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Chemical Composition and *In vitro* Digestibility of Fodder Trees and Shrubs Consumed by Goats in the Low Mixteca Region of Oaxaca, Mexico

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Abstract: The aim of this study was to evaluate the potential for animal nutrition of leaves and pods of fodder trees and shrubs consumed by goats, according to their chemical composition, cell walls and *in vitro* digestibility. Plants of the genera Acacia (*A. cymbispina* Sprague, *A. farnesiana*, *A. couteri* Benth, *A. Milibekii*), Mimosa (*M.* sp., *M. pudica*, *M. fasciculata*), Quercus and Prosopis (*P. laevigata*) in the municipality of Cosoltepec, Oaxaca, Mexico were evaluated. A total of 22 trees were identified and collected in 2 years in the Summer and Winter. In Summer, the minimum value of protein was 61.9 g kg^{-1} DM, the species that presented the highest was *Mimosa* sp., containing 243.8 g kg^{-1} DM. Crude protein in the Winter time followed the same trend as in Summer, the minimum value corresponded to *Hymenqea coubaril* protein, 61.3 g kg^{-1} DM, the highest value refers to *Mimosa* sp., with a value of 225.3 g kg^{-1} DM. The Summer IVDNDF ranged from 328.8-683.5 g kg^{-1} DM, the highest value corresponds to *Eysenhartia polystachya* family Fabaceae. In the Winter time ranged from 252.8-683.3 g kg^{-1} DM, a 11.76% of the studied species had values above 60%, *Liquidambar styraciflua* of the family Hamameliceae and *Cassia pringlei* of Leguminoseae family. Pods had a minimum of 120 g crude protein kg^{-1} DM and in the case of *A. farnesiana*, *P. Laevigata* and *Pithecellobium dulce* exceed the IVDNDF at 600 g kg^{-1} DM. It is concluded that based on its chemical composition, the tree is a potential resource for goat silvopastoral production in the Mixteca region.

Key words: Arid and semiarid, forages, goats, leaves, pods, rangeland

INTRODUCTION

Developing countries have explored alternatives in the study of natural resources as animal feed, aimed at the problems posed by farmers whose main activity is the raising of small ruminants as economic resource and self consumption. Agricultural production systems for ruminants in the tropics based on forages are limited by its quality, voluntary intake and digestibility (Salem *et al*., 2006). The growth of ruminants and the production of milk or meat is a function of the nutritional value of diets consumed and transformed into products. The use of trees and shrubs in animal production systems in Latin America is not new (Garcia-Montes de Oca *et al*., 2011), these represent an option for silvopastoral systems due to its appropriate levels of protein, macro elements and digestible organic matter (Garcia-Montes de Oca *et al*., 2011). Digestibility of organic matter varies in due to lignification of cell walls, secondary compounds such as tannins (Salem *et al*., 2006), phenols, saponins and alkaloids (Norton, 1994), age, maturity, seasonal changes, variability in diets and feeding system provided to ruminants.

Mexico has arid and semiarid areas that cover almost half the national territory. The main environmental impact on this habitat type is caused by agricultural activities which implies the removal of many desert plants. Goat production in the state of Oaxaca, Mexico is carried out in semiarid and arid conditions and represents the main source of income for community and family economic self-sufficiency. The breeding of goats in the low Mixteca region of Oaxaca is carried out under free-range system based on the browsing of leaves, pods and fruits and bushes consumption. Despite the importance of shrubs in

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the silvopastoral systems of the low Mixteca region of Oaxaca, Mexico there are few studies on its chemical composition, nutritional quality and secondary metabolites. Thus, it is necessary to know their nutritional value in order to determine their potential use in a sustainable way.

The aim of the present study was to evaluate the proximate composition, cell walls and *in vitro* digestibility by gas production technique in leaves and pods of trees and bushes consumed by goats in the low Mixteca of Oaxaca, Mexico.

MATERIALS AND METHODS

Study area: The study was carried out in the municipality of Cosoltepec, located Northwestern of the state of Oaxaca at the low Mixteca region, coordinates 97°47' West and 18°08' North latitude. The climate is semiarid and the average annual temperature ranges between 25 and 30°C. The maximum height above sea level is 1825 m; rainfall varies between 300 and 400 mm year^{-1} distributed between July and September. The soils have been formed from the disintegration and decomposition of igneous, sedimentary and metamorphic resulting in young soils called Regosols. There is a great diversity of xeric shrubs, medicinal, forage and ornamental cacti plants.

Sample collection: Participatory tours were conducted trough 5 usual grazing routes in order to sampling leaves of trees and shrubs in 2 seasons, one in Summer (August, 2003 and 2005), a month after the onset of the rainy season. The villagers provided the local names of plants. A second collection period took place in the Winter (December, 2003 and 2004), 3 months after the end of the rainy season. The pods were collected during their time of availability in December, 2004. In the paths of the routes were collected approximately 500 g per species for the respective analysis. In total, researchers identified 22 species among trees, shrubs and an herbaceous and the collection of pods of 10 shrubs. The botanical identification of the species collected was done according to Dorado and Martinez.

Analysis of chemical composition and digestibility: The Dry Matter (DM) of the samples was determined on the day of collection by an infrared balance. It was later determined the proximate analysis and organic matter (AOAC, 1990), Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL) (Van Soest *et al*., 1991). *In vitro* digestibility of NDF was determined by the technique of gas production (Menke *et al*., 1979).

Statistical analysis: The data obtained from the samples were grouped, according to their level of consumption by goats which were determined by producer's experiences. The level of consumption was categorized as very high, high and low which was determined by the perception of goat producers on the order of preference of plants for their goats. The proximate chemical composition data, NDF, ADF, ADL and *in vitro* organic matter digestibility were analyzed using Chi-square test.

RESULTS AND DISCUSSION

Identification of tree species consumed by the goats: Table 1 presents the names of the trees collected and their classification. The 4 species of shrubs belonged to Leguminoseae had a very high consumption (Table 2) (*P. acatlense* Benth, *A. cymbispina* Sprague *P. laevigata*, *A. farnesiana*), Hernandez agreed that consumption of *P. acatlense* Benth in the Mixteca of Puebla is higher for goats. The 2 species (*P. laevigata*, *A. farnesiana*) retain their foliage production during the months of January to June during the dry season as in other parts of the country like the semi desert scrub of Tamaulipas.

These are also the most abundant species and are therefore considered relevant because there are consumed by goats in the dearth of other forages. Moreover, the consumption of 5 species was considered high, 4 belonging to the family Leguminoseae (*L. divaricatum*, *M.* sp., *M. pudica*, *C. pringlei* rose) and Fagaceae (*Quercus* sp.), Olivarez commented that the legume shrub

Table 1: Tree species from Cosoltepec by common and scientific names, family and type

Common names	Scientific names	Family	Type
Barba de Chivo	*Pithecollobium acatlense* Benth	Leguminoseae	Shrub
Cubata	*Acacia cymbispina* Sprague	Leguminoseae	Shrub
Mezquite	*Prosopis laevigata*	Leguminoseae	Shrub
Huizache	*Acacia farnesiana*	Leguminoseae	Shrub
Tlahuitol	*Lysiloma divaricata*	Leguminoseae	Tree
Una de gato	*Mimosa* sp.	Leguminoseae	Shrub
Vergonzosa	*Mimosa pudica*	Leguminoseae	Shrub
Encino	*Quercus* sp.	Fagaceae	Tree
Guamuchil	*Pithecellobium dulce*	Leguminoseae	Tree
Rompebotas	*Cassia pringlei* Rose	Leguminoseae	Shrub
Estoraque	*Liquidambar styraciflua*	Hamamelidaceae	Tree
Nanche	*Bunchosia* sp.	Malpigiaceae	Shrub
Manzanita	*Arctostaphylos* sp.	Ericaceae	Shrub
Palo de Herrero	*Mimosa fasciculata*	Leguminoseae	Tree
San Pablito	*Wigandia caracasana*	Boraginaseae	Shrub
Papalo de venado	*Porophyllium* sp.	Asteraseae	Herbaceous
Silvato	*Hymenqea coubaril*	Leguminoseae	Shrub
Palo Blanco	*Acacia couteri* Benth	Leguminoseae	Tree
Oregano de Campo	*Brickellia veronicaefolis*	Asteraseae	Shrub
Tehuistle	*Acacia milibekii*	Leguminoseae	Shrub
Hierba de Guajolote	*Colubrina greggii*	Rhamnaceae	Shrub
Palo Dulce	*Eysenhartia polystachya*	Fabaceae	Tree

Table 2: Tree leaves collected and consumption levels

Scientific names	Summer[1]	Winter[2]	Consumption
Pithecollobium acatlense Benth	X	X	Very high
Acacia cymbispina Sprague	X		Very high
Prosopis laevigata	X	X	Very high
Acacia farnesiana	X	X	Very high
Lysiloma divaricatum	X	X	High
Mimosa sp.	X	X	High
Mimosa púdica	X		High
Quercus sp.	X	X	High
Pithecellobium dulce	X	X	High
Cassia pringlei Rose	X	X	High
Liquidambar styraciflua	X	X	Low
Bunchosia sp.	X	X	Low
Arctostaphylos sp.	X	X	Low
Mimosa fasciculata	X	X	Low
Wigandia caracasana	X	X	Low
Porophyllum sp.	X		Low
Hymenqea coubaril	X	X	Low
Acacia couteri Benth	X		Low
Acacia milibekii	X	X	Low
Brickellia veronicaefolis	X	X	Low
Colubrina greggii	X	X	Low
Eysenhartia polystachya	X		Low

[1]August, 2003-2005; [2]December, 2003-2004

are very important for their nutritional value and nutritional stability in their maturation as occurs in these regions of the low Mixteca. The remaining species were classified as low consumption. Most foliage production occurs during the rainy season (July to September) when the leaves of trees and shrubs have greater amount of biomass. In October foliage production begins to decline gradually and in November is accentuated until the month of December when it ceases completely. In the case of *Quercus* sp., re-growth of leaves begins in March and foliage remains until late December. In their biological form 65% of the identified species were classified as shrubs, 30% as trees and grass which represented 5%. The use of these forage species is in the form of extensive browsing at all times of year depending on availability whilst in severe drought, agricultural byproducts, such as beans an maize straw are supplemented to goats. It is also common that during the drought the animals lose part of the weight gained in the rainy season.

Table 3 presents the names of the pods that are eaten by goats. Leguminoseae pods belong to the family whose consumption is very high, the ripening and drying in the case of *P. laevigata* is between May and July, *A. farnesiana* in December and March. The pods of *Leucaena esculenta* in the region are used for culinary purposes and in other parts of the country are collected in the month of May. The rest is collected in the month of December when the consumption of pods is greater due to their availability in the soil and the scarcity of woody plant foliage as other studies have found.

Table 3: Dried pods collected in Winter with a very high level of consumption

Scientific names	Common names
Acacia cymbispina Sprague	Cubata
Acacia farnesiana	Huizache
Pithecollobium acatlense Benth	Barba de Chivo
Cassia pringlei Rose	Rompebotas
Mimosa sp.	Una de gato
Mimosa fasciculata	Palo Herrero
Leucaena esculenta	Huaje
Pithecellobium dulce	Guamuchil
Prosopis laevigata	Mezquite

Chemical composition and digestibility of foliage of tree species: Table 4 presents the results of chemical analysis of leaves of trees and shrubs in the Summer. With respect to crude protein, there is great variation in the values found among different species. Total 59% of harvested species belonged to the Leguminoseae family which showed minimum values of 61.9 g protein kg^{-1} DM, the shrub that presented the highest was *Mimosa* sp., containing 243.8 g kg^{-1} DM. Protein differences found are consistent with reports from other researchers for different tree species. Moreover, 31% of the other families had values ranging from 92.10 g kg^{-1} DM for *Brickellia veronicaefolis* and *Eysenhartia polystachya* with a value of 233.10 g kg^{-1} DM. *Hymenqea coubaril* only had a lower content of 80 g kg^{-1} CP for what is considered inadequate to provide the minimum ammonia required by ruminants (AFRC, 1998; NRC, 1981, 1985). The crude protein analysis of samples collected in the Winter season (December) (Table 5) followed the same trend as in Summer, 58.8% belonged to the Leguminoseae family within these, the minimum value of protein corresponded to *Hymenqea coubaril* (61.3 g kg^{-1} DM) and the highest value was for *Mimosa* sp., with a value of 225.3 g kg^{-1} DM. Total 41.2% of the other families had values ranging between 63.9 g kg^{-1} DM for *Liquidambar styraciflua* and *Arctostaphylos* sp., with a value of 168.6 g kg^{-1} DM.

These legumes and other families here studied for their high protein may contribute to the local livestock production and represent a strategy in agro forestry systems. The supply of energy and shrub foliage nitrogen to the ruminal ecosystem represents a potential to increase a sustainable way goat production in the low Mixteca region, since shrubs are an important local source of protein. The importance of these species lies in the fact that these legumes contribute to the maintenance and production units of the Mixteca region goats.

Regarding the Chi-square analysis for protein content in the two collection periods, this indicated no significant differences in the content of PC ($p>0.05$). The Summer IVDNDF ranged from 328.8-683.5 g kg^{-1} DM (Table 4). A 13.63% of shrubs had greater values than

Table 4: Chemical composition of foliage of trees and shrubs in Summer season (g kg^{-1} of DM)

	DM (g kg^{-1})						
Scientific names	FM	CP	NDF	ADF	DAL	IVDNDF	OM
Pithecollobium acatlense Benth	605	169.0	433	336	90.7	404	878
Acacia cymbispina Sprague	494	173.0	486	285	138.0	551	884
Prosopis laevigata	436	217.0	549	362	173.0	390	937
Acacia farnesiana	388	228.0	494	312	174.0	551	870
Lysiloma divaricatum	608	148.0	380	237	99.2	373	930
Quercus sp.	498	108.0	499	367	148.0	379	953
Cassia pringlei Rose	496	151.0	466	260	90.3	626	904
Mimosa sp.	409	244.0	407	229	65.1	578	920
Mimosa pudica	607	114.0	396	341	114.0	329	938
Liquidambar styraciflua	662	96.9	392	291	151.0	429	915
Mimosa fasciculata	545	168.0	537	432	226.0	479	942
Arctostaphylos sp.	412	159.0	501	373	115.0	455	913
Bunchosia sp.	502	143.0	466	357	126.0	577	909
Acacia couteri Benth	558	216.0	387	227	100.0	452	925
Prophylium sp.	496	93.3	500	390	126.0	368	873
Wigandia caracasana	377	141.0	563	424	167.0	468	902
Hymenqea coubaril	440	61.9	411	299	114.0	496	892
Acacia milibekii	524	133.0	596	374	212.0	340	914
Brickellia veronicaefolis	395	92.1	429	252	74.0	586	928
Colubrina greggii	437	197.2	540	325	131.0	613	806
Pithecellobium dulce	441	194.0	512	309	118.0	522	890
Eysenhartia polystachya	341	233.0	523	272	92.4	684	899

Table 5: Chemical composition of folliages of tres and shrubs in Winter season (g kg^{-1} of DM)

	DM (g kg^{-1})						
Scientific names	FM	CP	NDF	ADF	ADL	IVNDF	OM
Pithecollobium acatlense Benth	622	162.0	341	272	83.5	349	870.2
Prosopis laevigata	577	212.0	515	335	161.0	362	911.0
Acacia farnesiana	603	195.0	544	323	190.0	528	919.0
Lysiloma divaricatum	557	142.0	360	168	67.8	277	940.0
Quercus sp.	623	117.0	468	352	128.0	253	923.0
Cassia pringlei Rose	413	134.0	324	148	41.1	683	868.0
Mimosa sp.	486	225.0	488	243	64.5	548	831.0
Liquidambar styraciflua	466	63.9	374	222	103.0	643	823.0
Mimosa fasciculata	530	143.0	487	409	240.0	379	910.0
Arctostaphylos sp.	447	169.0	398	321	98.1	571	864.0
Bunchosia sp.	497	108.0	552	329	80.8	587	821.0
Wigandia caracasana	460	105.0	497	412	153.0	595	860.0
Hymenqea coubaril	503	61.3	365	225	68.2	543	856.0
Acacia milibekii	640	152.0	625	459	293.0	266	927.0
Brickellia veronicaefolis	485	116.0	402	306	162.0	587	882.0
Colubrina greggii	595	119.0	549	460	156.0	409	850.0
Pithecellobium dulce	448	190.0	541	329	116.0	515	902.0

600 g kg^{-1} DM, the highest value corresponded to *Eysenhartia polystachya* of the Fabaceae family. In Winter time, values ranged from 252.8-683.3 g kg^{-1} DM (Table 5), a 11.76% of the studied species had values above 60% of IVDNDF. Moreover, the proportion of cell walls is related to the digestibility of shrubs in ruminants. As the values are higher, NDF digestibility has lower values. In this study, some species showed NDF values below 500 g kg^{-1} of MS and had digestibility above 50%, other species even with high content of NDF digestibility had acceptable values of IVD. These variations have the same effect with the results of ADL and agree with other researchers that even with high amounts of lignin and NDF, the effects on the effective degradability of cell wall and lignin vary shrubs in Northeastern Mexico (Ramirez *et al*., 2000; Moya-Rodriguez *et al*., 2002). Secondary compounds such as tannins, the nature of the components of the NDF and lignin percentages are factors that influence tree and shrub foliage degradation, especially in arid and semiarid regions. Other researchers have found the likely effect they have some secondary metabolites in the consumption of *P. dulce*, *A. Cymbispina* Sprague and *A. Farnesiana* (Garcia-Montes de Oca *et al*., 2011).

Statistical analysis using Chi-square test for species collected in both Summer and Winter season in these nutritional parameters of the cell wall were not significant (p>0.05).

Table 6: Chemical composition of pods of trees and shrubs in Winter season (g kg^{-1} de MS)

	MS (g kg^{-1})						
Scientific names	FM	PC	FDN	FDA	LAD	DIVFDN	MO
Pithecollobium acatlense Benth	927	151	644	471	193.0	433	950
Acacia cymbispina Sprague	898	121	591	440	203.0	456	932
Prosopis laevigata	889	120	414	284	73.1	670	941
Acacia farnesiana	802	153	376	227	68.5	609	907
Cassia pringlei Rose	873	141	619	471	131.0	343	909
Mimosa sp.	914	207	558	414	132.0	370	951
Mimosa fasciculata	860	145	653	457	165.0	481	935
Acacia couteri Benth	897	204	644	451	150.0	392	933
Leucaena esculenta	915	206	435	304	124.0	346	932
Pithecellobium dulce	782	140	536	253	72.4	643	921

The Summer species evaluated presented variations in their content of Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF) and Acid Detergent Lignin (ADL). The 7 species studied, accounting for 31.82% of total of studied species had values >501 g kg^{-1} DM of which 18.18% were legumes. The highest value of NDF corresponded to *A. milibekii* with 596.1 g kg^{-1} DM. The NDF corresponds to the insoluble cell wall whose availability is related to the structure that binds to cellulose, hemicelluloses and lignin degradation factors that control cell wall. In this sense, values >50% affect the consumption and digestibility of trees and shrubs. According to this situation, a 68.18% of the species collected in Summer and Winter 64.71% of the species studied were according to NDF. Noteworthy is the coincidence between species highly rated by the producers and the appropriate values of NDF reported for the same tree. According to Norton (1994) values <50% of NDF digestibility are considered good. On the other hand, 6 species collected in Winter have values above 50 and 23.53% of them are legumes, the highest percentage of NDF was collected in Winter for *A. milibekii* with a value of 625.3 g kg^{-1} DM, on the other hand values of <500 g kg^{-1} DM in 11 species.

The ADF are obtained when the samples are treated in an acid detergent, leaving the insoluble fraction represented by cellulose and lignin as major components. In this research, the ADF over the Summer are attributed to *M. fasciculata* with an amount of 431.9 g kg^{-1} DM. As you increase the values of ADF are less digestible fodder, this is directly related to the amount of lignin they contain. Some studies have reported trees ADF values between 434.8 and 672.4 g kg^{-1} of MS in Southern Mexico or shrubs with smaller amounts of 197.3 g/kg/MS to 575.9 g kg^{-1} DM which showed significant differences the content of ADL. The tree in Winter ranged from FDA 147.5 (*Cassia pringlei* Rose) to 459.5 g kg^{-1} DM (*Colubrina greggii*). With regard to the ADL in Summer values ranged from 65.1 (*Mimosa* sp.) and 272 g kg^{-1} DM (*Eysenhartia polystachya*). In the Winter season, Table 4 presented a range of 41.1 (*Cassia pringlei* Rose) to 292.8 g kg^{-1} DM (*Acacia milibekii*). In these cases, the amounts of lignin for bushes and shrubs vary in different ranges, similar results are found in bushes in Northern Mexico (Ramirez *et al*., 1997, 2000; Moya-Rodriguez *et al*., 2002).

Chemical composition and digestibility of pods in tree species: Pods studied here belong to the Leguminoseae, 70% are shrubby trees and 30% are trees. With respect to chemical composition (Table 6), Crude Protein (CP) had values of 119.7-207.0 g kg^{-1} DM. Species with larger amounts of 200 g kg^{-1} DM were *Couteri* Benth, *Leucaena esculenta* and *Mimosa* sp., representing 30% of pods examined, 20% had values >15% CP and 50% with values <15% are generally accepted as food by goats in the Mixteca region.

They have a great importance because they possess a minimum of 12% protein and may represent an alternative in the diets of native goats in the dry season due to protein deficiency. The IVDNDF had values between 343.1-669.6 g kg^{-1} DM, 30% had amounts >60% of IVDNDF, *A. Farnesiana*, *P. dulce*, *P. laevigata*, the pods had less variation in the NDF and lignin content, the high digestibility affects both, only one case of *P. dulce* does not meet the high content of NDF as a digestibility was 642.8 g kg^{-1} DM but was low in ADF and ADL that influence digestibility, so it is a potential resource silvopasture. The nutritional value of woody plants in arid and semiarid areas, especially in the IVDNDF is primarily influenced by the environment arid soils poor in organic matter, less biomass available for animals, low nutritional value but in some cases their values are high even with its underlying nutritional differences goat production systems in arid and semiarid regions of the country.

The NDF ranged from 376.0 g kg^{-1} DM for *Acacia farnesiana* to 653.0 g kg^{-1} DM for *Mimosa fasciculata*, the value of ADF was lower for *Acacia farnesiana* with an amount of 226.5 g kg^{-1} DM and higher for *Pithecollobium acatlense* Benth, 471.2 g kg^{-1} DM. The ADL ranged from 68.5-203.1 g kg^{-1} DM, 7 species having higher values stand at 7.5%, being lower for (*A. farnesiana*, *P. dulce*, *P. laevigata*). Studies elsewhere have confirmed the importance of the chemical composition of pods and use in ruminant *L. Leucocephala*, *A. farnesiana*, *P. dulce*, *Prosopis laevigata*.

CONCLUSION

The low Mixteca region at Oaxaca, Mexico has a great diversity of forage tree and shrub species which is commonly, consumed in goat production units. According to the chemical composition found in this study, it is possible to establish that most of the studied species have a very good potential to be used in silvopastoril systems.

The nutritional characteristics of the foliage of some of the species studied as is the case of *Acacia farnesiana*, *Acacia cymbispina* Sprague with crude protein amounts of 227.5 g kg^{-1} and 551.3 IVDNDF g kg^{-1} DM and 172.7 g kg^{-1} crude protein and 550.8 IVDNDF correspond to a very high consumption.

In the case of *Cassia pringlei* Rose (133.6 g crude protein kg^{-1} DM) and *Mimosa* sp. (225. 3 g crude protein kg^{-1} DM), both had values above 550 g kg^{-1} IVDNDF MS and also had high intakes. Of all, 2 species were more important, *Prosopis laevigata* and *Acacia bilimekii* because their foliage was prevalent in the severe drought and sustained the survival of the goats. For the first, the consumption was very high and the second had a high crude protein content (212.3 g kg^{-1} DM), although with low IVDNDF.

It is important to note the tree contribution in this study to provide foliage and pods such as *Mimosa* sp., *A. farnesiana*, *Pithecellobium dulce* (Garcia-Montes de Oca *et al*., 2011), *P. laevigata* (Andrade-Montemayor *et al*., 2009) as well as pods contain small amounts of crude protein 120 g kg^{-1} DM, in the case of *A. farnesiana*, *P. Laevigata*, *Pithecellobium dulce*, the IVDNDF exceed 600 g kg^{-1} DM. It is necessary to extend the study in the qualitative and quantitative identification of secondary anti-nutritional factors, phenolic compounds, alkaloids and saponins and driving conditions of trees and shrubs to improve animal production in the area of the Mixteca.

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