Contribution of woody plants to horses' diets in Mediterranean rangelands

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Summary

In Mediterranean countries, shrubby and woody areas provide herds with cheap fodder. However, some horse farmers are reluctant to use woody rangelands, which they associate with low-quality feed. In this article, we explore some aspects of the feeding behavior of horses on Mediterranean shrubby and woody rangelands, in order to document their pastoral interest for horses. We observed the feeding choices of young horses grazing on typical peri-Mediterranean rangelands. Observations were repeated at two sites, with four horses per site, over four days with two observers. At each site, two horses were fitted with GPS (positioning system) collars to determine their presence in different areas of the paddocks. Ingested plants were classified in a coding grid. The chemical characteristics of each feed item were estimated by near-infrared spectroscopy (NIRS). A hierarchical classification of NIRS spectra defined four classes. Leaves, twigs, and flowers of several woody species were ingested (1–18% of recorded bites), although herbaceous species were preferred (> 80% of bites). Horses explored the entire paddocks but grazed preferentially in open areas. The differences observed between sites suggested a strong effect of local grazing conditions. The chemical composition of feed from shrubs and trees was close to that of herbaceous forbs but quite different from that of grasses. Three out of four classes associated woody plants and forbs. These classes had interesting nutritional characteristics (protein > 12%). These results confirm the positive contribution of woody plants to horses' nutrition, in addition to the other roles of woody plants in the well-being of horses on pasture.

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■ INTRODUCTION

Traditionally extensive sheep and cattle grazing systems have declined in northern Mediterranean areas in terms of head number, and large areas of rangeland have been virtually abandoned (Bernués et al., 2011). In order to secure the ecosystem services provided by extensive, pasture-based systems, a number of technical, organizational and political options are under study for ruminant farms (Jouven et al., 2019). In addition, the development of the horse sector could be an opportunity to secure a pastoral utilization of areas of natural vegetation where ruminants are no longer grazed.

Horses graze a variety of rangeland environments across the world, e.g. salt marshes in France (Duncan, 1983) and the Netherlands (Nolte et al., 2017), upland shrubby pastures in France (Orth, 2011) and Spain (López-López et al., 2017), coastal areas in Belgium (Lamoot et al., 2005), cold and wet northern pastures in Iceland (Gudmundsson and Dyrmundsson, 1994), and semi-arid rangelands in the United States (feral horses; Beever, 2003). Rangeland-based equine farming systems already exist. For example, Jouven et al. (2016) investigated the contribution of rangeland vegetation to horses' diets. They reported that in French Mediterranean areas rangelands could provide up to 80% of the feed ingested by young horses (situation observed in several farms in the Camargue and on the calcareous plateaux of the Causses). The main reason for the more frequent underuse of rangeland pastures observed in the other farms investigated was farmers' lack of confidence in the ability of rangelands to feed their horses adequately. The reduction of production costs is a major issue for professional horse breeders since feed may account for over 50% of total costs as reported in France (REFErences, 2013). Thus, using more and better natural pastures is a promising perspective to improve the economic viability of equine farms. Moreover, grazing can provide beneficial physical exercise for the horse and contribute to its well-being (Duncan, 1992; Minero and Canali, 2009; Praud et al., 2013). The increased availability of rangelands can thus be considered as an opportunity for horse farms.

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Research carried out on horses that graze in shrubby areas, usually in mixed herds including cattle, suggests that horses are mainly grass eaters with low consumption of forbs and avoidance of shrubs, as observed in wetlands in the Netherlands (Cornelissen and Vulink, 2015; Nolte et al., 2017), in heathlands in Spain (Ferreira et al., 2013; Lòpez Lòpez et al., 2019), and in dune areas along the Belgian coast (Lamoot et al., 2005). These studies focused on particular natural environments. Unfortunately, very little information is available on more common grazing environments that associate areas of open vegetation (grassland, open shrubland) and woodland or dense shrubland, whereas such environments are at the crossroads of biodiversity issues, e.g. high biodiversity in rangelands and mosaic landscapes (Fraser et al., 2022), environmental issues, e.g. higher carbon sequestration in natural and diverse grazing environments (Lorenz and Lal, 2018), and animal welfare issues, especially the provision of shelter (Snoeks et al., 2015). A long-term study in the medium-high mountains of central France showed that a mixed cattle-horse herd could reopen an encroached rangeland more efficiently than cattle alone (Orth, 2011). Unfortunately, animal behavior was not monitored and the interaction of horses with the woody vegetation could not thus be described. Based on evidence from other studies, we can hypothesize that the contribution of horses was both direct (trampling woody plants and breaking branches) and indirect (keeping the grass layer short, thus encouraging browsing by cattle).

A better understanding of horses' interactions with woody plants in common grazing environments is needed to (1) encourage the use of shrubby rangelands as pastures for horses, (2) provide the necessary knowledge for the design of efficient equine pastoral systems, and (3) clarify the ecosystem services rendered by horse grazing. This issue is especially important in Mediterranean areas where the uncontrolled development of shrubs and trees is a major threat in terms of fire risk (Bernués et al., 2011).

The objective of the study was to document the feeding behavior of horses in Mediterranean rangeland, especially with regard to shrubs and trees. Based on the literature on horse grazing on rangeland (Jouven et al., 2016) and on farmers' opinions recorded in a previous project (Jouven et al., 2013), we hypothesized that horses feed on a variety of plants and plant parts in Mediterranean rangelands, including foliage from trees and shrubs, and that the latter might provide medium- to high-quality feed items. Based on direct observations in commercial farms, this article analyzes the feeding choices of young horses that graze Mediterranean rangelands in spring, and the qualitative and quantitative contributions of shrubs and trees to their diet. The potential impact of woody vegetation on the spatial distribution of horses and on their activities is discussed.

■ METHODS

Study sites

This research took place in 2019 in two large paddocks of rangeland belonging to two equine farms located in southeastern France (department of Alpes de Haute Provence). The pre-Alpine environment benefits from a sub-Mediterranean climate: the average temperature is around 10°C with warm and dry summers; precipitation (around 700 mm/year, with wide variations between years) is mainly caused by storms that are unevenly distributed throughout the year. The soils are calcareous and shallow. A few land plots around the farms are cultivated (mainly lavender), but most of the area is covered by natural vegetation and used as extensive pastures.

The farms and paddocks were chosen according to the following criteria: (1) professional farm (over five mares, clear production objectives) rearing horses for sport (endurance); (2) large contribution of rangeland vegetation to the feeding system (young horses and mares fed exclusively on it for at least five months a year); (3) young horses grazing in groups of five individuals or more; and (4) rangeland paddocks with vegetation typical of peri-Mediterranean areas and with over 30% of shrub and tree cover with woody species known to be eaten by ruminants.

We referred to the experimental paddocks as 'site A' and 'site B'. Both sites were almost the same size (12.5 ha for site A; 11.5 ha for site B), were at the same altitude (1100 m), and had the same type of vegetation (mix of grassland and shrubland with a few wooded areas), with a high diversity of plant species and a high proportion of woody plants. In site B, the paddock was well known by the horses. In site A, the paddock usually grazed was unavailable that year; the horses thus grazed on a paddock nearby with similar vegetation. They were introduced to this new pasture at least one week before the observations began. Based on the references proposed by the Institut Français du Cheval et de l'Equitation, and considering the breed of the horses (Arabian – around 450 kg for an adult horse) and the age or status of the individuals composing the groups, we estimated the stocking rate at 0.36 livestock unit (LSU) per hectare in each site (LSU used for the calculations: 0.7 if < 3 years; 0.65 if > 3 years; 1.0 for mare with foal).

Vegetation characteristics

Sites A and B had different shapes: site A was oblong, whereas site B was rounder (Figure 1). Both contained woodland, shrubland and open areas (open shrubland, grassland) and had their water point located in a wooded area. A simple ecopastoral diagnosis of each site was carried out with the MIL'OUV method (IDELE, 2018), which makes it possible to describe the spatial characteristics in terms of topography, vegetation structure and pastoral resource. Based on direct observations and global positioning system (GPS) data, the main topo-facies (i.e. areas with homogeneous topography and vegetation) were identified and described for each site. Since the aim of the study was to focus on the browsing behavior of horses, a list of woody species was established for each site (Table I), but we did not carry out a comprehensive botanical survey of the herbaceous layer. Based on the straightforward information gathered with MIL'OUV, the herbaceous layer in site A was dominated by low-productive grasses such as *Festuca* sp. in areas with shallow soil, or *Bromus* sp. and *Brachypodium* sp. in areas with deeper soil, and included a low proportion of legumes (mainly *Vicia* sp. and *Astragalus* sp.). In site B, the herbaceous layer was more productive with grasses such as *Festuca* sp., *Brachypodium* sp., *Bromus* sp. and sometimes *Dactylis glomerata*, associated with a variety of legumes (*Trifolium* sp., *Lotus corniculatus, Vicia* sp., *Onobrychis viciifolia*) in moderate quantities. The main woody species observed were *Fagus sylvatica, Genista cinerea, Pinus sylvestris, Pinus nigra* and *Rosa canina* in site A, and *Quercus alba, Rosa canina, Genista cinerea, Carpinus betulus* and *Crataegus monogyna* in site B.

Wooded areas in site A were small and distributed over the paddock. The northern part mostly comprised open areas with small tree clusters, whereas the southern part was covered with dense shrubland on steeper slopes or open shrubland in lowland areas. The paddock also contained a small piece of fallow land covered by sparse vegetation. In site B, a dense woodland separated the paddock into a large upper part with low shrub and tree density and a narrow lower part dominated by shrubland. The topography was rough with a variable slope. Shrubs and trees could be found both in flat and steep areas in both sites.

Animals

Each site was grazed by a group of young horses chosen for experimental purposes after discussion with the farmers. For each site, the groups were designed to (1) produce a moderate stocking rate, (2) avoid major disruptions of the horses' habits, and (3) be representative of what can be found in French equine farms. Since young horses are the animals most grazed on rangelands (Jouven et al., 2016), each

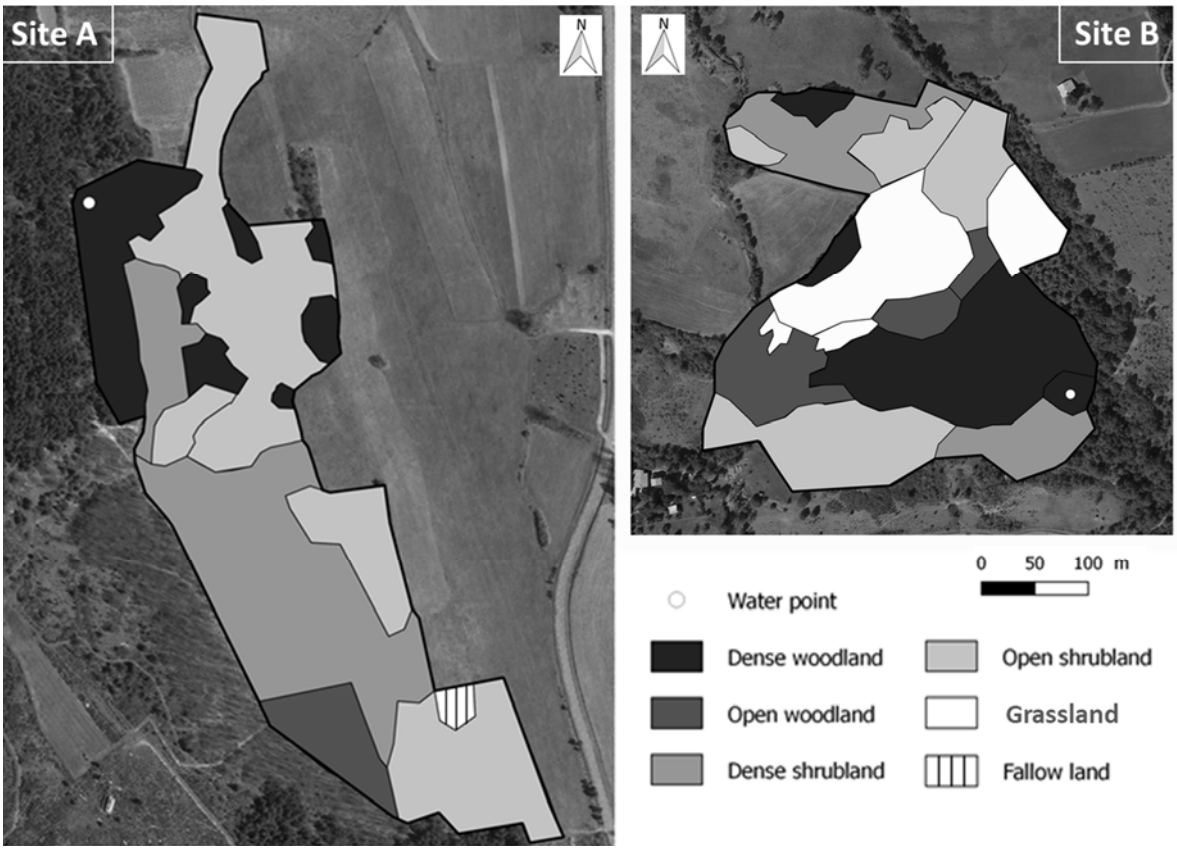

Figure 1: Spatial distribution and abundance of woody plants in the two study sites in Mediterranean France. For both sites, the darker the color, the taller or denser the cover of woody plants. Black or dark gray: woodlands (more than 25% of surface area covered by trees). Medium or light gray: shrublands (less than 25% of trees and more than 30% of shrubs). White: grasslands (less than 25% of trees and less than 30% of shrubs). Striped white: fallow land dominated by bare soil /// *Distribution spatiale et abondance des plantes ligneuses dans les deux sites d'étude en France méditerranéenne. Pour les deux sites, plus la couleur est foncée, plus la couverture de plantes ligneuses est haute ou dense. Noir ou gris foncé : zones boisées (plus de 25 % de la surface est couverte d'arbres). Gris moyen ou clair : zones arbustives (moins de 25 % d'arbres et plus de 30 % d'arbustes). Blanc : prairies (moins de 25 % d'arbres et moins de 30 % d'arbustes). Blanc rayé : parcelle en friche dominée par un sol nu*

group contained four young horses aged 2 to 4, associated with two older horses added by the farmers to keep them calm. In site A, one of the older horses was a mare with its suckling foal. Consequently, the group comprised a total of seven individuals (Supplementary Material [Suppl. Mat.] SI presents horses' characteristics within each group and their function in the study).

Within a group, all of the horses knew each other and the hierarchy between individuals was well established, which was confirmed by the rare agonistic interactions observed. All of the horses (including the foal) were accustomed to foraging on this type of rangeland, without supplementation.

Data collection

In both farms, the sites considered corresponded to summer pastures where the horses did not receive any supplementation. For this short-term study, we chose to observe the horses in the first weeks of grazing in the paddocks when the available diversity of plants and plant parts was at its peak and the animals were not limited by resource availability. The experiment lasted two weeks (20–31 May for site A, 11–21 June for site B) and involved two observers for both sites.

The first week, the horses were introduced into the paddock and three of them were fitted with GPS collars. Four days were devoted to training the observers and the horses. The latter needed to familiarize themselves with the constant and close (one or two meters away) presence of the observers, which would enable an accurate characterization of their feeding choices without any change or disturbance in their behavior (Bonnet at al., 2015). Firstly for site A, a list of horse behaviors was established and different options on the timing of the observations were tested in order to find the best compromise between the total number of bites recorded per horse and the number of horses observed. A list of potential bites was established for both sites based on the plants and plant parts ingested by the horses. The periods of the day when the horses grazed most were determined, as well as the affinities between individuals. The young horses usually grazed by pairs in both sites. It was thus decided that each observer would follow a pair.

The second week was devoted to experimental observations and data collection. On Sunday evening, two young horses (one per pair) were fitted with GPS collars designed by SELMET research unit (CIRAD, INRAE, Montpellier, France). An additional commercial GPS collar fitted on a friendly horse in the group continuously transmitted its position and was used to locate the horses in the morning and in the afternoon. The other two GPS collars were programed to record the horses' positions seven times in a row, every five minutes. The data was not transmitted but stored in the GPS memory so that its integrity did not depend on the communication network. For each five-minute record, the seven successive points were averaged in order to reduce the impact of outliers.

Behavioral observations

Four young horses were observed in each site during the day from Monday to Thursday (four days). The observations were carried out in two sessions, the timing of which was deduced from the pre-experimental phase. From a practical point of view, the observers

Table I: Codes according to the plant type used to qualify the bites ingested by horses /// *Codes selon le type de plante utilisé pour qualifier les bouchées ingérées par les chevaux*

Woody plants		Herbaceous plants	
Species or genus	**Code**	**Class**	**Code**
Quercus alba L.	Cb	Grasses	G
Ligustrum vulgare L.	Tr	Legumes	L
Rubus ulmifolius Schott	Ro	Forbs (neither G nor L)	D
Crataegus monogyna Jacq.	Au	Mixed	M
Prunus spinosa L.	Pr	Not identified	X
Juniperus sp.	Ge		
Genista hispanica L.	Gh	**State of the bite**	**Code**
Genista cinerea (Vill.) D.C.	Gc	Green (> 80% green leaves)	V
Acer sp.	Er	Dry (< 20% green leaves)	S
Cornus sanguinea L.	Co	Mixed	M
Rosa canina L.	Eg	+ 'e' if there are flowers or ears	
Pinus sylvestris L.	Ps	+ 'ep' if the only parts ingested are the ears or the stems+ears	
Pinus nigra J.F. Arnold	Pn		
Lavandula sp.	La		
Fraxinus sp.	Fr		
Fagus sylvatica L.	He		
Sorbus aria (L.) Crantz	Ab		
Carpinus betulus L.	Cc		
Other	Xx		
Plant parts ingested	**Code**		
Leaves	F		
Shoots + flowers	Ti		
Shoots + leaves	Tf		
Non-lignified shoots	Tp		
Shoots + fruits	Fr		
Flowers	I		

Table II: Horses' behavior recorded from observations mainly used to identify the meals (time when most of the horses are foraging) and to document the diversity of individual behaviors around/within a meal /// *Comportement des chevaux enregistré à partir d'observations principalement utilisées pour identifier les repas (moment où la plupart des chevaux s'alimentent) et pour documenter la diversité des comportements individuels autour/au sein d'un repas*

Behavior	Description	Recording of feeding choice
Moving head up	The horse moves at least two steps* without picking up vegetation with the head ABOVE the chest	No
Moving head down	The horse moves at least two steps* without picking up vegetation with the head BELOW the chest	No
Foraging head up	The horse picks up vegetation with the head above the chest and is thus browsing	Yes
Foraging head down	The horse picks up vegetation with the head below the chest and is thus either grazing or browsing bushes / low branches	Yes
Resting	The horse is lying or motionless and relaxed	No
Agonistic behavior	The horse interacts angrily with another horse	No
Other behavior	All other cases, e.g. non-agonistic interactions, scratching	No

* One step = the four hooves strike the ground successively /// * One step *(un pas)* = *les quatre sabots frappent successivement le sol*

arrived at the site in the morning (at around 8 AM) or in the afternoon (at around 4 PM). Each horse's behavior was observed and recorded from the onset of a meal until 15 minutes after at least three of the young horses had stopped foraging. A meal is defined as a period of time when most of the horses in a group graze (i.e. make many consecutive bites) and when they are more widely spaced apart than when they rest (Tyler, 1972; Duncan, 1992). During a session, if the meal lasted less than one hour, the observers stayed for a second meal in order to secure a sufficient number of observations and cover a significant part of the daily feeding time. A few afternoon meals lasted until after sunset; in this case, the observations stopped when it became impossible to see what the horses were eating.

Each observer followed a pair of horses, alternatively observing one horse then the other. The observers changed pairs over time in order to balance the observer effect between day and session. They had synchronized chronometers that rang every 2.5 minutes; at each ring, the observer noted the location of the horse in the topo-facies (Figure 1) and recorded the horse's behavior using the scan sampling method (Altmann, 1974). The different behaviors are reported in Table II.

If the horse's behavior was 'foraging', then 20 consecutive bites were recorded using the code grid presented in Table III. A bite was described differently depending on whether it was taken from woody or herbaceous plants. Browsing activity was thus recorded, regardless of the height of the woody plant. In either case, two types of information were noted: the botanical species, genus or class, and the plant parts taken or their state. Since the main objective addressed the consumption of woody plants, the description was kept simple for bites from herbaceous plants. In any case, most of the bites the horses took on herbaceous plants contained more than one species, making extending the description difficult. If the horse observed stopped eating for more than 10 seconds, the sequence was interrupted before the 20th bite. If the horse did not graze for more than 10 seconds after the chronometer rang, no bites were recorded. When the chronometer rang again, the observer started a new set of observations for the other horse of the pair. Thus, the feeding choices of the four horses were documented daily. For each observation session, the first 15 minutes were considered as an adaptation period to the presence of the observers and were not analyzed.

Plant samples and chemical analysis

After four days of observations, the fifth day (Friday) was devoted to the sampling of feed items corresponding to the bites ingested by the young horses. Each feed item was sampled in a way that mimicked the horses' behavior (cut with scissors if the horses had cut it with their teeth, or pulled). If a given feed item had been ingested in a different topo-facies, the sampling was distributed in similar areas. For herbaceous feed items comprising a mix of plants, separate samples were taken in each topo-facies. The samples were gathered in paper bags identified with a code, kept cool in a large bag with ice during sampling, then immediately stored in an icebox and brought to the laboratory of the French Agricultural Center for International Development (CIRAD) in Montpellier. Despite the three-hour drive, the samples arrived in optimal state at the laboratory (fresh if not already half-frozen) and were stored in a freezer at -21°C. The samples were

Table III: Proportion of horses' bites recorded during observations, listed by plant type and by species in each site /// *Proportion de bouchées enregistrées chez des chevaux lors des observations, classée par type de plante et par espèce dans chaque site*

Bites with woody plants						Bites with herbaceous plants					
Total % of bites		**18%**		**1%**		**Total % of bites**		**82%**		**99%**	
Bite description	**Code**	**Site A (%)**		**Site B (%)**		**Bite description**	**Code**	**Site A (%)**		**Site B (%)**	
Leaves of *Fagus sylvatica*	HeF	X	29.3[d]			Green grass	GV	X		X	
Shoots + leaves of *F. sylvatica*	HeTf	X				Green grass with ears	GVe	X		X	
Leaves of *Sorbus aria*	AbF	X	12.1[c]		5.6[ab]	Green ears only	Gvep	X	86.2[d]	X	47.4[d]
Shoots + leaves of *S. aria*	AbTf	X		X		Dry grass	GS	X			
Leaves of *Crataegus monogyna*	AuF	X	0.6[a]		1.4[a]	Dry grass with ears	GSe			X	
Shoots + leaves of *C. monogyna*	AuTf	X		X		Green forbs	DV	X	3.5[b]	X	1.5[a]
Leaves of *Quercus alba*	CbF	X	7.4[b]	X	59.0[c]	Green forbs with flowers	DVe	X		X	
Shoots + leaves of *Q. alba*	CbTf	X		X		Green legumes	LV	X	2.3[a]	X	6.7[b]
Leaves of *Rosa canina*	EgF	X	<1[a]	X	17.4[b]	Green legumes with flowers	LVe	X		X	
Non-lignified shoots of *R. canina*	EgTp	X		X		Green mixed species	MV	X	7.9[c]	X	44.5[c]
Shoots + flowers of *R. canina*	EgTi			X		Green mixed sp. with flowers	MVe	X		X	
Shoots + leaves of *R. canina*	EgTf			X		Green and senescent mixed sp.	MM	X			
Shoots + leaves of *Fraxinus* sp.	FrTf	X	<1[a]			Green and senescent mix with flowers	MMe			X	
Leaves of *Prunus spinosa*	PrF	X	<1[a]								
Shoots + leaves of *P. spinosa*	PrTf	X									
Flowers of *Genista hispanica*	GhI	X	49.4[e]								
Shoots + flowers of *G. hispanica*	GhTi	X									
Shoots + leaves of *Acer* sp.	ErTf			X	13.9[ab]						
Leaves of other species	XxF	X	0.6[a]		2.8[a]						
Shoots + leaves of other sp.	XxTf	X		X							

X = the bite was observed; [a,b,c,d,e] In a column, values with different superscripts significantly differ (Marascuilo pairwise comparison, $p < 0.05$) /// *X = la bouchée a été observée ;* [a,b,c,d,e] *Dans une colonne, les valeurs avec des exposants différents diffèrent significativement (comparaison par paire de Marascuilo, $p < 0,05$)*

subsequently dried (in an oven at 55°C) and ground in a cutter mill with a 1-mm sieve for further analysis and spectrum collection.

The 47 samples (21 for site A, 26 for site B) were scanned in duplicate on a near-infrared (NIR) spectrometer (NIRSystem 5000, FOSS, Hilleroed, Denmark) in reflectance mode from 1100 nm to 2500 nm (with 2-nm steps). The chemical composition was predicted for each sample using its NIR spectrum with existing calibrations (Meuret et al., 1993; CIRAD, unpubl.). The analytical parameters considered were based on the Kjeldahl method for the calibration of crude protein (CP), and on the sequential analysis of Van Soest et al. (1991) for the calibration of neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL).

Statistical analysis

Plant bite classification based on NIR spectra

Mathematical pretreatment was applied to the spectra (2nd derivative, normalization and de-trending) of plant samples in order to minimize non-informative content. Hierarchical ascendant classification of samples (Ward aggregation criterion) was performed on the mathematically pretreated spectra with XLSTAT software (Addinsoft, Paris, France). The chemical composition of each class was then determined and ANOVA with Tukey's honestly significant difference (HSD) was used to compare classes.

Analysis of horses' feeding choices

The composition of the horses' diets was described from the bite type or class of feed items. The proportion of plant parts was analyzed separately for woody and herbaceous plants in order to analyze more precisely the woody bites, which were in lower proportion, especially in site B. Within each category, the proportions were compared pairwise using Marascuilo procedure in XLSTAT. The effect of site or session (morning vs afternoon) on the proportion of classes in the intake was tested using ANOVA with Tukey HSD.

GPS data

GPS data were analyzed with Q-GIS (QGIS Development Team, 2018) in order to calculate the daily distance traveled by horses and the proportion of time spent on each type of vegetation cover. These data were only used as supplementary information.

■ RESULTS

Grazing dynamics during the day

The behavior of the young horses was recorded for a total of 19 hours in site A and 14 hours in site B. Meals lasted on average 140 min in site A and 80 min in site B, probably because of a higher intake rate on the grassland of site B compared to the lower-density vegetation

types of site A. To compensate for this, two consecutive meals were observed twice in site B. In site A, the meals lasted longer and comprised short breaks when the horses either rested one at a time or reduced their bite frequency.

Generally, the horses synchronized their foraging and resting behaviors within a group. Unsurprisingly (considering our protocol), the horses were mostly in 'foraging' mode during our observation sessions (74% of scans for site A and 79% for site B). 'Foraging head up' behavior, corresponding to bites taken on tree foliage, accounted for only 5% of scans in site A and 1% in site B. In site A, the horses would walk from one feeding area to another during a meal, following a rather straight direction. Between meals, the whole group would rest, usually in the shade of trees or sometimes in the area of fallow land; in the evening, they would rest in the woodland around the water point. In site B, the horses walked a lot during their meals, following a loop pattern that started and ended in the densely wooded area, which was their preferred resting spot: 88% of the scans corresponding to resting behavior were observed there. Even if the horses synchronized their foraging behavior within the group, the number of bites and certain behavioral patterns were different between horses within a given site. For example, in site B, horse FA (Suppl. Mat. SI for additional information on individual horses) was systematically the first to stop eating during hot afternoons and to go back to the cool and shaded resting area. Thus, fewer bites were recorded for horse FA compared to the other horses.

Horses' diet

The proportion of bites taken on woody plants (including those taken on the lower plants and branches) was significantly different between sites ($p < 0.0001$): 18% for site A vs 1% for site B. The woody plants ingested also differed (Table III). In site A, horses foraged on *Genista hispanica, Fagus sylvatica, Sorbus aria, Quercus alba* and, to a lesser extent, on other woody species; flowers and shoots with flowers from *G. hispanica* represented half of the bites observed on woody plants, hence 9% of the total number of bites. In site B, horses browsed mainly *Quercus alba, Rosa canina, Acer* sp. and *Sorbus aria*. The statistical analysis was not performed for horses from site B since the number of bites on woody plants was very low. In site A, there was no particular pattern of intake for the different plant categories within a meal. Nevertheless, the intake of grasses was rather continuous, whereas the ingestion of forbs and woody plants occurred from time to time and rarely took up a whole 20-bite sequence.

Nutritive value of horses' diets

In general, grass bites had a lower nutritive value than other samples (Figure 2). In particular, their CP values were among the lowest in the bite samples from the two sites, whereas their NDF values were the highest. Grasses also had a high dry matter (DM) content, indicating a higher stage of maturity. Bites from woody forages and non-grass herbaceous plants had overlapping chemical composition, with a trend toward higher ADL values for woody forages (indicating lower digestibility) but toward similar CP content. For example, the CP content of *Quercus alba* leaves (CbF code) in site A was as high (> 15% DM) as that of flowers and leaves of Fabaceae (LVe code); it was slightly lower when the leaves were eaten with the shoots. ADL of *Genista hispanica* shoots with flowers was low and comparable to that of herbaceous legume samples (< 8% DM).

The classification of feed items on the basis of their NIR spectra led to four classes that were relevant to the analysis of animal behavior. Table IV presents the botanical and chemical characteristics of these classes. All classes contained samples from both study sites, confirming that the classification did not occur on superficial differences between sites but, instead, on the intrinsic properties of samples. Indeed, when the same plant parts were sampled in both sites, they were statistically attributed to the same class (Suppl. Mat. SII details chemical composition of all samples).

Class 1 included all grass bites and displayed the highest fiber (NDF) and lowest ADL contents ($p < 0.05$). It was also the class with the highest DM content at harvest. This class was very homogeneous, with a lower standard deviation than the other classes for most of the chemical parameters. Class 3 contained herbaceous Fabaceae as well as *Genista hispanica* flowers and flowering stems from site A. On average, class 3 had the highest CP content (18.7%, $p < 0.05$), low NDF content and the lowest ADL content of non-grass classes, indicating high digestibility. Its DM content at harvest was the lowest (27.8%). The other two classes associated herbaceous and woody plants (forbs and tree leaves), and displayed similar average CP. Class 2 had a lower lignin content than class 4 ($p < 0.05$). The higher DM at harvest in class 4 could be explained by the older plant parts, whereas class 2 contained young leaves, flowers and fruits. The samples from woody

Table IV: Classes obtained with the near-infrared spectra of bite samples, and dry matter and average chemical composition /// *Classes obtenues à partir du spectre dans le proche infrarouge d'échantillons de bouchées, et matière sèche et composition chimique moyenne*

Class	Types of bites within classes	DM	CP	NDF	ADF	ADL
		% ± SD	%DM ± SD	%DM ± SD	%DM ± SD	%DM ± SD
1	Grasses	41.5^{a} ± 7.0	9.2^{c} ± 2.5	66.3^{a} ± 2.9	36.6^{a} ± 2.5	5.2^{c} ± 0.7
2	*Sorbus aria, Fagus sylvatica* from site A, forbs (not Fabaceae) from site A, forbs with flowers from site B and mix of herbaceous plants	30.7^{bc} ± 8.2	13.0^{b} ± 2.2	46.2^{b} ± 7.7	29.6^{b} ± 4.5	9.2^{b} ± 2.7
3	*Genista hispanica* from site A and herbaceous Fabaceae	27.8^{c} ± 6.8	18.7^{a} ± 3.3	39.4^{c} ± 5.6	24.8^{c} ± 5.3	7.6^{bc} ± 2.1
4	*Quercus alba, Rosa canina, Crataegus monogyna, Acer* sp. from site B, herbaceous forbs without flowers from site B	37.4^{ab} ± 7.3	12.9^{b} ± 2.1	39.6^{c} ± 5.1	25.8^{bc} ± 3.5	13.8^{a} ± 2.1

DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin; SD: standard deviation; ^{a,b,c} Different letters in a given column indicate a significant difference between classes (Tukey test, $p < 0.05$) /// *DM : matière sèche ; CP : protéine brute ; NDF : fibre insoluble au détergent neutre ; ADF : fibre insoluble au détergent acide ; ADL : lignine au détergent acide ; SD : écart-type ; ^{a,b,c} Des lettres différentes dans une même colonne indiquent une différence entre classes significative (test de Tukey, $p < 0,05$)*

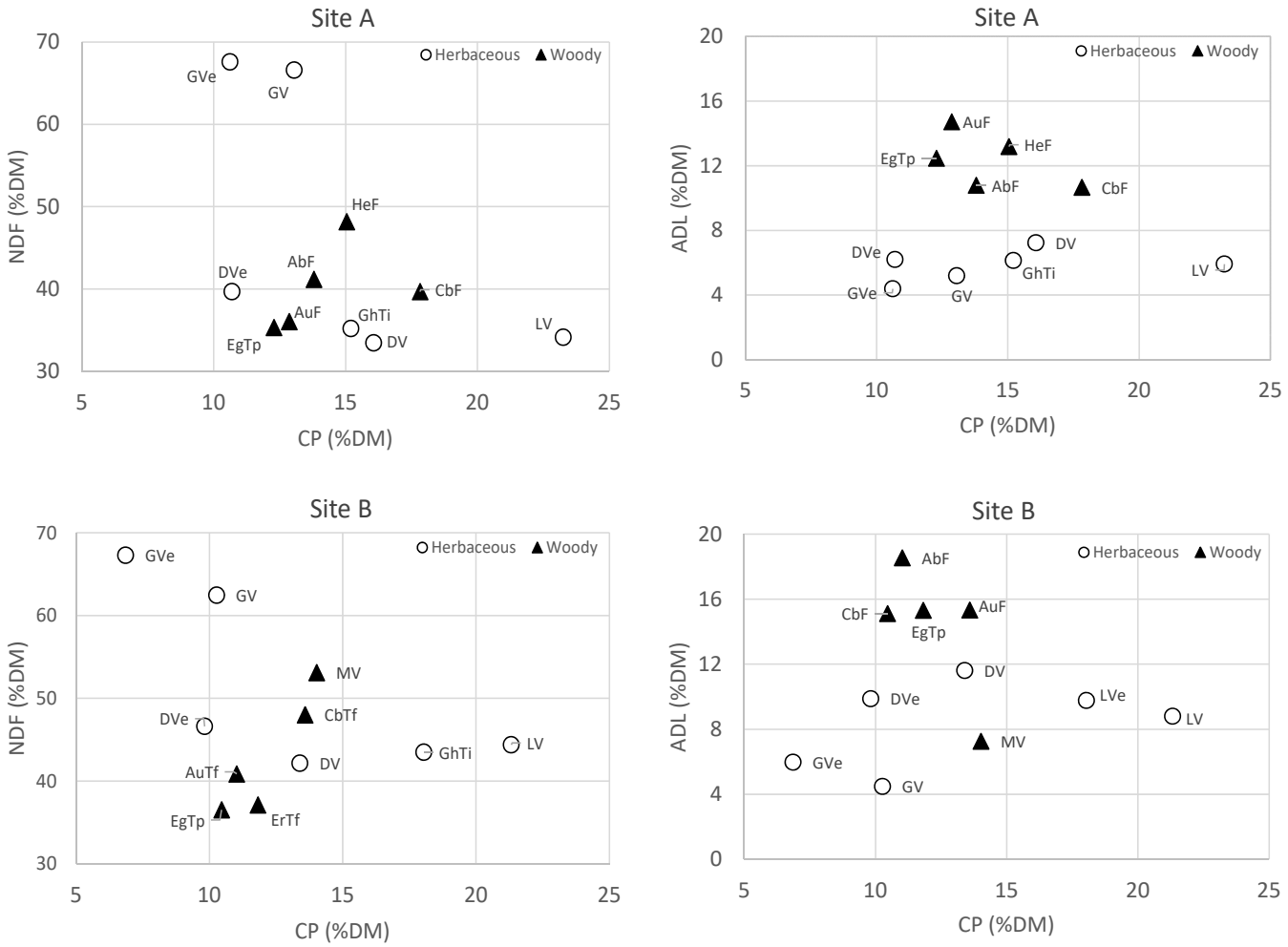

Figure 2: Chemical composition of the main horses' bites observed in sites A and B. Crude protein (CP) is plotted against neutral detergent fiber (NDF) and acid detergent lignin (ADL) contents. For each site and each plant species, only the most frequent bite types are represented and identified with their codes (Table II). GV and GVe : codes for grass bites /// *Composition chimique des principales bouchées des chevaux observées dans les sites A et B. Les protéines brutes (CP) sont représentées en fonction de la teneur en fibres à détergent neutre (NDF) et en lignine au détergent acide (ADL). Pour chaque site et chaque espèce végétale, seuls les types de bouchées les plus fréquents sont représentés et identifiés par leur code (tableau II). GV et GVe : codes pour les bouchées de graminées*

plants in these two classes had similar chemical composition, suggesting that their separation in the classification could be attributed, at least in part, to other characteristics, probably secondary compounds or certain physical or chemical properties.

Contribution of forbs and woody plants to horses' diets

For both sites, horses ate mostly from classes 1 and 2 (Figure 3; Table V). Whereas class 1 (grass) clearly dominated horses' diets in site A, with 71% of the bites observed, in site B it accounted for only 47% of the bites observed, with class 2 providing another 45%. Class 4 (mostly lignified plant parts) was very little consumed. Diet composition was quite similar among horses within a site (Figure 3).

The contribution of bites taken on legumes and woody species (classes 3 and 4) was rather constant between sites. In site A, horses took many bites of *Genista hispanica* (class 3)*;* in site B, where such small shrubs were not present, horses ate more herbaceous Fabaceae (class 3). In site B, because the sward was denser and more diverse than in site A, a larger proportion of bites contained a mix of herbaceous plants, and less bites were composed of grasses only. Nonetheless, this did not necessarily mean that the total intake of grasses was lower since grasses were also present in the 'mixed' bites of class 2. The proportion of the four classes in the diet was rather constant between days in site B, whereas some differences were observed in site A. However, there was no significant difference in the proportion of different classes between morning and evening meals (Table V).

Table V: Proportion of classes (%) in the horses' diets recorded in two sites depending on the time of the day. 'Other' represents the less frequent bites recorded during the trial but not sampled, hence not classified with near-infrared spectroscopy /// *Proportion de classes (%) dans l'alimentation des chevaux enregistrée dans deux sites en fonction du moment de la journée. «* Other *» représente les bouchées moins fréquentes enregistrées pendant l'essai mais non échantillonnées, donc non classées par spectroscopie proche infrarouge*

		Class 1	Class 2	Class 3	Class 4	Other
Site A	Morning	76.4[a]	12.9[a]	8.6	0.9	1.2
	Evening	69.6[a]	20.1[a]	6.8	3.2	0.3
Site B	Morning	48.4[b]	45.4[b]	4.2	1.7	0.3
	Evening	44.8[b]	46.2[b]	7.3	1.5	0.2

[a,b] Different letters indicate significant differences between sites (Tukey test, $p < 0.05$); no differences were found between morning and evening meals for either site /// [a,b] *Des lettres différentes indiquent des différences significatives entre les sites (test de Tukey, $p < 0,05$) ; aucune différence n'a été constatée entre les repas du matin et du soir pour les deux sites*

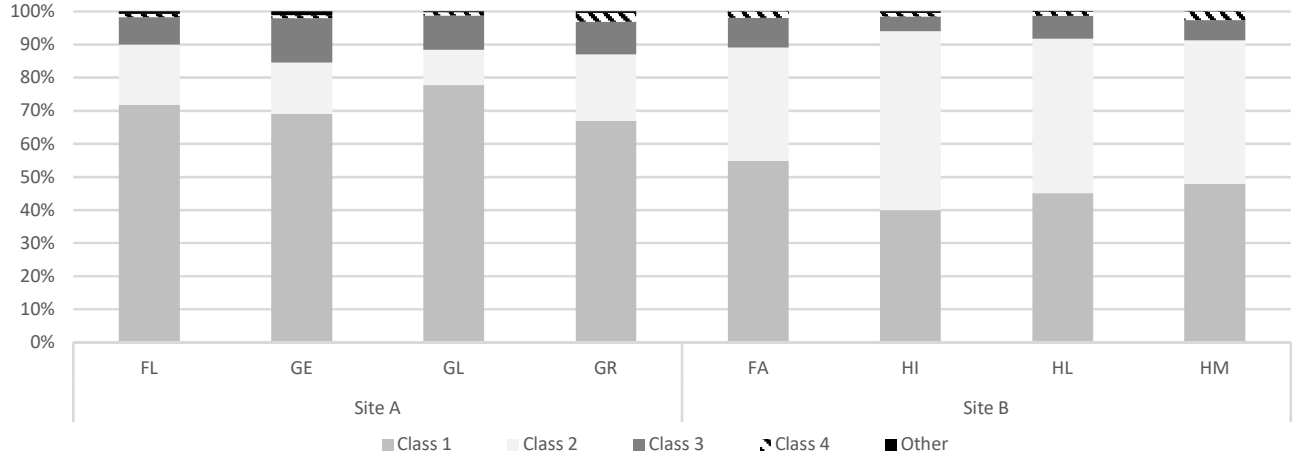

Figure 3: Proportion of each bite class (% of total number of bites) in the horses' diets. FL, GE, GL, GR, FA, HI, HL and HM are the codes of the horses (Suppl. Mat. SI). The nutritional quality of bites taken less than ten times in a site (all sessions and horses included) was not characterized; these bites were therefore not included in the four classes and make up the category 'Other' /// *Proportion de chaque classe de bouchées (% du nombre total de bouchées) dans le régime alimentaire des chevaux. FL, GE, GL, GR, FA, HI, HL et HM sont les codes des chevaux (Mat. Suppl. SI). La qualité nutritionnelle des bouchées prises moins de dix fois dans un site (en incluant toutes les sessions et tous les chevaux) n'a pas été caractérisée ; ces bouchées n'ont donc pas été incluses dans les quatre classes et se retrouvant dans la catégorie «* Other *»*

Preliminary observations of the spatial distribution of horses as a function of shrub and tree cover

GPS data were collected continuously over 115 hours in site A and 111 hours in site B. In site A, as the electronic circuit of one of the two GPS devices was damaged, the distance traveled and the spatial occupation were calculated for only one horse (GL, Suppl. Mat. SI). For site B, the two GPS devices worked, which made it possible to describe the spatial behavior for two horses (HL and HM). In both sites, the GPS tracks obtained had no generic value but could still provide interesting insight into spatial behavior since the horses generally moved in a group. Based on such limited GPS data, the estimated distance traveled differed between sites and between horses and ranged from 6 $km.day^{-1}$ (site A) to 9 $km.day^{-1}$ (site B). In each site, the horses explored the whole paddock, although the spatial distribution of GPS points was uneven (Figure 4): horses spent more time in open areas dominated by herbaceous vegetation. Based on GPS data and direct observations, the areas of shrubland or woodland were used for a variety of purposes, both during the day and at night, e.g. to find shade during the hottest hours (especially in site B where the observations took place in June), to graze or browse, to scratch and try to get rid of stinging flies.

■ DISCUSSION

Assessing diet composition in complex environments: methodological considerations

Diet composition can be assessed by (1) behavioral observations, (2) microhistology on fecal samples, (3) near-infrared spectroscopy on fecal, ingesta or forage samples, (4) stable isotope analysis, and (5) DNA-barcoding. Garnick et al. (2018) analyzed the cost, accuracy, resolution and appropriateness of these techniques for rangeland environments, depending on the objectives pursued. The last three methods, based on the association between plant and animal samples, require expensive technologies and may over-represent rare species, whereas the first two, based on morphological observation of plant parts, are inexpensive but time-consuming. The authors conclude that behavioral observations are well adapted in situations where the animals can be readily observed and if the necessary labor is available. Behavioral observations can be carried out either with continuous bite monitoring or with scan sampling (Bonnet et al., 2015). In both cases, the observers need to determine appropriate bite categories and the animals need to adapt to the close presence of an observer. Whereas scan sampling makes it possible to document the behavior of various animals at a time, continuous bite monitoring requires an observer for each animal, thus making synchronized observations impossible and confusing 'individual' and 'day' effects. In our study, we wanted to describe feeding choice dynamics for various individuals within a group and for a series of days. We therefore tried to find a compromise between scan sampling and continuous bite monitoring.

The diversity of potential bites is very high in Mediterranean rangelands (Silué et al., 2016). Since our study focused on woody forage, we reduced the number of bite classes for herbaceous plants, omitting information about plant species (many bites being, in fact, a mixture of various herbaceous species) and about bite depth, which was not as discriminant in this type of vegetation in spring and at the onset of grazing in the paddocks. Comprehensive herbaceous classes were also used in other studies on rangeland environments, e.g. coastal shrubland (Lamoot et al., 2005) and Pampa rangeland (Azambuja et al., 2020). Despite this simplification, given the diversity of potential bites, it seemed necessary to observe a sufficient number of bites per scan, per animal, per meal and per day in order to estimate accurately the diet and the intake dynamics.

As there was no significant difference in the composition of the meals observed in the morning or in the afternoon, we could assume our observations to be representative of the horses' diets, at least during the day. Ferreira et al. (2013) hypothesized an increased consumption of woody plants at the very beginning and very end of the day, when the herbivores (in their study: cattle, horses, sheep and goats) grazed close to the resting area, which was in shrubby vegetation communities. In our study, given the huge availability of woody plants in both sites, such a bias was unlikely. We removed the first 15 minutes of each observation session as an additional security to avoid disruptions in the normal feeding behavior of horses. During those 15 minutes, the horses often started foraging in their resting area (usually woodland), and would take a few bites on tree foliage. Those bites were not accounted for and it is therefore possible that woody plant consumption might have been slightly underestimated.

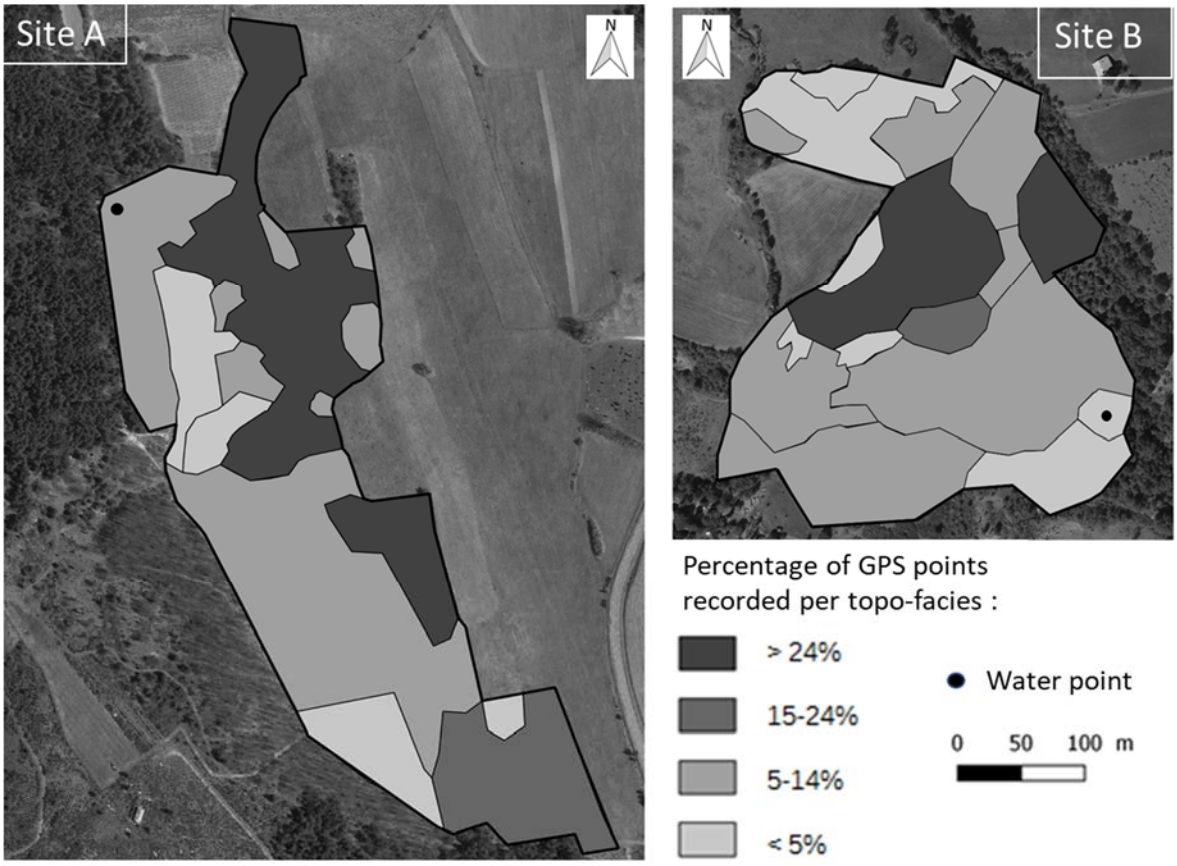

Figure 4: Percentage of GPS points recorded in the various topo-facies (Figure 1) of the grazed paddocks. Only one horse was tracked in site A, whereas two horses were tracked in site B /// *Pourcentage de points GPS enregistrés dans les différents topo-faciès (figure 1) des paddocks pâturés. Un seul cheval a été suivi sur le site A, alors que deux chevaux l'ont été sur le site B*

Horses do forage on shrubs and trees, although grasses and herbaceous plants are consumed to a greater extent

Past research suggests that horses select feed items with a high nutritional quality, especially in terms of crude protein (Edouard et al., 2010). In this experiment, all four classes of feed items were always represented in the horses' diets, regardless of the site, the individual horse and the day. The relative abundance of each class in the daily intake did change, however, depending on the context.

The horses observed in the study ingested plant parts from *Quercus alba* (white oak), *Fagus sylvatica* (beech) and *Sorbus aria* (whitebeam), and less frequently from *Rosa canina* (rosehip), *Crataegus monogyna* (hawthorn) and *Acer* sp. (maple). Overall, the contribution of woody plants to horse intake was low (1% of bites, site B) to moderate (18% of bites, site A). In a way, our study confirms higher consumption of herbaceous plants by horses, as documented in various rangeland environments such as Camargue (Duncan, 1992), coastal shrubland (Lamoot et al., 2005), heathland (Celaya et al., 2011; Ferreira et al., 2013) and wetland (Cornelissen et al., 2014). It also confirms a non-zero contribution of woody vegetation to horses' diets, as suggested by Van den Berg et al. (2015) on the basis of a survey with Australian horse keepers. The quantitative contribution of woody plants to horses' diets could not be precisely determined because our bite categories were not accurate enough to estimate the bite mass of the hand-plucked samples. Tree and shrub foliage are known to provide large bites; not taking bite mass into account could have resulted in an underestimation of the contribution of woody plants to the diet. We believe this was not the case here because observations were carried out in spring, with a high availability of small bites (young leaves, sprouts and flowers). In site A, half of the bites on woody species consisted of small bites of *Genista hispanica* flowers; in site B, horses ingested small bites from *Rosa canina* and *Crataegus monogyna*. Ferreira et al. (2013) observed that horses foraged on gorse (*Ulex gallii*) despite the thorns, probably attracted by its high protein content (López López et al., 2019). Similarly, in our study sites, the thorns of *Genista hispanica* and *Rosa canina* did not seem to discourage horses from consuming them.

The grazing context has a huge impact on diet composition. The difference in the consumption of woody plants between our study sites could be explained by the differences in the vegetation structure. For example, *Genista hispanica,* highly appreciated for its flowers, was only present in site A. Site B included a large open area with dense grass, which did not exist in site A. We observed the horses at the beginning of the grazing season; over time, grass availability would have dropped in both sites, especially in the grassland area of site B, encouraging the horses to rely more on woody forage. In fact, during a preliminary visit to site B in winter 2018, we observed traces of browsing on shrubs and trees. Context-dependent feeding preferences have been widely documented (Provenza and Papachristou, 2009). Ferreira et al. (2013) observed a variable contribution of woody plants to horses' diets during the grazing season (May-November), with an increased consumption at the end of the season. Cornelissen et al. (2014) observed an impact of the site, season and their interaction on the proportion of browsed plants in horses' diets.

Woody forage: a feed similar to herbaceous forbs?

Herbaceous and woody plants are usually separated into different categories for the analysis of diet composition (Duncan, 1992; Celaya

et al., 2011). However, in our study, the chemical composition of woody plant parts was close to that of many herbaceous forbs: three out of the four classes of feed items produced with an ascending hierarchical classification by the NIR spectrum associated both plant categories. Only grasses were isolated in a separate class. Compared to grasses, feed items from forbs and woody plants contained less fiber, which is likely to lead to a higher digestibility. Protein content was lowest in grasses, and highest in class 3 (Fabaceae), which also showed a relatively low lignin content. Most of the woody plants consumed were not Fabaceae and displayed intermediate nutritive values in terms of both fiber and protein contents. A similar chemical composition of woody plants and herbaceous forbs may be interesting to compensate for the quality of horses' diets despite the changes in their grazing environment due to season, paddock or degree of forage depletion. In fact, feed items from both plant types might be exchangeable to a certain extent. In our results, horses browsed more on woody plants in site A where a diversity of shrubs and trees was offered, and grazed more on herbaceous forbs in site B. However, we cannot draw conclusions because we used different horses in each site; this hypothesis will thus need to be tested in other studies.

During the treatments applied to plant samples, a number of volatile secondary compounds might have been lost. Others might have remained and could explain the separate classification of classes 2 and 4, which are quite close in terms of proximal chemical composition, except for a higher lignification level in class 4. Based on our observations, in both sites and for all of the horses, the intake of classes 2 and 4 together would never exceed 15% of the total number of bites. It would be interesting to check whether such a limitation would persist with seasons and forage depletion within the paddock. In fact, in the case of picketed packhorses grazing in high-altitude pastures, Olson-Rutz et al. (1996) observed an increased consumption of forbs after eight hours of grazing. Moreover, a number of plants that compose these classes are known to contain secondary compounds (Papachristou et al., 2005). López López et al. (2019) observed a voluntary consumption of white clover by horses despite its potential toxicity. In fact, horses are known for their low ability to detoxify secondary compounds.

Feed and non-feed functions of shrubs and trees might impact grazing distribution

As discussed before, various parts of woody plants were ingested by horses and provided them with interesting nutrients, especially fiber and protein (and probably micronutrients and useful secondary compounds that were not specifically investigated here). Based on such results and on previous data reported in the literature (Ferreira et al., 2013; Cornelissen et al., 2014), we can assume that woody plants are an interesting forage resource for horses, although certain plants are more easily consumed than others and the foraging context widely impacts the precise composition of the horses' diets. However, this is far from being the only function of woody plants.

Shrubs and trees have a number of non-feed functions that are very important, considering that the grazing animals spend 24 hours a day outdoors. During our study, we observed that horses would preferentially rest under a tree cover, searching for shade and cool air as well as protection against the wind or damp air at night. Saïdi (1998) and Boyd and Bandi (2002) reported the use of high trees (beech or pine) as resting areas during hot days. We also observed the use of certain tall shrubs, such as broom, to fight insects either by resting with the head in the branches (thus protecting the eyes and nostrils) or by scratching the anal region, often infested with stinging flies. This function of protection against insects has already been reported (Tyler, 1972; Duncan, 1992). Finally, horses used trees and shrubs as scratching stands for different parts of their body, taking advantage of the diversity of shapes, sizes and resistance of woody branches.

In both sites, the horses explored the whole paddock, although certain areas were preferred, and traveled up to nine kilometers a day within the 12-hectare paddocks. Such high activity and exploratory behavior of horses have been previously reported (Duncan, 1983; Lamoot et al., 2005; Nolte et al., 2017). These authors, together with Ferreira et al. (2013), observed an uneven spatial distribution of activities, with forested or shrubby areas preferentially devoted to resting, and open areas preferentially devoted to grazing. In our study, a similar spatial pattern was observed, although a diversity of activities was performed in each topo-facies, meaning that the horses were partly opportunistic in their use of the vegetation patchwork. This was especially true in site A where a continuous gradient of shrub and tree density was available. In site B, the topo-facies were more contrasted, with little forage resources in the wooded areas, which encouraged a spatial specialization within the paddock.

■ CONCLUSION

The objective of this work was to document the feeding behavior of horses in Mediterranean rangelands, especially with regard to shrubs and trees. Our observations confirm that horses, like other herbivores, feed on a variety of either herbaceous or woody plants. The significant contribution of woody plants to the diet at one of the sites (18% of the total number of bites observed) and the interesting nutritional characteristics of the corresponding feed items (close to that of herbaceous forbs) suggest that Mediterranean rangelands can offer an interesting forage resource for horses. Moreover, shrubs and trees provide additional features (shade, protection against insects, scratching), which contribute to the horses' welfare.

This study was conducted on real farms, with the drawback of producing data that may be site dependent. However, we cannot overlook the value of gathering data in real situations, and meta-analyses of such data in the future will hopefully clarify the factors that lead horses to increase their consumption of forbs and trees. In the present study the marked difference between sites in terms of the contribution of woody plants to the horses' diets (18% vs 1%) suggests that the grazing environment plays a major role in horses' foraging behavior. Based on our results and on previous works, we hypothesized that the season, the availability and spatial distribution of woody plants and the level of forage depletion might be crucial factors. Further research on the subject is needed in order to propose management practices or at least general principles aimed at encouraging the consumption of woody plants by horses. The concentration of secondary compounds in the main woody plants eaten should also be investigated since it might impact their nutritional function.

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Conflicts of interest

The authors declare no conflict of interest.

Author contributions statement

EM and RZ were Master's students. The study was planned and prepared by MJ and LE. Methods and observations were conducted by EM and RZ under the co-supervision of MJ and LE, who both also contributed to data collection in the field. DB supervised sample characterization and laboratory analyses. Data analysis was conducted by EM under the supervision of MJ and DB. The manuscript was prepared by EM, MJ and DB.

REFERENCES

Altmann J., 1974. Observational Study of Behavior: Sampling Methods. *Behaviour,* **49**: 227–266, doi: 10.1163/156853974X00534

Azambuja J., Carvalho P., Bonnet O., Bastianelli D., Jouven M., 2020. Functional classification of potential bites in Pampa grassland based on their NIR spectrum. *Rangeland Ecol. Manag.,* **73**: 358-367, doi: 10.1016/j.rama.2020.02.001

Beever E., 2003. Management Implications of the Ecology of Free-Roaming Horses in Semi-Arid Ecosystemsof the Western United States. *Wildlife Soc. Bull.*, **31** (3): 887-895

Bernués A., Ruiz R., Olaizola A., Villalba D., Casasús I., 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. *Livest. Sci.,* **139**: 44-57, doi: 10.1016/j.livsci.2011.03.018

Bonnet O.J.F., Meuret M., Tischler M.R., Cezimbra I.M., Azambuja J.C.R., Carvalho P.C.F., 2015. Continuous bite monitoring: a method to assess the foraging dynamics of herbivores in natural grazing conditions. *Anim. Prod. Sci.,* **55** (3): 339–349, doi: 10.1071/AN14540

Boyd L., Bandi N., 2002. Reintroduction of takhi, Equus ferus przewalski, to Hustai Natianal Park, Mongolia: time budget and synchrony of activity pre- and post-release. *Appl. Anim. Behav. Sci.*, **78**: 87-102, doi: 10.1016/S0168-1591(02)00088-6

Celaya R., Ferreira L.M.M., Garcia U., Rosa Garcia R., Osoro K., 2011. Diet selection and performance of cattle and horses grazing in heathlands. *Animal*, **5**: 1467–1473, doi: 10.1017/S1751731111000449

Cornelissen P., Bokdam J., Sykora K., Berendse F., 2014. Effects of large herbivores on wood pasture dynamics in a European wetland system. *Basic Appl. Ecol.*, **15**: 396-406, doi: 10.1016/j.baae.2014.06.006

Cornelissen P., Vulink J.T., 2015. Density-dependent diet selection and body condition of cattle and horses in heterogeneous landscapes. *Appl. Anim. Behav. Sci.*, **163**: 28–38, doi: 10.1016/j.applanim.2014.12.008

Duncan P., 1983. Determinants of the use of habitat by horses in Mediterranean wetland. *J. Anim. Ecol.*, **52**: 93-109, doi: 10.2307/4590

Duncan P., 1992. Horses and Grasses. The nutritional ecology of equids and their impact on the Camargue. Ecological Studies 87, Springer-Verlag, New York, USA, 316 p.

Edouard N., Duncan P., Dumont B., Baumont R., Fleurance G., 2010. Foraging in a heterogeneous environment—An experimental study of the trade-off between intake rate and diet quality. *Appl. Anim. Behav. Sci.*, **126**: 27-36, doi: 10.1016/j.applanim.2010.05.008

Ferreira L.M.M., Celaya R., Benavides R., Jàuregui B.M., Garcìa U., Santos A.S., Rosa Garcìa R., et al., 2013. Foraging behavior of domestic herbivore species grazing on heathlands associated with improved pasture areas. *Livest. Sci.*, **155**: 373-383, doi: 10.1016/j.livsci.2013.05.007

Fraser M.D., Vallin H.E., Roberts B.P., 2022. Animal board invited review: Grassland-based livestock farming and biodiversity. *Animal*, **16**: 100671, doi: 10.1016/j.animal.2022.100671

Garnick S., Barboza P.S., Walker J.W., 2018. Assessment of Animal-Based Methods Used for Estimating and Monitoring Rangeland Herbivore Diet Composition. *Rangeland Ecol. Manag.*, **71**: 449–457, doi: 10.1016/j.rama.2018.03.003

Gudmundsson O., Dyrmundsson O.R., 1994. Horse grazing under cold and wet conditions: a review. *Livest. Prod. Sci.*, **40**: 57-63, doi: 10.1016/0301-6226(94)90265-8

IDELE (Institut De l'Elevage), 2018. Méthode Mil'Ouv [Mil'Ouv Method] (standing for MILieux OUVerts/open landscapes), Available online at: idele.fr/reseaux-et-partenariats/life-milouv/publication/idelesolr/recommends/methode-milouv.html

Jouven M., Launay F., Geiger A., Guillaume C., 2013. Place des parcours dans les élevages équins du Sud de la France ; cas des élevages endurance (race PSA) et Camargue en Languedoc-Roussillon, 39ème Journées de la recherche Equine, 28 février 2013, Paris, France.

Jouven M., Vial C., Fleurance G., 2016. Horses and rangelands: perspectives in Europe based on a French case study. *Grass Forage Sci.,* **71** (2): 178-194, doi: 10.1111/gfs.12204

Jouven M., Casasùs I., Franca A., 2019. Improving the use of grazed forage in Mediterranean ruminant systems: issues, options and perspectives. Joint meeting of the FAO-CIHEAM networks on sheep and goats and Mediterranean pastures, 23 to 25 October 2019, Meknès, Morocco.

Lamoot I., Meert C., Hoffmann M., 2005. Habitat use of ponies and cattle foraging together in a coastal dune area. *Biolog. Conserv.*, **122**: 523–536, doi: 10.1016/j.biocon.2004.09.009

López López C., Celaya R., Ferreira L.M.M., García U., Rodrigues M.A.M., Osoro K., 2019. Comparative foraging behaviour and performance between cattle and horses grazing in heathlands with different proportions of improved pasture area. *J. Appl. Anim. Res.*, **47** (1): 377-385, doi: 10.1080/09712119.2019.1649679

López-López C., Ferreira L.M.M. García U., Moreno-Gonzalo J., Rodrigues M.A.M., Osoro K., Ferre I., Celaya R., 2017. Diet selection and performance of horses grazing on different heathland types. *Animal*, **11**: 1708-1717. Doi: 10.1017/S1751731117000465

Lorenz K., Lal R., 2018. Carbon Sequestration in Grassland Soils. In: Carbon Sequestration in Agricultural Ecosystems. Springer International Publishing, Cham, Switzerland, 175-209, doi: 10.1007/978-3-319-92318-5_4

Meuret M., Dardenne P., Biston R., Poty O., 1993. The use of NIR in predicting nutritive value of Mediterranean tree and shrub foliage. *J. Near Infrared Spectrosc.*, **1**: 45-54, doi: 10.1255/jnirs.5

Minero M., Canali E., 2009. Welfare issues of horses: an overview and practical recommendations. *Ital. J. Anim Sci.*, **8:** 219-230, doi: 10.4081/ijas.2009.s1.219

Nolte S., van der Weyde C., Esselink P., Smit C., Van Wieren S.E., Bakker J.P., 2017. Behaviour of horses and cattle at two stocking densities in a coastal salt marsh. *J. Coastal Conserv.*, **21**: 369-379, doi: 10.1007/s11852-017-0515-7

Olson-Rutz K.M., Marlow C.B., Hansen K., Gagnon L.C., Rossi R.J., 1996. Packhorse Grazing Behavior and Immediate Impact on a Timberline Meadow. *J. Range Manag.*, **49** (6): 546-550, doi: 10.2307/4002297

Orth D., 2011. Impact sur la végétation ligneuse d'un troupeau mixte de bovins et d'équins en conditions de sous chargement. *Fourrages*, **207**: 201-209.

Papachristou T.G., Dziba L.E., Provenza F.D., 2005. Foraging ecology of goats and sheep on wooded rangelands, *Small Rum. Res.*, **59** (2–3): 141-156, doi: 10.1016/j.smallrumres.2005.05.003

Praud A., Dufour B., Robert C., Valette J.P., Denoix J.M., Crevier-Denoix N., 2013. Effects of management practices as risk factors for juvenile osteochondral conditions in 259 French yearlings. *Vet. J.*, **197**: 72–76, doi: 10.1016/j.tvjl.2013.03.044

Provenza F.D., Papachristou T.G., 2009. Behavior-based management of ecosystems. *Options Méd. series A*, **85**: 13-28.

QGIS Development Team, 2018. QGIS Geographic Information System. Open Source Geospatial Foundation Project. Available online at: http://qgis.osgeo.org

REFErence (Réseau Economique de la Filière Equine), 2013. Synthèse des exploitations équines suivies dans le cadre des réseaux équins du Sud-Ouest : Repères techniques et économiques 2011. Institut Français du Cheval et de l'Equitation, Saumur, France, 24 p.

Saidi M.S., 1998. Evolution d'une pelouse post-ovine sous l'effet du pâturage du cheval de Przewalski, Thèse Doct., Université Paul Valéry, Montpellier III, France, 206 p.

Silué N., Bastianelli D., Meuret M., Hassoun P., Jouven M., 2016. Functional classification by NIRS of plant parts selected by sheep on a shrubby rangeland. *Options Médit. Ser A*, **114**: 71-74

Snoeks M.G., Moons C.P.H., Ödberg F.O., Aviron M., Geers R., 2015. Behavior of horses on pasture in relation to weather and shelter — A field study in a temperate climate. Journal of Veterinary Behavior, **10**(6): 561-568, doi: 10.1016/j.jveb.2015.07.037

Tyler S., 1972. The behavior and social organization of the New Forest ponies. *Anim. Behav. Monographs*, **5**: 87-196, doi: 10.1016/0003-3472(72)90003-6

Van den Berg M., Brown W.Y., Lee C., Hinch G.N., 2015. Browse-related behaviors of pastured horses in Australia: A survey. *J. Vet. Behav.*, **10**: 48-53, doi: 10.1016/j.jveb.2014.11.001

Van Soest P.J., Robertson J.B., Lewis B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. *J. Dairy Sci.*, **74**: 3583-3597, doi: 10.3168/jds.S0022-0302(91)78551-2

Résumé

Mikicic E., Jouven M., Etienne L., Zoungrana S.R., Bastianelli D.
Contribution des plantes ligneuses à l'alimentation des équins sur parcours méditerranéens

Dans les pays méditerranéens, les zones arbustives et boisées fournissent aux troupeaux un fourrage bon marché. Cependant, certains éleveurs équins sont réticents à utiliser les parcours boisés qu'ils associent à une alimentation de faible qualité. Dans cet article nous explorons quelques aspects du comportement alimentaire des chevaux sur des parcours arbustifs et boisés méditerranéens, afin de documenter leur intérêt pastoral pour les équins. Nous avons observé la sélection alimentaire de jeunes chevaux pâturant sur des parcours typiques des zones périméditerranéennes. Les observations ont été répétées sur deux sites, avec quatre chevaux par site, pendant quatre jours, avec deux observateurs. Dans chaque site, deux chevaux ont été équipés de collier à système de localisation GPS afin de déterminer leur présence dans les différentes zones du parc. Les plantes ingérées ont été classées dans une grille de codage. Les caractéristiques chimiques de chaque aliment ont été estimées par spectroscopie dans le proche infrarouge (SPIR). Une classification hiérarchique des spectres SPIR a permis de définir quatre classes. Les feuilles, les brindilles et les fleurs de plusieurs espèces ligneuses ont été ingérées (1 à 18 % des bouchées enregistrées), bien que les espèces herbacées aient été préférées (> 80 % des bouchées). Les chevaux ont exploré l'ensemble des parcs mais ils ont pâturé de préférence dans les zones ouvertes. Les différences observées entre les sites suggèrent un effet important des conditions locales de pâturage. La composition chimique des aliments provenant des arbustes et des arbres était proche de celle des plantes herbacées mais assez différente de celle des graminées. Trois classes sur quatre associaient les plantes ligneuses et les plantes herbacées. Ces classes présentaient des caractéristiques nutritionnelles intéressantes (protéines > 12 %). Ces résultats confirment une contribution positive des plantes ligneuses à la nutrition des chevaux, en complément des autres rôles des ligneux dans le bien-être des chevaux au pâturage.

Mots-clés : cheval, alimentation au pâturage, comportement animal, parcours, valeur nutritive, zone méditerranéenne

Resumen

Mikicic E., Jouven M., Etienne L., Zoungrana S.R., Bastianelli D.
Contribución de las plantas leñosas a la alimentación de los equinos en los pastos mediterráneos

En los países mediterráneos, las zonas arbustivas y boscosas proporcionan forraje barato para los rebaños. Sin embargo, algunos ganaderos de equinos se muestran reacios a utilizar los pastos arbolados, que asocian a una alimentación de baja calidad. En este artículo exploramos algunos aspectos del comportamiento alimentario de los caballos en los pastos mediterráneos de matorral y de bosque, con el fin de documentar su interés pastoral para los equinos. Observamos la selección alimenticia de varios caballos jóvenes que pastaban en pastos típicos de zonas perimediterráneas. Las observaciones se repitieron en dos lugares, con cuatro caballos por lugar, durante cuatro días, mediante dos observadores. En cada lugar se equipó a dos caballos con collares de sistema de posicionamiento GPS para determinar su presencia en distintas zonas del parque. Las plantas ingeridas se clasificaron en una tabla de codificación. Las características químicas de cada alimento se estimaron mediante espectroscopia de infrarrojo cercano (NIRS). Una clasificación jerárquica de los espectros NIRS nos permitió definir cuatro categorías. Se ingirieron hojas, ramitas y flores de varias especies leñosas (1–18 % de los bocados registrados), aunque se prefirieron las especies herbáceas (> 80 % de los bocados). Los caballos exploraron la totalidad de los parques, pero pastaron preferentemente en las zonas abiertas. Las diferencias observadas entre los lugares sugieren un importante efecto de las condiciones locales de pastoreo. La composición química de los alimentos procedentes de arbustos y de árboles era parecida a la de las plantas herbáceas, pero bastante diferente a la de las gramíneas. Tres de las cuatro categorías combinaban plantas leñosas con herbáceas. Estas categorías tenían características nutricionales interesantes (proteína > 12 %). Los resultados confirman una contribución positiva de las plantas leñosas en la nutrición de los caballos, complementando las demás funciones de las plantas leñosas en el bienestar de los caballos que pastan.

Palabras clave: caballos, alimentación en pastoreo, comportamiento animal, tierras de pastos, valor nutritivo, zona mediterránea