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Exploring carob and mastic: key forages for sustainable livestock nutrition in northwestern Tunisia

Mlawhi Belgacem
University of Jendouba, Higher School of Agriculture of Kef
Sourour Abidi
university National Institute of Agronomic Research of Tunis (INRAT)
Sadreddine Beji
beji_sadreddine@yahoo.fr

University of Jendouba, Higher School of Agriculture of Kef

Research Article

Keywords: carob, mastic, nutritional value, protein, tannins, northwestern Tunisia

Posted Date: November 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11706161/v1

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Additional Declarations: No competing interests reported.

Abstract

Carob and mastic are multipurpose trees and shrubs that structure Mediterranean silvopastoral systems, where they provide fodder, shade, soil protection and income alongside livestock production, yet their nutritional value as fodder remains poorly documented which limits their integration into agroforestry management. This study investigates the nutritional value of two sylvopastoral species, carob (*Ceratonia siliqua*) and mastic (*Pistacia lentiscus*), by assessing their primary chemical composition and secondary metabolite contents. Samples were collected from three regions in northwestern Tunisia: Béja, Tabarka, and Jendouba. Significant regional variations were observed in the chemical composition of both species. Carob had a higher crude protein (CP) content than mastic (11.40 vs. 9.20% of dry matter, DM), with a maximum of 12.3% DM in carob from the Béja region. Neutral detergent fiber (NDF) did not differ between species, whereas mastic had higher acid detergent fiber (ADF; 29.16 vs. 27.68% DM) and acid detergent lignin (ADL; 23.62 vs. 21.65% DM) contents than carob, indicating higher lignification that could reduce its digestibility and palatability for ruminants. Carob had more total phenols than mastic (0.110 vs. 0.102 g tannic acid equivalent, AT, per kg DM), suggesting better adaptation to arid conditions, where phenolic compounds mitigate oxidative stress. Mastic, however, had significantly more condensed tannins (21.20 vs. 8.85 mg catechin/kg DM), suggesting a stronger defense against herbivores and pathogens. Carob and mastic are promising supplements for livestock diets in northwestern Tunisia, where forage is limited, especially in winter. However, careful management is needed in grazing systems, given the high fiber content of mastic and the impact of tannins on feed intake.

1 Introduction

Forest pastures play an essential role in supporting livestock production in the northwest region of Tunisia, particularly by contributing to the feeding systems of local livestock. However, in recent years, the availability of pastoral and forest species has declined significantly, resulting in low feed quality and, consequently, increased livestock undernutrition. This situation has highlighted the urgent need for alternative and sustainable feed sources. Among the promising species for agro-sylvopastoral systems are carob (*Ceratonia siliqua*) and mastic (*Pistacia lentiscus*), both of which provide considerable socio-economic and ecological benefits in the region.

These two species have developed specialized adaptations to thrive in the harsh environmental conditions of the Mediterranean basin, particularly in arid and semi-arid climates. As documented by Hariri et al. (2009), Bacchetta et al. (2015), and Gharnit and Ennabili (2009), carob and mastic have evolved various strategies to cope with water scarcity and poor soil quality, enhancing their resilience to environmental stress. These adaptive traits, including deep root systems and drought tolerance mechanisms, allow these species to sustain their productivity even in challenging environments.

Besides their capacity for ecological resilience, carob and mastic trees have long been recognized for their wide range of medicinal, agro-food, and nutritional applications. As highlighted by Sbay and

Abourouh (2006), Berrougui (2007), and Pachi et al. (2020), both species have been traditionally used for various human food and medicinal purposes, making them integral components of local agroforestry systems. Moreover, carob and mastic provide valuable forage resources for livestock, particularly ruminants, which play an important role in the economy of Tunisia's mountainous regions. These areas frequently face forage scarcity, particularly during the winter months when traditional pastures become less accessible. This highlights the importance of these tree species as alternative nutritional sources (Belhadj 2003; Ait Chitt et al. 2007).

Carob, in particular, is rich in carbohydrates and fiber but relatively low in protein (6.7% dry matter, DM), with negligible lipid levels (Avallone et al. 1997; Bengoechea et al. 2008). Similarly, mastic trees, particularly those found in Tunisia, are low in protein (ranging from 3.6% to 7% DM). However, they contain secondary metabolites that may act as antinutritional factors (Azouzi et al. 2020). Despite the presence of these compounds, mastic remains a valuable source of supplemental nutrition for livestock.

Additionally, both species are characterized by significant levels of total neutral detergent fiber (NDF), which includes cellulose, hemicellulose, and lignin, as shown by Ayadi et al. (2022). Specifically, carob contains about 55% DM of NDF, while mastic has a slightly lower NDF content of 49% DM. This high fiber content reflects the structural complexity of these plants, which can provide bulk and support the gut health of ruminants, although it may also limit their digestibility.

The primary objective of this study is to provide a detailed nutritional analysis of carob and mastic plants from the governorates of Jendouba and Béja, focusing on their chemical composition. By evaluating their proximate analysis, fiber content, and specific nutritional properties, this study aims to enhance our understanding of the potential of these species as alternative feed sources for livestock. The findings of this research could inform improved management practices and support the development of agro-sylvopastoral systems that enhance livestock nutrition and productivity, particularly in regions facing seasonal feed shortages.

2 Materials and methods

2.1 Plant material

The plant material used in this study consists of mature whole plants of carob (*Ceratonia siliqua*) and mastic (*Pistacia lentiscus*) collected from three regions in northwestern Tunisia. Three samples from each tree were collected and dried in a ventilated oven at 50°C, ground to pass through a 1 mm screen, and stored for subsequent chemical analysis.

The collection sites are located in the governorates of Jendouba (Ras Rajel in Tabarka, and Balta) and Béja (Sidi Ismail) (Table 1). The first area belongs to the humid bioclimatic zone, with an average annual rainfall of approximately 800 mm, while the second and third areas fall within the subhumid bioclimatic zone, with average annual rainfall of 480 mm and 510 mm, respectively.

Table 1
Locations of plant material collection sites

Zone	Latitude	Longitude	Altitude (m)
Ras Rajel	36°57'13"N	8°52'20"E	122
Balta	36°43'03"N	8°57'54"E	431
Sidi Ismail	36°34'22"N	9°09'25"E	221

2.2 Laboratory analyses

Samples of carob (*Ceratonia siliqua*) and mastic (*Pistacia lentiscus*) were analyzed to determine their dry matter (DM), ash (MM, 550°C for 8 h), N (Kjeldahl-N) and ether extract (EE) content, according to the AOAC (1990) method. The wall constituents (NDF, ADF and ADL) were determined as described by Van Soest et al. (1991).

Total phenols, total tannins (expressed as g of tannic acid equivalent per kg of dry matter (DM)) and condensed tannins (expressed as mg catechin/kg DM) were analyzed according to the procedure described by Makkar (2000).

2.3 Calculations and statistical analysis

Organic matter digestibility (OMD) and energy content (UFL: milk forage unit and UFV: meat forage unit) were calculated according to the method described by Chibani et al. (2010), using the following equations:

Chemical OMD (%) = − 0.90 × ADF + 1.177 × ash + 82.25 (1)

UFL = − 0.0192 × ADF + 1.4333 (2)

UFV = − 0.0219 × ADF + 1.4349 (3)

where ADF is the acid detergent fiber content.

Data were subjected to analysis of variance using the GLM procedure of SAS (1992, version 6.07), evaluating the effects of trees (carob and mastic) and regions according to the following model:

$Y_{ij} = \mu + R_i + A_j + e_{ij}$ (4)

where Y_{ij} represents the response variable (e.g., dry matter content, nitrogen content), R_i is the effect of the *i*th region (Jendouba or Béja), A_j is the effect of the *j*th tree species (carob or mastic), and e_{ij} is the residual error term accounting for random variation.

The statistical significance was assessed at the 5% level, with pairwise comparisons and treatment means evaluated using the Least Squares Means (LSMEANS) procedure in SAS. This method provided

insight into how different regions and tree species contribute to variations in nutritional characteristics, allowing for a clear understanding of the geographic and species-specific influences on the nutritional potential of these plants as livestock feed.

3 Results and discussion

3.1 Mastic and carob nutritional composition

The chemical composition, including organic matter (OM), crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and crude fat (CF), is presented in Table 2.

The mastic samples collected in the Béja region exhibited the lowest OM content (93.27% DM), whereas the highest value was recorded in carob samples from Tabarka (94.92% DM). Although significant differences were observed among collection zones ($P < 0.001$), both species showed similar average OM content, reaching 94.19% DM and 94.16% DM for mastic and carob, respectively. These values are considerably higher than those reported for other forages commonly grazed in Tunisia, such as rosemary (88–92% DM) and thyme (90–92% DM).

Table 2
Chemical composition of carob and mastic plants collected from Tabarka, Jendouba, and Béja (% DM)

Item	Carob	Mastic	SE	Pr		
				Tree	Region	Tree × Region
OM	94.16 a	94.19 a	0.128	0.8755	0.0001	0.0558
CP	11.40 a	9.20 b	0.286	0.0002	0.0007	0.1373
NDF	51.89 a	50.73 a	0.577	0.1802	0.0011	0.0001
ADF	27.68 a	29.16 b	0.612	0.0210	0.0001	0.0433
ADL	21.65 a	23.62 b	0.334	0.0013	0.0001	0.0001
CF	2.24 a	3.16 b	0.2583	0.0004	0.3601	0.5746

OM, organic matter; CP, crude protein; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; CF, crude fat. a, b: average values in the same row marked with different letters are significantly different ($P < 0.0001$). SE, standard error of the mean; Pr, probability.

The results highlight a significant difference in protein content (CP) ($P < 0.05$), with carob (11.40%) exhibiting a higher protein content than mastic (9.20%). The collection area also significantly affected this parameter ($P < 0.001$). The highest CP content was observed in plants collected in the Béja region (11.82%), whereas samples from Tabarka and Jendouba regions showed lower CP content, averaging 9.58% and 9.51% DM, respectively.

For both carob and mastic, CP content was higher than the minimum threshold of 7–8% required by Norton (2003) to sustain optimal rumen microbial activity. Specifically, carob harvested from the Béja region revealed a maximum CP content of 12.3% (DM), which is higher than those reported for other forage species.

The high CP content in carob highlights its potential as an important protein source for livestock, particularly during periods when conventional protein supplements are scarce or expensive. Given the rising costs of traditional protein-rich feedstuffs such as soybean or faba beans, carob foliage could represent a valuable and cost-effective alternative feed resource in Tunisian livestock production systems. Furthermore, carob's nitrogen content aligns with its potential role in supplementing nitrogen-deficient diets, making it an important resource in areas with poor soil fertility or low nitrogen fixation capabilities.

However, regional variations should be taken into account when interpreting these results. For instance, Al Gharad (2021) reported lower crude protein content for both carob and mastic in Morocco, ranging from 6.58% to 9.74% DM. Such discrepancies suggest that environmental factors, including soil type, climate, and agronomic practices, can have a significant impact on the protein content of these plants. It is likely that the higher CP content observed in this study reflects the relatively more favorable growing conditions in the northwest of Tunisia, characterized by slightly higher rainfall and more fertile soils compared to the drier regions of Morocco.

Furthermore, both species exhibited similar energy values (Table 3), ranging from 0.67 to 0.69 UFV/kg DM and from 0.75 to 0.76 UFL/kg DM. These values are similar to those reported for forage shrubs commonly used in Tunisia such as *Atriplex* spp., whose energy value ranged from 0.6 to 0.8 UFL/kg DM (Nefzaoui and Chermiti 1991). However, they remain lower than the energy value reported for *Acacia* spp. (0.94 UFL/kg DM) by Selmi et al. (2013).

Table 3
Energy content (UFV and UFL, units/kg DM) and digestible crude protein (DCP, g/kg DM) of carob and mastic

Item	Tree			Region				Pr		
	Carob	Mastic	SE	1	2	3	SE	Tree	Region	Tree × Region
UFV	0.69 a	0.67 a	0.0119	0.68 ab	0.64 a	0.73 b	0.0145	0.2832	0.0043	0.0007
UFL	0.75 a	0.76 a	0.0105	0.77 ab	0.73 a	0.81 b	0.0129	0.2842	0.0037	0.0006
DCP	20.1 a	18.4 b	0.2583	18.8 a	18.6 a	20.4 b	0.3164	0.0004	0.0038	0.2009

UFV, meat forage unit; UFL, milk forage unit; DCP, digestible crude protein. a, b: average values in the same row marked with different letters are significantly different ($P < 0.05$). SE, standard error of the

mean; Pr, probability.

Neutral detergent fiber (NDF), which represents the slowly digestible and indigestible fraction of plant cell walls, ranged from 43.5% DM in mastic collected from Béja to 53.8% DM in mastic collected from Tabarka. Although species had no significant effect on NDF content, collection zone had a significant effect on this parameter ($P < 0.05$). Environmental conditions, particularly high temperatures and low precipitation, may contribute to increased NDF level, as reported by Pascual et al. (2000) and Yerou et al. (2023). NDF is an indicator for total fiber content and is commonly used to predict the voluntary dry matter intake by ruminants. As NDF content increases, dry matter intake generally decreases because the fibrous fraction occupies more space in the rumen and slows its rate of passage.

Acid detergent fiber (ADF), a fiber fraction closely associated with lignification and reduced digestibility, varied significantly according to both species and collection zones ($P < 0.001$). The highest ADF value was recorded in mastic collected from Jendouba (33.82%), followed by samples from Béja (27.4% DM) and Tabarka (26.26% DM). These values are in line with those reported by previous studies, although they remain lower than those reported by Al Gharad (2021) for carob and mastic in Morocco. Acid detergent lignin (ADL) also varied among species and collection zones, reflecting differences in the degree of lignification of the plant material. The ADF and ADL fractions are key indicators of forage quality because they directly affect digestibility and energy availability. Higher ADF and ADL levels are associated with lower digestibility and reduced energy value, as lignin and cellulose are less accessible to rumen microorganisms. Higher ADF and ADL contents observed in mastic suggest a more fibrous and less digestible forage compared to carob, which may reduce its palatability and nutritional value for livestock, especially under limited feed availability.

The significant difference in ADF and ADL content between the two species ($P < 0.01$) may be attributed to variation in environmental conditions across the collection zones. According to Pascual et al. (2000), plants growing under conditions of high temperature and limited precipitation tend to exhibit increased NDF content, greater lignification, and lower solubility. These adaptations generally result in higher lignification and reduced forage digestibility. This explanation aligns with the observed higher fiber content in mastic, particularly in the drier regions such as Jendouba.

Despite their high fiber content, both carob and mastic can be considered valuable forage sources for small ruminants, particularly when integrated into feeding systems that include more digestible forages or concentrate supplements. High NDF and ADF content of these species also suggests that these species may be better suited for grazing systems that incorporate other feed resources, ensuring that ruminants receive a balanced diet that meets their energy and protein requirements.

The fiber contents of carob and mastic observed in this study are consistent with other grazed sylvopastoral species. Boubeuker (2018) reported NDF values of 52.36% for mastic and 64.45% for carob, which are quite similar to those observed in the current study. These findings confirm that, despite the relatively high fiber content, both species remain suitable for ruminant production systems, particularly in sylvopastoral systems, where alternative feed resources are often limited.

Similarly, the ADF values obtained in this study are within the range reported in other species. El Hammadi (2019) reported ADF contents ranging from 18% to 39% in sylvopastoral species such as acacia and rosemary. Therefore, the fiber content in carob and mastic is within the range typically found in other drought-tolerant, woody forage species, and thus, these plants should be considered as suitable components of a diversified grazing system.

Acid detergent lignin (ADL) content, which is negatively correlated with forage digestibility, was highest in mastic harvested from Tabarka (27.51% DM). Overall, the average lignin content in mastic (23.62% DM) was significantly higher than in carob (21.65% DM). These findings corroborate those of Ayadi et al. (2022), who reported similar trends in Morocco.

3.2 Secondary metabolites: total phenols and condensed tannins

Carob showed a significantly higher total phenols content (0.110 g AT/kg DM) than mastic (0.102 g AT/kg DM) (P = 0.0124, Table 4). The difference may be attributed to the greater adaptation of carob to arid environmental conditions, where phenolic compounds play an important role in protecting plants against oxidative stress. These secondary metabolites have strong antioxidant properties and contribute to anti-inflammatory response (Favier 2003).

In contrast, mastic contained a significantly higher level of condensed tannins (21.20 mg catechin/kg DM) than carob (8.85 mg catechin/kg DM) (P = 0.0001). Condensed tannins are important secondary metabolites involved in plant defense, owing to their antimicrobial properties and their capacity to protect plants against fungal and bacterial infections (Wang 2018). In addition to their ecological functions, these compounds may provide significant benefits for animal and human health, particularly the reduction of gastrointestinal infections and the protection of food against oxidative deterioration.

Table 4
Total phenols (TP, g AT/kg DM) and condensed tannins (CT, mg catechin/kg DM) content of carob and mastic

Item	Carob	Mastic	SE	Pr		
				Tree	Region	Tree × Region
TP	0.110 a	0.102 b	0.002	0.0124	0.0001	0.0787
CT	8.85 a	21.20 b	0.381	0.0001	0.0001	0.0017

AT, tannic acid equivalent; SE, standard error of the mean; Pr, probability. a, b: average values in the same row marked with different letters are significantly different (P < 0.05).

The significant differences observed among collection zones for both total phenols and condensed tannins (P = 0.0001) highlight the strong influences of environmental conditions (such as soil composition, water availability, and sunlight exposure) on the biosynthesis of these secondary

metabolites. Studies by Treutter (2010) and Jan et al. (2021) demonstrate that climatic and edaphic factors play a crucial role in regulating the synthesis of these bioactive compounds, which constitute essential components of plant defense strategies against biotic and abiotic stresses.

The phenolic compounds present in carob and mastic may provide additional benefits for livestock. Owing to their antioxidant and anti-inflammatory properties, they can improve immune function, reduce oxidative stress and improve the overall health and resilience in ruminants. Consequently, the incorporation of these plants in grazing systems may contribute to improved animal welfare and disease resistance.

Condensed tannins, a subclass of phenolic compounds, have received considerable attention because of their potential impact on livestock health. These tannins possess anti-herbivory properties, which deter herbivores from grazing on plants, and antimicrobial properties that protect plants from fungal and bacterial infections. However, excessive tannin intake can negatively affect animal performance by reducing feed palatability and forming complexes with dietary proteins, thereby decreasing nutrient digestibility and voluntary feed intake.

In this study, mastic contained significantly higher levels of condensed tannins (21.20 mg catechin/kg DM) than carob (8.85 mg catechin/kg DM). This higher tannin content may have important implications for livestock health. On the one hand, mastic's higher tannin content may provide additional health benefits, such as reduced gastrointestinal infections and enhanced protection against oxidative stress. On the other hand, excessive tannins could reduce feed intake and digestibility, especially in high-tannin diets. This suggests that mastic could be used as a supplementary feed, but care must be taken to avoid overconsumption by ruminants, which could lead to negative effects on growth and overall feed efficiency.

The significant variation in tannin content between carob and mastic among collection zones further emphasizes the influence of environmental conditions on secondary metabolite production. Factors such as soil composition, temperature, and precipitation can affect the biosynthesis of secondary metabolites in plants, including tannins. Consequently, local environmental conditions should be taken into account in the management of these species to optimize their use as forage.

4 Conclusions

This study provides a comprehensive evaluation of the nutritional value of two important sylvopastoral species in Tunisia, carob (*Ceratonia siliqua*) and mastic (*Pistacia lentiscus*). The findings revealed significant variation in their nutritional composition among collection zones, highlighting the influence of environmental factors such as temperature, rainfall, and soil composition.

Both species were relatively high in crude protein (CP) and digestible crude protein contents (DCP), and energy levels (UFV, UFL), confirming their potential as alternative feed resources for ruminants. However, carob showed higher CP and DCP contents than mastic, making it a promising alternative for

supplementing protein-deficient livestock diets. In contrast, mastic presented higher fiber content, particularly in terms of ADF, which may reduce its digestibility and palatability for ruminants. Despite these differences, both carob and mastic can be considered as valuable forage resources when integrated into a diversified grazing system, especially during periods of forage shortages. The profile of secondary metabolites, including phenols and condensed tannins, also differed significantly between species and collection zones. Carob revealed higher content of total phenols, compounds linked to enhanced resistance to environmental stress and oxidative damage, while mastic contained higher levels of condensed tannins, which offer protective benefits such as antimicrobial and antiparasitic effects but may reduce feed intake and nutrient absorption when consumed in excessive amounts. Overall, carob and mastic represent promising forage resources for livestock, particularly in Tunisia's northwest, where conventional forages are often insufficient. By quantifying how the nutritional value of these two species varies between sites, this study supports their deliberate management as fodder components of silvopastoral and agroforestry systems, helping farmers and land managers to buffer winter forage shortages while conserving woody vegetation. However, their use should be carefully managed to balance their nutritional benefits and to avoid any negative effects associated with their high fiber or tannin content. Further studies are needed to optimize the use of these species in grazing systems, considering their regional variability and long-term impact on livestock health and productivity.

Declarations

Funding.

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Author Contribution

Authors contributed equally to this work.

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