

Forage production and quality of key pastoral species browsed by goats in Mediterranean forest rangelands

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goats, rangelands, browse plant, chemical composition, feed value, Morocco

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Summary

Background: The rich pastoral ecosystems, which are widespread in the Mediterranean, are essential for extensive goat farming. Their varied vegetation supplies the necessary nutrients for browsing goats. **Aim:** The aim of the present study was to assess the seasonal variations in the forage availability and nutritional quality of plants browsed by goats in a Mediterranean forest rangeland in northern Morocco. **Methods:** Key pastoral species browsed by goats were sampled seasonally, and their yield, chemical composition and *in vitro* digestibility were determined using standard laboratory analyses. **Results:** The results indicated high variation in the parameters under investigation depending on the grazing season. Total dry matter (DM) yield peaked at 1860 kg DM/ha in spring. Shrubs provided the major contribution to total DM yield throughout the year. The crude protein content ranged between 58 g/kg DM (observed in *Erica arborea* in summer) and 228 g/kg DM (recorded in *Calicotome villosa* in the autumn). With plant maturation, there was a notable increase in fiber fractions, including neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). Condensed tannin content ranged from 2.3 g/kg DM (observed in herbaceous species in spring) to 186 g/kg DM (observed in *Pistacia lentiscus* in summer). Most species exhibited the highest levels of *in vitro* digestibility in spring and the lowest in summer. Some plants, such as *C. villosa*, *Olea europaea*, and *Myrtus communis*, had higher crude protein and digestibility, and lower lignin concentrations throughout the year, making them particularly valuable during the dry season. **Conclusions:** The results show that forage availability and the nutritive value of plant species browsed by goats vary significantly across seasons. Some shrub species maintain relatively good nutritional quality and, therefore, may represent important forage resources for goats in the dry season.

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■ INTRODUCTION

Mediterranean forests have interesting and dynamic ecosystems that underpin wildlife communities, livestock, agricultural practices, and game management (Caballero *et al.*, 2009; Sokos *et al.*, 2013). These forest ecosystems represent an important food source for grazing goats, the most important farm animal in livestock systems in mountain areas in the southern Mediterranean region (Chebli *et al.*, 2021).

The Moroccan forest rangelands represent an integral part of extensive livestock systems, providing unfenced, all-year-round forage opportunities for grazing livestock. It is estimated that about four million goats (equivalent to 70% of the national goat population) depend on the forest pastures for their subsistence. In the mountains, such as the High Atlas and in northern Morocco, the forage provided by the pastures meets about 80% of the livestock's nutritional requirements. In socio-economic terms, goat production in the northern region is extremely important for the local herders, contributing to more than 68% of their farm income (Chentouf *et al.*, 2015). While previous research has examined goat diets in Mediterranean rangelands (Chebli *et al.*, 2022a), much remains unknown about the impact of forage availability and the nutritive value of browse plant species in the southern Mediterranean region, particularly in northern Morocco. So

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far, most studies have focused on a limited range of plant species and/or specific plant parts, without considering the dynamic and seasonal variations in forage availability and quality that markedly affect animal performance. Furthermore, few studies on forage availability and the nutritional value of pastoral species in the forest rangelands of the Bouhachem Natural Park in northern Morocco have been carried out.

Suitable forage management for the purposes of maximizing live-stock productivity requires in-depth insight into forage availability, as well as the chemical composition and digestibility of specific forage plants. Forage quality and availability depend on several parameters, like the age of the plants, environmental conditions, and plant diversity (Movedi *et al.*, 2024).

The aim of the present work was to evaluate seasonal variations in forage availability and to determine the chemical composition and *in vitro* digestibility of the main pastoral plant species browsed by goats in the Mediterranean forest rangelands of northern Morocco.

■ MATERIAL AND METHODS

Study area

This study was performed in a Mediterranean forest rangeland, called *Akerat pasture*, situated in the Bouhachem Natural Park, in northern Morocco (35° 05' N, 5° 18' W).

The soils in the study area are predominantly acidic and derived from siliceous substrates. The site elevation ranges from 510 to 750 m, and the climate is Mediterranean. Both annual and seasonal fluctuations in temperature and precipitation occur between April and June, during the active vegetative growing season. The climate is wet, with a cold winter (3–14°C) and heavy rainfall, and a hot summer (18–38°C). Bouhachem Natural Park is one of the wettest areas in Morocco, with annual rainfall ranging from 1000 to 1400 mm.

In the study area, the main activities are mountain farming and extensive grazing. The forest rangelands are characterized by mountains and unique vegetation types that can only be grazed by goat flocks. Goats often browse shrubs, which supplement their diet during the rainy and drought seasons (Chebli *et al.*, 2022b). The goat population is composed primarily of crossbred and indigenous goats (especially the local north Moroccan breed), that are well-adapted to the mountainous area and the different types of vegetation. Most agricultural activities are concentrated around the farms, reducing pasture access.

Forage availability

The forage availability in the forest rangeland studied was calculated based on the estimated biomass production for all pastoral vegetation in units of kg DM/ha. The data was recorded using the quadrat method during the three principal seasonal grazing periods (spring, summer, and autumn) for the region studied. Winter data were excluded from the seasonal analysis given that grazing is strongly reduced in the study area during this period. Indeed, winter grazing conditions are not representative of the typical browsing dynamics observed during the main grazing seasons.

In the studied forest rangeland, 30 quadrats were placed along three transect lines. According to the height and size of the woody species, the quadrat's size was as follows: for trees and shrubs with a height of less than 1.5 m, an area of 200 m² (20 m × 10 m) was used; for herbaceous species, the quadrat was 1 m² (1 m × 1 m).

Forage quality

For each plant species, samples were collected from the plant parts selected by local goats as observed by Chebli *et al.* (2022b). The plant organs consumed vary depending on plant phenology and season. The main browsed parts of each species across seasons are presented in Table I.

For each plant species and each grazing season, three replicate samples were collected and analyzed to determine chemical composition and tannin content. Samples were dried in an oven at 40°C ± 1°C until a constant weight was reached to avoid any technical changes in tannin activity and content (Makkar & Singh, 1991). The dried samples were then ground through a 1-mm screen.

The crude protein (CP), ether extract (EE), and organic matter (OM) were measured as described by the AOAC (Association of Official Analytical Chemists Method, 1997). Total nitrogen (N) was determined following the Kjeldahl method (AOAC 984.13), and CP was calculated by multiplying N by 6.25. The Soxhlet extraction method was used to determine EE (AOAC 920.39). The OM was estimated by ashing in a muffle furnace at 550°C for eight hours (AOAC 942.05).

Fiber components were determined according to the Van Soest detergent system and expressed as neutral detergent fiber (NDF), acid detergent fiber (ADF), and acid detergent lignin (ADL). These parameters represent detergent fiber fractions rather than crude fiber.

Table I: Seasonal plant parts browsed by goats for the main pastoral species in the Mediterranean forest rangelands of northern Morocco
/// Parties des plantes consommées par les chèvres selon les saisons, pour les principales espèces de bétail dans les pâturages forestiers méditerranéens du nord du Maroc

Plant species	Spring	Summer	Autumn
<i>Arbutus unedo</i> L.	Young leaves, tender shoots	Mature leaves, young shoots	Leaves, ripe fruit
<i>Calicotome villosa</i> (Poir.) Link	Young shoots, leaves, flowers	Leaves, green stems	Leaves, pods
<i>Cistus crispus</i> L.	Young leaves, tender shoots	Leaves	Leaves, young shoots
<i>Cistus monspeliensis</i> L.	Young leaves, shoots	Leaves	Leaves
<i>Cistus salviifolius</i> L.	Young leaves, shoots	Leaves	Leaves
<i>Erica arborea</i> L.	Young shoots, leaves	Leaves, tender stems	Leaves, young shoots
<i>Lavandula stoechas</i> L.	Leaves, flowers, tender shoots	Leaves	Leaves
<i>Myrtus communis</i> L.	Young leaves, shoots	Leaves	Leaves, berries
<i>Olea europaea</i> L.	Young leaves, shoots	Leaves	Leaves, fruit (when available)
<i>Pistacia lentiscus</i> L.	Young leaves, shoots	Leaves	Leaves, fruit
<i>Quercus coccifera</i> L.	Young leaves, shoots	Leaves	Leaves, acorns

NDF, ADF, and ADL were analyzed using an ANKOM fiber analyzer (ANKOM 200 Technology, US), and expressed including residual ash. The NDF content was determined as defined by the Mertens method (2002). The ADF and ADL were estimated using the AOAC method 973.18 and the Robertson and Van Soest method (1981). The condensed tannins (CT, g/kg of DM) were quantified according to the reagent method using butanol-HCl and ferric reagent and expressed as leucocyanidin equivalents (Porter *et al.*, 1985).

DM digestibility (IVDMD) and OM digestibility (IVOMD) were estimated using the DAISYII Incubator (ANKOM Technology Corporation, US). Rumen fluid was collected from the rumen of five donor goats slaughtered at a collective slaughterhouse close to the laboratory. The slaughtered goats had browsed similar available tree and shrub species in forest rangelands within the study area. A set of ruminal fluid was placed in pre-warmed thermos flasks at 39°C to preserve the viability and diversity of the rumen microbiota, and was used promptly for incubation (El Otmani *et al.*, 2019). Blank bags were included in each DAISYII incubation run to correct for bag residues.

Statistical analyses

Forage availability and quality were analyzed using one-way ANOVA (with season as a factor) according to the general linear model (GLM) procedure in SAS, based on the following statistical model:

$$Y_{ij} = \mu + S_i + e_{ij}$$

Where Y_{ij} is forage quality (chemical composition or digestibility); μ is the overall mean; S_i is the fixed seasonal effect (spring, summer, and autumn); e_{ij} is the residual error.

Correlation analysis was used to establish the relationships between the chemical composition and digestibility. All tests were done at a significance level $p < 0.05$. In cases where the effects were significant, a post-hoc test (Tukey) was then conducted to compare means. In addition, nutritional data were analyzed using Principal Component Analysis (PCA) on standardized variables to evaluate botanical and seasonal effects. To track seasonal stability, nutritional trajectories were modeled using species-specific centroids for each season. The degree of variation was quantified by the Euclidean distance between seasonal coordinates in the PCA space.

RESULTS AND DISCUSSION

Forage availability

Forage availability in the forest rangeland studied is distinctly seasonal and modulated primarily by the vegetation's growing cycles and climatic conditions (Figure 1). Total DM production peaked at 1860 kg DM/ha in the spring, which coincides with optimal conditions for plant growth. In contrast, production drops to 1134 kg DM/ha in summer and 724 kg DM/ha in the autumn, mainly due to lower rainfall and higher temperatures in summer, and the gradual perishing of biomass resources in the autumn.

The DM patterns show that shrubs contribute more than 85% of the overall DM production throughout the year. They provide the main source of forage in the spring when productivity is highest, but also play a major role when forage availability is declining in other seasons. *A. unedo*, *C. salviifolius*, *E. arborea*, and *P. lentiscus* consistently contribute to biomass regardless of the time of the year. Their seasonal resilience means they are important in the grazing environment. Indeed, like any legumes, they can provide forage even during drought periods. This may be due to their deep root systems or their adaptation to Mediterranean climates, where the capacity to resist long dry periods is a prerequisite for survival. Different plant species provide forage at different times of the year in Mediterranean forest pastures. A study in this region has shown the selectivity of goats for shrubs and trees across the seasons (Chebli *et al.*, 2022a).

Herbaceous plants showed high seasonality, achieving peak production at 167 kg DM/ha in spring, which corresponds to the optimal vegetation period for annual and perennial species in Mediterranean systems. Their available biomass is reduced to 50 kg DM/ha during the autumn because of summer aridity and natural aging in herbaceous species, which limit their contribution to fodder during the drier months.

Nutritional value of pastoral species

The studied pastoral vegetation included several shrub, tree, and herbaceous species, whose nutritional characteristics and contribution to forage availability differ. These species show contrasting levels of CP, fiber fractions, and digestibility (Table II) (Kökten *et al.*, 2012).

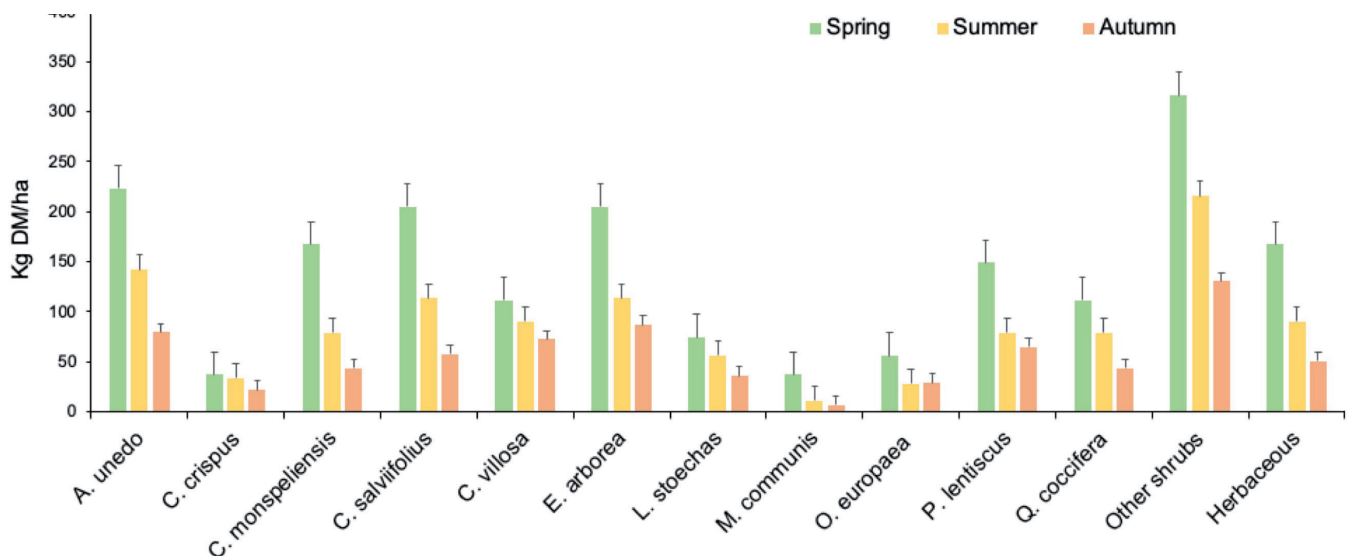


Figure 1: Seasonal changes in forage availability (Kg DM/ha) for each plant species in a Mediterranean forest pasture in northern Morocco
 /// Variations saisonnières de la disponibilité fourragère (kg de matière sèche/ha) de chaque espèce végétale dans un parcours forestier méditerranéen du nord du Maroc

Table II: Chemical composition (g/kg DM) and *in vitro* digestibility (g/kg DM) of pastoral species selected by goats in a Mediterranean forest pasture in northern Morocco /// *Composition chimique (g/kg de matière sèche) et digestibilité in vitro (g/kg de matière sèche) d'espèces fourragères sélectionnées par des chèvres dans un parcours forestier méditerranéen du nord du Maroc*

Plant species	Seasons	DM	OM	EE	NDF	ADF	ADL	CP	CT	IVDMD	IVOMD
<i>Arbutus unedo</i>	Spring	550 ^b	972 ^a	71.6 ^b	349 ^c	245 ^c	107 ^b	82.0 ^a	89	678 ^a	632 ^a
	Summer	652 ^a	968 ^a	92.6 ^a	500 ^a	314 ^b	186 ^a	61.3 ^b	114	570 ^b	509 ^b
	Autumn	447 ^c	951 ^b	61.3 ^b	470 ^b	341 ^a	168 ^a	67.0 ^b	110	466 ^c	404 ^c
	SEM	7.22	2.31	6.06	7.64	7.37	2.85	5.51	1.20	30.9	6.18
	p-Value	***	*	*	***	***	*	*	N.S	***	***
<i>Calicotome villosa</i>	Spring	236 ^c	924 ^b	31.6	522 ^c	415 ^b	94.7 ^c	184	3.83	586 ^a	537 ^a
	Summer	489 ^a	978 ^a	26.3	622 ^a	462 ^a	128 ^a	188	2.87	479 ^b	429 ^b
	Autumn	371 ^b	927 ^b	31.3	600 ^b	407 ^c	107 ^b	228	3.69	402 ^c	352 ^c
	SEM	7.97	10.8	3.48	8.82	9.85	1.76	15.1	1.29	26.9	10.1
	p-Value	***	*	N.S	***	***	***	N.S	N.S	***	***
<i>Cistus crispus</i>	Spring	418 ^b	935 ^a	15.5 ^b	304 ^b	259 ^a	103 ^c	116 ^a	14.7 ^c	686 ^a	638 ^a
	Summer	534 ^a	947 ^a	23.3 ^a	255 ^c	202 ^b	142 ^b	68.0 ^c	66.0 ^a	454 ^c	402 ^c
	Autumn	356 ^c	915 ^b	16.1 ^b	377 ^a	242 ^a	167 ^a	77.0 ^b	56.7 ^b	544 ^b	487 ^b
	SEM	5.49	2.65	1.13	10.8	4.41	6.43	6.43	4.84	33.9	2.19
	p-Value	***	*	***	***	**	***	***	***	***	***
<i>Cistus monspeliensis</i>	Spring	584 ^b	900 ^c	56.6 ^c	376 ^c	210	147	107 ^a	45.0 ^c	621 ^a	578 ^a
	Summer	686 ^a	943 ^a	92.3 ^a	484 ^a	252	158	85.7 ^b	62.3 ^b	444 ^c	395 ^c
	Autumn	375 ^c	925 ^b	86.6 ^b	429 ^b	270	170	65.0 ^c	79.7 ^a	528 ^b	484 ^b
	SEM	7.31	3.84	2.96	5.69	36.2	34.5	9.24	8.69	25.5	3.38
	p-Value	***	***	**	***	N.S	N.S	*	*	***	***
<i>Cistus salviifolius</i>	Spring	490 ^a	884 ^b	25.6 ^c	413 ^c	220 ^c	141 ^c	113 ^a	28.3 ^c	633 ^a	584 ^a
	Summer	452 ^b	857 ^c	61.6 ^a	511 ^a	347 ^a	224 ^a	83.3 ^b	78.3 ^a	470 ^c	418 ^c
	Autumn	376 ^c	903 ^a	42.3 ^b	472 ^b	269 ^b	210 ^b	74.7 ^b	59.0 ^b	499 ^b	435 ^b
	SEM	3.18	3.28	6.12	4.10	5.13	2.89	6.17	3.06	25.2	6.94
	p-Value	***	**	***	***	***	***	**	***	***	***
<i>Erica arborea</i>	Spring	570 ^b	950	93.0 ^a	427 ^c	317 ^c	206 ^c	88.7 ^a	109	510 ^a	489 ^a
	Summer	644 ^a	953	85.3 ^b	534 ^b	406 ^b	316 ^a	58.0 ^c	116	373 ^c	318 ^c
	Autumn	506 ^c	952	49.3 ^c	571 ^a	434 ^a	295 ^b	66.0 ^b	122	482 ^b	417 ^b
	SEM	10.3	7.22	7.62	5.93	11.9	4.48	5.51	7.06	21.1	2.65
	p-Value	***	N.S	***	***	***	***	***	N.S	***	***
<i>Lavandula stoechas</i>	Spring	270 ^c	954 ^a	87.7 ^a	413 ^b	239 ^c	153 ^c	115 ^a	3.10	734 ^a	696 ^a
	Summer	479 ^a	940 ^b	32.3 ^b	522 ^a	308 ^a	214 ^a	79.0 ^b	4.07	531 ^c	487 ^c
	Autumn	414 ^b	907 ^c	33.3 ^b	441 ^b	278 ^b	196 ^b	71.3 ^b	2.77	564 ^b	512 ^b
	SEM	5.17	2.65	1.86	7.09	5.81	3.84	2.67	0.26	31.6	6.39
	p-Value	***	***	***	*	***	***	***	N.S	***	***
<i>Myrtus communis</i>	Spring	556 ^a	952	46.3 ^a	369	217	111	87.3 ^a	101 ^c	566 ^a	492 ^b
	Summer	541 ^b	947	48.0 ^a	371	210	97.0	74.0 ^b	130 ^a	593 ^a	555 ^a
	Autumn	447 ^c	944	23.3 ^b	346	237	83.7	86.3 ^a	119 ^b	553 ^b	503 ^b
	SEM	4.81	6.36	1.20	6.39	8.82	3.53	2.33	4.84	7.29	2.89
	p-Value	***	N.S	***	N.S	N.S	N.S	*	**	*	***
<i>Olea europaea</i>	Spring	463 ^a	957 ^a	90.0 ^b	403 ^c	237	150	75.7	4.53 ^a	539 ^b	479 ^b
	Summer	434 ^b	915 ^b	131.3 ^a	454 ^a	273	144	79.3	2.57 ^c	593 ^a	520 ^a
	Autumn	422 ^c	904 ^b	72.7 ^c	434 ^b	271	154	86.7	3.70 ^b	581 ^a	529 ^a
	SEM	5.36	2.52	4.70	3.00	7.88	3.71	2.85	0.06	8.80	4.48
	p-Value	***	***	***	***	N.S	N.S	N.S	**	**	***

Table II (continued): Chemical composition (g/kg DM) and *in vitro* digestibility (g/kg DM) of pastoral species selected by goats in a Mediterranean forest pasture in northern Morocco /// *Composition chimique (g/kg de matière sèche) et digestibilité in vitro (g/kg de matière sèche) d'espèces fourragères sélectionnées par des chèvres dans un parcours forestier méditerranéen du nord du Maroc*

Plant species	Seasons	DM	OM	EE	NDF	ADF	ADL	CP	CT	IVDMD	IVOMD
<i>Pistacia lentiscus</i>	Spring	553 ^c	958 ^a	26.3	445	261 ^a	109 ^b	90.3 ^b	174	550 ^a	495 ^a
	Summer	626 ^a	927 ^b	26.7	467	241 ^b	155 ^a	90.3 ^b	186	504 ^b	438 ^c
	Autumn	594 ^b	956 ^a	25.0	441	262 ^a	153 ^a	107 ^a	172	525 ^a	446 ^b
	SEM	4.16	3.28	1.15	9.61	6.64	2.96	2.91	10.1	7.53	6.43
	p-Value	***	***	N.S	N.S	*	***	*	N.S	**	***
<i>Quercus coccifera</i>	Spring	563 ^c	932 ^b	18.3 ^c	483 ^c	333 ^b	120 ^b	94.3 ^a	22.3	628 ^a	575 ^a
	Summer	663 ^a	961 ^a	27.3 ^a	543 ^a	382 ^a	155 ^a	63.7 ^b	29.3	470 ^b	411 ^c
	Autumn	636 ^b	943 ^b	23.5 ^b	537 ^b	395 ^a	167 ^a	70.0 ^b	24.0	492 ^b	439 ^b
	SEM	8.00	1.00	0.50	1.50	6.00	11.0	7.00	5.00	25.1	16.5
	p-Value	***	*	**	***	***	*	**	N.S	***	***
Herbaceous	Spring	458 ^c	915 ^a	22.6	515 ^b	335 ^a	60.0 ^b	161 ^a	2.30	837 ^a	788 ^a
	Summer	636 ^a	864 ^b	22.3	550 ^a	353 ^a	75.3 ^a	76.3 ^b	3.93	687 ^c	646 ^b
	Autumn	502 ^b	867 ^b	23.0	456 ^c	237 ^b	57.7 ^b	59.7 ^c	3.70	771 ^b	689 ^b
	SEM	2.03	15.4	1.15	5.24	6.96	4.06	2.85	0.57	22.1	6.96
	p-Value	***	*	N.S	***	***	*	***	N.S	***	***

DM: dry matter; OM: organic matter; CP: crude protein; CT: condensed tannins; EE: ether extract; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: lignin; IVDMD: *in vitro* dry matter digestibility; IVOMD: *in vitro* organic matter digestibility; SEM: standard error of the means. Values in the same row followed by different letters differ significantly ($p < 0.05$) /// DM : matière sèche ; OM : matière organique ; CP : protéines brutes ; CT : tanins condensés ; EE : extrait éthéré ; NDF : fibre au détergent neutre ; ADF : fibre au détergent acide ; ADL : lignine ; IVDMD : digestibilité in vitro de la matière sèche ; IVOMD : digestibilité in vitro de la matière organique ; SEM : erreur-type des moyennes. Les valeurs d'une même ligne suivies de lettres différentes présentent des différences significatives ($p < 0,05$)

The seasonal variations in the chemical composition and *in vitro* digestibility of the plant species ingested by goats were studied in a representative forest of northern Morocco. These plant species included *Arbutus unedo*, *C. villosa*, *Cistus spp.* (*Crispus*, *monspeliensis*, and *salviifolius*), *Erica arborea*, herbaceous species (e.g., perennial grasses and legumes), *Lavandula stoechas*, *Myrtus communis*, *Olea europaea* var. *sylvestris*, *Pistacia lentiscus*, and *Quercus coccifera*. Results showed strong seasonal effects on nutritional properties determined by the interactions of CP, fiber components, CT, and digestibility properties.

During the growing season, a gradual and systematic increase in the DM of plant and tree species is generally observed from spring to summer. DM production peaks in summer, when plants reach maturity and moisture content is low, which aligns with previous works by Ammar *et al.* (2004) and Kökten *et al.* (2012). Similar increases in DM concentration during dry seasons in Mediterranean silvopastoral systems have been shown in other studies, particularly in open forest rangelands. This pattern reflects plant responses to seasonal variations in moisture (Kökten *et al.*, 2012; Chebli *et al.*, 2021). There was a significant variation in DM content, with higher percentages generally in spring ($p < 0.05$), reflecting better forage quality at this time of year. The OM variation corresponds to previous studies on other Mediterranean pastures and shows that the spring is conducive to high-quality forage availability (Nefzaoui & Ben Salem, 2002).

There was a high variation in plant CP levels in the spring, with the maximum values recorded in *C. villosa* (184-228 g/kg DM). In the summer, however, the concentration of CP decreased substantially due to lignification in plants and lower nitrogen content. The herbaceous species identified were significant in terms of CP content, reflecting their essential role in the goats' diet in spring. In Mediterranean woody plants, we also observed seasonal decreases in the CP level, suggesting that phenological variations affect forage quality (Chebli *et al.*, 2021). EE varied with the seasons ($p < 0.05$). The

maximum and minimum EE contents were in *O. europaea* in summer (131.3 g/kg DM) and in *C. crispus* in the spring (15.5 g/kg DM), respectively. The increase in lipid levels during the summer may reflect plant physiological responses to drought and heat stress. The authors of a study on Mediterranean shrubs suggest that enhanced lipid levels may offset the impact of low digestibility due to higher crude fiber (Mole *et al.*, 1988).

The detergent fiber fractions (NDF, ADF, and ADL) found in plants, such as *E. arborea* and *Q. coccifera* were higher during the summer ($p < 0.01$ for NDF, ADF, and ADL), than in other seasons. The high fiber fraction (primarily lignin content) decreased the digestibility of these species. For instance, *E. arborea* contained over 200 g/kg DM of lignin throughout the year, which contributes to its low digestibility. In the dry summer, the high rates of fiber reduce plant digestibility, making browsing difficult for goats. This finding corresponds to an earlier report on Mediterranean rangelands (Khazaal *et al.*, 1993). With the exception of *C. monspeliensis*, *C. villosa* and *O. europaea*, most species had higher levels of CT in the summer ($p < 0.01$), especially *P. lentiscus*, *A. unedo*, *E. arborea*, and *M. communis*, with values exceeding 100 g/kg DM. Moderate concentrations of CT, like other secondary metabolites, have beneficial health effects, including anthelmintic effects. In contrast, excessive CT levels can negatively affect protein utilization and reduce overall digestibility (Min *et al.*, 2003). The seasonal increases in CT found in this study are similar to other findings from Mediterranean regions (Mueller-Harvey, 2006), where plants generally produce more tannins during the dry period to cope with the harmful effects of drought. IVOMD and IVDMD were highest in spring and lowest in summer ($p < 0.001$) for most species (except *A. unedo*, *C. villosa*, *M. communis*, and *O. europaea*). IVOMD for herbaceous species, *A. unedo*, *C. crispus*, and *L. stoechas* exceeded 630 g/kg in spring, with IVDMD values ranging from 678 to 734 g/kg. In contrast, during the summer, both IVDMD and IVOMD significantly decreased for fibrous and CT-rich species, such as *C. monspeliensis*

and *C. salviifolius*. Seasonal declines in the digestibility of many Mediterranean browse species have been widely reported (Nefzaoui & Ben Salem, 2002). The decrease in the nutritive value of these plant species is due to the high lignin content, which limits the access of microbiota to the plant's cell wall, thereby reducing digestibility.

Chemical composition and in vitro digestibility correlation

The correlation analysis revealed significant relationships between the chemical composition parameters and nutritional values of the plant species studied. All fiber fractions were highly correlated with each other, with NDF positively correlated with both ADF ($r = 0.85$, $p < 0.01$) and ADL ($r = 0.75$, $p < 0.01$). Negative significant correlations were observed for digestibility parameters with fiber components. IVOMD was negatively correlated with ADF ($r = -0.75$, $p < 0.01$) and NDF ($r = -0.70$, $p < 0.01$), indicating that a higher fiber content reduces the digestibility of plant material. A negative correlation between fiber content and the digestibility of browsed plant species was also reported by Ammar *et al.* (2004). As mentioned above, this negative correlation can be explained by the fact that fibers, essentially lignin, limit the access of microbiota to OM, which affects digestibility.

Moderate negative correlations ($r = -0.45$ to -0.55 , $p < 0.05$) were found between CP and fiber components, suggesting lower levels of CP in high-fiber species. Overall, forage species with higher crude protein and digestibility, and a lower fiber content are more likely to be selected by goats, as reported in the literature (Chebli *et al.*, 2021).

Condensed tannins showed moderate correlations with some nutritional parameters, particularly CP and digestibility, suggesting potential negative effects on protein utilization and the overall nutritive value of the plants. Overall, weak relationships were observed ($r < 0.40$) between OM and DM content and most parameters, which suggests that these fundamental composition parameters are not

strongly correlated with the most relevant nutritional quality indicators. These results may shed light on the interrelationships between chemical composition and other parameters that could contribute to predicting the nutritive value of Mediterranean species.

Multivariate analysis of nutritional dynamics and seasonal trajectories

Beyond individual nutrient fluctuations, the global nutritional behavior of each species was captured through a multivariate lens. By projecting these profiles into a reduced-dimension space, we were able to characterize the stability of certain botanical taxa versus the high plasticity of others throughout the seasonal cycle. The PCA explained 55.15% of the total variance through the first two axes (PC1: 32.65%; PC2: 22.50%). The variable correlation circle (Figure 2A) indicates that PC1 is primarily defined by the opposition between fiber fractions (NDF, ADF, and ADL), located on the positive side, and digestibility on the negative side. PC2 is mainly influenced by organic matter (OM) and secondary metabolites, such as condensed tannins (CT).

The analysis of seasonal trajectories (Figure 2B) reveals two distinct nutritional adaptation patterns among the studied species:

High nutritional stability species: *P. lentiscus*, *M. communis* (ID 9), and *O. europaea* (IDs 9, 10, and 11) exhibited the shortest trajectories (Variation Indices < 1.25). Their nutritional profiles remained remarkably constant despite seasonal shifts. Thus, they were identified as reliable "buffer" forage resources during critical periods.

High seasonal variability species: *C. crispus*, *E. arborea*, and *C. monspeliensis* (IDs 3, 4, and 6) showed the greatest variations (Variation Indices > 4.60). Their trajectories stretched significantly toward the positive side of PC1 during the spring to summer transition, indicating rapid lignification and a severe decline in nutritive value during the dry season.

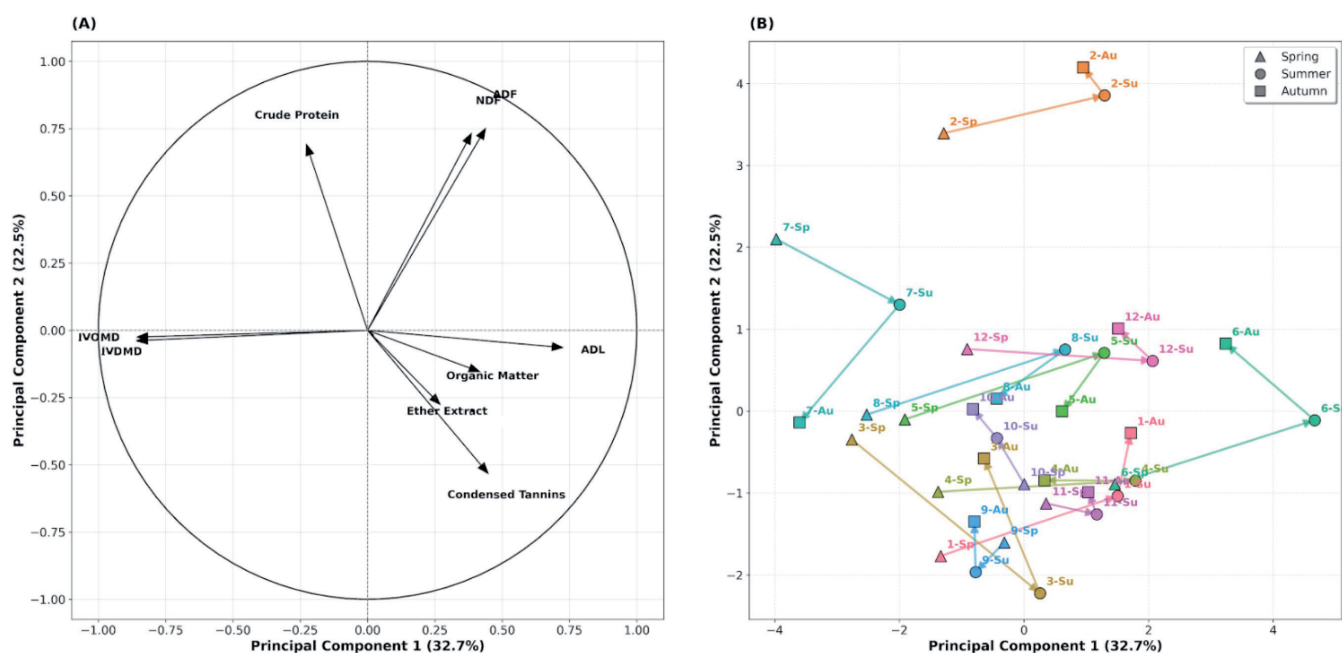


Figure 2: Multivariate assessment of nutritional variability. (A) Correlation circle of nutritional parameters on the first two principal components; (B) Seasonal nutritional trajectories of species centroids (Sp: Spring, Su: Summer, Au: Autumn). Species ID: 1: *A. unedo*, 2: *C. villosa*, 3: *C. crispus*, 4: *C. monspeliensis*, 5: *C. salviifolius*, 6: *E. arborea*, 7: *Herbaceous*, 8: *L. stoechas*, 9: *M. communis*, 10: *O. europaea*, 11: *P. lentiscus*, 12: *Q. coccifera* /// Analyse multivariée de la variabilité nutritionnelle. (A) Diagramme de corrélation des paramètres nutritionnels sur les deux premières composantes principales ; (B) Trajectoires nutritionnelles saisonnières des centroïdes des espèces (Sp : printemps, Su : été, Au : automne). Identifiants des espèces : 1 : *A. unedo*, 2 : *C. villosa*, 3 : *C. crispus*, 4 : *C. monspeliensis*, 5 : *C. salviifolius*, 6 : *E. arborea*, 7 : *Herbacées*, 8 : *L. stoechas*, 9 : *M. communis*, 10 : *O. europaea*, 11 : *P. lentiscus*, 12 : *Q. coccifera*

These results demonstrate that the pastoral value of the study area depends not only on species richness, but specifically on the presence of “stable” species. These species are capable of providing a supply of baseline nutrition throughout the summer, unlike “variable” species, which are strictly seasonal.

From an animal management perspective, the seasonal decline in crude protein and digestibility during summer suggests that supplementation may be needed to maintain goat performance during the dry period. In contrast, spring forage appears to provide a greater contribution to animals’ nutritive requirements. Shrub species, such as *C. villosa*, *O. europaea* and *M. communis*, which maintained relatively good nutritional value across seasons, may be particularly important forage resources during periods of scarcity. Therefore, grazing planning should take into account seasonal forage dynamics, with greater use of herbaceous vegetation in spring and browse species in summer and autumn.

CONCLUSION

In the Mediterranean forest rangeland studied, there is a natural seasonal variation in the quality and quantity of forage. In spring, browse species are characterized by high dry matter, crude protein, and digestibility, making this season favorable for goat grazing. In contrast, in the summer and autumn, vegetation has poor nutritional value, low biomass yield, high fiber, and low digestibility. Innovative practices (e.g., supplementation and rotational grazing), should be adopted to maintain goat productivity and mitigate the seasonal difficulties that occur in southern Mediterranean ecosystems. Valuable shrubs (e.g., *Erica arborea*, *Olea europaea* var. *sylvestris*, and *Myrtus communis*) should be conserved because they provide an important source of forage for livestock all year round when alternative feed resources are scarce. These practices are important for maintaining ecosystem balance and sustainable livestock production. In addition, they enhance livestock productivity, while conserving the diversity and functions of pasture.

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Conflict of interest

The authors declare no conflict of interest.

Author contributions

YC: study design and planning; YC, MC, and SEO: data collection and drafting of the first version of the manuscript; YC, MC, and SEO: data analysis and interpretation; YC and SEO: critical revision of the manuscript and editing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Data availability

The data were not deposited in an official repository. The data that support the study findings are available from the authors upon request.

Declaration of generative AI in the writing process

The authors did not use any artificial intelligence-assisted technologies in the writing process.

REFERENCES

- Ammar, H., López, S., González, J. S., & Ranilla, M. J. (2004). Chemical composition and *in vitro* digestibility of some Spanish browse plant species. *Journal of the Science of Food and Agriculture*, 84(2), 197–204. <https://doi.org/10.1002/jsfa.1635>
- Association of Official Analytical Chemists. (1997). *Official methods of analysis* (16th ed.). AOAC International.
- Caballero, R., Fernández-González, F., Pérez-Badia, R., Molle, G., Roggero, P. P., Bagella, S., D'Ottavio, P., et al. (2009). Grazing systems and biodiversity in Mediterranean areas: Spain, Italy and Greece. *Pastos*, 39, 3–154. <https://polired.upm.es/index.php/pastos/article/view/1712>
- Chentouf, M., Boulanour, B., & Bister, J. L. (2015). *Élevage caprin au nord du Maroc*. INRA-Éditions Press.
- Chebli, Y., El Otmani, S., Chentouf, M., Hornick, J. L., & Cabaraux, J. F. (2021). Temporal variations in chemical composition, *in vitro* digestibility, and metabolizable energy of Mediterranean woody forage. *Animals*, 11(5), 1441. <https://doi.org/10.3390/ani11051441>
- Chebli, Y., Boulaich, H., Chentouf, M., & El Otmani, S. (2022a). Seasonal feeding behavior of goat kids browsing in Mediterranean forest rangeland of Bouhachem Natural Park, Northern Morocco. *Livestock Research for Rural Development*, 34(12), #107. <http://www.lrrd.org/lrrd34/12/34107cheb.html>
- Chebli, Y., El Otmani, S., Hornick, J. L., Bindelle, J., Cabaraux, J. F., & Chentouf, M. (2022b). Estimation of grazing activity of dairy goats using accelerometers and global positioning system. *Sensors*, 22(15), 5629. <https://doi.org/10.3390/s22155629>
- El Otmani, S., Chentouf, M., Hornick, J. L., & Cabaraux, J. F. (2019). Chemical composition and *in vitro* digestibility of alternative feed resources for ruminants in Mediterranean climates: Olive cake and cactus cladodes. *The Journal of Agricultural Science*, 157(3), 260–271. <https://doi.org/10.1017/S0021859619000558>
- Khazaal, K., Dentinho, M. T., Ribeiro, J. M., & Ørskov, E. R. (1993). A comparison of gas production during incubation with rumen contents *in vitro* and nylon bag degradability as predictors of apparent digestibility *in vivo* and voluntary intake of hays. *Animal Science*, 57(1), 105–112. <https://doi.org/10.1017/S0003356100006668>
- Kökten, K., Kaplan, M., Hatipoğlu, R., Saruhan, V., & Çınar, S. (2012). Nutritive value of Mediterranean shrubs. *The Journal of Animal & Plant Sciences*, 22(1), 188–194.
- Makkar, H. P. S., & Singh, B. (1991). Composition, tannin levels and *in sacco* dry matter digestibility of fresh and fallen oak (*Quercus incana*) leaves. *Bioresource Technology*, 37(2), 185–187. [https://doi.org/10.1016/0960-8524\(91\)90209-3](https://doi.org/10.1016/0960-8524(91)90209-3)
- Mertens, D. R. (2002). Gravimetric determination of amylase-treated neutral detergent fiber in feeds with refluxing in beakers or crucibles: Collaborative study. *Journal of AOAC International*, 85(6), 1217–1240. <https://doi.org/10.1093/jaoac/85.6.1217>
- Min, B. R., Barry, T. N., Attwood, G. T., & McNabb, W. C. (2003). The effect of condensed tannins on the nutrition and health of ruminants fed fresh temperate forages: A review. *Animal Feed Science and Technology*, 106(1–4), 3–19. [https://doi.org/10.1016/S0377-8401\(03\)00041-5](https://doi.org/10.1016/S0377-8401(03)00041-5)
- Mole, S., Ross, J. A. M., & Waterman, P. G. (1988). Light-induced variation in phenolic levels in foliage of rainforest plants: Chemical changes. *Journal of Chemical Ecology*, 14(1), 1–21. <https://doi.org/10.1007/BF01022527>
- Movedi, E., Paleari, L., Argenti, G., Vesely, F. M., Staglianò, N., Parrini, S., & Confalonieri, R. (2024). Application of a plant community model to evaluate adaptation strategies for alleviating climate change impacts on grassland productivity, biodiversity and forage quality. *Ecological Modelling*, 488, 110596. <https://doi.org/10.1016/j.ecolmodel.2023.110596>
- Mueller-Harvey, I. (2006). Unravelling the conundrum of tannins in animal nutrition and health. *Journal of the Science of Food and Agriculture*, 86(13), 2010–2037. <https://doi.org/10.1002/jsfa.2577>
- Nefzaoui, A., & Ben Salem, H. (2002). Nutritive value and utilization of fodder shrubs and trees in arid and semi-arid zones of West Asia and North Africa. *Small Ruminant Research*, 46(1), 25–37. [https://doi.org/10.1016/S0921-4488\(02\)00064-6](https://doi.org/10.1016/S0921-4488(02)00064-6)
- Porter, L. J., Hrstich, L. N., & Chan, B. G. (1985). Conversion of procyanidins and prodelphinidins to cyanidin and delphinidin. *Phytochemistry*, 25(1), 223–230. [https://doi.org/10.1016/S0031-9422\(00\)94533-3](https://doi.org/10.1016/S0031-9422(00)94533-3)
- Robertson, J. B., & Van Soest, P. J. (1981). The detergent system of analysis. In W. P. T. James & O. Theander (Eds.), *The analysis of dietary fiber in food* (pp. 123–158). Marcel Dekker.
- Sokos, C. K., Mamolos, A. P., Kalburtji, K. L., & Birtsas, P. K. (2013). Farming and wildlife in Mediterranean agroecosystems. *Journal for Nature Conservation*, 21(2), 81–92. <https://doi.org/10.1016/j.jnc.2012.11.001>

Résumé

Chebli Y., Chentouf M., El Otmani S. Production et qualité fourragères des principales espèces pastorales broutées par les chèvres dans les pâturages forestiers méditerranéens

Contexte : La région est dominée par des écosystèmes pastoraux riches qui soutiennent l'élevage extensif de caprins. La végétation variée disponible dans ces écosystèmes fournit les nutriments nécessaires aux chèvres en parcours. **Objectif :** La présente étude visait à évaluer les variations saisonnières de la disponibilité fourragère et de la qualité nutritionnelle des plantes broutées par les chèvres dans un parcours forestier méditerranéen du nord du Maroc. **Méthodes :** Les principales espèces pastorales consommées par les chèvres ont été échantillonnées de façon saisonnière, et leur rendement, leur composition chimique et leur digestibilité *in vitro* ont été déterminés à l'aide d'analyses de laboratoire standardisées. **Résultats :** Les résultats ont montré une forte variabilité des paramètres étudiés selon la saison de pâturage. Le rendement total en matière sèche (MS) a culminé à 1860 kg MS/ha au printemps, avec une contribution dominante des arbustes à la production annuelle de MS. La teneur en protéines brutes variait entre 58 g/kg MS (observée chez *Erica arborea* en été) et 228 g/kg MS (enregistrée chez *Calicotome villosa* en automne). Avec la maturation des plantes, une augmentation notable des fractions de fibres détergentes a été observée, notamment la fibre au détergent neutre (NDF), la fibre au détergent acide (ADF) et la lignine au détergent acide (ADL). La teneur en tanins condensés variait de 2,3 g/kg MS (observée chez les espèces herbacées au printemps) à 186 g/kg MS (observée chez *Pistacia lentiscus* en été). La plupart des espèces présentaient les niveaux les plus élevés de digestibilité *in vitro* au printemps et les plus faibles en été. Certaines plantes, telles que *C. villosa*, *Olea europaea* et *Myrtus communis*, se sont distinguées par une teneur plus élevée en protéines brutes et une digestibilité supérieure, associées à de faibles concentrations en lignine tout au long de l'année, ce qui les rend particulièrement précieuses durant la saison sèche. **Conclusions :** Les résultats montrent que la disponibilité fourragère et la valeur nutritive des espèces broutées par les chèvres varient fortement selon les saisons. Certaines espèces arbustives conservent une valeur nutritive relativement élevée et peuvent constituer des ressources fourragères importantes pour les chèvres durant la saison sèche.

Mots-clés : caprins, parcours, plante d'abrouissement, composition chimique, valeur nutritive, Maroc

Resumen

Chebli Y., Chentouf M., El Otmani S. Producción y calidad del forraje de las principales especies forrajeras de los pastizales forestales mediterráneos que consumen las cabras

Contexto: La región mediterránea está dominada por ricos ecosistemas pastorales que sostienen la ganadería caprina extensiva. La variada vegetación disponible en estos ecosistemas proporciona los nutrientes necesarios para las cabras en pastoreo. **Objetivo:** El presente estudio tuvo como objetivo evaluar las variaciones estacionales en la producción de forraje y la calidad nutricional de las plantas consumidas por cabras en un pastizal forestal mediterráneo del norte de Marruecos. **Métodos:** Se muestrearon estacionalmente las principales especies pastorales consumidas por las cabras, y se determinaron su rendimiento, composición química y digestibilidad mediante análisis de laboratorio estandarizados. **Resultados:** Los resultados mostraron una gran variabilidad en los parámetros estudiados según la estación de pastoreo. El rendimiento total de materia seca (MS) alcanzó un máximo de 1860 kg MS/ha en primavera, con una contribución dominante de los arbustos a la producción anual de MS. El contenido de proteína bruta osciló entre 58 g/kg MS (observado en *Erica arborea* durante el verano) y 228 g/kg MS (registrado en *Calicotome villosa* durante el otoño). Con la maduración de las plantas, se observó un aumento notable en las fracciones de fibra detergente, incluyendo fibra neutro detergente (FND), fibra ácido detergente (FAD) y lignina ácido detergente (LAD). El contenido de taninos condensados varió entre 2,3 g/kg MS (observado en especies herbáceas en primavera) y 186 g/kg MS (observado en *Pistacia lentiscus* durante el verano). La mayoría de las especies presentaron los niveles más altos de digestibilidad *in vitro* en primavera, y los más bajos en verano. Algunas plantas, como *C. villosa*, *Olea europaea* y *Myrtus communis*, mostraron mayores niveles de proteína bruta y digestibilidad, y menores concentraciones de lignina a lo largo del año, lo que las hace particularmente valiosas durante la estación seca. **Conclusiones:** Los resultados muestran que la producción de forraje y el valor nutricional de las especies que pastorean las cabras varían considerablemente según la estación. Algunas especies arbustivas conservan un valor nutricional relativamente alto y pueden constituir importantes recursos forrajeros para las cabras durante la estación seca.

Palabras clave: caprino, tierra de pastos, planta de ramoneo, valor nutritivo, Marruecos