2025 SCIENCELINE

Online Journal of Animal and Feed Research

Volume 15, Issue 1: 01-07; January 30, 2025

ISSN 2228-7701

DOI: https://dx.doi.org/10.51227/ojafr.2025.1

CALCIUM AND PHOSPHORUS STATUS OF GOATS GRAZING IN NORTHWEST MOROCCAN FOREST

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Supporting Information

RESEARCH ARTICLE

PII: S222877012500001-15

Received: October 04, 2024

Revised: January 10, 2025

Accepted: January 11, 2025

ABSTRACT: In the present study, leaves and twigs from 17 shrubs and trees consumed by the west-north Moroccan indigenous goats were collected and evaluated for their calcium and phosphorus (Ca and P) content. The potential mineral needs of adults and young goats of both sexes (male and female) from three localities were estimated to assess their mineral deficiency. This assessment was based on their weight and the diet composition determined through direct observation and the bites method. The browse species had a higher Ca content than P (1.79 vs 1.57 g/kg DM). The adult female goats had the highest P intake (2.04 g/day) with the highest deficit compared to the male adult (-29 vs -26) % of their daily requirements. Young kids (males and females) had the lowest Ca intake (0.81 and 0.75 g/day, respectively) and recorded the lowest deficit (-17 vs -19) %, respectively. Goats also showed a higher Ca deficit than P. In conclusion, the present results offer valuable information about the main mineral intake of the goats in the forest pasture of this region. Supplementing these two minerals is essential for enhancing goat performance in the traditional semi-extensive goat farming system that relies on forest pastures in the western-northern region of Morocco.

Keywords: Diet composition, Goat, Indigenous breeds, Mineral requirement, Pastoral plants.

INTRODUCTION

Calcium (Ca) and phosphorus (P) play pivotal roles in the productivity and health of small ruminants, particularly goats, as they are essential macrominerals for bone development, metabolic processes, and overall performance. Adequate levels of these minerals are critical for growth, reproduction, lactation, and maintaining physiological functions, including energy metabolism and enzymatic activity. Deficiencies in Ca and P can lead to reduced productivity, poor skeletal development, and metabolic disorders, highlighting the importance of understanding their availability and contribution to grazing systems (Drogoul et al., 2004).

In Morocco's northern region, recognized as the most forested area in the country with a woodland rate of 26% (MAPMDREF, 2018), forest pastures serve as a vital year-round feed source for grazing goats. Trees and shrubs, the primary feed sources in this region, provide energy, protein, and potentially essential minerals to support the nutritional needs of goats. These forest ecosystems underpin traditional smallholder livestock production systems, where farmers rely heavily on grazing goats (Chebli et al., 2021; Ayadi et al., 2022; Chebli et al., 2022a, 2022b).

While numerous studies have explored goat feeding behavior in Mediterranean regions (Glasser et al., 2012; Manousidis et al., 2016, and 2018), research on forage mineral content, mainly Ca and P, remains limited. Most evaluations focus on the chemical composition of forage, such as protein and energy, with insufficient attention to the quantitative assessment of mineral contributions to animal productivity (Chebli et al., 2022c; Jimenez et al., 2024). Understanding the mineral content of forage and its contribution to goat requirements is essential for improving feeding and grazing strategies and enhancing the sustainability of livestock production systems.

This study aims to estimate the Ca and P contents in pastoral shrubs and trees and evaluate their potential intake by four goat categories grazing in forest pastures in the western-northern region of Morocco. This information is crucial for addressing potential mineral deficiencies and optimizing the productivity and sustainability of goat farming in the region.

MATERIALS AND METHODS

Study area

This study was conducted in the Chefchaouen region, specifically in the Talassemtane high mountains. This region is characterized by local goat breeding. The herds are managed in an extensive system on natural forest pastures, from which the animals obtain over 90% of their nutritional needs, which the breeders consider "free" feed. The climate of the

Citation: Al Rharad A, Bouassab A, Acherkouk M and Ayadi M (2025). Calcium and phosphorus status of goats grazing in northwest Moroccan forest. *Online J. Anim. Feed Res.*, 15(1): 01-07. DOI: https://dx.doi.org/10.51227/ojafr.2025.1

study area is Mediterranean, with dry summers. The mean annual temperature is 18.6°C, with an average rainfall of around 640 mm yearly (Acherkouk et al., 2022).

Animals and feeding behaviors

The study was conducted in the autumn and winter of 2022. It took place in three localities to represent the Chefchaouen region: Bouhalla (35°6'0" N and 5°6'36" W), Chrafat (35°4'60" N and 5°6'8" W), and Kalaâ (35°3'50" N and 4°31'46" W), with one breeder by locality. A group of 21 indigenous goats of each category (male adult, female adult, male kids, female kids) was chosen from each breeder. Each group within each category had approximately the same age and similar body weight (Table 1). The goats grazed on natural pasture for about seven hours daily when conditions permitted.

Diet selection

For each goat category, we were interested in two key parameters: (i) their daily dry matter intake (DDMI) on forest pasture and (ii) their weight. DDMI (Table 2) was deduced by the difference in the goat's weight before being released for grazing and upon their return in the evening, taking into account excretion-related losses (Delagarde et al., 2019). The importance of grazed pastoral species in the four categories of animal diets (Table 3) was assessed by direct observation of the animals during their grazing in the cold season during the study period and by the bite method described by Meuret et al. (1985).

Table 1 - The age and body weight of the chosen goats

Animal categories	Heads/category number	Age (months)	Mean body weight (kg)
Male adult	7	24-30	36±9.07
Female adult	7	24	33±9.81
Male kids	7	9	17±1.02
Female Kids	7	9- 12	18±6.56

Table 2 - The goat's daily dry matter intake in the three localities

Daily dry matter intake (g) / Animal category	Breeder 1	Breeder 2	Breeder 3
Male adult	1500	1500	1800
Female adult	1500	2000	2500
Male kids	1200	1000	1200
Female Kids	1000	1000	1200

Table 3 - Qualitative and quantitative diet composition of the goats

Breeder 1		Breeder 2		Breeder 3	
Species	Percentage (%)	Species	Percentage (%)	Species	Percentage (%)
Quercus ilex	67	*Quercus ilex*	50	*Quercus ilex*	80
Quercus ilex fruit	22	*Quercus ilex fruit*	20	*Pistacia lentiscus*	10
Phillyrea media	5	*Phillyrea media*	15	*Cistus albidus*	5
Cistus albidus	4	*Arbutus unedo*	5	Grass plants	5
Grass plants	2	Grass plants	10		

The mineral content of the browse species grazed by the goat in forest pasture

17 collected samples of shrubs and tree species from forest pastures in the mountainous region of northwest Morocco were collected to determine their Ca and P content. The collected samples were dried in an oven until a constant weight at 40°C temperature. Then, the dried samples were milled with a sieve mesh size of 1 mm to evaluate their Ca and P content. The analyses were conducted on triplicate from each species, which were subjected to dry ashing at 600 °C for 4 hours and then prepared for mineral analysis using the wet ashing (HCl–HNO3) procedure. The Ca content analysis was performed using the manganometric method according to AOAC (1997), and for P determination, the nitrovanadomolybdate technique was employed (AOAC, 1997).

Data analysis

The Ca and P content were analyzed using a general linear model (GLM) with the SAS software 9.4 version. To determine the variability between forage species, the variance of the means was analyzed according to a one-factor variation model Yij=μ+Ti+eij with μ: overall mean, Ti: forage species, and ei: residual error. Differences between mean values were tested using the LSD "Last Square Deviation" test.

Estimation of the macromineral deficit of the goats

A) The macromineral requirement for goats

The primary mineral (Ca and P) requirements for goats are expressed in absorbable elements obtained by the equations of Meschy (2007) (1 and 2) based on the dry matter intake (DMI) in kg/day and body weight (BW) in kg. They are expressed by g per day.

P abs= 0.905 DMI+ 0.3 + 0.002 BW (1)

Ca abs= 0.67 DMI + 0.01 BW (2)

B) The mineral deficit of the goat's diet

With the data collected previously (daily feed intake, diet composition, and Ca and P requirement), the potential mineral intake was calculated based on their daily dry matter intake and Ca and P absorbable of the feed using the real absorption coefficients (RAC) for Ca and P by Meschy (2007). Then, we define the deficit by subtracting the intakes from the calculated needs based on each animal's body weight. Finally, the deficit is estimated as a percentage of the requirements.

RESULTS

Mineral content of pastoral fodder

The mineral content of the pastoral fodder selected by indigenous grazing goats is presented in Table 4. The P concentration ranged from 0.99±0.07 to 2.30±0.01 g/kg DM, which varies significantly between the forage species (P<0.001). The pastoral species with the highest P content are *Olea europaea* L. (2.30 g/kg DM), *Rosmarinus officinalis* L. (2.25 g/kg DM), *Ceratonia siliqua* L., and *Erica arborea* L. (1.93 and 1.91 g/kg DM, respectively). The other species' content varies between 1.78 and 0.99 g/kg DM. Moreover, the average Ca content of the selected plants is 1.79 g/kg DM. *Erica arborea* L. and *Genista scorpius* L. showed the lowest content (0.86 and 0.75 g/kg DM, respectively). At the same time, the highest values were observed in *Olea europaea* L., *Arbutus unedo* L., and grass plants (2.63, 2.61, and 2.42 g/kg DM, respectively). The Ca and P ratio oscillates between 0.45 and 2.39 (Table 4). The higher ratios were observed in grass plants (2.39), *Cistus ladanifer* L. (1.88), and *Arbutus unedo* L. (1.71). In contrast, *Vaccinium myrtillus* L., *Genista scorpius* L., and *Erica arborea* L. showed lower ratios (0.62, 0.58, and 0.45, respectively).

Table 1 - Average content of macrominerals in species browsed by goats in forest pasture of Northwest Morocco (g/kg DM)

Pastoral species	Phosphorus (g/kg DM)	Calcium (g/kg DM)	Ca:P ratio
Olea europaea L. (Olive tree)	2.30^{a}	2.63^{a}	1.14^{fg}
Cistus albidus L. (White-Leaf Rockrose)	1.78^{c}	2.17^{cd}	1.21^{fg}
Cistus ladanifer L. (Gum Rockrose)	1.02^{j}	1.92^{e}	1.88^{b}
Quercus canariensis (Algerian Oak)	1.15^{i}	1.35^{fg}	1.17^{fg}
Phillyrea media L. (Mock privet)	1.41^{g}	2.31^{bcd}	1.64^{cd}
Quercus Ilex (Holm Oak)	1.44^{fg}	1.91^{e}	1.32^{ef}
Quercus Ilex (Fruit)	1.64^{de}	1.18^{gh}	0.72^{jk}
Arbutus unedo L. (Strawberry tree)	1.53^{ef}	2.61^{a}	1.71^{bc}
Pistacia lentiscus L. (Mastic tree)	1.60^{de}	2.37^{bc}	1.48^{de}
Ceratonia siliqua L. (Carob tree)	1.93^{b}	2.19^{bcd}	1.14^{fg}
Erica arborea L. (White heather)	1.91^{b}	0.86^{ij}	0.45^{l}
Quercus suber L. (Cork oak)	1.68^{cd}	1.46^{f}	0.87^{ij}
Genista scorpius L. (Mediterranean broom)	1.30^{h}	0.75^{j}	0.58^{kl}
Vaccinium myrtillus L. (European blueberry)	1.78^{c}	1.10^{h}	0.62^{kl}
Lavandula stoechas L. (Butterfly lavender)	0.99^{j}	1.06^{hi}	1.07^{gh}
Rosmarinus officinalis L. (Rosemary)	2.25^{a}	2.09^{de}	0.93^{hi}
Grass plants	1.01^{j}	2.42^{ab}	2.39^{a}
Mean	1.57	1.79	1.20
SEM	0.06	0.09	0.07
Probability (P) value	<0.0001	<0.0001	<0.0001

^{a,b,c}: Mean values in the same row with different letters are significantly different. DM: Dry Matter SEM: Standard error of the means

Macro mineral balance of goats

Based on the previous results, we derived the Ca and P intake (Table 5). The female goat's intake from forest pasture resulted in a moderately high average daily P intake of approximately 2.04 g/day, representing a deficit of about 6% of requirements. As for Ca, the forage intake was 1.07 g/day, representing a deficit of approximately 29% of requirements. On the other hand, the intake by male goats from forest pastures resulted in an average daily P intake of 1.63 g/day (i.e., a deficit of about 10% of requirements). Regarding Ca, the male goat's intake from forest pastures was about 1.06 g/day (i.e., a deficit of about 26% of requirements). The male kids' daily absorbable P intake was 1.15 g/day, corresponding to a 14% deficit of requirements. In contrast, female kids had an intake of 1.27 g/day of absorbable P (i.e., a deficit of 11% of requirements) and an intake of 0.81 g/day of absorbable Ca, reflecting a 19 % deficit of requirements compared to an intake of 0.75 g/day in absorbable Ca for the male kids (i.e., a deficit of 17% of requirements).

Table 5 - Phosphorus and Calcium intake by goats in forest pastures (g/day).

Mineral intake and deficit	Male goats		Female goats		Male kids		Female kids	
	P	Ca	P	Ca	P	Ca	P	Ca
Daily potential mineral intake per day [a] (g/day)	1.63	1.06	2.04	1.07	1.15	0.75	1.27	0.81
Daily potential mineral requirements [b] (g/day)	1.82	1.44	2.18	1.51	1.33	0.91	1.42	1
Deficit (g/day)	-0.19	-0.37	-0.13	-0.44	-0.18	-0.16	-0.15	-0.19
Deficit (% of daily requirements)	-10%	-26%	-6%	-29%	-14%	-17%	-11%	-19%

a: assumed daily DM intake by the method cited in Delagarde et al. (2019) (in g/day). b: Recommended average requirements by Meschy (2007) equations (in g/day).

DISCUSSION

The phosphorus content in the studied plant species oscillates between 0.23 % and 0.10 % DM. In contrast, Dione et al. (2022) showed that the highest P content in forage plants in the agro-pastoral zone of Senegal varies between 0.82 % and 0.06 % DM. Additionally, Abdelkefi et al. (2004) reported a P concentration among some pastoral species in semi-arid and arid North Africa that varied from 0.05 to 0.52 % DM. However, Abdullah et al. (2013) found a lower P concentration in some browse species used as feed for livestock (0.016%).

Phosphorus has been known as a "master mineral" given that it affects the majority of metabolic processes (Rasby et al., 1997). The National Research Council (1984) recommended a P range of 0.12 to 0.48% for all ruminant classes, which aligns with present findings regarding the P concentration in the pastoral species used as feed for the northern goats of Morocco. The soil's P status, the plant's maturation stage, and the climate all impact the P content of forages, which varies widely (Underwood and Suttle, 1999).

The average Ca concentration in the studied pastoral plants was 1.79 g/kg DM. However, present findings were lower than the results reported by Abdullah et al. (2013) for browse species fed to livestock (1.79 vs 3 g/kg DM). Mirzaei (2012) revealed Ca concentration ranging from 4.17 to 2.42 g/kg in grass plants grazed by ruminants, which the results of the present experiment for grass plants (24.2 g/kg) are consistent with the findings of these researchers. Moreover, Chhabra et al. (2015), reported higher Ca content, approximately 0.77% (equivalent to 7 g/kg), in winter fodder in India.

These pastoral plants have Ca concentrations lower than the levels recommended by the NRC literature cited in Ghazanfar et al. (2011) and by Kessler (1991) in Ramírez-Orduña et al. (2005) for goat requirement. An exceeding of 1% of Ca content can decrease DM intake and reduce the absorption of trace minerals, especially zinc. However, the Ca requirements in grazing animals are a widely debated subject, as they are influenced by factors such as the type of animal, age, and production level (Khan et al., 2007).

The variations in Ca levels between the results of this study and values published in the literature are attributed to differences in forage species, species composition, seasonal and maturational stages, and changes in soil properties (Mirzaei, 2012). However, information about minerals in pastoral species, particularly those browsed by ruminants, is limited. These findings will provide a comprehensive knowledge of the mineral composition of grazing forage, thereby improving and ensuring goats' welfare and growth. In cases of deficiency, coupled with previous research regarding energy and protein content, they will enable the optimization of goat diets through informed adjustments.

Ca and P were studied together due to their close metabolic association, as an excess of either in the diet restricts the availability of both nutrients. The Ca:P ratio ranged from 0.45 to 1.88, which is in line with the recommended ratio by Abdulrazak et al. (2000), except for the grass plants with the highest Ca:P ratio (2.39). A higher ratio might interfere with the animal's ability to use Ca effectively (Fadel Elseed et al., 2002), and can also decrease livestock P absorbance.

The mineral elements are not produced in the body; the feed usually provides them. The concentrations of these elements in bodily fluids will vary depending on the availability of minerals, the quantity of dietary sources consumed, and the mineral content of feed (Suttle, 2010). The mineral concentrations of fodder plants are influenced by a wide range of environmental and plant parameters, such as the type of soil, species or strain/variety, seasonal circumstances during plant growth, plant maturity stage, and other management techniques (Underwood and Suttle, 1999).

P is a crucial mineral for animals, essential for their nutritional requirements. Approximately 80% of P is found in their skeleton, a critical bone and teeth component. Moreover, it plays a vital function in the transfer and utilization of energy. A P deficiency can decrease ruminant appetite, reduce fiber digestibility, and lower growth rates, weight gain, and reproduction (Drogoul et al., 2004). In cattle and small ruminants, a severe P deficiency (less than 1g/kg DM) can cause locomotor abnormalities, followed by paralysis of the rear end and spontaneous fractures (Meschy, 2010). P deficiency can also lead to losing appetite and consuming abnormal materials, such as bones, soil, wood, and flesh (Underwood and Suttle, 1999). Ramírez-Orduña et al. (2005) reported that the potential P intake of goats consuming shrubs in Mexico didn't fulfill their requirement, especially during years of low rainfall, which can harm goat performances.

Calcium is the most abundant mineral in the body, comprising 99% of the skeleton. A Ca deficiency can cause soft, weak, or deformed bones, leading to lameness, a condition known as osteomalacia or rickets. Ca is also required for blood clotting, nerve conduction, and muscular contraction (Hart, 2009). It was advised that the Ca requirements for maintaining, growing, and lactating sheep should be 1.2 to 2.6 g/kg (Mirzaei, 2012), which is higher than the potential mineral intake of the studied goats.

An excess or deficiency of these macrominerals can cause disruptions, slow growth, and limit the digestion of nutrients (NRC, 2007). To optimize animal well-being, it is preferable to provide them with the precise amounts they need based on their species and body weight. Mineral deficiency can also be caused by the feeding behavior of goats and the quality of their forage. As mentioned by Chebli et al. (2022a), there was a notable decline in forage production in the forested rangeland of Beni Arouss, located in the northern region of Morocco, with a 31% reduction in summer and a 47% decrease in autumn compared to the spring season. Furthermore, the intake rate was lower in the summer and autumn compared to the spring (4.94, 4.52 vs 5.57 g DM/min). The intake rate is influenced by season, as the goats tend to extend the duration of their grazing during summer days in comparison to the rainy season, as they strive to meet their intake requirements (Safari et al., 2011).

In this study, it is imperative to acknowledge several limitations that may have influenced the results to ensure the transparency and integrity of this research's findings. Methodological constraints, particularly concerning the estimation of dry matter intake on pasture and the estimation of mineral requirements, may have contributed to uncertainties in the results. In summary, present findings contribute to identifying the deficiencies in P and Ca within the goats' diet, thus emphasizing the necessity of considering them in ration formulation.

CONCLUSION

Mineral concentrations in browse plants differ significantly. Most plants had higher Ca levels than P during the rainy season (0,15 vs 0,10 g/kg DM). The levels of these macrominerals found in the browse shrubs grazed by goats in the northern region of Morocco were insufficient, resulting in a deficiency in their estimated daily mineral requirement, especially during the cold season (-0,23% deficit in Ca vs – 0,10 % deficit in P). To fulfill the mineral needs of goats, it is essential to formulate feeding strategies and implement grazing management. To ensure a balanced diet for goats, it is essential to include supplements rich in calcium (Ca) and phosphorus (P), such as a vitamin-mineral complex. The diet can also be enhanced by incorporating concentrated feed options like bitter vetch, barley, wheat bran, and sorghum.

This approach aims to meet their mineral requirement and improve the production and performance of goats. The findings could offer valuable and specific information for herders to design supplementary diet formulations, considering grazing activities and the quality of the consumed plant species.

DECLARATIONS

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Ethical approval

All procedures involving animals in this study have been conducted according to the ethical standards of the Regional Center of Agricultural Research of Tangier. All the authors complied with the ARRIVE guidelines

Authors' contribution

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Acknowledgements

The National Center for Scientific and Technical Research of Morocco, through the Research Excellence Grants Program, financially supported this research.

Consent to publish

All authors agree to the publication of this manuscript.

Competing interests

The authors have not declared any conflict of interest.

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