Effect of supplementation with barley and calcium hydroxide on intake of Mediterranean shrubs by goats

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Abstract

Maquis plant communities are one of the most varied vegetation types in the Mediterranean region and an important habitat for wild and domestic herbivores. Although the majority of these shrubs are nutritious, the secondary compounds are the main impediments that reduce their forage value. In five experiments, we determined the effect of supplementing the diets of goats with calcium hydroxide plus barley and with barley alone on their intake of five dominant shrubs (Quercus ilex, Erica multiflora, Arbutus unedo, Viburnum tinus and Pistacia lentiscus) of the Mediterranean maquis community. The combination of calcium hydroxide plus barley and barley alone increased the utilisation of Q. ilex, E. multiflora and P. lentiscus, while the intake of A. unedo and V. tinus was not statistically significantly different. Calcium hydroxide and barley (energy) enhance the use of secondary compound-containing plants, which may increase the production of alternate forages and create a more diverse mix of plant species in the Mediterranean maquis plant community.

Introduction

Mediterranean maquis shrubby vegetation is traditionally grazed and is a significant source of forage for small ruminants, particularly during the dry summer in the Mediterranean region including the Adriatic part of Croatia (Rogosic, 2000; Rogosic et al., 2006b). The vegetation of these plant communities in southern Croatia usually consists of 20 to 25 shrub species, but typically only a couple of them are dominant (Quercus ilex, Erica multiflora, Arbutus unedo, Viburnum tinus and Pistacia lentiscus) and represent the major dietary components for wild and domestic herbivores (Rogosic, 2000). The nutrient composition of these shrubs varies considerably (Rogosic et al., 2006b), ranging from low to intermediate diet quality. However, utilisation of the Mediterranean shrubs is often limited by secondary compounds such as tannins, terpenes and saponins (Perevolotsky et al., 1993; Silanikove et al., 1994; Rogosic et al., 2003, 2006a, 2007, 2008). High concentrations of these compounds can adversely affect forage intake and animal health.

Goats browsing on Mediterranean shrublands cannot avoid ingesting secondary compounds that commonly occur in the shrubs. Several different management practices and diet additives to increase intake of secondary metabolite-laden but otherwise highly nutritious shrub species have been examined (Rogosic et al., 2006a, 2008). One approach involves supplementation of various nutrients that would be expected to enhance clearance of these compounds. Depletion of body protein and glucose may occur during detoxification to counteract losses from conjugation, enzyme synthesis, maintenance of acid/base balance, etc.; consequently, supplementation and improved nutrient status should permit animals to consume more phytotoxins (Foley et al., 1999). Sheep consumed more total toxins when fed three diets containing terpenes, tannins or oxalates in association with a high quality diet (both in terms of protein and energy) than with a low quality diet, presumably because the high quality diet supplied the necessary nutrients for ruminal and hepatic detoxification (Shaw et al., 2006).

In addition to nutritional manipulation, the effects of a variety of treatments and dietary additives that enhance detoxification, reduce absorption, or otherwise counteract limitations of secondary compounds on intake have been examined. The effects of nutrients and activated charcoal on terpene-rich sagebrush intake have been examined by Banner et al. (2000), Burrit and Provenza (2000) and Illalaba et al. (2002a), and the effects of supplemental macronutrients and polyethylene glycol on tannin-containing food have been examined by Titus et al. (2000) and Villalba et al. (2002b). Calcium hydroxide (Ca(OH)2) is commonly used in veterinary medicine for the oral treatment of acidity in the gastrointestinal system, diarrhea and acid poisoning in domesticated animals. Wanapat et al. (2009) showed that urea combined with Ca(OH)2 improves rumen degradability. The concentrated alkaline agents can chemically break the ester bonds between lignin and hemicellulose and cellulose, and physically make structural fibres swell. These effects enable rumen microbes to attack the structural carbohydrates more easily, increasing digestibility and, at the same time, increasing palatability of the treated straw. Supplements of Ca(OH)2 have been used in the treatment of tannin-rich plants as an antidote for hydrolysable tannin poisoning in rabbits (Dollahite and Camp, 1962; Dollahite et al., 1966). Wina et al. (2005) reported that in vitro soaking of Accacia ciliata leaves in Ca(OH)2 solution caused the deactivation and/or extraction of 75% of the total tannins and 52% of the condensed tannins probably owing to oxidation of tannins at high pH. High pH-mediated oxidation of tannin on the addition of urea or wood ash has also been reported (Makkar and Singh, 1992). On the other hand, according to Mirdia et al. (1990), binding of Ca(OH)2 with tannins to form insoluble complexes that prevent absorption is the likely method of detoxification. These authors report that Ca(OH)2 reduces the toxicity of Clidemia hirta in goats, although lesions in the abomasum and rumen as well as minor pathologies in the liver and kidney were recorded. Supplementation with energy and Ca(OH)2 significantly improved the average daily weight gain in goats, relative to the same diet without energy (Wina et al., 2005).

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Thus, we hypothesise that macronutrients (energy) and supplements like Ca(OH)₂ alleviate the aversive effects of secondary compounds in five dominant shrubs of the Mediterranean maquis plant community, thereby allowing an increase in the use of those shrubs by herbivores. The aim of our trials was to evaluate the role of supplemental barley and Ca(OH)₂ on the intake of five biologically diverse Mediterranean shrubs by goats. We conducted five independent trials over a four-month period with three treatment groups of animals.

**Materials and methods**

The study was conducted at the university experimental farm, 25 km from Split, Croatia, in the Central part of the Adriatic seaside. The experiments were conducted during autumn (October - November, 2007) and spring (April - May, 2008). We conducted five experimental trials of 10 days each.

**Study shrubs**

We studied five evergreen dominant shrub species: *Quercus ilex* L. (Fagaceae), *Erica multiflora* L. (Ericaceae), *Arbutus unedo* L. (Ericaceae), *Viburnum tinus* L. (Caprifoliaceae) and *Pistacia lentiscus* L. (Anacardiaceae) of the Mediterranean maquis plant community. Together they constitute about 70% of the shrubby vegetation from a total of 25-30 browse species occurring in the *Myro-Quercetum ilicis* maquis plant community (Rogosic, 2000). All of the studied species are important dietary components for sheep and goats (Rogosic et al., 2006b).

All shrubs were hand-harvested each week within 2 km of the research station. Leaves and one-year-old twigs (about 10 cm in length) were clipped and placed in paper bags. Within one hour, the plant material was ground to 1 cm in length with a chipper, mixed for uniformity, placed in woven polyethylene bags and refrigerated at 4°C. During the experiment, bags with the shrubs to be fed that day were removed from cold storage in the morning and immediately offered to the animals.

**Phytochemical characteristics of shrubs**

Woody species in Mediterranean maquis generally have low crude protein content and high lignin and tannin content. The investigated shrub leaves are rich in free condensed tannins, being from 71 g/kg of dry matter (DM) in *Q. ilex* (Getachew et al., 2000) to 383 g/kg of DM in *P. lentiscus* (Cabiddu et al., 2000; Ammar et al., 2005; Gasmi-Boubaker et al., 2006). Four shrubs were analysed for the tannin activity index using the spectrometric method as described by Kouki and Manetas (2002). Tannin activity, expressed as the tannin index (mg protein precipitated per mg phenols), was highest for *E. multiflora* (1.98), followed by *P. lentiscus* (1.50), *A. unedo* (1.26) and *Q. ilex* (0.96) (Rogosic et al., 2006b).

Additionally, the investigated shrubs contain other secondary metabolites that have an adverse effect on forage intake by ruminants. *Q. ilex* contains the monoterpenes α-pinene, β-pinene, sabinein, myrcene and limonene (Staudt et al., 2001). The main polyphenols found are epicatechin, queratin, kaempferol and rhamnetin (Brossa et al., 2009). The main components of the extract of *E. multiflora* are the monoterpenes α-pinene, β-myrcene, limonene and Δ3-carene (Lluisia et al., 2008). Furthermore, the main constituents of essential oils from leaves of *A. unedo* are (E)-2-decenal, α-terpineol, hexadecanoic acid and (E)-2-undecenal (Kivicak et al., 2001), while the main flavonoid (0.52-2.00%) constituents are quercitrin, isoquercitrin, hyperoside and rutin (Males et al., 2006). *V. tinus* contains two acylated iridoid glucosides, coumarin digluco-side scopoletin dinicotin acid ester and 2,6-di-C-methyl-nicotinic acid 3,5-diethyl ester, two bidesmosidic saponins, a hexamethoxy-flavone and five flavonol glycosides, as well as suspensolide A and oleandolic acid (Mohamed et al., 2005). The main constituents of the essential oils from leaves of *P. lentiscus* are myrcene, limonene, β-ergurjune, germacrene, α-pinene, muurolene, α-humulene, epi-bicycloisophellandrene and β-pinene (Amhandi et al., 2009).

**Experimental animals**

Eighteen domestic goats (Saanen and Alpine cross-breed, 5 months of age, n=8 male and 10 female) weighing 26.03±3.25 kg (mean±SEM) were used. Throughout the experiments, animals were individually penned (1.5×2 m pens) and had free access to trace mineral blocks and fresh water. All animals were raised on the same farm and were adapted to the shrubby vegetation of the Mediterranean maquis. To establish a baseline, *ad libitum* intake of alfalfa was measured for five days. After the baseline was established, all animals were submitted to a five-day preconditioning period (to reduce neophobia) where 20 g of finely ground Ca(OH)₂ mixed with 200 g of barley was offered from 08h00 to 08h30, and all five shrubs were offered in individual feeding boxes, continually replenished from 08h30 to 14h00. We mixed Ca(OH)₂ with barley to accustom the animals to the supplement and to facilitate initial acceptance of the shrubs as well as to reduce the possibility of taste aversions (Banner et al., 2000).

**Experimental protocol**

After this preconditioning period, all animals were fed 200 g of ground barley mixed with 20 g of Ca(OH)₂ from 08h00 to 08h30 and offered all five shrubs simultaneously from 09h00 to 14h00 for five days. The shrub intake of each animal was monitored, and 18 goats were divided into three groups (Ca(OH)₂ plus barley, barley alone and control) based on total shrub intake, by ranking animals and using all odd ranks as one treatment (Group I: 26.12±2.80 kg; Group II: 25.45±3.53 kg; Group III: 26.50±3.75 kg). Treatment groups were unaltered during the experiments. We used a washout period between experiments, when animals were fed with alfalfa pellets and barley at a maintenance level for three days.

From 08h30 to 09h00, the first group of goats (n=6/treatment) were offered Ca(OH)₂ plus barley (20 g + 200 g, respectively), the second group of goats were offered barley (200 g) only and the third group of goats did not receive any supplement. Subsequently, all animals were offered 200 g of shrub biomass in food boxes from 09h00 to 14h00 daily for ten days. Animals and food boxes were checked every 30 minutes and additional ground material was added as needed. Food refusals were collected and shrub consumption was calculated. Goats had *ad libitum* access to alfalfa pellets for 30 minutes each afternoon, from 15h30 to 16h00. This experiment was repeated for each shrub species in the following sequence: *Q. ilex, E. multiflora, A. unedo, V. tinus* and *P. lentiscus*.

**Statistical analyses**

The experimental design for the shrubs fed individually to the goats was a completely random design with a separate analysis for each shrub. The model included three treatments (Ca(OH)₂ plus barley, barley alone and no supplement), with individual animals nested within treatments, and repeated measures over the 10 days. ANOVA analysis on the three treatments was used to compare both average daily intake and trial mean intake. The total daily amount consumed of each shrub offered in each trial was used as the dependent variable in the analysis. Analyses were conducted using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC; Version 9.1 for Windows). Goats-within-treatment was the error term for treat-
ments. The model also used days as a repeated measure with all other interactions included. Goats-within-treatment × day was the error term for day and its interaction with treatment. All analyses on shrub intake were adjusted for body weight (g/kg BW) prior to the analysis.

Results

Effect of calcium hydroxide and barley on shrub intake

In all five experiments, the supplemented groups (Ca(OH)2 plus barley and barley alone) tended to increase intake of the shrub species in comparison with the control group (no supplements) (Figure 1). The combination of Ca(OH)2 plus barley had the best effect on the intake of Q. ilex, E. multiflora, V. tinus and P. lentiscus. The effect of Ca(OH)2 on the intake of Q. ilex (three-fold) and of E. multiflora (two-fold) was particularly pronounced. The barley alone gave the best effect on foliage intake of A. unedo, but also of Q. ilex and E. multiflora, as well as showing some weaker influence on the intake of P. lentiscus.

Although goats supplemented with Ca(OH)2 plus barley and with barley alone consumed higher quantities of Q. ilex compared with the control group (P<0.05), the differences between the two treatment groups were not significant (P>0.05) (Figure 1a). Comparing the groups each day, it was seen that the goats in the Ca(OH)2 plus barley treatment group consumed more Q. ilex than the control group (P<0.05) on all of the 10 days, but the differences between the barley treatment group and the control group were found on all days except days 2, 5 and 6 (Figure 1a). Concerning E. multiflora, the effect of supplementation with Ca(OH)2 plus barley and barley alone was similar to Q. ilex. Goats supplemented with Ca(OH)2 plus barley and barley alone consumed more E. multiflora compared to the control group (P<0.05). The differences between the two treatment groups were not significant (P>0.05) (Figure 1b). Goats in the Ca(OH)2 plus barley treatment group ate more E. multiflora than the control group (P<0.05) on all 10 days, while in the barley alone treatment group the differences were not found on days 1, 2 and 5.

The mean intake of A. unedo by goats in the Ca(OH)2 plus barley and barley alone treatment groups (16.16±1.78 g/kg BW; 17.96±3.71 g/kg BW) was higher than in the control group (11.68±2.22 g/kg BW) (Figure 1c), but these differences were not significant at P=0.05. However, there was the tendency for the goats in the barley alone treatment group to eat more A. unedo than the goats in the control group (P=0.12). In the experiment with V. tinus, goats supplemented with Ca(OH)2 plus barley consumed more biomass on the first four days than the goats in the control group, but the differences on the last five days were not confirmed statistically. Likewise, goats in the Ca(OH)2 plus barley treatment group ate more V. tinus biomass on days 4 and 5 (P<0.05) than goats in the barley alone treatment group. The differences between the barley alone and control groups were not established on any days in the experiment. Here, the differences were as in the experiments with Q. ilex and E. multiflora, but the differences were less pronounced and not significant (Figure 1d). Goats supplemented with Ca(OH)2 plus barley consumed higher quantities of P. lentiscus than goats in the control group (P<0.05), while the intake by goats supplemented with barley alone was not statistically different (P>0.05) to the control group, although the numeric values clearly differ. Comparing the intake per day, goats in the Ca(OH)2 plus barley treatment group ate more P. lentiscus (P<0.05) than goats in the control group on days 3, 6, 9 and 10 (Figure 1e).

The mean amount of shrub vegetation consumed across all five experiments and treatments in rank order (greatest to least) was: E. multiflora (18.85±4.03 g/kg BW), Q. ilex (16.01±4.04 g/kg BW), A. unedo (15.27±1.87 g/kg BW), V. tinus (5.85±0.77 g/kg BW) and P. lentiscus (2.66±0.47 g/kg BW). Thus, the goats preferred E. multiflora, Q. ilex and A. unedo to V. tinus and P. lentiscus.

In the first experiment, goats supplemented with Ca(OH)2 plus barley or alone generally consumed more Q. ilex (22.88±3.09 g/kg BW; 16.55±2.91 g/kg BW) than those not supplemented (8.90±0.91 g/kg BW; P<0.05), but there were no differences between the Ca(OH)2 plus barley and barley alone treatment groups (Figure 2). Likewise, in the second experiment, the goats supplemented with Ca(OH)2 plus barley or alone consumed more E. multiflora (24.19±3.49 g/kg BW; 21.63±3.85 g/kg BW) than those not supplemented (11.02±1.42 g/kg BW; P<0.05), but there were not differences between the Ca(OH)2 plus barley and barley treatment groups. In the third experiment, the goats supplemented with Ca(OH)2 plus barley and barley alone consumed similar quantities of A. unedo (16.16±1.78 g/kg BW; 17.96±3.71 g/kg BW) and goats no supplemented consumed somewhat smaller amounts of A. unedo (11.68±2.22 g/kg BW), but these differences were not significant (P=0.05). In the fourth experiment (as in the experiment with A. unedo), the goats supplemented with Ca(OH)2 plus barley and barley alone consumed very similar quantities of V. tinus in all three treatments (7.37±0.92 g/kg BW; 5.20±0.87 g/kg BW; 4.97±0.72 g/kg BW). In the last experiment with P. lentiscus, the goats supplemented with Ca(OH)2 plus barley and barley alone consumed more biomass (3.39±0.64 g/kg BW) than those not supplemented (1.78±0.18 g/kg BW; P=0.039), but there were no differences between the Ca(OH)2 plus barley and barley treatment groups (2.80±0.57 g/kg BW; P>0.05).

Figure 1. (a – c) Average daily shrubs intake of six goats (g/kg, body weight) over 10-day trial periods. (●), barley + Ca(OH)2; (○), barley alone; (★), no supplement; vertical bars indicate standard error; for each day, points having common letter(s) do not differ at 5% level of significance.
Discussion

Plant secondary compounds as browsing deterrents in Mediterranean maquis

The Mediterranean maquis vegetation consists of numerous plant species differing in growth patterns and concentrations of nutrients and secondary compounds, and possessing a variety of flavours and intensities that contribute to the differential palatability of these shrubs for browsing goats. In our experiments, the goats preferred E. multiflora, Q. ilex and A. unedo compared to V. tinus and P. lentiscus. Presumably the reason for the low intake of these shrubs was not poor nutritional quality (Rogosic et al., 2006b), but because they contained high concentrations of secondary compounds. High concentrations of tannins in Q. calliprinos (Perevolotsky et al., 1993) have been found to reduce preference for that shrub by sheep and goats. Tannins also limit the intake of strawberry trees (A. unedo) and holly oak (Q. ilex), dominant shrubs in Mediterranean maquis vegetation (Rogosic et al., 2006a, 2006b).

As most Mediterranean shrubs contain secondary compounds, consumption of a variety of plants and plant parts by herbivores affects the kinds and concentrations of secondary compounds (Rogosic, et al., 2007). In this sense, toxins compel herbivores to select a variety of plants to meet their needs for nutrients because pathways of detoxification are saturable (Freedland and Janzen, 1974; Foley et al., 1999). Thus, as animals satiate on particular toxins, they must find alternative forage sources containing complementary nutrients and toxins (Rogosic et al., 2006a). While herbivores have evolved mechanisms to deal with phytochemicals to a certain extent, practical management methods to safely increase shrub intake by livestock are needed. A variety of management practices and diet additives to increase intake of secondary metabolites have been examined (Provenza et al., 2000). One approach involves supplementation of various nutrients that would be expected to counteract the negative effects on nutrient absorption in the intestinal tract and/or enhance clearance of secondary compounds post-absorption. In addition to nutritional manipulation, a variety of treatments and dietary additives that enhance detoxification, reduce absorption, or otherwise counteract limitations of secondary compounds on intake have been studied (Provenza et al., 2000; Rogosic et al., 2006c, 2008, 2009). Increased dietary diversity (greater number of shrub species consumed) and complementarity of shrubs containing different classes of secondary compounds have also been investigated as methods to increase the ability of ruminants to consume shrubs (Rogosic et al., 2007). The potential of macronutrients (energy) and forage additives such as Ca(OH)2 to increase intake of Mediterranean shrubs by goats is discussed as follows.

Effect of calcium hydroxide supplementation

Nutrients and medicines like polyethylene glycol (PEG) (Silanikove et al., 1994, 1997; Titus et al., 1999; Villaiba et al., 2002b; Rogosic et al., 2006a), activated charcoal (Banner et al., 2000; Poage 2000; Rogosic et al., 2006c) and Ca(OH)2 (Dollahite, et al., 1966; Muradiati et al., 1990) enhance intake and improve efficiency of detoxification by providing substrates for eliminating toxins (Illius and Jessup, 1996; Foley et al., 1999). When chemically defended plants are abundant relative to alternative forages in plant communities such as Mediterranean maquis (which contains roughly 25 shrub species), intake is limited owing to the lack of adequate nutrients and medicines to enhance detoxification (Freedland and Janzen, 1974; Bryant et al., 1991). However, when chemically defended plants occur in association with plants with higher nutritive value or if animals are supplemented with medicines (e.g. PEG, activated charcoal or Ca(OH)2), intake of defended plants may be proportionally higher (Bryant et al., 1991; Banner et al., 2000; Provenza et al., 2000; Rogosic et al., 2006a, 2006c), leading to an increased utilisation of all five Mediterranean shrubs investigated; therefore, the intake of A. unedo and V. tinus was not statistically significant.

The intake of the three tannin-rich shrubs Q. ilex, E. multiflora and P. lentiscus (Figure 1) individually offered to goats was increased by barley plus Ca(OH)2 or barley alone compared to the control treatment. For the other two shrubs, the positive effect of Ca(OH)2 plus barley (A. unedo) and barley alone (V. tinus) was not established. Overall, there was no significant difference in the intake of all five Mediterranean shrubs with the barley plus Ca(OH)2 and barley alone treatments, indicating that the Ca(OH)2 alone was not effective in the reduction of the toxic effects of all the investigated shrubby species. When Ca(OH)2 is recommended for practical application, one should consider the cost/benefit ratio. However, a positive trend of Ca(OH)2 on the intake of Q. ilex, E. multiflora, V. tinus and P. lentiscus was recorded as the intake was higher in the barley plus Ca(OH)2 compared to the barley alone treatments. Contrary to the oxidation of tannins proposed by Wina et al. (2005) and binding of Ca(OH)2 with tannins to form insoluble complexes proposed by Makkar and Singh (1992), we ascribed the positive effect of Ca(OH)2 on the intake of shrubs in our experiments to the increase in the pH of the rumen. Possibly, Ca(OH)2 affected the higher alkalinity of the consumed tannin-rich shrubs and thus could help in maintaining the optimal pH for growth of microorganisms in the rumen (Alam et al., 2005). Likewise, Ca(OH)2 might mediate in the breakdown of lignin, hemichelluloses and cellulose, and might alleviate the microbiological digestion of carbohydrates. We presumed that the effect of Ca(OH)2 on the intake of A. unedo was least because it has the lowest content of crude fibre and neutral detergent fibre (NDF) (Rogosic et al. 2006b) compared to the other shrubs investigated. Finally, before instituting the wider use of Ca(OH)2 in diets composed of Mediterranean shrubs, it is necessary to precisely determine its proportion in the diet based on the chemical composition of the plant used, the animal species and other supplements.

However, on the high biodiversity diet, when six shrubs were simultaneously offered to sheep and goats, the beneficial effect of PEG (Rogosic et al., 2008), activated charcoal (Rogosic et al., 2006c) and Ca(OH)2 (unpublished data) on the intake of shrubs was not determined, possibly because the greater variety of shrubs attenuated any effects of PEG, activated charcoal and Ca(OH)2. Thus, small ruminants may be more able to meet their needs for nutrients and regulate intake of toxins when offered a variety of foods (shrubs) that differ in nutrients and toxins than when constrained to a single food (one shrub), even if the food is nutritionally balanced (Provenza et al., 2001). When three shrubs (moderate biodiversity) were offered to sheep and goats, PEG (Rogosic et al., 2008), activated charcoal (Rogosic 2006c) and Ca(OH)2 increased the intake (P<0.03) of high-tannin shrubs (Rogosic et al., 2010, unpublished). Many authors attribute a similar function to PEG (i.e. binding with tannins) to increased intake and digestion of tannin-containing shrubs (Silanikove et al., 1994, 1996, 1997; Provenza et al., 2000; Titus et al., 2000; Rogosic et al., 2008), but the method of this influence is not the same.

Effect of barley supplementation

In all our experiments (Figure 1), the controls did not receive barley in order to deter-
mine the effect of energy on the intake of a high - secondary compound shrub. Macronutrient supplemented animals or plants of high nutritive value enhance intake and improve efficiency of detoxification by providing the substrate for eliminating toxins. In our study, barley supplementation significantly increased the intake of shrubs Q. ilex and E. multiflora, but for A. unedo and V. tinus the difference was not significant and, for P. lentiscus, the high-energy grain mixed with Ca(OH)₂ increased biomass intake (Figure 2). Herbivores are likely to respond to ingested toxins by modifying their feeding behaviour (Foley et al., 1999). Food intake and dry matter digestibility of tannin-containing forages are often higher for goats than for sheep (Silanikove et al., 1996), and goats often use protein more efficiently than sheep (Kronberg and Malechek, 1997). Food selection by herbivores depends on their nutritional state and supplemental macronutrients increase the intake of foods that contain toxins (Villalba et al., 2002).

Supplemented sheep and goats likely spent more time feeding on Mediterranean shrubs owing to the increased efficiency of detoxification from an adequate supply of nutrients required for deactivation of tannins and terpenes by conjugation and elimination (Silanikove et al., 1994, 1996, 1997; Rogosic et al., 2006c, 2008, 2009). Faster rates of elimination enable animals to eat more Mediterranean shrubs because they can better maintain tannin and terpene concentrations in the central circulation below the critical levels that limit intake (Illius and Jessop, 1995; Foley et al., 1999). While the role of nutrients in enhancing detoxification and intake has been recognised (Freeland and Janzen, 1974; Silanikove et al., 1994, 1996, 1997; Jessop and Illius, 1997; Rogosic et al., 2006c, 2008), until now the effect of supplemental macronutrients on the utilisation of Mediterranean shrubs in maquis had not been demonstrated. Adequate supplemental nutrients and adaptation alter the consequences of ingesting toxin-containing foods and facilitate the learning process in which new behaviours and dietary patterns are adopted (Provenza, 1996). Adaptation and supplemental nutrients allowed the animals to better cope with secondary compounds and to feed more readily on Mediterranean shrubs. Without supplemental nutrients, secondary compounds have considerable negative effects on the intake of shrubs, although the mechanisms are not well known (Villalba et al., 2002c). Generally, in our study, goats fed with secondary compound-rich shrubs benefited from eating barley, which suggests that energy from supplements is likely to influence the intake and preference for shrubs in goats browsing on Mediterranean bush-lands. Additionally, increased ingestion of secondary compound-rich Mediterranean shrubs may influence the intake and preference for other plant species contained in the Mediterranean maquis. Thus, supplementation improves the possibility of using livestock to control Mediterranean shrubbery (rich in secondary compounds) where it is too dense. Goats browsing can be a means of enhancing bush-land biodiversity if the right conditions are set to facilitate training animals to eat secondary compound-rich shrubs. Supplemented goats can be used as an environmentally safe and economically sound means to reduce the abundance of secondary compound-rich Mediterranean vegetation.

Conclusions

Most of the Mediterranean maquis dominant shrub species are nutritious, but secondary compounds (tannins, terpenes, alkaloids, saponins, etc.) reduce their forage value. Nutrients and medicines like PEG, activated charcoal and Ca(OH)₂ have the potential to enhance intake and improve efficiency of detoxification by providing substrates for eliminating toxins.

Our study showed that supplemental Ca(OH)₂ plus barley and barley alone increase the utilisation of three Mediterranean shrubs (Q. ilex, E. multiflora and P. lentiscus), although the intake of A. unedo and V. tinus was not statistically significant. Thus, supplemented diets in goats are likely to be more effective in controlling secondary compound-rich Mediterranean shrubs where their abundance threatens biodiversity. This can be facilitated by browsing dominant Mediterranean shrubs, which has been shown to be effective in managing Mediterranean maquis density. Our studies with five dominant shrubs in Mediterranean maquis indicate that there is good potential for using goats to enhance biodiversity by increasing consumption of the secondary compound-rich shrubs in the Mediterranean maquis ecosystem.

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Figure 2. Mean of ten measurements of maquis shrub daily intake (g/kg, body weight) in each treatment (barley + Ca(OH)₂, barley, no supplements) consisting of six goats for Quercus ilex, Erica multiflora, Arbutus unedo, Viburnum tinus and Pistacia lentiscus feeding trials. BW, body weight; error bars are ± standard error of the mean; for each feeding trial, bars having common letter(s) do not differ at 5% level of significance.

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