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Feeding Redberry Juniper (*Juniperus pinchotii*) at Weaning Increases Juniper Consumption by Goats on Pasture

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Abstract

Redberry (*Juniperus pinchotii* Sudw.) and ashe (*Juniperus ashei* Buchh.) juniper dominate rangelands throughout central Texas. Our objective was to attempt to improve the efficacy of goats as a biological control mechanism for juniper through behavioral training. Conditioning sheep and goats to increase the palatability of chemically defended plants can be a useful tool in brush control. Previous research illustrated that goats can be conditioned to consume more juniper while in individual pens when foraging choices are limited. To test whether this creates a longer-lasting increase in juniper preference, we determined if goats would continue to consume juniper on pasture for one year after being fed juniper in individual pens for 14 d. Female Boer-cross goats ($n = 40$) were randomly divided into two treatments: conditioned and naive to juniper. At approximately 12 mo of age, conditioned goats were placed in individual pens and fed redberry juniper 1 h daily for 14 d, while naive goats received only alfalfa pellets to meet maintenance requirements. After the pen-feeding phase of the study, goats were placed in one of four pastures (10 goats $\cdot$ pasture^{-1}) for 12 mo. Two pastures housed conditioned goats, and two pastures housed naive goats at a moderate stocking rate (1 animal unit $\cdot$ yr^{-1} $\cdot$ 8 ha^{-1}). Bite count surveys were conducted twice per month, while herbaceous standing crop and monoterpene levels were measured once per month. Juniper preference varied monthly; however, conditioned goats consistently ate more ($P < 0.05$) juniper than naive goats except for April, when the study began, and March, when the study ended. When selection of herbaceous forages decreased, conditioned goats increased selection of juniper, while naive goats increased selection of other palatable shrubs. Seasonal changes of monoterpene levels in juniper had no apparent effect on juniper preference. We contend that feeding juniper at weaning will increase use of the plant in grazing situations.

Resumen

Juniperus pinchotii Sudw y *J. ashei* Buchh son dominantes en pastizales naturales del centro de Texas. Nuestro objetivo fue intentar mejorar la eficacia del pastoreo de caprinos como mecanismo de control biológico de *Juniperus* mediante entrenamiento de comportamiento ingestivo. El condicionamiento de ovejas y cabras para que incrementen la palatabilidad de plantas que contienen defensas químicas podría ser una herramienta útil en el control de especies arbustivas. Trabajos de investigación previos demostraron que se puede condicionar un incremento en el consumo de *Juniperus* en cabras mantenidas en bretes individuales cuando las opciones de forrajeo son limitadas. A fin de determinar si este protocolo crea un incremento duradero en la preferencia de *Juniperus*, determinamos si las cabras continuarían consumiendo *Juniperus* en condiciones de pastoreo durante un año luego de haber recibido *Juniperus* en bretes individuales por 14 días. Hembras cruza Boer ($n = 40$) se dividieron al azar en 2 tratamientos, uno condicionado y el otro sin experiencia previa. A los 12 meses de edad aproximadamente, las cabras condicionadas fueron ubicadas en bretes individuales y alimentadas *J. pinchotii* durante una hora diaria por 14 días mientras que las cabras en el tratamiento sin experiencia previa recibieron solamente pellets de alfalfa para suplir sus requerimientos de mantenimiento. Luego de la fase de alimentación a corral las cabras fueron puestas en 1 de 4 potreros (10 cabras $\cdot$ potrero^{-1}) durante 12 meses. Dos potreros fueron pastoreados por cabras condicionadas y dos por cabras sin experiencia previa con una carga animal moderada (1 Unidad Animal Año $\cdot$ 8 ha^{-1}). Se realizaron conteos de bocados bimestrales y monitoreos mensuales de disponibilidad herbácea y niveles de monoterpenos. La preferencia por *Juniperus* varió mes a mes; sin embargo, las cabras condicionadas consumieron consistentemente más ($P < 0.05$) *Juniperus* que las cabras sin experiencia previa excepto durante abril cuando comenzó el estudio y durante marzo cuando el estudio finalizó. En momentos de menor preferencia por forrajes herbáceos, las cabras condicionadas mostraron un incremento en la selección de *Juniperus*, mientras que las cabras sin experiencia previa incrementaron la selección de otros arbustos palatables. Cambios estacionales en los niveles de monoterpenos aparentemente no tuvieron un efecto sobre la preferencia de *Juniperus*. Sostenemos que alimentado *Juniperus* al destete incrementará el uso de esta planta en situaciones de pastoreo.

Key Words: ashe, conditioning, intake, monoterpenoids, preference, seasonal

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INTRODUCTION

Redberry (*Juniperus pinchotii* Sudw.) and ashe (*Juniperus ashei* Buchh.) juniper cover continues to increase throughout the southwestern states, including Texas, Oklahoma, New Mexico, Arizona, and the country of Mexico (Ansley et al. 1995). Both species of juniper are evergreens historically found on rocky outcrops and north-facing slopes where both were protected from intense grass fires (Ellis and Schuster 1968). During the past century, juniper has encroached onto adjacent slopes and grasslands, reducing the amount of available forage for grazing animals (Dye et al. 1995).

Most livestock species avoid juniper because of monoterpenoids found in the plant that cause aversive postingestive feedback and the formation of conditioned food aversions (Riddle et al. 1996; Pritz et al. 1997). In addition, monoterpene levels vary seasonally (Owens et al. 1998a; Riddle et al. 1999), which probably accounts for some of the variation reported in seasonal consumption when livestock and wildlife do consume the plant. It appears that goats can adapt to the monoterpenoids in juniper if they are exposed to the plant slowly over several days (Bisson et al. 2001). Two studies confirmed this observation by feeding juniper to goats in individual pens for 10–14 d (Ellis et al. 2005; Dunson et al. 2007). Goats increased intake daily until an apparent toxic threshold was reached. Thereafter, intake leveled off and remained high throughout the studies. Preliminary evidence also suggests that goats will continue to consume juniper on pasture after feeding juniper in pen situations (Ellis 2001); however, the pasture phase of the Ellis (2001) study was not replicated, and goats were on pasture for only 6 wk.

This study compared juniper preference in the pasture environment for 1 yr for goats conditioned to juniper and for goats naive to juniper. We hypothesized that goats would select juniper more frequently on pasture after feeding redberry juniper and a basal diet of alfalfa pellets (2% body weight [BW]) for 14 d in individual pens. In addition, we hypothesized that juniper selection (preference) would vary monthly/seasonally in response to changes in herbaceous forage availability and changes in monoterpene concentrations in juniper.

MATERIALS AND METHODS

Forty Boer-cross female goats (average weight 29.2 ± 0.6 kg, 12 mo old) were used for this study. In February 2005, 20 goats were randomly selected, placed individually in pens (1×1.5 m), and fed redberry juniper for 1 h daily for 14 d (treatment 1: conditioned goats). All goats within this treatment also received alfalfa pellets (2% BW) in addition to juniper to meet daily maintenance requirements (National Research Council 1981). The pen-feeding phase of this study was conducted at the Angelo State University Management, Instruction, and Research Center, San Angelo, Texas (lat 31.38, long 100.5). The remaining 20 goats were housed together and fed alfalfa pellets (2% BW) for 14 d (treatment 2: naive goats) at the same location.

Redberry juniper was harvested at the Texas AgriLife Research Center, Sonora, Texas (lat 30.58, long 100.65) from trees randomly selected in pastures adjacent to the pastures used during the pasture phase of this study (described below). Leaves were stripped by hand, and juniper foliage from all trees was composited. Leaf material was then stored at 4°C until feeding (Utsumi et al. 2006). Juniper was fed at the same time each day for 1 h, and refusals were weighed back to determine intake. One hundred grams of juniper were offered daily on an as-fed basis. If goats consumed the entire amount of juniper offered, the amount fed was increased daily until refusals were evident. Goats were allowed free access to freshwater and a HiPro 12% calcium/12% phosphorus mineral with trace elements (Hi-Pro Feeds, Slaton, TX) throughout the pen-feeding phase of the study.

Table 1. Initial percent (%) canopy cover and average monthly herbaceous standing crop ($kg \cdot ha^{-1}$) of the major plant components. Each treatment consisted of two equal-sized pastures.

Shrub species	Treatment		SEM
	Conditioned	Naive	
	----------% Canopy cover ----------		
Juniper	20.3	19.6	4.9
Liveoak	11.7	8.0	5.8
Other shrubs	3.2 b[1]	8.6 a	1.6
Total shrub	35.2	36.2	8.5
	---------- $kg \cdot ha^{-1}$ ----------		
Herbaceous standing crop	1 189	1 349	75.6

[1]Means within rows with different letters differ ($P < 0.05$).

After the 14-d conditioning period, all goats were transported to the Texas AgriLife Research Center, Sonora, Texas, and placed in pastures depending on treatment allocation. Goats were placed in pastures in April 2005 and remained in pastures for 12 mo. Ten goats were placed on one of four equally sized pastures (16.2-ha pastures) with similar woody plant cover (Table 1). Pastures were characterized by an overstory of juniper and liveoak (*Quercus virginiana* Mill.) and an understory of short- and midgrasses. The grass component consisted of buffalograss (*Buchloe dactyloides* [Nutt.] Engelm.), curly mesquite (*Hilaria berlangeri* [Steud.] Nash), Texas wintergrass (*Nassella leucotricha* Trin. & Rupr.), sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), little bluestem (*Schizachyrum scoparium* [Michx.] Nash), hairy grama (*Bouteloua hirsuta* Lag.), hairy tridens (*Erioneuron pilosum* [Buckl.] Nash), and threeawns (*Aristida* spp. Nutt.). Two pastures housed goats that were conditioned to consume juniper and two pastures housed goats that were naive to juniper. Goats were allowed free access to freshwater and a HiPro 12% calcium/12% phosphorus mineral with trace elements (Hi-Pro Feeds) throughout the pasture phase of the study. In addition, goats were dewormed using Ivermectin in the spring, fall, and summer, when internal parasites often cause health problems.

To monitor forage preference (i.e., forage species most commonly selected), bite count surveys were conducted twice monthly for individual goats (Lehner 1987). One of four observers was randomly assigned to each pasture during each collection. Beginning at 0630 hours and again at 1400 hours, every sample day, individual animals were focally sampled in a random order. Bite count data were recorded by watching each goat in turn for 10 min until all goats were observed. The

process was repeated during the afternoon active grazing period. All pastures were observed on each sample day. Bite count data were recorded as the number of bites of juniper, herbaceous species, or other shrubs.

Canopy cover of all shrubs and herbaceous standing crop were measured at the initiation of the study in March 2005. Eight 30-m transects were established at random points in each pasture. Canopy cover by species was determined by measuring shrub foliage that intersected the transect line. Herbaceous standing crop was also estimated in each pasture. Clip samples were taken in March 2005 and then at the end of each month of the study. Ten 0.3-m^2 quadrats were clipped by species to ground level in each pasture at random points throughout each pasture. Forbs were present as small rosettes in March 2005 and April 2006 but were not included in the clip samples because of insignificant weight contributions. Samples were dried at 60°C for 48 h and then weighed to estimate dry-matter weight of standing crop.

Once per month, juniper (redberry and ashe) was collected to measure monoterpene levels for correlation to preference. Fresh juniper was collected from five randomly selected redberry and five randomly selected ashe juniper trees in each pasture during the second collection period during each month. Fifty grams of leaf and small stem tissue were collected by hand clipping from the apical portion of shoots from each tree and immediately placed in liquid nitrogen to halt physiological activity and prevent volatilization. Leaf tissue was then stored at −50°C in order to halt leaf tissue metabolism and monoterpene volatilization.

Monoterpene levels from samples (collected during each month of the study) were determined by taking 15 g of frozen leaf material from each plant. Samples were individually combined with 150 mL of distilled water in a modified Clevenger (1928)-type distillation apparatus. Hexane (5 mL) was used as a solvent for the distillate in the condensation tube, and the distillation time period was 8 h to ensure maximum recovery of oils. Five microliters of tetradecane were added to condensate as an internal standard (Campbell and Taylor 2007).

The chromatographic system consisted of a Clarus 500 GC (Perkin Elmer, Shelton, CT) equipped with a flame ionization detector. The analytical column was a 30-m × 0.25-mm Rtx-5, 0.25 μm (Restek, Bellefonte, PA). One-microliter splitless injections (split time of 0.1 min) were made under the following conditions: the injection temperature was 200°C, and the detector was 300°C. The initial oven temperature of 40°C was held for 0.5 min. The first oven ramp took the oven to 110°C at a rate of $5°C \cdot min^{-1}$ (0-min hold time). The final ramp of $20°C \cdot min^{-1}$ took the oven to its final temperature of 300°C (0-min hold time). The total run time was 23 min. The carrier gas was helium delivered at a constant 39 $cm \cdot s^{-1}$ by employing electronic pressure control. The detector gases were hydrogen (45.0 $mL \cdot min^{-1}$) and air (450 $mL \cdot min^{-1}$). Analytical procedure followed a modification of the procedure described in Kimball et al. (2004).

Detector responses were evaluated for each analyte over the range of 0.25–1.0 $\mu g \cdot mL^{-1}$. For each compound, three hexane solutions with concentrations in the range of interest were injected into the GC in triplicate. Linear regression analyses were conducted, and external standard calibrations were used by comparing detector responses of the analytes from the sample extracts to responses from commercially available standards (Acros Organics, Geel, Belgium).

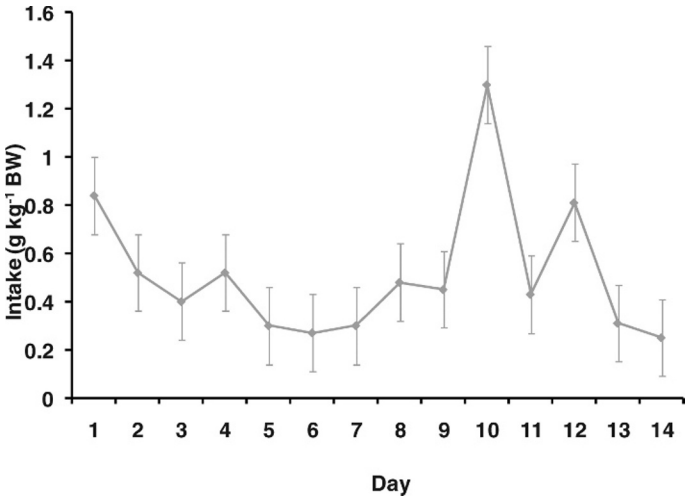

Figure 1. Juniper intake for goats fed redberry juniper in individual pens for 14 d prior to release on pasture.

During the initial feeding of juniper, means and standard errors for juniper intake were compared among days of feeding for individual goats. For the pasture phase of the study, forage preference data, standing crop, and monoterpene concentration data were analyzed, and differences between treatments, months, and seasons were compared using repeated-measures analysis of variance. For seasonal comparisons, winter included data from December, January, and February; spring included data from March, April, and May; summer included data from June, July, and August; and fall included data from September, October, and November. Pastures served as replication and data collection period as the repeated measure. Initial canopy cover was compared among pastures and between treatments using analysis of variance. Means were separated using least significant difference with $P < 0.05$. Any relationships between forage preference, forage availability, juniper preference, and monoterpene concentration were identified using linear regression analysis. Data were analyzed using the statistical computer package JMP (SAS 2007).

RESULTS

Intake of redberry juniper varied throughout the conditioning phase of this study (Fig. 1). On the first day of feeding, goats consumed juniper but were reluctant to consume juniper from day 2 through day 9. Intake increased on days 10 and 12 before declining on days 13 and 14.

Initial canopy cover was similar ($P > 0.05$) among pastures and treatments for juniper and liveoak, the two predominant shrubs (Table 1). Combined cover of other shrubs (e.g., algerita [*Berberis trifoliolata* Moric.], lotebush [*Ziziphus obtusifolia* T.&G.], and persimmon [*Diospyros texana* Scheele]) was higher in the naive pastures.

Variability in monthly estimates of standing crop were very high, and consistent differences between treatments were not detected (Table 1). Thus, we were unable to accept or reject the hypothesis that juniper intake would increase as forage avail-

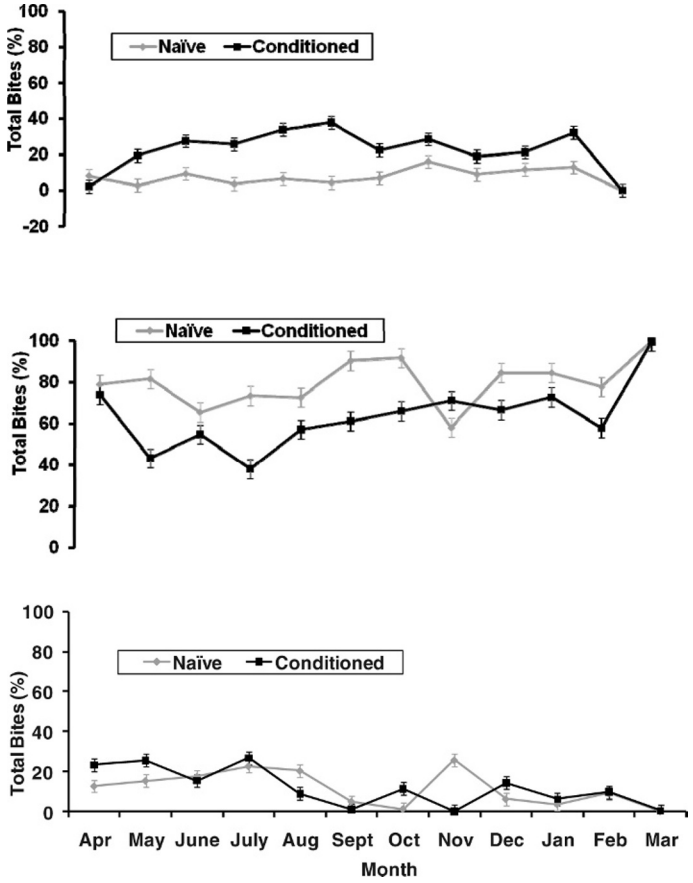

Figure 2. Percent of total bites of juniper (top), herbaceous forages (middle), and other shrubs (bottom) by goats conditioned or naive to juniper. Conditioned goats had been fed juniper in individual pens for 14 d prior to release on pasture.

ability declined. All pastures were stocked at a moderate rate for continuous year long grazing (1 animal unit · yr^{-1} · 8 ha^{-1}). Given the conservative stocking rate, standing crop was never depleted, nor was there a consistent decline in forage availability in the conditioned or naive pastures (data not shown).

Juniper preference for both conditioned and naive goats varied by month ($P < 0.05$; Fig. 2). Conditioned goats selected more ($P < 0.05$) juniper than naive goats over the 12 mo of the study (22.5% ± 1.6 of total bites vs. 7.7% ± 1.6 of total bites) with the exception of the first and last month of the study.

Herbaceous and shrub preference varied by treatment and by month (Fig. 2). Naive goats selected more herbaceous forage than conditioned goats with the exception of March, November, and April. Naive goats typically selected primarily herbaceous forage (80% ± 1.5 of total bites vs. 64% ± 1.6 of total bites for conditioned goats). Other shrub intake varied by month with no consistency of one treatment selecting other shrubs over the other treatment.

When data were pooled within seasons, conditioned goats selected more juniper seasonally and increased juniper preference when selection of herbaceous forage declined ($r^2 = 0.50$; $P < 0.05$; Table 2). Conversely, naive goats selected other browse plants when herbaceous selection declined ($r^2 = 0.57$; $P < 0.05$). Conditioned goats selected other shrubs as well, but intake of other shrubs was not strongly related to herbaceous

Table 2. Seasonal forage selection by conditioned and naive goats foraging on native rangeland, Sonora, Texas.

	Season				
Treatment/species	Spring	Summer	Fall	Winter	SEM
Conditioned	% Total bites				
Juniper	8.42 c[1]	29.08 a	30.15 a	23.27 b	2.5
Herbaceous	71.92 a	49.94 b	66.25 a	65.89 a	3.9
Other shrubs	15.15	17.85	3.60	10.84	3.4
Naive	% Total bites				
Juniper	2.71 b	6.62 ab	9.11 a	11.20 a	2.5
Herbaceous	88.87 a	70.29 c	79.92 b	83.09 ab	3.9
Other shrubs	8.42	23.09	10.96	5.71	3.4

[1]Means within rows with different letters differ ($P < 0.05$).

standing crop ($r^2 = 0.21$; $P < 0.05$). Similarly, naive goats consumed some juniper, but intake of juniper by naive goats was not strongly related to herbaceous standing crop ($r^2 = 0.36$; $P < 0.05$).

Total monoterpene levels in both ashe and redberry juniper varied monthly (Fig. 3), and some individual monoterpene levels varied seasonally (Tables 3 and 4). Total monoterpene levels were higher in November and March for both redberry and ashe juniper. When monoterpene levels were compared by seasons, limonene and terpineol levels differed in redberry juniper samples. Limonene levels were higher in the fall, while terpineol levels were lower in the winter for redberry juniper (Table 3). α-Pinene, α-terpinene, borneol, and bornyl acetate levels differed seasonally for ashe juniper (Table 4). However, monoterpene levels appeared to have little impact on variations in juniper preference. We hypothesized that juniper preference would decline as monoterpene levels increased. This hypothesis was rejected; juniper preference was not related ($P > 0.05$) to individual or total monoterpene levels in either ashe or redberry juniper for conditioned or naive goats across months or seasons.

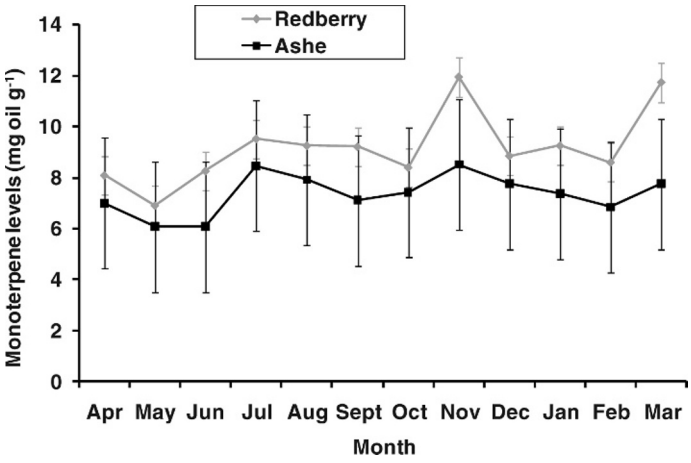

Figure 3. Monthly changes in total monoterpene levels for both redberry and ashe juniper during this study.

Table 3. Seasonal changes of monoterpene levels (mg oil · g^{-1} leaf material) in redberry juniper.

Monterpene	Season				SEM
	Spring	Summer	Fall	Winter	
α-Pinene[1]	0.25	0.29	0.30	0.25	0.02
Sabinene/β-pinene[1]	2.47	2.51	3.00	3.04	0.20
Myrcene[1]	0.69	0.72	0.78	0.65	0.04
Camphene[2]	0.08	0.09	0.09	0.07	0.01
Limonene[1]	0.61 b[3]	0.67 b	0.73 a	0.57 b	0.04
γ-Terpinolene	0.72	0.72	0.72	0.59	0.04
α-Terpinolene	0.30	0.31	0.32	0.26	0.02
Linalool	0.05	0.06	0.06	0.07	0.01
Fenchyl alcohol	0.03	0.03	0.03	0.03	0.01
Camphor[2]	1.19	1.05	1.10	1.00	0.12
α-Citronellal	0.16	0.13	0.16	0.15	0.01
Borneol	0.05	0.06	0.06	0.05	0.01
Terpinen4ol	1.86	1.81	1.74	1.53	0.10
Terpineol[1]	0.09 a	0.09 a	0.09 a	0.08 b	0.003
Citronellol	0.28	0.31	0.30	0.29	0.04
Bornyl acetate[2]	0.26	0.30	0.38	0.21	0.05
Total[1]	9.10	9.15	9.87	8.84	0.93

[1]Denotes monoterpenes inversely correlated with intake (Riddle et al. 1996).
[2]Denotes monoterpenes positively correlated with intake (Riddle et al. 1996).
[3]Means within rows with different letters differ ($P < 0.05$).

Table 4. Seasonal changes of monoterpene levels (mg oil · g^{-1} leaf material) in ashe juniper.

Monterpene	Season				SEM
	Spring	Summer	Fall	Winter	
α-Pinene[1]	0.12 abc[2]	0.18 a	0.17 a	0.15 ab	0.01
Sabinene/β-pinene[1]	0.01	0.11	0.01	0.01	0.04
Myrcene[1]	0.28	0.30	0.34	0.32	0.02
Camphene[3]	0.30	0.36	0.35	0.33	0.02
Limonene[1]	0.65	0.80	0.77	0.70	0.05
α-Terpinene	0.08 ab	0.09 a	0.06 b	0.07 b	0.01
α-Terpinolene	0.05	0.07	0.07	0.06	0.01
γ-Terpinolene	0.06	0.10	0.10	0.09	0.01
Linalool	0.10	0.10	0.12	0.12	0.02
Fenchyl alcohol	0.05	0.04	0.04	0.04	0.01
Camphor[3]	3.89	3.70	4.18	4.25	0.30
α-Citronellal	0.13	0.16	0.15	0.21	0.04
Borneol	0.14 b	0.26 a	0.18 b	0.16 b	0.02
Terpinen4ol	0.02	0.09	0.03	0.02	0.03
Terpineol[1]	0.04	0.05	0.05	0.05	0.01
Citronellol	0.01	0.01	0.03	0.01	0.01
Bornyl acetate[3]	0.94 c	1.38 ab	1.16 bc	0.78 c	0.11
Total[1]	6.87	7.80	7.81	7.38	0.50

[1]Denotes monoterpenes inversely correlated with intake (Riddle et al. 1996).
[2]Means within rows with different letters differ ($P < 0.05$).
[3]Denotes monoterpenes positively correlated with intake (Riddle et al. 1996).

DISCUSSION

Prior to the initiation of this study, it was clear that goats would increase consumption of juniper when fed the plant at weaning in individual pens (Bisson et al. 2001; Ellis et al. 2005; Dunson et al. 2007). These trials relied on feeding juniper for 10–14 d and resulted in the same outcome. Goats were reluctant to consume juniper initially, but by the end of the feeding trials, juniper would account for up to 32% of the diet. In these studies, there was very little variation among individuals, and intake typically increased daily until the end of the feeding trial. In the current study, intake fluctuated more daily than in other studies (Bisson et al. 2001; Ellis et al. 2005; Dunson et al. 2007). Goats in this study were older than goats used in previous studies (12 mo vs. 6 mo), which may have accounted for the daily variation in juniper consumption. Goats in this study were also offered redberry juniper for a longer period during each daily feeding bout than in previous studies. Ruminants typically sample new foods cautiously during initial feeding bouts. Providing novel foods for longer periods of time should increase initial consumption and the likelihood of consuming sufficient amounts to induce aversive postingestive feedback (Provenza et al. 1994). In this study, increased exposure time may have increased intake to the point of goats receiving aversive postingestive feedback and caused the formation of a mild aversion to juniper during the initial days of the conditioning trial.

Monoterpene levels in juniper vary monthly (Owens et al. 1998b) and probably vary from year to year depending on ambient conditions. The redberry juniper fed in the preconditioning phase of this study may have contained higher monoterpene levels than juniper fed in previous years. The purpose of the pen-feeding phase of this study was to introduce goats to the plant prior to release on pasture. Despite the variation in intake across days of feeding, exposure in individual pens did improve acceptance of the plant, as evident from the differences in preference between conditioned and naive goats when released on pasture. More important, conditioning led to a sustained preference for juniper once goats are released on pasture. Conditioned goats clearly selected juniper more frequently than naive goats throughout the year and included juniper in their diet even though herbaceous forage remained available throughout the year (Fig. 3).

The general consensus among ranchers and land managers is that goats will select nutritious herbaceous forages and shrubs if available and avoid juniper once released on pasture, with juniper intake increasing only when availability of more palatable forages decreases. The results of this study indicate that Boer-cross female goats will select juniper at levels up to 40% of total bites taken on pasture when conditioned for 14 d at weaning. Experiences early in life influence preferences later in life for both ruminants and nonruminants (Provenza 1995, 1996). In some cases, exposure to toxic plants has resulted in increased preference and use (Distel and Provenza 1991; Walker et al. 1992; Olson et al. 1996).

The mechanisms that allow ruminants to adapt to plants that cause aversive postingestive feedback and/or toxicosis remain unclear. However, changes in rumen or liver function may result in adaptation to toxic forages (Weimer 1998). A previous study (Dunson et al. 2007) illustrated that rumen function in goats does not change to the point of detoxifying the terpenes in juniper. Hepatic involvement is more likely. Monoterpenes are converted from lipophilic compounds to hydrophilic conjugated compounds by phase I and phase II detoxification

enzymes in the liver before urinary excretion (Foley et al. 1995). Moderate doses of juniper oil at levels nearing exposure levels seen at maximal intake levels of free-ranging goats (0.18 g oil $\cdot$ kg^{-1}) resulted in mild hepatic injury in the form of lipid vacuolization. At higher dose levels (0.36 g oil $\cdot$ kg^{-1} BW), cellular necrosis and lobular encapsulation were evident (Straka et al. 2004).

Goats typically avoid juniper during the spring and summer and when alternative herbaceous forage is available (monoterpene levels are also reportedly higher; Riddle et al. 1996; Owens et al. 1998b). In contrast, conditioned goats selected juniper every month of this study except March and April, when herbaceous forage intake increased. Selection varied monthly, which was apparently in response to decreased selection for herbaceous forage. Changes in forage quality were not measured in this study, but observers did note that as dry conditions prevailed and herbaceous forages entered dormancy, juniper preference increased particularly for conditioned goats. Conversely, naive goats increased intake of other browse plants as herbaceous forage selection decreased seasonally. Liveoak (data not presented) was the most preferred alternative forage.

Monthly and seasonal changes in monoterpene levels did not appear to affect juniper preference. Negative correlations between monoterpene content (Estel et al. 2002; Dziba et al. 2006) and intake of juniper (Riddle et al. 1996) have been documented. Explanations for the difference in results from other studies and the current study remain unclear. Riddle et al. (1996) reported that some monoterpenes in juniper were inversely correlated with intake. As ingestion of α-pinene, sabinene/β-pinene, myrcene, limonene, and terpineol increased, intake declined. In this study, α-pinene, sabinene/β-pinene, and myrcene levels did not differ seasonally in redberry juniper. Terpineol levels in redberry juniper were lower in the winter, when juniper preference increased. However, selection for herbaceous forage also declined during the winter, which may account for the increased acceptance of juniper. α-Terpinene and borneol levels in ashe juniper were higher in the summer. Despite these increases in monoterpene levels, juniper intake remained relatively high for conditioned goats (29%), and naive goats continued to consume some juniper (6%).

Composition and concentration of monoterpenes differs by species. Ashe juniper contains a slightly different composition and lower levels of monoterpenes. Ashe juniper was preferred over redberry juniper in previous feeding trials (Pritz et al. 1997), and while not measured directly, it was our observation at the end of the study that most (approximately 80%) of the browsed juniper plants examined were ashe juniper.

Juniper dominates rangelands in central and western Texas because it gains a competitive advantage over herbaceous forages and other shrubs that are consumed for forage while juniper is avoided (Archer 1994). In both conditioned pastures, browse lines became apparent on mature junipers throughout both pastures, and several immature junipers were defoliated. Although it was not measured in this study, others have observed greater juniper seedling mortality when pastures were stocked with goats (C. A. Taylor, unpublished data, 1997). In short, conditioning goats to consume juniper should attenuate the invasion of juniper on rangelands and create browse lines on juniper, allowing for increased herbaceous production (Fuhlendorf et al. 1997) below the canopies of the plant.

IMPLICATIONS

Collectively, the results of this study indicate that goats fed juniper at weaning will consume a diet that consists of juniper and herbaceous forage, while goats naive to juniper will consume a diet consisting primarily of herbaceous forages and other browse plants. While other studies had shown that goats would increase intake of redberry juniper in individual pens, this study illustrated that a preference for juniper would persist for up to a year when goats are grazing on pastures. Performance data are lacking; however, one study did show that juniper consumption did not affect reproductive performance of pregnant female goats (Owens et al. 2010). Likewise, juniper is moderately nutritious (Huston et al. 1981) and could serve as alternative forage if goats are successful in avoiding aversive postingestive feedback from the monoterpenes in the plant. Based on the results of this study, we contend that producers should feed juniper at weaning to replacement does to increase use of the plant. Fresh limbs of juniper could be hand-cut and placed in pens where replacement does are being weaned in confinement. The potential success of pasture exposure during this time period has yet to be evaluated, but pasturing replacements in juniper-dense pastures to ensure exposure may also have merit. Once juniper is included in the diets of goats, the plant community dynamics and competitive dominance of the plant community could change in response to selective goat browsing.

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