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Technical note

Similarity in plant species consumed by goat flocks in the tropical dry forest of the Cañada, Oaxaca

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Abstract:

Management of goats (*Capra hircus*) in extensive systems is a common practice in the Tehuacán-Cuicatlán Biosphere Reserve (TCBR), Mexico. This study analyzes the similarity in plant consumed by goat flocks in landscape at the Cañada region, Oaxaca. Eight (8) flocks were sampled in different locations during the 2012 rainy season and 2013 dry season. To determine spatial and temporal similarity among the flocks, depending upon the consumed plant species, it was used hierarchical agglomerative clustering methods in the R program. The goats consumed a total of 84 plant species, of which 30 constituted 75 % of the diet. According to the similarity analysis, *Mimosa* sp. and *Acacia cochiliacantha* were the species consumed by all flocks in both seasons; while *Eleusine indica*, *Prosopis leavigata* and *Opuntia* sp. were the next most important, depending on the season. The Tecomavaca herd showed lower similarity than the other flocks. The results of the present study contribute to furthering the knowledge regarding the foraging habits of goats in tropical dry regions where the seasonality of the resources is very contrasting.

Key words: *Capra hircus*, Extensive systems, Multivariate methods, Tehuacán-Cuicatlán Biosphere Reserve.

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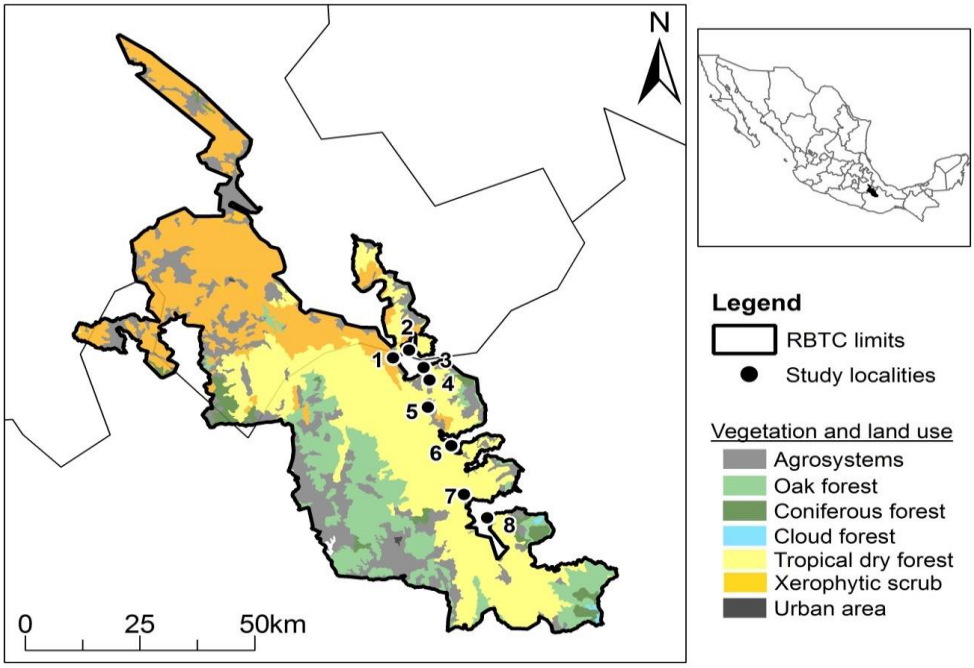
In Mexico, goats represent an important source of protein[1,2]. For example, the national census of 2011 estimated a population of 9 million goats[3]. Management of goats is a particularly widespread practice in the state of Puebla[4,5], but it is less developed in Oaxaca[6]. The Tehuacán-Cuicatlán Biosphere Reserve (TCBR) in the states of Puebla and Oaxaca in central Mexico is characterized by high biodiversity of species and endemism[7]. Within the Tehuacán-Cuicatlán Valley, there are estimated to be around 5,000 goat farmers[8], who mainly practice subsistence farming[9]. The goats have been present since their introduction during the colonial period and currently represent one of the main productive activities in many villages in and around the TCBR[4]. In common with other arid and semi-arid regions[2,3], the extensive system is the main practice in the TCBR. This is based on leading the herds along fixed or migratory routes to browse on the hills, roadsides and riparian areas[4].

Considering that the TCBR is a natural protected area, it is important to evaluate the influence of goats on the vegetation structure[2,10,11] and identify possible competitive interactions with wild ungulates such as the white-tailed deer *Odocoileus virginianus*[12]. In this context, this study analyzes the similarity in plant consumed by goat herds in landscape at the Cañada region, Oaxaca, using hierarchical agglomerative clustering methods. To determine similarities among the herds in terms of the plant species consumed, in this study were used hierarchical agglomerative clustering methods through multivariate cluster analyses[13]. The objective of clustering is to recognize discontinuous subsets in an environment that is sometimes discrete and most often perceived as continuous in ecology[14]. Specifically, clustering consists of partitioning the collection of objects under study. For this propose several similarity indices, as for example Sorensen, Jaccard and Morisita, had been employed for computing similarity or dissimilarity among pairwise collection objects. Clustering methods, as for example, single linkage, complete-linkage, average agglomerative and Ward's minimum variance, are employed to agglomerate objects on basis of pairwise distance given the similarities or dissimilarities, depending on each case[13]. To interpret and compare the hierarchical clustering results, cophenetic correlation distances were calculated for each clustering. Briefly, the cophenetic index between two objects in a dendogram is the distance at which the objects become members of the same group. The interpretation of this index is similar to the Pearson's r correlation coefficient[14]. Therefore, to test the hypothesis of the present study, hierarchical agglomerative clustering methods were employed.

The study was conducted at the region of the Cañada in Oaxaca, within the Tehuacán-Cuicatlán Biosphere Reserve (TCBR) in Mexico (Figure 1). The TCBR is locate in the extreme southeast of the state of Puebla and northeast of Oaxaca, between 17° 39' - 18° 53'

N and 96° 55' - 97° 44' W. It is 490,187 ha in area and the altitude ranges from 600 to 2,950 m asl. Annual mean temperature ranges from 18 and 22 °C, while the annual precipitation varies between 250 and 500 mm[15]. The main vegetation types in the region are: crassicaule scrub dominated by columnar cacti of the genus *Neobuxbaumia* (8 % of the reserve territory) and rosetophyllous scrub (10 %), mostly in the northern area of the TCBR; while tropical dry forest (29 %) dominate mainly in the Cañada region; oak and pine forest in the upper mountains (21 %); as well as other vegetation types (10 %). Land use is mostly for agriculture, livestock and forestry (22 %)[15].

Figure 1: Geographic location of the eight studied sites at La Cañada in the Tehuacán-Cuicatlán Biosphere Reserve, Mexico. Sites: Casa Blanca (1), Coxcatlán (2), Teotitlán (3), Toxpalan (4), Los Cues (5), Tecomavaca (6), Cuicatlán (7) and Chicozapotes (8)



The study was conducted in eight locations: Coxcatlán state of Puebla, and Casa Blanca, Teotitlán, Toxpalan, Los Cues, Tecomavaca, Cuicatlán and Chicozapotes state of Oaxaca (Figure 1). At each location, it was follow the same flock once during the rainy season (September to November 2012) and once again in the dry season (April to June 2013). The selection of these flocks depended on the interest of the goat farmers in participating in the study. Traditionally, the extensive system consists of moving the flock daily to foraging sites along predefined routes. In addition, the flock size and total foraging time depends upon the owner's experience, among other factors[16]. In the studies sites, the mean herd size and forage time were 70 goats and 4.2 h, respectively.

To determine the main plants consumed by the goats, the animals were directly observed during foraging[17]. The selection of these herds depended on the interest of the goatherds in participating in the study. In the study site, the goat farmers move their animals to forage outside the villages almost every day. The goats are therefore accustomed to the presence of people, which eliminates the possibility of bias during observation of foraging activities[18]. Every 20 min, a different focal animal was selected and the number of plants of each species consumed was recorded over a period of 10 min. For each flock, it was recorded the number of plants species consumed per the flock during both the rainy and dry seasons, was recorded[18,19]. The number of focal animals varied depending of the travel time of the sampled flock (n= 57 and 58 goats for rainy and dry seasons, respectively). Simultaneously, there were collected plants for taxonomic determination in the herbarium strata and by other sources[20]. However, the rugged topography, dense vegetation and speed of movement by the goats made it impossible to collect all plants consumed.

Individually observed goats cannot be true replicates as they do not take grazing decisions independently from one another[21]. Therefore, the information was grouped considering flock as replicate. It was calculated the cumulative curve of the number of species consumed by the goats during the rainy and dry seasons. A relatively arbitrary shortcut of 75 % was employed to determine the principal plant species and was used a Chi-square test to evaluate differences between seasons[22].

To determine similarities among the eight flocks in terms of the plant species consumed, hierarchical agglomerative clustering methods were used through multivariate cluster analyses[23]. For this purpose, the species that represented 75 % of the total consumed plants was employed for clustering the flocks. This shortcut percent is subjective but represents the point where the cumulative curve of the relationship between number of species consumed species, begins to reach the asymptote. Analyses were performed separately for each season. The Horn-Morisita similarity index was selected for the number of plants consumed by species in this study. Four clustering methods were calculated: single linkage, complete-linkage, average agglomerative (UPGMA) and Ward's minimum variance[23]. To examine the species content of the clusters depending on group memberships, it was used the *vegan* R package[23]. This package provides tools for descriptive community ecology. Specifically, it has the most basic functions of diversity analysis, community ordination and dissimilarity analysis. Finally, the results of these analyses are presented as a heat map of the doubly ordered table of the consumed plants, with a dendrogram of cluster sites. All analyses in this study were performed in R version 3.2.3[24].

The goats consumed 82 and 65 species during the rainy and dry season, respectively (Table 1). However, according to the cumulative curve, 75 % of the diet was constituted by 30 species: 24 species during the rainy season and 20 species in the dry season (Figure 2). The main species in both seasons were *Mimosa* sp., *Acacia cochiliacantha* and *Eleusine indica;* during the rainy season was *Dalea carthagenensis*; while in the dry season were *Prosopis*

leavigata, *Opuntia* sp. and *Ceiba parvifolia*, which differed significantly (Figure 3; *P*= 0.0001).

Table 1: List of plant species consumed by goats during the rainy and dry seasons at La Cañada, Oaxaca

Plant species	Abbreviation	Rainy season		Dry season	
		Number of plants	% *	Number of plants	%
Eleusine indica	*Elin*	56	8.6	28	5.4
Mimosa sp.1	*Misp*	51	7.8	50	9.6
Acacia cochliacantha	*Acco*	49	7.5	61	11.7
Dalea carthagenensis	*Daca*	27	4.2	10	1.9
Agrostis stolonifera	*Agst*	21	3.2	10	1.9
Viguiera dentata	*Vide*	16	2.5	18	3.4
Cordia curassavica	*Cocu*	16	2.5	5	1.0
Eysenhardthia polystachya	*Eypo*	14	2.2	8	1.5
Senna wislizeni	*Sewi*	14	2.2	10	1.9
Aegopogon sp.	*Aesp*	13	2.0	16	3.1
Opuntia sp.	*Opsp*	13	2.0	24	4.6
Ceiba parvifolia	*Cepa*	12	1.8	22	4.2
Waltheria indica	*Wain*	12	1.8	14	2.7
Amphipterygium	*Amad*	9	1.4	3	0.6
adstringens	*Ligr*	8	1.2	-	-
Lippia graveolens	nd	8	1.2	-	-
nd	*Phau*	8	1.2	2	0.4
Phragmites australis	*Papr*	7	1.1	16	3.1
Parkinsonia praecox	*Prle*	7	1.1	43	8.2
Prosopis leavigata	*Zipe*	7	1.1	11	2.1
Ziziphus pedunculata	*Buli*	7	1.1	2	0.4
Bursera linanoe	*Glgl*	7	1.1	2	0.4
Glycyrrhiza glabra	nd	6	0.9	5	1.0
nd	*Busp*	6	0.9	6	1.1
Bursera sp.	*Sapr*	5	0.8	-	-
Sanvitalia procumbens	nd	5	0.8	4	0.8
nd	*Crpr*	5	0.8	-	-
Cyrtocarpa procera	*Ledi*	5	0.8	12	2.3
Leucaena diversifolia	nd	5	0.8	6	1.1
nd	*Mame*	4	0.6	-	-

Malpighia mexicana	*Ipsp*	4	0.6	4	0.8
Ipomoea sp.	*Cili*	4	0.6	5	1.0
Citrus limon	*Pool*	3	0.5	-	-
Portulaca oleracea	*Brde*	3	0.5	3	0.6
Brachiaria decumbens	*Laca*	3	0.5	3	0.6
Lantana camara	*Sosp*	3	0.5	-	-
Solanum sp.	*Agho*	3	0.5	2	0.4
Agave horrida	*Ages*	3	0.5	1	0.2
Ageratina espinosarum	*Lyac*	3	0.5	4	0.8
Lysiloma acapulcense	*Lyte*	3	0.5	4	0.8
Lysiloma tergeminum	nd	3	0.5	-	-
nd	*Pafo*	3	0.5	-	-
Passiflora foetida	*Plru*	3	0.5	7	1.3
Plumeria rubra	*Sotr*	3	0.5	-	-
Solanum tridynamum	*Tudi*	3	0.5	-	-
Turnera diffusa	*Maza*	2	0.3	2	0.4
Manilkara zapota	*Sila*	2	0.3	-	-
Simsia lagascaeformis	*Acfa*	2	0.3	12	2.3
Acacia farnesiana	*Anle*	2	0.3	-	-
Antigonon leptopus	*Busp1*	2	0.3	2	0.4
Bursera sp.1	*Caza*	2	0.3	-	-
Calea zacatechichi	*Guul*	2	0.3	7	1.3
Guazuma ulmifolia	*Lele*	2	0.3	9	1.7
Leucaena leucocephala	*Matr*	2	0.3	3	0.6
Matelea trachyantha	*Pawe*	2	0.3	3	0.6
Pachycereus weberi	*Pidu*	2	0.3	11	2.1
Pithecellobium dulce	*Plsp*	2	0.3	-	-
Platanus sp.	*Plbu*	2	0.3	-	-
Plocosperma buxifolium	*Posp*	2	0.3	-	-
Polygonum sp.	*Saal*	2	0.3	2	0.4
Salix alba	*Sppu*	2	0.3	11	2.1
Spondias purpurea	*Amhy*	1	0.2	4	0.8
Amaranthus hybridus	*Titu*	1	0.2	2	0.4
Tithonia tuberformis	*Alch*	1	0.2	2	0.4
Allionia choisyi	*Cnte*	1	0.2	1	0.2
Cnidoscolus tehuacanensis	*Acco*	1	0.2	1	0.2
Acacia coulteri	*Acme*	1	0.2	1	0.2
Acrocomia mexicana	*Agke*	1	0.2	1	0.2
Agave kerchovei	*Agpo*	1	0.2	1	0.2
Agave potatorum	*Bufa*	1	0.2	1	0.2

Bursera fagaroides	*Cesp*	1	0.2	1	0.2
Ceiba sp.	*Cepa*	1	0.2	2	0.4
Celtis pallida	*Cosc*	1	0.2	-	-
Commicarpus scandens	*Come*	1	0.2	1	0.2
Condalia mexicana	*Hete*	1	0.2	2	0.4
Hechtia tehuacana	*Mool*	1	0.2	1	0.2
Moringa oleifera	*Psan*	1	0.2	1	0.2
Pseudosmodingium	*Scba*	1	0.2	2	0.4
andrieuxii	*Soro*	1	0.2	-	-
Schinopsis balansae	nd	1	0.2	1	0.2
Solanum rostratum	nd	1	0.2	1	0.2
nd	*Asvi*	-	-	5	1.0
nd	*Pade*	-	-	2	0.4
Astianthus viminalis	*Stpr*	1	0.2	4	0.8
Panicum decolorans					
Stenocereus pruinosus					

(*) percentage of the total in each season, (nd) non-determined species.

Figure 2: Cumulative curve of the relationship between number of species consumed by goats during the dry and rainy seasons. Dashed red lines show that, considering arbitrary shortcut of 75 %, 20 and 24 plants species were consumed in each season

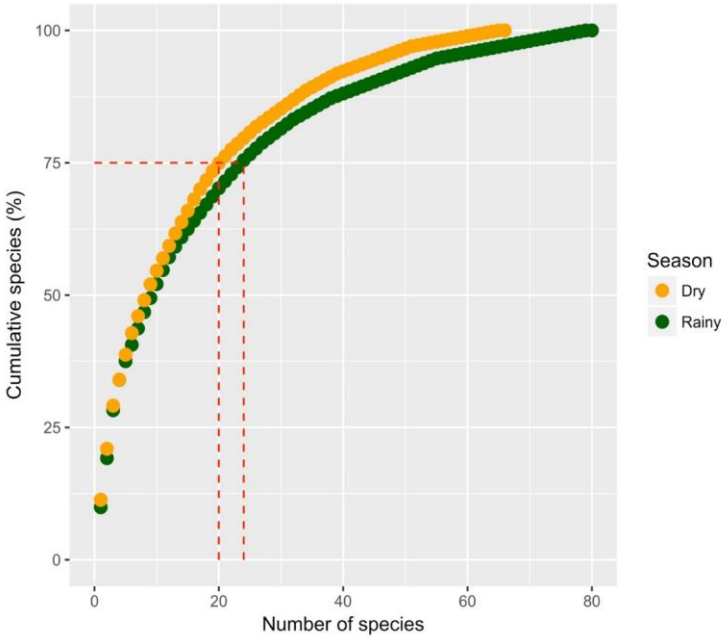
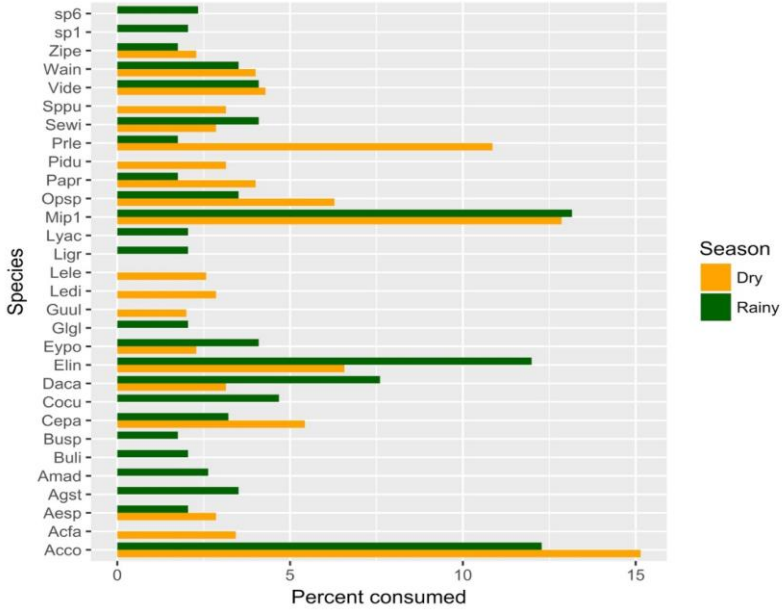


Figure 3. Percentage of the principal plant species (75 % of the total) consumed by goats during the dry and rainy seasons.



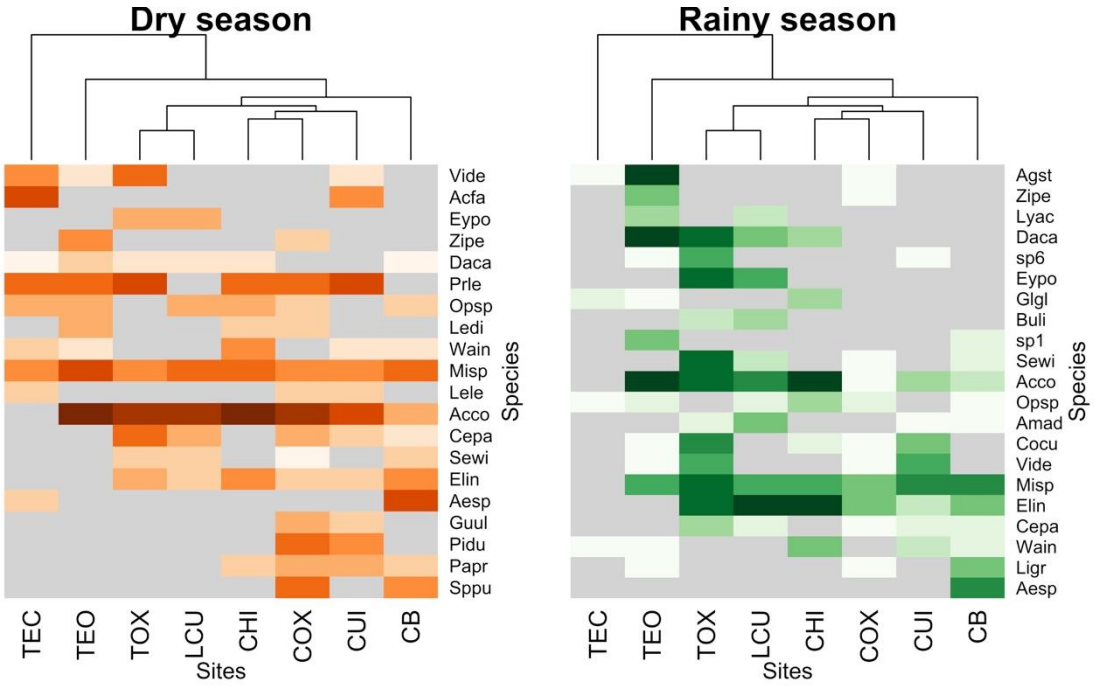
The four clustering methods (single linkage, complete-linkage, UPGMA and Ward) produced slightly different dendrograms. Calculation of the cophenetic distance correlation coefficient (r= 0.92 in the rainy season and r= 0.86 in the dry season) suggested that UPGMA was the optimum clustering method for the matrix data. The Horn-Morisita similarity coefficients varied among pairwise locations and seasons (Table 2). *Mimosa* sp. and *Acacia cochiliacantha* were the species consumed by all flocks in both seasons; while *Eleusine indica*, *Prosopis leavigata* and *Opuntia* sp. were the next most important, depending on the season. During the rainy season flocks from Tecomavaca and Teotitlán showed lower similarity relative to the other flocks; while dry season, flocks from Tecomavaca and Casa Blanca showed lower similarity relative to the other flocks (Figure 4).

Table 2. Horn-Morisita similarity coefficients among pairwise sites during the rainy and dry seasons

	CB+	CHI	COX	TOX	CUI	LCU	TEO
Rainy season							
CHI	0.582						
COX	0.707	0.72					
TOX	0.471	0.604	0.601				
CUI	0.536	0.640	0.694	0.685			
LCU	0.549	0.723	0.664	0.800	0.499		
TEO	0.353	0.547	0.401	0.481	0.401	0.495	
TEC	0.080	0.369	0.138	0	0.088	0.04	0.256
Dry season							
CHI	0.610						
COX	0.590	0.685					
TOX	0.480	0.678	0.611				
CUI	0.454	0.718	0.808	0.700			
LCU	0.633	0.705	0.579	0.761	0.526		
TEO	0.456	0.844	0.669	0.675	0.617	0.673	
TEC	0.381	0.477	0.35	0.463	0.615	0.275	0.511

+ Sites abbreviations: Coxcatlán (COX), Casa Blanca (CB), Teotitlán (TEO), Toxpalan (TOX), Los Cues (LCU), Tecomavaca (TEC), Cuicatlán (CUI) and Chicozapotes (CHI).

Figure 4: Classification of the sites according with the similarity in plant species consumed by goats during the dry and rainy seasons. The dark—light color gradient represents from more to less species consumed. Very low or no consumption it is represent by gray color. In the upper part, the dendrogram of studied sites classification uses the UPGMA average agglomerative clustering method



The species richness of plants consumed by the goats in the region of La Cañada was similar to that reported in regions neighboring the TCBR. For example, in the northern region, between 40 and 80 species have been reported to be consumed by the goats in the dry and rainy seasons, respectively[5,25]. Among the principal genera consumed by goats were *Bursera, Jatropha, Fouquieria, Leucaena, Pithecellobium, Acacia, Guazuma,* and *Prosopis*[25,26]. In other tropical region has been reported that, of the 19 trees species consumed during the year, *Mimosa* was by far the most frequently selected species; grass was a large component of the goat diet in the early wet period, while browsed leaves were an important source of forage during the dry periods[28]. In particular, the dry season is the most critical phase for the maintenance of flocks in this region. It has been documented that the goats lose bodyweight significantly during this period due to deficiencies in dietary protein

and phosphorus[29]. The animals mainly browse on leguminous plants during the dry season[30].

During periods of forage scarcity, goats typically increase their search effort as nutrient intake decreases. The increased consumption of woody species observed during this period increases the grazing pressure on local vegetation[29]. For this reason, such as *Opuntia* spp. and *Agave salmiana* have been suggested as dietary supplements, along with the fruits of *Yucca periculosa* and pods of *Prosopis laevigata* and *Acacia subangulata* combined with the traditional maize stubble[29]. In other semiarid regions, *Prosopis laevigata* and *Opuntia* sp. are used as supplements, considering their nutritional characteristics and their capacity for growth in conditions of low water availability[31]. In particular, the cladodes of the cacti and their fruits are used as an emergency food source, providing energy and water in times of drought, while the herbaceous plants provide protein in the rainy season[3].

Small ruminants, such as goats and sheep, and even wild animals such as the white-tailed deer, select their diet from a broad range of plant species, which differ in terms of nutrient content and availability over the course of the year[19]. At the end of fall and beginning of winter, there is a lack of quality forage for which reason it is necessary to supplement the diet of the goats. The deficiency of crude protein in the goat´s diet limits the digestion of fiber and minerals by the animals, causing slow growth, reduced immunological function, anemia, edema and death[32]. Of the plant species consumed, those with the highest contents of protein (>20 %) are *Ziziphus pedunculata*, *Prosopis laevigata* and *Ceiba parvifolia;* other species that fulfill the minimum requirements for the goats are *Mimosa* sp., *Viguiera dentate*, *Walteria indica* and *Solanum tridynamum*[33]. Fiber contributes significantly to balance nutritional requirements[32,34]. Of the plants analyzed, the highest fiber content is presented by *Agrostis stolonifera* collected in the rainy season. Of the consumed plants, those with the highest quantity of neutral detergent fiber, acid detergent fiber were *Mimosa* sp., *Opuntia* sp., *Viguiera dentate*, *Acacia farnesiana*, *Opuntia* sp. and *Ziziphus pedunculata*[33]. The shrub species of the genera *Prosopis*, *Mimosa* and *Acacia* presented high metabolizable energy compared to some tree, cactus and herbaceous plants[3]. The metabolizable energy in *Prosopis* and *Acacia* during the dry season exceeded the requirements of the goats[35].

Hierarchical agglomerative clustering methods through multivariate cluster analyses[13] allowed determination of similarities among the eight flocks depending upon the consumed plant species. These methods are common in taxonomic and ecological studies[14]. Based on 75 % of the principal species consumed and using heat maps, the eight studied flocks were classified into different clusters in each season. Specifically, the Tecomovaca flock showed lower similarity compared to the other flocks. Local differences in plant species abundance

and the presence of some specific species, explained the clustering of the flocks in the rainy and dry seasons.

Finally, the results of the present study contribute to furthering the knowledge regarding the foraging habits of goats in tropical dry landscapes where the seasonality of the resources is very contrasting, as is the case in the Cañada which has been little studied compared to the arid and semiarid zones of Mexico. Some of the plants consumed could be used in the production of silage by family microbusinesses in order to feed the goats with native plants. Due to their availability in the zone as well as nutritional content, the species *Ceiba parvifolia*, *Waltheria indica*, *Prosopis leavigata*, *Solanum* sp. and *Sanvitalia procumbens* could be collected in the rainy season for tedding or ensilaging and subsequent use as a food supplement in the dry season or when the animals are corralled. These results are valuable for the management and conservation of the studied habitats as they further the understanding of goat habitat and diet selection in different periods.

The studied goat flocks consumed 65 to 82 plant species during the dry and rainy seasons in the Cañada region of Oaxaca State. However, the main species were *Mimosa* sp., *Acacia cochiliacantha*, *Eleusine indica*, *Dalea carthagenensis*, *Prosopis leavigata*, *Opuntia* spp. and *Ceiba parvifolia*. Some of these species have been reported in other regions. Hierarchical agglomerative clustering methods through multivariate cluster analyses allowed the determination of similarities among the eight flocks according to the plant species consumed. These analyses show that the goats of different locations in the Cañada region consumed relatively similar plant species.

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