these conditions, farmers can reduce the impact of drought and ensure a relia- ble source of income and food security. Although our research highlights these contributions, it is im- portant to recognise the limitations of the study, such as its regional context and the need for further inves- tigation into long-term effects on livestock health. Future research could focus on refining feeding strat- egies, assessing economic feasibility, and consider- ing the wider ecological implications of integrating

alternative fodders into traditional livestock prac- tices. This would advance our knowledge of sustain- able agricultural practices in arid environments.

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Appendix D

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Effect of using Cladodes of Cactus (*Opuntia Ficus-Indica*) and *Atriplex Halimus* L. as Alternative Diet for Barbarine Pregnant Ewes: Effects on Blood Metabolites

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Abstract

THIS STUDY aimed to determine whether opuntia ficus indica and atriplex halimus-based diets can serve as potential fodder for Barbarine sheep in arid and semi-arid regions. it investigated the effect of using opuntia ficus indica and atriplex halimus l. as alternative diets on blood metabolites of Barbarine pregnant ewes. thirty-six barbarine ewes in their second half of pregnancy were randomly distributed into nine groups the control group included: 0.45 kg barley and 1.8 kg barley straw (d1). ewes in the experimental groups; d2 to d6, were fed barley straw ad libitum with 100% cactus, (75% c+ 25% atriplex), (50% c + 50% atriplex), (25% c + 75% atriplex), 100% atriplex. ewes on d7, d8 and d9 were fed 100% barley straw, 100% atriplex, and 100% cactus respectively. the results revealed a significant decrease in glucose in d8 and a significant decrease in cholesterol in groups d7 and d9 but increased significantly in group 8. triglyceride decreased in d2, d3, d4, d5, d7 and d9 and increased in d8. total protein and albumin decreased slightly in groups: d1, d3, d4 and d5. blood urea and creatinine decreased significantly in groups d7 and d9. the enzymes aspartate transferase and alanine transferase showed a significant decrease in d7 and d9 and a significant increase in d8 after feeding treatment. the results also showed a significant decrease in calcium and phosphorus levels in groups: d7, d8 and d9. it could be concluded that the mixture of opuntia ficus indica and atriplex halimus can be used as alternative diets for Barbarine pregnant ewes with no adverse effects.

Keywords: Atriplex Halimus, Barbarine Ewes, Blood metabolites, Opuntia Ficus Indica, Pregnant Ewes.

Introduction

Semi-arid regions comprise approximately 15% of the world's land surface and are widespread throughout Africa, Eurasia, Oceania, North, South, and Central America [1, 2, 3]. Arid and semi-arid regions suffer from extreme climate conditions such as droughts, irregular rainfall, and deteriorating soils that are all exacerbated by climate change (Food and Agriculture Organization [4,5]. Besides, these regions are home to many of small ruminants facing these difficult conditions and feed scarcity [6, 7]. One of the animal populations inhabiting these environments is the Algerian Barbarine sheep, known for its adaptability to the fragile conditions of arid and semiarid areas [8]. Despite this, the Algerian Barbarine population has suffered from size reductions in recent years [9]. The Algerian government and neighboring North African countries recognised that small ruminant herds were at risk in arid and semi-arid regions and that solutions were required. Consequently, steps were taken towards combatting feed shortage, including the growing extensive lands of cactus crops and Atriplex Halimus in these countries [10, 11]. This was because both plants were reported to be sustainable alternatives to feeding sheep in arid and semi-arid regions [12, 13]. A key characteristic of Cladodes of cacti is its rich supply of energy ingredients and its abundant water supply [14]. *Atriplex halimus* has a high crude protein concentration and neutral detergent of fiber [15, 16]. This study aims to determine whether

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Opuntia and Atriplex-based diets can serve as potential fodder for Algerian Barbarine sheep. It was hypothesised that incorporating an optimal mixture of Cladodes of *Opuntia ficus Indica* and *Atriplex Halimus* in the diet of pregnant Barbarine ewes would not adversely affect blood parameters. In the current global crisis caused by the conflict in Ukraine and the spike in droughts caused by climate change, cereals have become increasingly scarce to meet the needs of both humans and animals. Thus, the current study is timely and will have wide-ranging implications for governments, stakeholders, sheep farmers, and environmental activists. Furthermore, local steppic plants could provide a viable alternative to cereals for small ruminants, and the crisis associated with their importation would be alleviated.

Material and Methods

Location

The study was conducted on a private farm in Bayadha commune, El-Oued province, Algeria. El- Oued is located 700 km southeast of the capital: Algiers, and 80 km from Tunisian borders. The experimental animal protocol was ethically approved by the Laboratory of Agro-biotechnology and Nutrition in Semi-arid Zones, and the scientific committee of the Faculty of Natural and Life Sciences, Tiaret University, Algeria.

Plant Material Collection

The plant Opuntia Ficus Indica was obtained from a private farm based in Bedjene commune, Tebessa province, Algeria. The cladodes of cactus were collected at the end of March 2022, and were stored in a cool chamber at -5 C. *Atriplex halimus* plant was obtained from the steppic zone: Zeribet El- Oued, Biskra province, Algeria. As a point of clarification, both regions belong to the same geographical area but are administered separately. The plants were collected at the beginning of April 2022, at the flowering stage. Similarly, Atriplex was stored at -5 C. Barley grains and barley straw were obtained locally.

Animals, diets and experiments

Thirty-six pregnant Babarine ewes – also named Oued Souf sheep or 'Guebliya' [17]; are characterised by their fat tail [18]; common breed in El-Oued region and the east of Algeria 6-4 – years old; with an initial live body weight 57 + 4.6 kg. The first author of this paper vaccinated the ewes against prevalent diseases and parasites. The ewes were placed in individual digestibility boxes and randomly distributed into nine lots (four each). The ewes have undergone heat synchronization by vaginal sponges (FGA = 20mg (Intervet, France) and PMSG = 300 UI).

The experiment was conducted in two periods, twenty-nine days each (between 25 April- 21 June 2022), following a crossover design. The experiment was carried out in the second half of ewes' pregnancy. Figure 1 shows the experimental design adopted for the current study along with the diets fed to animals. The percentages in the figure represent the following: D1 (500g Barley grain + 1550g barley straw). D2 (5500g cactus + barley straw ad libitum), D3 (4125g cactus + 650g Atriplex+ barley straw ad libitum), D4 (2750g cactus + 1300g Atriplex + barley straw ad libitum), D5 (1375g cactus +1950g Atriplex + barley straw ad libitum), D6 (2600g Atriplex + barley straw ad libitum), D7 (1800g barley straw), D8 (2600g Atriplex), D9 (5500g cactus). The ewes were fed fresh intake and according to INRA (1988) [19].

The ewes received two diets across the two periods: D1 followed by D5; D2 followed by D4; D3 followed by D6. The researchers decided to stop the experiment for the ewes taking: D7, D8 and D9 and eliminate them from the study after the first period to avoid the potential adverse effects of the diets. It has been observed that the ewes in these experimental groups suffered from cachexia and miscarriages.

Chemical Analyses

Representative samples from all plants/grains were dried in an air oven; at 103 C for 24h to determine DM; and ground on a mill with a 0.8-1mm screen. Samples were analysed for Ash by placing DM in a muffle furnace at 550 °C (AOAC 2000; method 942.05) [20]. The crude fiber was determined according to Weende (AFNOR NF V03-40 1993) [20]. Total nitrogen was determined using the method of Kjeldahl (AOAC 2005; method 954.01)
[21] Crude protein was calculated by multiplying the total nitrogen by 6.25. Neutral detergent fiber (NDF) and Acid detergent fiber (ADF) were determined according to Van Soest et al. (1991) [22]. The minerals (Ca, P, K, Mg) were determined by atomic absorption spectrometry (AAS) at FATILAB2 (El Oued).

Blood Sample Collection

The first researcher collected four blood samples (5ml) during both periods: two samples per period; two samples per period and diet were taken. Blood samples were collected through the jugular vein in sterile heparin tubes. The centrifugation of blood was performed at 300 rounds for 10 minutes. Plasma samples were placed in microtubes at -20 C for later analysis. Serum glucose (Glu), total cholesterol (TC), total protein (TP), triglyceride (TG), urea, creatinine (Crea), albumin (AL), Aspartate aminotransferase (AST), Alanine aminotransferase (ALT), calcium (Ca), phosphorus (P) concentrations were analysed

using commercial kits (spinreact kits, Spain), and Beckman Coulter Diagnostic for reading the results.

Statistical Analysis

The data obtained from the chemical analyses were handled using IBM SPSS Statistics software to calculate the mean and the standard deviation as well as one-way analysis of variance (ANOVA). The significant differences were set at $P<0.05$, according to Duncan (1955) [23].

Results and Discussion

Chemical Composition

The obtained data revealed that the cladodes of opuntia have lower dry matter content (14.63%) compared to *Atriplex halimus*, barley grain and barley straw (42.43%, 92.28% and 91.24, respectively). The lower DM content in opuntia can be explained by its high level of water, which can reach 90% [24, 25]. Ash level was higher in Opuntia and Atriplex (24.69% and 19.26%, respectively) compared to barley grain and straw (3.5% and 5.4%, respectively). This result concurs with previous studies reporting that Atriplex contains high salts [26,27]. Researchers have reported that the high level of ash may urge ruminants to consume greater amounts of water, causing consequential influences on rumen functions [27, 28]. Crude protein in Opuntia was found to be within the range stated by Nefzaoui et al. [24]; from 3 to 6%, while it exhibited a higher level in Atriplex (12.87%). Earlier research reported that the high level of protein in Atriplex does not account for the nutritive value they offer as protein supplements, particularly since approximately 66% of its total nitrogen is soluble and degradable in the rumen [26, 28, 29]. CF, NDF and ADF values were lower in Opuntia (13.37%, 30.33% and 15.2%, respectively) [29] compared to Atriplex (27.12%, 50.29% and 35.43%, respectively). The NDF and ADF values reported in the current study showed that they are higher than the norms reported in other fodder shrubs by Ben Salem et al. [15], which were 30-45% and 15- 29%, respectively [28]. This can be explained by the type of soil, the age of the plant and the botanic composition. It is noticeable that Opuntia is high in Ca (6.81%) compared to Atriplex (1.44%). Our finding agrees with those reported in previous work [8].

Blood Parameters of Energy Metabolism

Table 2 shows the blood parameters of ewes in all the experimental groups. The values of Glucose were within the range (0.4 and 0.7g/l) as reported by Haddad [31] before the incorporation of experimental diets. This can be explained by the impact of concentrate ingested before the experiments. Despite remaining within the range, blood glucose levels showed a slight decrease in diets D1, D2, D3, D4, D5, D6 and D7 after the incorporation of experimental feeds. However, a significant decrease was observed in the glucose level of the animals fed D8, but it remained stable in animals fed D9. Plasma glucose is a critical indicator of ruminants' satisfaction with energy needs and provides a rapid assessment of animals encountering different sources of stress [25, 32, 33]. Lower glucose levels in animals fed from D1 to D7; might be due to the stress of changing diets and the status of animals in the second half of pregnancy. Higher levels of Opuntia in D9 preserved plasma glucose stability, which might be attributed to Opuntia plants' therapeutic characteristic and ability to ameliorate glycemic control by blocking the hepatic glucose output, as reported [34]. Our results are consistent with those obtained by Louacini et al. [25], who reported that feeding non-pregnant Rembi ewes 100% Opuntia did not alter blood glucose concentrations. Similar results were reported by an increasing body of research on the incorporation of different levels of cactus into goats' diets [35, 36, 37,7]. Additionally, a similar pattern was observed with cows fed cactus cladodes with different levels of concentrate [38]. However, the present result differs from those obtained by Cardoso et al. [3], who reported that incorporating different levels of spineless cactus (*Nopallea cochenillifera* Salm Dyck) in the diet of male Ines lambs increased serum glucose. Similarly, El Gindy et al. [33] found that serum glucose increased significantly in Barki lactating ewes with low levels of prickly pear cactus peels. According to Deldicque et al. [39] _ who focused on healthy males in their study_ this can be explained by the combination of Opuntia Ficus Indica fruit skin with leucine increasing the rate of glucose appearance from the intestine and liver. Other researchers have reported differences in glucose concentrations based on sampling time. For example, Rekik et al. [40] reported that plasma glucose increased two weeks before lambing and decreased two weeks after lambing in Barbarine ewes. The fluctuation in results regarding plasma glucose of sheep in the reported studies; including the current study, can be explained by the difference in Opuntia concentrate, animals' condition and characteristics.

Glucose concentrations in D3, D4, D5, and D6 _containing Atriplex combined with Opuntia and barley straw_ remained within the range. This result is in line with those obtained by Kewan [28], who reported that feeding Barki ewes fresh Atriplex and silage Atriplex combined with barley grain did not affect glucose concentrations. Similarly, previous research showed that the inclusion of Atriplex with

different concentrates: Opuntia, barley grain, and barley straw; did not affect plasma glucose in lambs and ewes' diets [41, 42]. However, our results do not agree with previous work, which reported increased sanguine glucose levels in Barki ewes-fed Atriplex plants compared to those fed Barseem hay or control diets [27, 43]. On the other hand, plasma glucose decreased significantly in D8 (100% Atriplex feed) to 0.37 g/l, which might be due to a combination of several factors: the Atriplex plant is a high-protein and low-energy feed; the ewes being in late-stage pregnancy and in dire need for high-energy feed.

The concentrations of cholesterol and triglycerides were within the reference range for sheep: (0.52–0.76 g/L); (0.2-0.4 g/l), respectively, according to [44], in the control and experimental groups before incorporating experimental feed. The values of serum cholesterol remained within the range after being fed D1 (control), D2, D3, D4, D5 and D6. But animals in D7 and D9 experienced a significant decrease ($P<0.05$) with mean values of
0.39 and 0.20 g/l, respectively (Table 2), while it increased insignificantly (0.91 g/l) in D8. The values of Triglycerides after incorporating the experimental diets did not alter in the control group (D1) and D6. However, they decreased significantly ($P<0.05$) in D2, D3, D4, D5, D7, D9, and showed a significant increase ($P>0.05$) in D8. Our results regarding the decrease in cholesterol levels in diets rich in Opuntia (D9) are consistent with previous research [25, 33, 42]. This can be due to the interference of pectin in Opuntia with cholesterol synthesis by binding to bile acids [45, 33], which then reinforces cholesterol catabolism [25]. The result of the increase in cholesterol level in D8 concurs with the work of Sabry et al. [46], who studied the impact of feeding *Atriplex lentiformise ad libitum* to Barki male sheep. Unfortunately, we did not estimate fat and carbohydrate concentrations in the Atriplex plant in this study as both constituents significantly influence cholesterol levels [47]—a direction for future studies that might explain this result. It can be concluded that integrating the mixture of Atriplex and Opuntia
regardless of their differing concentrations did not have any adverse effects on cholesterol levels. Our results regarding the decrease in triglyceride levels in Opuntia-based diets are similar to previous research reported by Chilliard et al. [48], who incorporated the cladodes of Opuntia in Wistar mice. This could be due to the interference of pectin with the absorption of lipids [49]. However, the present results differ from other researchers who found no difference in triglyceride levels after the incorporation of Opuntia [3, 7, 37]. Similarly, the increase in triglycerides in Atriplex based diet (D8) is consistent with the results of [42, 43]. This probably could be due to poor nutrition at the critical stage of late-stage pregnancy _ which requires a balanced energy and protein-based diet _ which might have negatively affected the synthesis of triglycerides in the liver.

Blood Parameters of Protein Metabolism

Serum concentrations for total protein (TP) and albumin before and after treatments are summarised in Table 2. After treatment and for ewes in treatment groups: D1, D3, D4, D5; D6 for albumin only; and D7 for protein only, there was a slight but insignificant decrease in TP and albumin values. This could be attributed to the effect of time because a slight decrease was also recorded in the control group (D1). Thus, the treatments introduced in these groups did not affect serum TP and albumin. The finding of the present study on the decrease in TP and Albumin for ewes at the end of pregnancy is similar to previous work [40, 50, 51]. During pregnancy, serum protein concentrations decrease due to foetal growth and especially amino acid utilization by the fetus for protein synthesis [52, 53, 54]. There was a significant decrease in albumin levels for the treatment groups: D2, D7 (25.07 g/l and 20.17 g/l, respectively) and D9 for TP and albumin (52.57 g/l and 16.85 g/l). This finding is consistent with the results obtained by El Gindy et al. [30]. We argue that this is because of the Opuntia- based diet in these treatment groups (particularly D2 and D9). Cladodes of Opuntia are reportedly very low in protein [36], which is also congruent with what we found in the plant's chemical composition (Table 1). Besides colostrum production, mammary epithelial cells use approximately 80% of the nutrients found in blood [40, 55]. On the other hand, there was a significant increase ($P<0.05$) for treatment groups: D6 and D8 for serum TP and D8 for albumin (Table 2.). El Saadani et al. [43] observed a similar pattern of a significant increase in serum total protein between different experimental diets, including *Atriplex halimus* vs Barseem Hay. This could be attributed to Atriplex being high in crude protein (Table 1). Regarding albumin, El Gohary et al. [56] reported a significant increase in plasma albumin in Barki lambs fed a mixture of Acacia and *Atriplex nummularia*. The present result could be explained by albumin coping with salt stress and regulating the body's fluid balance [57]. However, our findings differ from those obtained by Badawi et al. [58], who reported that the Barki lambs fed *Atriplex nummularia* indicated a lower Al/Gl ratio. In addition, Sabry et al. [46] reported that Barki ram fed different *Atriplex lentiformis* rations showed a significant decrease in TP in all groups. To sum up, a balanced blend of Opuntia and Atriplex did not affect blood parameters, while an extreme diet containing any of these plants exhibited adverse effects.

Urea and creatinine concentrations showed no difference after the treatment in groups: D3, D4, D5, D6; D7 in urea only; and D2 in creatinine only. Blood urea and creatinine in these groups were similar to the control group (D1), indicating normal renal functions in animals fed on a mixture of Atriplex and Opuntia. This concurs with the results of [42]. Blood urea concentrations decreased significantly in animals fed the highest Opuntia (D2 and D9), and creatinine decreased significantly in animals fed the barley straw and Opuntia (D2 and D9, respectively). Regarding blood urea, our results are in the same direction as previous research [3, 25, 49]. This might relate to Opuntia's low crude protein [59]. Also, urea blood concentrations decreased significantly in the Atriplex-based diet (D8) with a mean of 0.15 g/l (Table 2). This result aligns with [60], who reported increased blood urea after feeding Atriplex to Barki lambs. The current result reflects a low CP intake [61]. On the other hand, creatinine concentrations decreased significantly in D7, D8 and D9 with means of 6.22 g/l, 5.20 g/l and 5.09 g/l, respectively. Two possible interpretations of this result might be: the negative effect of the less- balanced diets in D7, D8 and D9 compared to the control and the rest of the experimental diets; and the complications of the end of pregnancy in sheep. However, our results differ from others who found no difference in creatinine levels in goats fed spineless cactus [3]. Fayed et al. [60] reported increased creatinine concentrations in Barki lambs fed on a mixture of Alfafa and Atriplex.

Enzyme Metabolism Parameters

Enzymes Aspartate Transferase (AST) and Alanine Transferase (ALT) are important indicators of liver functions. AST and ALT concentrations were not affected in treatment groups: D2, D3, D4, D5; D6 for ALT only, compared to the control group (D1) (Table. 2). The obtained results agree with previous work that incorporated cacti in diets of lambs and lactating ewes [3, 33, 62]. Also, similar findings were obtained by Alhanafi et al. [42] who reported that a mixture of Atriplex and Opuntia did not alter the levels of AST and ALT. Thus, these experimental treatments; which included a mixture of Atriplex and Opuntia; have no adverse effects on the hepatic tissue.

Concentrations of AST and ALT decreased significantly after the treatment in groups: D7 and D9 recorded 53.5 and 42.75 IU / L, respectively, while the corresponding of ALT showed 5.5 and 4.0 IU, respectively. This can be attributed to the non- balanced diet in both groups and the complications of the end of pregnancy. However, AST and ALT concentrations increased significantly ($P<0.05$) after the treatment in D8 and D6 for AST only. Similar results were reported by Sabri et al. [46] and Fayed et al. [60], who reported that feeding Atriplex or a mixture of Atriplex and Alfafa increased serum enzyme AST in Barki lambs than that fed a control diet. Eissa et al. [63] also reported a significant increase in the two enzymes in Barki pregnant ewes fed on Accasia, Cassava and Atriplex. This can be attributed to the high tannins and salt in Atriplex

Blood Parameters of Mineral Metabolism

Regarding blood mineral concentrations, there were no significant changes in treatment groups: D1, D2, D3, D4, D5 and D6. This aligns with previous research [40, 42]. Plasma calcium concentrations increased numerically but remained within the range (90-110) according to Klashing et al. [64] in the following experimental groups: D2, D4, D5 and D6 (Table. 2). The slight increase might be due to the high concentration of calcium in the Opuntia plant, as reported in this study: 6.81% of DM and as was previously reported [8]. It is also noteworthy that earlier researchers have reported that high levels of Ca in blood composition do not reflect its status due to oxalates in the chemical composition of Opuntia [65]. Plasma phosphorus (P) decreased numerically but insignificantly in the control group and the following experimental group: D2, D3, D4, D5 and D6. This was similar to the findings of [37]. Ca and P decreased significantly in experimental groups: D7, D8 and D9. This might be explained by the unbalanced diet in these groups and the critical period of late pregnancy.

Conclusion

This study pinpoints that a measured mixture of Opuntia *Ficus Indica* and *Atriplex Halimus* with barley straw *ad libitum* (namely D2, D3, D4, D5 and D6) can be introduced to pregnant ewes in semi-arid regions, decreasing feeding costs without any adverse effects on health and pregnancy. Besides, a barley straw-alone, Atriplex-alone, or Cactus-alone diet (D7, D8, and D9) risks pregnant ewes' health and body functions, including kidney and liver. Therefore, if mixed at an optimal level, Atriplex and Opuntia plants can be an economical alternative to concentrate diets typically used by sheep keepers in Algeria and similar arid and semi-arid regions.

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Declaration of Conflict of Interest

The authors declare that there is no conflict of interest.

Ethical of approval

No experiments were conducted on animals before getting the ethical approval of the laboratory of Agro-biotechnology and Nutrition in Semi-arid

Zones, and scientific committee at the Faculty of Natural and Life Sciences, Tiaret University, Algeria (ethics approval number; 21/09/2021).

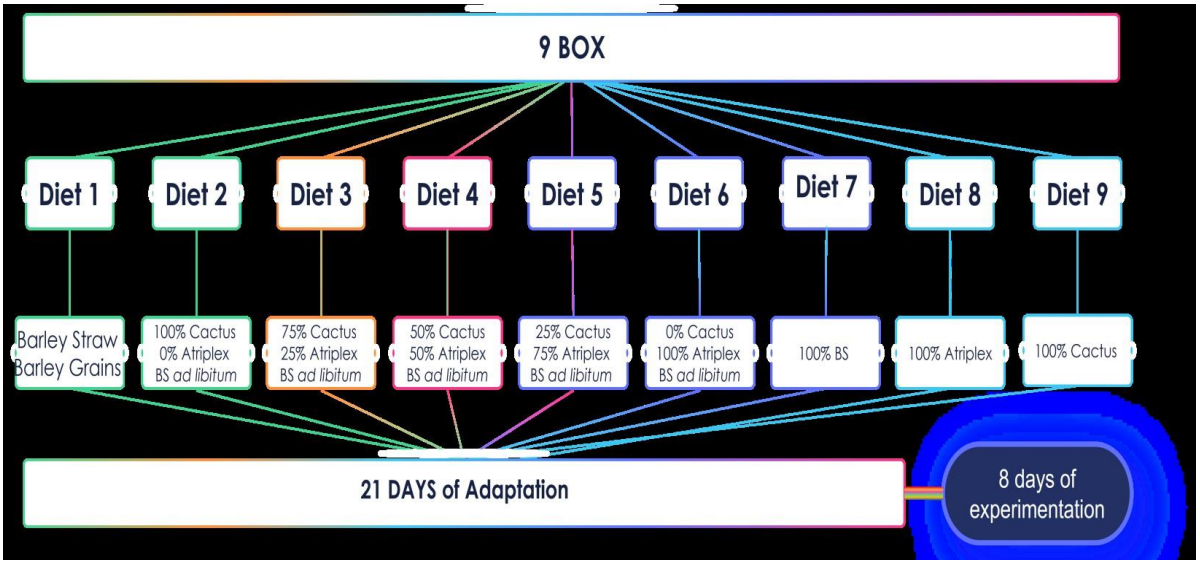

Fig. 1. Experimental design and diets.

TABLE 1. The Chemical Composition of the Experimental Feeds (in % DM)

	Opuntia Ficus Indica	***Atriplex Halimus***	**Barley grain**	**Barley straw**
DM	14.63±1.5	42.43±1.51	92.28±1.27	91.24±0.41
OM	75.31±1.1	80.74±1.3	96.5±0.15	94.6±0.7
Ash	24.69±0.9	19.26±1.17	3.5±0.4	5.4±0.23
CP	4.91±1.4	12.87±1.2	9.8±0.7	3.2±0.81
CF	13.37±1.35	27.21±1.08	6.83±1.02	48.07±1.75
NDF	30.33±2.9	50.29±0.85	25.9±0.8	67.8±2.6
ADF	15.2±1.9	35.43±1.34	6.8±0.57	45.4±3.59
Ca	6.81±0.57	1.44±0.6	0.1±0.28	0.2±0.37
P	0.35±0.66	0.25±0.2	0.4±0.76	0.12±0.9
Mg	0.49±0.12	0.98±0.56	0.2±0.14	0.11±0.48
K	2.91±0.21	0.38±0.13	0.6±0.93	1.20±0.11

Each value is the mean of four observations. ±: Standard deviation. DM: dry matter, OM: organic matter, CP: crude proteins, CF: crude fiber. NDF: neutral detergent fiber. ADF: acid detergent fiber. Ca: calcium. P: phosphorus. Mg: Magnesium. K: Potassium.

TABLE 2. Blood metabolites Concentration for Ewes fed Cactus and Atriplex.

		D1	D2	D3	D4	D5	D6	7D	D8	D9
Glu	before	0.51+- 0.01^{a}	0.54+-0.03^{a}	0.54+-0.04^{a}	0.52+-0.03^{a}	0.53+-0.03^{a}	0.55+-0.03^{a}	0.55+-0.05^{a}	0.53+-0.03^{a}	0.55+-0.05^{a}
	After	0.42+-0.02^{b}	0.45+-0.04^{b}	0.42+-0.05^{b}	0.44+-0.05^{b}	0.43+-0.06^{b}	0.44+-0.04^{b}	0.44+-0.05^{b}	0.37+-0.03^{c}	0.53+-0.05^{a}
TC	before	0.73+-0.08^{a}	0.83+-0.13^{a}	0.62+-0.06^{a}	0.71+-0.13^{a}	0.73+-0.07^{a}	0.74+-0.17^{a}	0.69+-0.09^{a}	0.59+-0.11^{a}	0.74+-0.12^{a}
	After	0.67+-0.15^{a}	0.70+-0.13^{a}	0.60+-0.08^{b}	0.61+-0.10^{b}	0.63+-0.13^{a}	0.73+-0.13^{a}	0.39+-0.05^{b}	0.91+-0.08^{a}	0.20+-0.08^{c}
TG	before	0.30+-0.73^{a}	0.32+-0.75^{a}	0.29+-0.79^{a}	0.30+-0.78^{a}	0.32+-0.92^{a}	0.30+-0.79^{a}	0.35+-0.85^{a}	0.35+-0.83^{a}	0.34+-0.38^{a}
	After	0.30+-0.08^{b}	0.10+-0.02^{c}	0.08+-0.02^{c}	0.13+-0.03^{c}	0.13+-0.02^{c}	0.27+-0.03^{b}	0.14+-0.04^{c}	0.75+-0.04^{a}	0.03+-0.01^{c}
AL	before	34.33+-2.98^{a}	33.21+-4.33^{a}	32.01+-5.11^{a}	32.35+-4.64^{a}	33.10+-3.62^{a}	33.58+-3.35^{a}	34.57+-3.56^{a}	31.07+-3.12^{a}	34.57+-3.56^{a}
	After	32.62+-4.07^{b}	25.07+-5.21^{c}	31.15+-5.61^{b}	30.83+-5.18^{b}	32.12+-4.49^{b}	35.76+-4.27^{b}	20.17+-1.12^{c}	56.25+-5.42^{a}	16.85+-3.62^{c}
TP	before	67.87+-5.86^{a}	76.8+-8.79^{a}	68.15+-5.5^{a}	70.3+-8.35^{a}	68.47+-5.53^{a}	72.32+-8.77^{a}	78.75+-7.22^{a}	70.02+-7.31^{a}	78.12+-5.84^{a}
	After	64.36+-5.82^{b}	70.23+-7.97^{a}	65.20+-3.93^{b}	69.18+-6.70^{b}	66.50+-6.05^{b}	80.65+-8.11^{ab}	63.85+-10.63^{b}	86.85+-4.38^{a}	52.57+-1.43^{b}
Urea	before	0.35+-0.06^{a}	0.35+-0.06^{a}	0.35+-0.06^{a}	0.35+-0.05^{a}	0.35+-0.05^{a}	0.35+-0.05^{a}	0.37+-0.06^{a}	0.35+-0.07^{a}	0.37+-0.05^{a}
	After	0.34+-0.07^{a}	0.17+-0.03^{ab}	0.27+-0.10^{a}	0.30+-0.06^{a}	0.28+-0.08^{a}	0.26+-0.09^{a}	0.28+-0.08^{a}	0.15+-0.02^{ab}	0.04+-0.03^{b}
Crea	Before	11.97+-1.13^{a}	11.45+-2.25^{a}	10.30+-2.02^{a}	10.09+-2.44^{a}	10.31+-2.44^{a}	9.65+-1.72^{a}	12.42+-2.41^{a}	11.08+-1.48^{a}	10.65+-2.49^{a}
	After	11.15+-1.83^{ab}	13.10+-2.56^{a}	11.33+-1.86^{a}	11.83+-2.31^{a}	11.48+-1.94^{a}	11.02+-2.40^{ab}	6.22+-0.79^{b}	5.20+-0.86^{b}	5.09+-1.42^{b}
AST	Before	88.25+-11.04^{a}	101+-12.36^{a}	71.12+-18.37^{a}	79.39+-17.98^{a}	74+-17.09^{a}	85.37+-17.47^{a}	74.5+-10.40^{a}	77+-11.16^{a}	78+-13.68^{a}
	After	78.62+-7.28^{bc}	70.5+-7.46^{bc}	75+-15.74^{bc}	77.62+-2.32^{bc}	102.37+-8.80^{b}	134.5+-30.31^{ab}	53.5+-5.32^{c}	172+-14^{a}	42.75+-6.02^{c}
ALT	Before	10.62+-3.24^{a}	11.37+-3.7^{a}	8.75+-2.12^{a}	12.62+-7.2^{a}	9.62+-2.66^{a}	9.12+-2.85^{a}	9.5+-2.08^{a}	11+-2.16^{a}	10.5+-1.29^{a}
	After	10.37+-2.72^{b}	7.62+-2.82^{b}	9.62+-3.24^{b}	12.37+-6.13^{b}	13.75+-4.83^{ab}	13.87+-4.29^{ab}	5.5+-1.29^{b}	23.25+-3.3^{a}	4+-0.81^{b}
Ca	Before	104.12+-6.17^{a}	96.96+-12.47^{a}	94.86+-10.44^{a}	102.67+-12.10^{a}	95.26+-15.45^{a}	93.63+-12.60a	95.2+-13.77^{a}	103.75+-12.81^{a}	97.22+-19.66^{a}
	After	100.15+-10.59^{ab}	98.21+-12.3^{ab}	93.93+-14.43^{ab}	103.07+-12.58^{a}	502.02+-6.12^{a}	105.12+-8.65^{a}	63.17+-4.91^{b}	74.2+-11.03^{b}	61.2+-5.63^{b}
P	Before	73.75+-16.17^{a}	76.68+-18.38^{a}	75.38+-14.69^{a}	76.89+-15.15^{a}	73.98+-15.70^{a}	65.50+-12.21^{a}	60.06+-11.60^{a}	69+-10.31^{a}	61.26+-15.09^{a}
	After	70.69+-15.26^{ab}	71.92+-12.66^{ab}	78.21+-18.43^{a}	75.36+-13.44^{ab}	68.93+-16.39^{ab}	63.69+-12.46^{ab}	42.15+-7.05^{b}	34.38+-9.29^{b}	28.42+-4.5^{b}

a, b, c: Means with different letters in the same raw are significantly different ($P<0.05$). Serum glucose (Glu), total cholesterol (TC), total protein (TP), triglyceride (TG), urea, creatinine (Crea), albumin (AL), Aspartate aminotransferase (AST), Alanine aminotransferase (ALT), calcium (Ca), phosphorus (P)

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تأثير نبات الصبار)أوبونتيا فيكوس إنديكا(والقطف)أتريبلكس هاليموس إل(كعلف بديل لنعاج البربرين الحوامل على الايض الدموي

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الملخص

تهدف هذه الدراسة إلى تحديد إمكانية استخدام الصبار الهندي (Opuntia Ficus Indica) والقطف (Atriplex Halimus) كعلف بديل لغنم سلالة البربرين في المناطق الجافة وشبه الجافة. حيث تطرقنا إلى دراسة تأثير إضافة الصبار الهندي والقطف على الايض الدموي لمجموعة نعاج حوامل من سلالة البربرين كبديل غذائي في ظل تأثيرات تغير المناخ. تم انتقاء ستة وثلاثون نعجة في النصف الثاني من الحمل وتقسيمهم بشكل عشوائي إلى تسع مجموعات.

تضمنت تغذية المجموعة الضابطة 0,45 كغ من الشعير و1,8 كغ من تبن الشعير (D1) .تم تغذية الأغنام في المجموعات التجريبية من D2 إلى D6 بتبن الشعير حسب الرغبة مع 100% صبار،)75%صبار + 25% قطف(،)50% صبار + 50% قطف(،)25% صبار + 75% قطف(، 100% قطف. تم تغذية النعاج في المجموعات D7 و D8و D9 بتبن الشعير 100%، وقطف 100%، وصبار 100% على التوالي. أظهرت النتائج انخفاضًا ملحوظًا في الجلوكوز في المجموعة D8 وانخفاضًا ملحوظًا في الكوليسترول في المجموعتين D7 و D9 ولكن زاد بشكل ملحوظ في المجموعة D8

انخفض الدهن الثلاثي في المجموعات D2 و D3 و D4 و D5 و D7 و D9 وارتفع فيD8 ، كما انخفض البروتين الكلي والألبومين بشكل طفيف في المجموعات D1 و D3 و D4 و .D5 انخفض اليوريا والكرياتينين في الدم بشكل ملحوظ في المجموعتين D7 و D9 أظهر إنزيمي الأسبارتات الأمينوترانسفيراز والألانين الأمينوترانسفيراز انخفاضًا ملحوظًا في المجموعتين D7 و D9 وزيادة ملحوظة في.D8

كما أظهرت النتائج أيضًا انخفاضًا ملحوظًا في مستويات الكالسيوم والفوسفور في المجموعات D7 و D8 و D9 لذلك، تم استنتاج أن الخليط الأمثل من الصبار الهندي والقطف مع تبن الشعير حسب الرغبة في المجموعات D2 و D3 و D4و D5 و D6 سيكون بديلًا غذائياً مناسبًا للنعاج الحوامل بدون آثار جانبية على صحتها.

الكلمات الدالة :القطف، الصبار الهندي، سلالة البربرين، مؤشرات الأيض الدموي، النعاج الحوامل.

Appendix E

Photos taken during the experiments

Photo 1: Weighting ewes.

Photo 2: Applying the vaginal sponge heat synchronisation

Photo 3: Preparing for the vaginal sponge heat synchronisation

Photo 4: Cutting the cladodes of Opuntia ficus-indica

Photo 5: Cladodes of Opuntia ficus-indica offered to the ewes.

Photo 6: Atriplex halimus offered to the ewes.

Photo 7: Ewes in their metabolism cages.