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Mineral content of shrubs from goat's production systems in two seasons in an arid zone

Contenido mineral de arbustos en sistemas de producción caprino en dos temporadas en una zona árida

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ABSTRACT. Minerals are needed in the diet of animals for maintenance, development, and reproduction. The aim was to determine mineral content of shrubs consumed by goats in an arid area from three production systems, during wet and dry seasons. The leaves, pods, stems, or flowers of 34 shrubs and one supplement were sampled manually and analyzed Ca, Mg, K, Na, P, N, Fe, Mn, Zn, Cu, B, and Cl. The shrubs showed enough K Ca, K, Mg, Na, B, Cl and N for goat requirements for all production systems; however, P was lower. The Zn, Cu, Fe, and Mn contents were lower in all shrubs. The results suggest that in the study area more non-legumes could be used in the goat diet to enhance nutritional value because of their higher mineral content. Considering the status of mineral content, 58% of all minerals had higher content in the semi-intensive production system, and possibly, it is the best production system. Adequate values of mineral content were found in *L. brevipes*, *T. lobaeformis* and *A. barclayana* in the semi-intensive system, while in the extensive system the mineral content was of good nutritional quality with *S. thurberi* and *C. gayana* for the intensive system. The 35 shrubs showed differences among macrominerals and the nutritional quantity/quality of these minerals for goats varied depending on production system, season, and types of shrubs.
Key words: Goat, nutrition, minerals, forage, arid zones.

RESUMEN. Los minerales son necesarios en la dieta de los animales para su mantenimiento, desarrollo y reproducción. El objetivo fue determinar el contenido de minerales en arbustos que consumen las cabras en una zona árida en tres sistemas de producción, durante las estaciones húmeda y seca. Las hojas, vainas, tallos o flores y un suplemento se muestrearon y se determinó en 34 arbustos Ca, Mg, K, Na, P, N, Fe, Mn, Zn, Cu, B y Cl. Los arbustos en los sistemas de producción mostraron suficiente K, Ca, K, Mg, Na, B, Cl y N para las necesidades de las cabras; sin embargo, el contenido de P fue bajo. El contenido de Zn, Cu, Fe y Mn fue menor en todos los arbustos. Los resultados sugieren que, en la zona de estudio es posible utilizar forrajes no leguminosos en la dieta para mejorar su valor nutricional, debido a su contenido mayor en minerales. El sistema de producción semi-intensivo mostró que, el 58% de los minerales fue mayor en este sistema, considerado como el mejor. El contenido mineral en *L. brevipes*, *T. lobaeformis* y *A. barclayana* en el semi-intensivo fueron adecuados para las cabras, mientras que en el extensivo el contenido mineral fue de buena calidad nutricional con *S. thurberi* y *C. gayana* para el sistema intensivo. Los arbustos mostraron diferencias entre los macrominerales y la cantidad/calidad nutricional de estos para las cabras difiere en función del sistema de producción, la estación y los tipos de arbustos.
Palabras clave: Cabras, nutrición, minerales, forrajes, zonas áridas.

INTRODUCTION

The ruminants are renowned for being hardy and being able to survive in harsh conditions or with little water or even saline water (Vosooghi-Postindoz *et al.* 2018). Nevertheless, despite their adaptability they require inorganic elements or minerals in their diets for development, maintenance, reproduction, and survival. To achieve the minimum required minerals grazing ruminants in the rangelands require to get their elements from the plants they consume (Stewart *et al.* 2021). Inorganic elements are needed in gram amounts are known as macrominerals and this group includes Ca, P, Na, Cl, K, Mg and S (Kumar *et al.* 2020). Macrominerals are essential for bone growth as well as in other tissues and are part of bodily fluids. The minerals that are needed in milligram quantities are known as trace minerals or micro-minerals (Nair *et al.* 2022). The typical micro minerals are Fe, F, Mo, Co, Mn, Se, Cu, Zn, and I (Arthington and Ranches 2021). The goat production occurs in areas of low income where milk and meat products derived from goats are essential in providing a sufficient nutritional diet for the poor (Miller and Lu 2019). In the Peninsula of Baja California, Mexico as in other arid areas of Mexico, the success goat production depends on various factors including low cost of production, an acceptable market price for meat and cheeses, and a limited milk yield for cheese production (Mellado *et al.* 2020). The majority employing the old-style extensive system of releasing goats into the field to allow them to roam for their food (Cousins *et al.* 2020). The use of modern systems is lacking since only a few farmers have the capital resources to carry out the intensive or semi-intensive systems (Costantini *et al.* 2021). The goats are let loose to roam the range to forage and in so doing they consume local plants under the typical pasture system (Singh *et al.* 2020). However, often during the year especially in arid climates such as in the Peninsula of Baja California the consumed shrubs do not meet the minimum mineral nutritional guidelines of the goats. The lack of adequate minerals at both the macro and trace levels can lead to reproductive failure and low milk production (Kumar *et al.* 2020). The ruminants need inorganic elements for metabolic health and reproduction in addition to protein and fiber, although excessive amounts of certain minerals can be toxic (Langova *et al.* 2020).

The importance of macrominerals and trace elements in the diet of ruminants from shrubs in the rangeland has been reported and has been attributed to inadequacies in the forages due to mineral deficiencies in the soils, thereby causing lower production as well as reproductive and developmental problems (Stewart *et al.* 2021). The lack of macro and micro-minerals affects ruminants that graze in the rangelands worldwide, macro-elements such as Na, Mg, S, P and Ca, as well as micro-minerals such as Cu, Mn, Zn, Co, Se, and I (Kubkomawa 2019). The number of inorganic elements in the forage from the rangeland has been found to be related to the quantities of the elements in the soils (McKenna *et al.* 2022). The mineral content of plants tend to vary with plant species, soil fertility, phenological stage of plant, water availability, plant tissue (leaves, pods, stems), tissue age, climate, and fertilizer application (Mlaza *et al.* 2022). In arid regions, resources are limited and hence sources must be used efficiently (Mihiretu *et al.* 2019). The grazing ruminant nutrition in terms of meeting its mineral needs is complex since it involves three separate components: (1) the animal, (2) the plants it consumes and (3) the mineral content of the soil (Arthington and Ranches 2021). The ruminant dietary intake of minerals is not only affected by climate but by its own specific genetic variability, growth stage, ruminant preferences and plant age and availability. The lack of macro minerals and trace elements in forages of grazing ruminants due to poor mineral content in soils has been long known to affect ruminant nutrition and milk production (Henry *et al.* 2018). In this research, we hypothesized that macro and minerals of shrubs (legumes and non-legumes) change through the most evident seasons of the year, the dry season, and the wet season and among production systems. The aim of this study was to determine the mineral content of shrubs of goat diets used in three production system during two seasonal periods (dry and wet) from non-legumes and legumes shrubs in a semiarid region of Mexico.

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MATERIALS AND METHODS

Study region

The study was carried-out in three arid areas of the Peninsula of Baja California, Mexico with creole goats under three different production systems, extensive, intensive, and semi-intensive.

Extensive system

This system of production is located at 25° 19' 51.75" N and 111° 25' 411.84" W and 160 masl. The temperature averages are 22.1 °C and 18.7 °C, during the dry and wet seasons, respectively, with annual average yearly rainfall of 180 mm (INEGI 2006). The goats are milked in the early morning by hand and afterwards, the animals are released into the rangeland, where they travel long distances in search of food sources, which are exclusively plants components. Some health practices are carried out when required on animals, which are mostly curative in nature than preventative. In the afternoon before sunset, the goats returned voluntarily to the farmer. There was no reproductive management or breeding control of the animals. Any genetic improvement is limited to the exchange of stallions with local goat farmers in the area for breeding. The goats consumed pods, flowers, and leaves of different shrubs species throughout the year due to seasonal availability. The goats consumed non-legumes and legumes species (Table 1).

Intensive system

This system is located at 25° 11' 55" N and 111° 42' 07" W. at 50 masl. The average temperatures are 22.1 °C (dry season) and 18.7 °C (wet season) with average yearly rainfall of 98 mm (INEGI 2006). In the farms with this system, goats are kept in confinement and fed hayed forages and concentrates grain freely available. The mechanical milking is done once a day where there is professional technical advice, to take care of proper control of animal health. The management includes separation of calves from the dairy herd, where they are only allowed to take colostrum the first day, afterwards the goats are separated from the mother and fed milk supplements. The composition of the diet of goats of this system consisted of different plant species throughout the year, consuming straw of legumes, straw of non-legumes (Table 1) and a dairy base concentrate.

Semi-intensive system

This system is located at 24° 57' 09" N and 111° 38' 25" W, 48 m.a.s.l. The averages temperatures during the dry and wet season are 22.1° C and 18.7° C, respectively, with yearly average rainfall of 98 mm (INEGI 2006). This type of system combines the two previous systems, most food intake is from rangeland grazing, but it is also supplemented with hayed forages such as *Medicago sativa*. The goats are hand milked in the morning like previous systems and released into the rangeland until noon and upon returning they received supplemental feeding with hayed forages, grazing times are determined by the goat farmer. The goats consumed leaves, pods, or stems of shrubs species (non-legumes and legumes) (Table 1).

Plants and shrubs sampling

The plant species and shrubs consumed by goats in the three production systems were collected during two periods. These samples were grouped according to two periods (wet and dry seasons). In the extensive and semi-intensive systems, after milking, lactating goats were released to the rangeland or to agricultural areas (semi-intensive), where they walked the trails searching for food. Three persons were behind the goats and collected the samples of plants or shrubs consumed by the goats. The samples (three) of the parts consumed were taken when most goats chose a particular pant or shrub for consumption. In the semi-intensive system, samples from the diet added with the hayed forages and additions were collected from the feeders and analyzed. The samples were placed in paper bags and then carried to the laboratory at Centro de Investigaciones Biologicas del Noroeste, S.C. to determine mineral content. In the intensive system, hayed forages and dairy base concentrates were sampled from the feeders.

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Table 1. Legumes and non-legumes species consumed by goats by each production system (extensive, semi-intensive and intensive).

Extensive		Semi-intensive		Intensive	
Legumes	Non-legumes	Legumes	Non-legumes	Legumes	Non-legumes
Cercidum floridum Benth. Ex A. Gray subsp. Peninsulare (Rose) Carter	*Bursera microphyla* Gray, *Ferocactus* spp.	*Acacia farnesiana* (L.) Willd.	*Tilhonia lobaeformis* (Jacq.) Cass.	*Medicago sativa* L.	*Pennisetum* sp. L.
Lysiloma candida Brandegee.	*Pachycereus pringlei* (S. Wats) Brit. & Rose.	*Cicer arietinum* L.	*Cynodon dactylon* L.	*Cicer arietinum* L.	*Zea mays* L.
Acacia peninsularis (Britt. and Rose) Standley	*Jatropha cinerea* (C.G. Ortega) Muell. Arg. In D.C.		*Atriplex barclayana* Benth,	*Phaseolus vulgaris* L.	
Cercidium microphyllum (Torr.) Rose and Johnston	*Ruellia californica* (Rose) I. M. Jhtn.		*Chloris gayana* Kunth,		
Acacia brandegeana	*Opuntia cholla* Weber		*Cenchrus ciliaris* L.		
Cercidium X sonorae Rose and Johnston	*Celtis reticulata* Torr.		*Amarantus palmeri* L.		
Prosopis palmeri S. Wats.	*Lycium brevipes* Benth.,		*Zea mays* L.		
Pithecellobium confine Standl,	*Phrygilanthus sonorae* S. Wats		*Convolvulus arvensis* L.		
Acacia farnesiana (L.) Willd.	*Lippia palmeri* L.,				
	Jatropha cuneata Wiggins and Rollins				
	Fouquieria diguetii (Van Tieghem) I. M. Jhtn.				
	Stenocereus thurberi (Engelm.) Buxbaum				

Mineral analysis

The parts or tissues collected from plants or shrubs were dried in an oven (HTP-80) at 70 ℃ until constant weight. The dry material was milled in a mixer (Braun 4-041 Model KSM-2). The Na, Fe, Mn, Zn, Ca, Mg, K and Cu contents were quantified by atomic absorption spectrophotometry (Shimadzu AA-660, Shimadzu, Kyoto, Japan) after digestion with H_2SO_4, HNO_3, and $HClO_4$ (1:10:4). The P content was estimated colorimetrically by measuring at 660 nm the specific blue colour of the phosphomolybdate complex from the same extract. The total N content was determined by Kjeldahl digestion utilizing a sulphuric acid and salicylic acid mixture with Cu and K_2SO_4 such as catalysts followed by NH^{+4} estimation using the Nessler calorimetric method. The chemical composition of all plants or shrubs was described previously (Toyes-Vargas *et al*. 2013a, Toyes-Vargas *et al*. 2013b, Toyes-Vargas *et al*. 2014).

Statistical analysis

The multivariate and univariate analysis of variance (MANOVA and ANOVA) of three ways of classification, considering seasons, shrubs, and production systems as study factors for a completely randomized design were performed. The MANOVA was used to determine if ANOVA results are not random or false positives and, in these terms, all differences of minerals among factors (shrubs, production systems, seasons and plant types) are due to effect of each factor (Johnson 1998). In the ANOVA analysis ($Y_{ijkl} = \mu + \alpha_i + \beta_j + \lambda_k + \varepsilon_{ijkl}$), the interaction was not included because there not exist synergism or interference among factors under study (Sokal and

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Rohlf 1998). The data collection from shrubs depended on the production systems, and the alimentary preferences of goats, therefore, the result was an incomplete design in terms of determining the factors and plant types. The plant type's factor was analyzed separately to determine the differences of mineral content among them. In all cases, differences among means were considered significant at $p < 0.05$. Means comparison were done by Tukey's HSD test ($p = 0.05$). Statistica v. 10.0 (StatSoft 2011) was used for all analyses.

RESULTS

Macrominerals

The MANOVA analysis indicated significant differences of macro and micro minerals among shrubs (Wilks = 0.000000000034, F = 38.16, p = 0.000001), production systems (Wilks = 0.130, F = 16.97, p = 0.000001), seasons (Wilks = 0.291, F = 23.29, p = 0.000001) and plant types (Wilks = 0.478, F = 13.68, p = 0.000001). The N content did not show significant differences among production systems; however, the N content from highest to lowest values was as follows semi-intensive>intensive>extensive systems (Table 2). The significant differences were observed between seasons, plant types and shrubs. The N content was higher during wet season (Table 3 and 4). The differences between shrubs showed that *T. lobaeformis* had the highest N and *O. cholla* the lowest (Table 5). The Ca content showed significant differences among shrubs, systems, seasons, and plant types. The Ca content was higher in extensive system, followed by semi-intensive and intensive, respectively. In addition, Ca in shrubs was higher during dry season and in non-legumes species (Tables 3 and 4). The average of Ca between seasons and plant types was higher than 10.0 g kg^{-1} dry-basis; all shrubs with exception of *Pennisetum* sp. had enough quantities to satisfy necessities of an adult goat (Table 5). The Mg content showed significant differences between shrubs, systems, seasons, and plant types. The Mg content was higher in plants and shrubs of the semi-intensive system and higher in those shrubs collected during dry season and in non-legumes. The Mg between shrubs indicated that *Tilhonia lobaeformis* collected in the semi-intensive system showed the highest Mg while *Phrygilantus sonorae* collected in the extensive system showed the lowest. The P content did not show significant differences among production systems and seasons; however, exhibited highest content in the diet from the intensive system and during dry season. The P showed significant differences among plant types and shrubs being higher in non-legumes species. Three species, *Acacia brandegeana*, *Pennisetum* sp. and *S. thurberi* had the highest K while *A. peninsularis*, *C. sonorae* and *J. cinerea* showed the lowest. The Na content was higher in plants and shrubs of the semi-intensive system and during the dry season; however, non-significant differences between production systems and seasons were found. The non-legumes had the highest Na.

Table 2. Differences between production systems in an arid area in the macro and micro mineral content (g or mg kg^{-1} dry-weight) of shrubs consumed by goats.

Macro and micro minerals	Extensive	Intensive	Semi-intensive	*Significance level*
Ca (g kg^{-1})	14.69^{a}	6.64^{c}	9.44^{b}	***
Mg (g kg^{-1})	4.64^{b}	4.44^{b}	6.88^{a}	***
K (g kg^{-1})	21.18^{a}	39.65^{a}	29.36^{a}	ns
Na (g kg^{-1})	2.75^{a}	1.95^{a}	4.41^{a}	ns
Fe (mg kg^{-1})	53.38^{c}	81.76^{b}	124.30^{a}	***
Mn (mg kg^{-1})	8.27^{c}	9.42^{b}	12.92^{a}	***
Zn (mg kg^{-1})	2.67^{b}	2.87^{ab}	3.17^{a}	***
Cu (mg kg^{-1})	4.20^{a}	4.68^{a}	4.28^{a}	ns
B (mg kg^{-1})	254.82^{c}	700.33^{b}	910.91^{a}	***
Cl (mg kg^{-1})	510.45^{a}	400.22^{b}	504.82^{ab}	***
P (g kg^{-1})	1.61^{c}	2.29^{a}	2.15^{b}	***
N (g kg^{-1})	22.80^{a}	19.23^{a}	23.71^{a}	ns

ns = Not significant; *** Significant at 0.001 probability level. Means followed by the same letter in the same row are not significantly different (Tukey HSD P = 0.05).

The Na was higher in *A. barclayana* and *L. brevipes*, both collected in the extensive system where three cacti species, *Ferocactus* spp., *P. pringleii* and *S. thurberii*, showed the lowest Na. The Cl content showed significant differences among systems, seasons, plant types and shrubs. The Cl was higher in extensive system, during wet season and in non-legumes. The Cl was higher in *L. brevipes* followed by *R. californica* while *L. candida* and *C. floridum* had the lowest Cl. Two species, *L. brevipes* and *A. barclayana* showed higher Na and Cl content than other shrubs; in addition, *A. barclayana* showed higher K content. The P content contrasted from highest to lowest values as follows intensive>semi-intensive>extensive systems. The P content was higher at wet season and non-legumes; however, no significant differences between seasons and plant types were found. The P content showed significant differences among shrubs, being higher in *T. lobaeformis* and C. *x sonorae* while the lowest content was in *P. sonorae*.

Microminerals

The Zn content showed significant differences among production systems and shrubs. The Zn was higher in semi-intensive system (Table 2). The Zn content was higher during dry season (Table 3) and legumes species (Table 4); however, no differences between seasons and plant types were found. The Zn content was highest in *C. floridum* which decreased in other species and reached a lowest in *C. reticulata* (Table 5). The average Cu content among seasons, plant type and shrubs were found to be different but no significant differences among production systems were shown; however, the highest Cu content was in the intensive system. The Cu was highest during dry season and in legumes species. The highest Cu content was found in *A. peninsularis* and the lowest in *F. diguetii*. Two species, *Acacia peninsularis* and *C. floridum* had Cu content that could meet adult goat necessities. In addition, the deficiency of Cu was evident between seasons, production systems and between plant types. The Fe content showed significant differences among systems, seasons, and shrubs. The shrubs from semi-intensive system had the greatest Fe content and was higher in shrubs collected during dry season. The Fe content was higher in non-legumes species; however, no significant differences between plant types was found. The Fe content in the shrubs showed that, only 46% of these shrubs had enough Fe content to satisfy goat requirements. The Mn content showed significant differences between production systems, seasons, plant types, and shrubs. The Mn was higher in shrubs collected in the semi-intensive system and higher in shrubs collected during dry season, while non-legumes showed the highest Mn content between plant types. The Mn showed the highest content in *C. gayana*, *P. pringleii*, *C. dactylon*, *S. thurberi* while *J. cinerea* while *L. candida*, *P. sonorae* and *R. californica* showed the lowest. The B content showed significant differences among production systems, seasons, and shrubs. The B was highest in the semi-intensive system and those shrubs collected during dry season. The non-legumes species showed the highest B content; although no differences between plant types were found. The species, *Atriplex barclayana* had the highest B and *C. ciliaris* had the lowest content.

Table 3. Differences between two seasons (wet and dry) in an arid area in the macro and micro mineral content (g or mg kg^{-1} dry-weight) of shrubs consumed by goats.

Macro and micro minerals	Wet	Dry	*Significance level*
Ca (g kg^{-1})	11.77^{b}	11.79^{a}	***
Mg (g kg^{-1})	4.78^{b}	5.59^{a}	***
K (g kg^{-1})	24.71^{a}	28.61^{a}	ns
Na (g kg^{-1})	2.81^{a}	3.28^{a}	ns
Fe (mg kg^{-1})	68.52^{b}	86.24^{a}	***
Mn (mg kg^{-1})	8.57^{b}	10.78^{a}	***
Zn (mg kg^{-1})	2.57^{a}	3.08^{a}	ns
Cu (mg kg^{-1})	2.53^{b}	5.85^{a}	***
B (mg kg^{-1})	87.80^{b}	886.45^{a}	***
Cl (mg kg^{-1})	885.19^{a}	146.36^{b}	***
P (g kg^{-1})	1.92^{a}	1.85^{a}	ns
N (g kg^{-1})	24.80^{a}	20.32^{b}	***

ns = Not significant; *** Significant at 0.001 probability level. Means followed by the same letter in the same row are not significantly different (Tukey HSD P = 0.05).

Table 4. Differences between two types of plants (legumes and non-legumes) in the macro and micro mineral content (g or mg kg^{-1} dry-weight) of shrubs consumed by goats in an arid area.

Macro and micro minerals	Legumes	Non-legumes	*Significance level*
Ca (g kg^{-1})	10.01^{b}	13.35^{a}	***
Mg (g kg^{-1})	3.95^{b}	6.33^{a}	***
K (g kg^{-1})	23.98^{b}	29.3^{a}	***
Na (g kg^{-1})	1.19^{b}	4.72^{a}	***
Fe (mg kg^{-1})	72.05^{a}	83.32^{a}	ns
Mn (mg kg^{-1})	7.05^{b}	12.15^{a}	***
Zn (mg kg^{-1})	3.01^{a}	2.69^{a}	ns
Cu (mg kg^{-1})	4.82^{a}	3.86^{b}	***
B (mg kg^{-1})	437.34^{a}	586.27^{a}	ns
Cl (mg kg^{-1})	213.64^{b}	732.22^{a}	***
P (g kg^{-1})	1.82^{a}	1.94^{a}	ns
N (g kg^{-1})	26.09^{a}	19.13^{b}	***

ns = Not significant; *** Significant at 0.001 probability level. Means followed by the same letter in the same row are not significantly different (Tukey HSD P = 0.05).

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Table 5. Differences between shrubs consumed by goats in an arid area in the acro and micro mineral content (g or mg kg^{-1} dry-weight).

Shrubs	Ca (g kg^{-1})	Mg (g kg^{-1})	K (g kg^{-1})	Na (g kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})	Cl (mg kg^{-1})	P (g kg^{-1})	N (g kg^{-1})
Pennisetum sp.	0.89^{m}	2.36^{mn}	52.75^{a}	0.20^{j}	17.04^{fg}	12.84^{b}	3.49^{bcdef}	5.73^{bcdef}	1167.8^{c}	288.59^{ghi}	2.28^{def}	7.87^{n}
Zea mays	1.42^{m}	3.94^{hijklm}	23.75^{fghijk}	0.49^{ij}	149.59^{cde}	11.1^{bcd}	4.6^{abcd}	4.41^{cdefg}	280.48^{defg}	212.54^{ghi}	2.9^{ab}	11.34^{mn}
Chloris gayana	1.94l^{m}	7.27^{def}	20.41^{jklm}	2.78^{def}	477.56^{a}	30.38^{a}	2.99^{defghi}	2.96^{fg}	3.12^{g}	575.72^{cdefg}	1.7^{efghij}	$19.53^{fghijklm}$
Cenchrus ciliaris	2.65l^{m}	2.73^{mn}	$27.31^{defghij}$	0.58^{hij}	28.99^{efg}	12.66^{bc}	2.34^{efghi}	2.14^{fg}	1.21^{g}	695.41^{cdefg}	1.79^{efghij}	13.52klmn
Dairy base concentrate	3.36l^{m}	2.95^{mn}	$25.12^{defghijk}$	2.92^{def}	63.65^{efg}	7.16^{defgh}	2.51^{efghi}	2.81^{fg}	2.28^{g}	597.18^{cdefg}	2.02^{defg}	18.87^{hijklm}
Cercidum floridum	4.94^{jklm}	$3.80^{hijklmn}$	29.14^{defghi}	1.16^{ghij}	13.63^{fg}	4.49^{fgh}	5.75^{a}	9.07^{ab}	76.67^{efg}	3.83^{i}	2.3^{bcdef}	30.35^{abcde}
Cynodon dactylon	5.52^{jklm}	5.09^{fghijk}	$23.13^{fghijklm}$	2.18^{fg}	272.27^{bc}	28.42^{a}	3.64^{abcdef}	5.55^{bcdefg}	848.22^{cdef}	85.57^{i}	1.34^{hijkl}	12.0^{mn}
Ferocactus spp.	5.72^{ijklm}	4.03^{hijklm}	20.51^{jklm}	0.10^{j}	11.45^{fg}	4.47^{fgh}	1.71^{efghi}	1.91^{fg}	2.88^{g}	261.82^{ghi}	1.98^{defgh}	15.98^{hijklm}
Cercidium x sonorae	6.13^{ijklm}	5.21^{fghij}	11.75^{m}	0.43^{ij}	120.59^{cdefg}	7.46^{cdefgh}	4.71^{abc}	6.7^{abcde}	75.79^{efg}	18.91^{i}	3.21^{a}	28.78^{efg}
Stenocereus thurberi	7.02^{ijklm}	6.33^{efg}	45.34^{a}	0.17^{j}	28.06^{efg}	27.48^{a}	$3.29^{bcdefghi}$	4.44^{cdefg}	864.4^{cd}	161.04^{ghi}	2.37^{bcde}	13.13lmn
Cercidium microphyllum	7.53^{ijklm}	$3.77^{hijklmn}$	19.33^{jklm}	0.30^{ij}	38.14^{efg}	5.0^{efgh}	3.97^{abcde}	4.75^{bcdefg}	82.12^{efg}	29.83^{i}	2.37^{bcde}	24.24^{fghij}
Medicago sativa	7.99^{ijkl}	4.31^{hijkl}	40.83^{c}	2.55^{fg}	114.01^{efg}	8.4^{cdefg}	3.18^{defghi}	4.31^{cdefg}	364.96^{defg}	555.21^{efg}	2.47^{bcd}	27.7^{fg}
Prosopis palmeri	8.18^{hijkl}	3.69^{jklmn}	21.59^{jklm}	0.48^{ij}	28.48^{efg}	3.96^{h}	2.99^{efghi}	3.24^{fg}	438.97^{defg}	121.85^{ghi}	1.61^{ghij}	29.19^{e}
Convolvulus arvensis	8.83^{hijkl}	5.48^{fgh}	31.07^{defgh}	1.20^{ghij}	168.53^{cd}	10.25^{bcde}	3.53^{bcdef}	4.98^{bcdefg}	798.67^{cdef}	520.79^{efgh}	2.25^{def}	23.03^{fghijk}
Acacia farnesiana	9.98^{hijk}	3.05^{mn}	13.98^{m}	0.50^{ij}	68.79^{efg}	9.08^{cdef}	2.53^{efghi}	4.4^{cdefg}	150.0^{efg}	148.29^{ghi}	1.53^{hijkl}	30.33^{e}
Atriplex barclayana	11.19^{ghijk}	4.55^{ghijkl}	53.40^{a}	23.97^{a}	29.07^{efg}	11.03^{bcd}	1.93^{efghi}	4.4^{cdefg}	3418.01^{a}	838.25^{cde}	1.8^{efghi}	21.95fg^{hijkl}
Lysiloma candida	11.36^{ghijk}	3.06^{klmn}	31.63^{cdefgh}	0.50^{ij}	26.67^{efg}	3.1^{h}	3.08^{defghi}	6.91^{abc}	302.19^{defg}	2.87^{i}	1.46^{hijkl}	$19.84^{fghijklm}$
Pachycereus pringlei	11.37^{ghijk}	9.51^{cd}	39.06^{cd}	0.11^{j}	29.16^{efg}	28.79^{a}	3.14^{defghi}	4.42^{cdefg}	353.39^{defg}	48.32^{i}	2.81^{abc}	13.91^{klmn}
Amarantus palmeri	12.11^{ghijk}	10.34^{bc}	37.87^{cde}	3.96^{d}	51.18^{efg}	11.7^{bcd}	1.69^{efghi}	2.13^{fg}	3.54^{g}	1057.6^{bcd}	2.41^{bcde}	26.77^{fgh}
Acacia brandegeana	12.32^{ghi}	2.48^{mn}	17.93^{jklm}	0.35^{ij}	108.24^{efg}	7.34^{defgh}	2.58^{efghi}	6.53^{bcde}	228.78^{efg}	98.46^{i}	1.19^{kl}	23.11^{fghij}
Phrygilanthus sonorae	13.16^{ghi}	1.62^{n}	$23.65^{fghijklm}$	0.30^{ij}	15.7^{fg}	3.43^{h}	2.87^{efghi}	3.89^{cdefg}	350.81^{defg}	14.16^{i}	0.84^{l}	15.41^{ijklmn}
Cicer arietinum	13.36^{ghi}	6.96^{ef}	$22.87^{fghijklm}$	3.29^{de}	64.25^{efg}	7.54^{cdefgh}	2.17^{efghi}	4.29^{cdefg}	2296.63^{b}	4.97^{i}	1.39^{hijkl}	10.33^{mn}
Pithecellobium confine	13.42^{ghi}	3.16^{klmn}	20.82^{jklm}	1.68^{fgh}	34.82^{efg}	6.11^{efgh}	3.01^{defghi}	3.86^{cdefg}	495.0^{defg}	492.99^{efghi}	1.33^{hijkl}	24.46^{fghi}
Fouquieria diguetii	13.58^{defghi}	3.15^{klmn}	13.09^{m}	3.28^{de}	11.6^{fg}	4.56^{fgh}	1.07^{hi}	1.18^{g}	8.77^{g}	353.41^{efghi}	1.61^{ghijk}	15.3^{ijklmn}
Celtis reticulata	16.70^{cdef}	5.61^{efgh}	13.23^{m}	0.17^{j}	21.76^{efg}	8.08^{cdefgh}	0.94^{i}	2.22^{fg}	6.31^{g}	90.46^{i}	1.37^{hijkl}	28.1^{efg}
Tilhonia lobaeformis	18.67^{cde}	19.0^{a}	41.0^{bc}	0.28^{ij}	59.61^{efg}	7.86^{cdefgh}	4.7^{abc}	4.48^{cdefg}	848.87^{cd}	744.38^{cdef}	3.43^{a}	38.65^{a}
Lippia palmeri	19.58^{bcde}	5.14^{fghijk}	18.71^{jklm}	2.56^{defg}	21.59^{efg}	4.38^{fgh}	1.7^{efghi}	2.01^{fg}	7.85^{g}	398.81^{efghi}	1.42^{hijkl}	$19.19^{fghijklm}$
Phaseolus vulgaris	20.48^{bcd}	11.3^{bc}	35.54^{cdef}	3.03^{def}	117.95^{cdefg}	9.92^{bcdef}	1.6^{efghi}	5.25^{bcdefg}	2281.3^{b}	37.96^{i}	2.26^{def}	10.78^{mn}
Jatropha cuneata	22.75^{bc}	5.47^{fghi}	13.4^{m}	16.73^{c}	13.99^{fg}	12.43^{bcd}	1.28^{ghi}	1.59^{fg}	9.52^{g}	1210.82^{bc}	1.13^{kl}	17.97^{hijklm}
Acacia peninsularis	23.73^{bc}	4.32^{ghijkl}	11.06^{m}	0.29^{ij}	24.65^{efg}	7.23^{defgh}	2.92^{efghi}	10.9^{a}	56.62^{efg}	18.7^{i}	1.36^{hijkl}	$19.86^{fghijklm}$
Bursera microphyla	24.79^{bc}	3.15^{klmn}	12.93^{m}	2.56^{defg}	18.95^{efg}	7.87^{cdefgh}	1.42^{fghi}	1.5^{fg}	9.31^{g}	716.2^{cdefg}	1.59^{ghijkl}	$19.27^{fghijklm}$
Jatropha cinerea	26.65^{ab}	7.56^{de}	11.75^{m}	21.0^{b}	424.63^{ab}	24.15^{a}	3.0^{defghi}	5.13^{bcdefg}	821.67^{cdef}	230.62^{ghi}	1.4^{hijkl}	14.59^{jklm}
Opuntia cholla	27.09^{ab}	12.46^{b}	28.75^{defghi}	0.22^{ij}	12.85^{fg}	12.21^{bcd}	2.17^{efghi}	4.73^{bcdefg}	610.81^{cdefg}	41.08^{i}	1.26^{hijkl}	$6.1n$
Ruellia californica b	33.51^{a}	10.14^{bc}	35.3^{cdef}	1.57^{fghi}	18.27^{efg}	3.41^{h}	1.82^{efghi}	2.11^{fg}	8.77^{g}	1654.4^{b}	1.3^{hijkl}	28.75^{efg}
Lycium brevipes	33.83^{a}	6.14^{efg}	$25.18^{defghijk}$	23.06^{a}	22.36^{efg}	7.42^{cdefgh}	1.04^{hi}	2.29^{fg}	4.57^{g}	7814.03^{a}	1.19^{hijkl}	30.75^{ab}
Significance level	***	***	***	***	***	***	***	***	***	***	***	***

*** Significant at 0.001 probability level. Means followed by the same letter in the same column are not significantly different (Tukey HSD P = 0.05).

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DISCUSSION

Macrominerals

The legumes species showed highest N content; these differences between legumes and non-legumes have been observed amongst some woody and herbaceous forage in rangeland (Mugloo *et al*. 2023). In this study, difference of N content between production systems were not found, the mineral content of various shrubs or plants species consumed by goats in these systems makes them a valuable supplement, but this can also limit the quantities that can be fed (Moorby and Fraser 2021). In the three production systems, the Ca content in the shrubs was enough to meet necessity of an adult goat with a range of 1.3-3.3 g Ca kg^{-1} (NRC 1981). In terms of preferences, goats grazed on non-legumes and legumes during both the wet and dry season. Ramírez-Orduña *et al*. (2008) reported a higher Ca content in goat diets after the wet season when temperatures are dropping. The same authors found that Ca content was higher in non-legumes than legumes, similar results were found this study. Ramírez *et al*. (2001) and Moya-Rodríguez *et al*. (2002) reported that Ca content was highest in *L. brevipes* and *R. californica* both collected in the rangeland from the extensive system while Pennisetum sp. showed the lowest; the same results were found in this study. In arid areas some studies have been carried out to evaluate Ca content in shrubs (Ramírez *et al*. 2006, Ramírez-Orduña *et al*. 2008). However, the variation of this mineral is difficult to interpret; because of, Ca vary according to the forage species, plant types, soil, climate conditions, and other factors in the same region (Ramírez-Orduña *et al*. 2005) which are in agreement with the results found in this study. Therefore, the Ca content in goat's production systems need to be determined according to the factors mentioned to meet the theoretical goat's Ca requirements. In the three production systems, the Mg content in the shrubs was enough to cover the requirement of an adult goat with a range of 0.8-2.5 g Mg kg^{-1} (NRC 1981). The goats in both seasons consumed shrubs with enough Mg to meet the requirements and both non-legumes and legumes contribute with enough Mg to satisfy requirements. The previous studies in similar areas (arid o semi-arid zones) (Barnes *et al*. 1990, Ramírez-Orduña *et al*. 2005, Ramírez *et al*. 2006, Badshah *et al*. 2012) reported that Mg is found in enough content to satisfy requirements of goats or other ruminant species. The Mg is present in ruminant body mass at about 0.05%. In this study, the plant K:Mg ratio was on average 0.21, with maximum and minimum of 0.6 and 0.04, respectively. In general, Mg differences in this study is partly due to differences in production systems, shrubs growth stage, plant species, Mg soil concentration, and seasons when the shrubs sampling was carried out. These results are supported by Müller *et al*. (2019) who reported significant deficiencies in P, protein and energy in the diets selected by herded and free-ranging goats and sheep in both wet and dry season in the Namaqualand Granite Renosterveld South Africa rangeland. The K content varied among non-legumes and legumes species and shrubs. Ramírez-Orduña *et al*. (2005) reported in an arid area of Baja California that K differed between species being higher in *O. cholla*. The variation of K content between shrubs depends on various factors (Boudjabi and Chenchouni 2022). Therefore, K may be a restrict mineral for livestock when they are consuming particularly ripe forage (Stewart *et al*. 2021). In this study, goats consumed sufficient amounts of K in the three production systems, during the two seasons, consuming both non-legumes and legumes since all shrubs showed enough K content to satisfy necessities of goats (1.8-2.5 g kg^{-1}; NRC 1981). The K content of shrubs could be associated with water availability because K assimilation by the root is related to soil moisture (Jákli *et al*. 2018). The K content was higher during dry season; this response could be explained by differences between goat diets not so much by season, because under water tension, K assimilation could be restricted, and K deficit may develop (Ahanger *et al*. 2017). The rainfall and temperature affect the mineral content, showing that some plants had higher mineral content during summer and autumn when rainfall and temperature are high (Ramírez-Lozano *et al*. 2018). There is a reduced possibility of K deficit in some

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areas of the world since K content is enough to meet ruminant requirements(Ramírez-Orduña *et al*. 2005, Ramírez and Núñez-González 2006, Khan *et al*. 2007, Ramírez-Orduña *et al*. 2008, Badshah *et al*. 2012, Ramírez-Lozano *et al*. 2018, Tan 2020).The Na content were analogous to those reported by Ramírez-Orduña *et al*. (2005) who found that Na content was greater during spring when rainfall was lower in both legumes and non-legumes. The Na content among production systems, seasons and plant types were found to be much higher than the recommended amounts for livestock except for legumes (1.4 g kg^{-1} NRC 1981). In an arid area of Baja California Sur Ramírez-Orduña *et al*. (2005) found that most plants had Na content to fulfil range goat necessities, but the contrary was described by Moya-Rodríguez *et al*. (2002) who found low and apparently deficient of Na content for goats needs in shrubs growing in arid regions. However, the analysis of Na content in this study showed that 46% of the shrubs evaluated had enough Na content to satisfy goat demands and all shrubs used in the intensive system, can cover the demand of goats. These deficiencies can be easily solved by supplementation, a common practice on some livestock farms in the arid and semiarid regions (Le Bodo *et al*. 2020).

The Cl content showed significant differences among production systems, shrubs, seasons, and plant types. Cabrera-Torres *et al*. (2009) determined the amount of micro and macro minerals in the most important forages species that grow in three zones of Quintana Roo, Mexico and found similar Cl content in forages and sample zones. The salt is irreplaceable in that animals have a much greater requirement for the Na and Cl in salt than for another mineral (Godswill *et al*. 2020). Because of some plants make available deficient Na for animal feeding and might lack acceptable Cl content, addition of salt is a serious part of a nutritionally well-adjusted diet for animals (Hassen *et al*. 2022). The P content was lower in all shrubs analyzed and was lower than those daily requirements (5.4 g kg^{-1}) indicating that the P might not meet goat necessities, particularly during dry season in the extensive system, which is the most common production system in the arid area of the Baja California Sur state, Mexico. The goat's diet in the three production systems may play a major role in P consumption, addition of P may be necessary to meet National Research Council necessities for goats (NRC 2007). In this case, P for goat in the extensive system could be partly covered by consuming two shrubs, *C. x sonorae*, and *P. pringleii*, while in the semi-intensive system, P could be partly covered by consuming *T. lobaeformis*, whereas in the intensive system goats should consume *Z. mays* or *M. sativa*. The P deficiencies in plants grown in arid zones was observed by Ramírez-Orduña *et al*. (2005); however, these results are in contradiction with those reported by Badshah *et al*. (2012), who found that P contents of the sampled plants were usually in the range of proposed limits. The values of P content in plants varied from 0.7 to 4.0 g kg^{-1} dry-basis (Ramírez *et al*. 2001, Khanal and Subba 2001). The study of Ramírez-Orduña *et al*. (2005) showed that P content varied between forages, seasons, plant types, years and so on. The P is the limited mineral to obtain for foraging animals in many regions, because of its low availability in rangeland plants and leach through soil erosion (Hussain and Durrani 2008, Ramírez-Lozano *et al*. 2018). This study did not include the possible variation of mineral content among plant tissues (stems, leaves, flowers and so on) which through diet selection could also disturb dietary P content (Grings *et al*. 1996). The Ca:P ratio is most important than actual content of either P or Ca. The ratio 2:1 was found best for optimum utilization and metabolism in goats (Ramírez and Núñez-González 2006). In this study, the Ca:P ratio varied from 0.14:1 in *Pennisetum* sp to 34:1 in *L. brevipes*, with an average value of 7.36:1. The high values of Ca:P ratio was reported by Ramírez-Orduña *et al*. (2005), Ramírez and Núñez-González (2006); however, higher ratios are acceptable without affecting P metabolism if acceptable vitamin D is available (Underwood and Shuttle 1999) which is produced in the skin of goats that are out in sunlight. In this case, vitamin D in goats could be enough in all three production systems, the goats are under sun all day (extensive system) or in some periods of the day (semi-intensive and intensive systems).

Microminerals

Ramírez-Orduña *et al*. (2008) found significant differences of the Zn content among legumes and non-legumes in a semiarid zone contrary to the results of this study. The same authors found some increments of Zn during summer and winter rainfall. The studies reported of some shrubs in Texas, USA (Barnes *et al*. 1990) and Northeastern Mexico (Ramírez *et al*. 2001, Moya-Rodríguez *et al*. 2002) had Zn that changed seasonally, but only a small number of them had Zn that meet requirements of livestock and white-tailed deer necessities in the diet. Ramírez and Núñez-González (2006) found higher Zn content during spring and fall than other seasons. However, the shrubs had lower Zn contents than the average necessity for ruminants with about 30 mg Zn kg^{-1} dry-basis (Nasrullah *et al*. 2003). The Zn content in the shrubs was not sufficient in none of the plants and shrubs collected in production systems, and seasons, for recommended requirements for goats with a range of 40-50 mg kg^{-1} dry-basis of Zn in their diets (Kessler 1991). In addition, Zn bioavailability due to plant maturity and tissue type (Kabata-Pendias and Pendias 2010) plays a significant role in its effective utilization in ruminant (Khan *et al*. 2007). The differences of Cu content among seasons, plant type and shrubs are comparable with those described by Ramírez *et al*. (2001) who found that Cu content in bushes, was higher for the period of spring than in other seasons, which is the epoch of active vegetative development and dry conditions. The Cu requirements in the diet for an adult goat ranged from 8 to 10 mg kg^{-1} dry-basis (Kessler 1991). In this study, some shrubs could meet adult goat necessities and are like those reported by Ramírez *et al*. (2004) and Ramírez-Lozano *et al*. (2018) who identified low Cu contents in shrubs from semiarid regions, where the main cause could be the high soil pH. Furthermore, low Cu contents are reported in tropical legumes species (Norton and Poppi 1995) where lands are slightly poor of Zn and Cu. Other studies have shown that Cu accessibility could be restricted by dietary fiber (Ramírez-Orduña *et al*. 2008); also, the high plant absorption of minerals, for example, Se and Mo could increase the Cu deficiency. The Cu requirements of goats may be higher (Ramadhan *et al*. 2022), being 40 mg kg^{-1} DM (NRC 2007) the maximum Cu tolerance level in the diet of goats. The Fe content differed among systems, seasons, and shrubs. Ramírez-Orduña *et al*. (2005) reported that non-legumes showed higher Fe content than legumes during fall and winter. The Fe content was found to be enough to meet requirements of 35 mg kg^{-1} dry-matter (NRC 1981) when Fe content was considered in average between production systems, seasons, and plant types. The Fe content vary between shrubs; *C. gayana* had the highest followed by J. cinerea while *Ferocactus* spp. and *F. diguetti* had the lowest content. Some shrubs showed values well over necessities, but not at toxic levels, so that these shrubs are able to contribute to the goat's diet to balance the Fe content. This result agrees with Ramírez *et al*. (2001) and Moya-Rodríguez *et al*. (2002) who discuss that Mexican bushes growing in semiarid areas had Fe content in significant content to meet necessities of goats. The differences in the Fe content between shrubs can be elucidated by forage species modifications and the effect of grazing parcels on the level of Fe in the soil. The forage Fe is a function of forage species, soil Fe concentration, source, and type of soil, which forages are grown (Ferreira *et al*. 2021); in addition, the fluctuating conditions of environment, as well as biological stage of plants, affect the Fe uptake by the plants (Kabata-Pendias and Pendias 2010, Trivedi *et al*. 2020). The Mn content showed significant differences between systems, seasons, plant types, and shrubs. These findings are in accordance with those reported by Ramírez-Orduña *et al*. (2005) who found a variation of Mn content between years, when rainfall was sparse. In this study non-legumes showed the highest Mn content. Comparable effects were obtained by Ramírez-Orduña *et al*. (2005) who described low Mn content in legumes than in non-legumes during winter. The dry season in the study area coincides with late winter, spring, and early summer. The results found here are similar with those reported by Ramírez *et al*. (2001) and Moya-Rodríguez *et al*. (2002) who reported that Mn concentration was highest in spring and winter than summer and autumn, whilst Ramírez

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and Núñez-González (2006) found higher Mn content in all forbs during spring and fall than other seasons. The variation of Mn content among shrubs may to complicate to exactly predict Mn concentrations in animal's diet. In this study, goats had diets with not enough Mn amounts to meet necessities with a range of 30-40 mg Mn kg^{-1} dry-basis (Kessler 1991). The Mn content among and within plant species differed by soil types, plant types, plants mature, plant tissues and seasons (Grings *et al.* 1996, Ramírez *et al.* 2001). This study revealed that *A. barclayana* had the highest B and *C. ciliaris* had the lowest content. The species related with *A. barclayana* such as *A. garner*, are commonly seeded in mixtures and established on reclaimed sites in Wyoming, USA which has been identified as having potentially high levels of B in soil (Winslow *et al.* 2009). The B is apparently not essential in the diet of ruminant animals (Abdelnour *et al.* 2018). The metabolism of B is closely related to that of Ca in ruminant animals and may regulate parahormone action and play a role as a cofactor of certain enzymatic reactions (Upadhaya and Kim 2020). The excess and toxic content of B in soils of semi-arid and arid regions are often more of a problem than due to deficiencies (Brdar-Jokanović 2020). The ruminant animals excrete excess amounts of dietary B in the urine avoiding toxicity (Suttle 2022). The B concentration in the tissues and fluids of ruminant animals appear to directly reflect B concentration in the diet (Yirga *et al.* 2018). The B contained in the tissues of forage plants is not necessarily present in a soluble form (Brdar-Jokanović 2020).

CONCLUSIONS

The shrubs showed differences among macro and minerals content and most of these macro and micro minerals showed changes through production systems (intensive, semi-intensive and extensive), seasons (wet and dry) and types of plants (legumes and non-legumes). The shrubs in the two production systems (extensive and semi-intensive) had acceptable content of Ca, Mg, K, Na, B, Cl and N for grazing ruminants; however, these shrubs had lower contents of Zn, Cu, Fe, and Mn, also lower contents of P than the diet necessities for some ruminants. The higher content of most macro and micro minerals in non-legumes added in the goat diets could be considered as good nutritional quality. In addition, the status of mineral content shrubs of the semi-intensive production system, 58% of all minerals showed higher values, and hence, could be the best production system in this arid region. The higher content of some essential minerals in *L. brevipes*, *T. lobaeformis*, *A. barclayana* all of them collected in the semi-intensive system; also *S. thurberi* from extensive system and *C. gayana* from intensive system, therefore, these shrubs can be considered a good nutritional quality.

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