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Replacement value of *Solanum elaeagnifolium* for alfalfa hay offered to growing goats

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ABSTRACT

In order to determine the nutritional properties of *Solanum elaeagnifolium* in goat diets, chemical analysis, *in vitro* techniques and a feeding trial were conducted. *S. elaeagnifolium* replaced alfalfa hay in the diet of confined growing goats at 0% (T0), 25% (T25), 50% (T50), 75% (T75), and 100% (T100). Roughage comprised 300 g kg^{-1} of total feed offered. Values of nutritional parameters for *S. elaeagnifolium* were *in vitro* OMD, 522 g kg^{-1}; crude protein (CP), 150 g kg^{-1}; metabolizable energy, 6.52 MJ kg^{-1} DM. Maximum average daily gain (ADG; 116 ± 22 g day^{-1}) was observed in T0 animals, while goats receiving *S. elaeagnifolium* gained weight in the range of 40–112 g day^{-1}. Most of the variation in weight gain was explained by ascending levels of *S. elaeagnifolium* in the diet ($R^2 = 0.92$), which decreased ($P < 0.05$) dry matter intake (DMI) and increased feed conversion ratio (FCR; DMI/ADG). These results indicate that *S. elaeagnifolium* at the flowering stage is not palatable and nutritious for goats. This forb can replace alfalfa hay only by 25% (DM basis) without adverse effect on DMI or ADG of growing goats.

1. Introduction

Solanum elaeagnifolium Cav. (silverleaf nightshade or trompillo), a forb native to the central US, is a noxious weed of prairies, open woods and disturbed soils in several states in the United States of America (Boyd et al., 1984). Interest in the plant increased in the 1970s as silverleaf nightshade began spreading outside its native range. It is now found in Australia, Egypt, Greece, India, Israel, Zimbabwe, Sicily, South Africa, Morocco, and Spain (Bouhache and Tanji, 1985; EPPO, 2007).

This forb has been implicated in reduced weight gains, lowered animal production, teratogenic effects (Baker et al., 1989; Keeler et al., 1990) and neurological disorders (Porter et al., 2003) in ruminants. *S. elaeagnifolium* contains the tropane alkaloid solanine, which acts on the gastrointestinal system. Solanidine, a steroidal alkaloid, is also present in this plant and affects the nervous system (Buck et al., 1960).

Despite of its toxicity, *S. elaeagnifolium* can become in certain seasons the most important component of the diet of goats on degraded rangelands in northern Mexico (Mellado et al., 2003, 2004), apparently without clinical toxicity effects (Boyd et al., 1984). Typical for most range plants and especially noxious weeds, despite their importance for the diets of free grazing ruminants, no nutritional information is available for *S. elaeagnifolium*. Given the importance of *S. eleagnifolium* as a forage for goats in the arid zone of Mexico, but also addressing its significance as an invasive weed in many arid areas

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world-wide, a study was conducted to evaluate the nutritional properties of this forb and examine its effects on the performance of growing goats under controlled conditions.

2. Material and methods

2.1. Animals and management

The experiment was conducted at the Universidad Autonoma Agraria Antonio Narro in northeastern Mexico (25°22′N, 101°00′W) during the fall 2004. The study area is located in an arid zone at 1500 m above sea level with 310 mm annual precipitation. Forty 2-month-old crossbred female goats (11.1 ±0.9 kg) (offspring of native does mated to European dairy goat bucks) were randomly allotted (two goats per pen) to five diets with different ratios of commercial alfalfa *(Medicago sativa* L.) to *S. elaeagnifolium* Cav. hay of 100:0 (T0), 75:25 (T25), 50:50 (T50), 25:75 (T75), and 0:100 (T100). Rations were fed at 1 kg DM/day/head with 300 g kg^{-1} roughage and 700 g kg^{-1} concentrate.

For the preparation of *S. elaeagnifolium* hay, whole plants from a rangeland site adjacent to the University were harvested by hand prior to the start of the experiment. *S. elaeagnifolium* was transported to the processing plant where it was sun-dried for 2 days to about 20% moisture. Forage was then ground to pass through a screen with a diameter of 5 cm.

Animals were fed in pairs in pens of 2.0 × 1.5 m size, located in a ventilated confinement facility with cement floors. Prior to early weaning, the experimental animals had grazed with their mothers a rangeland pasture typical of the Chihuahua desert ecoregion. Accordingly, they had been exposed to *S. elaeagnifolium* before the commencement of the confinement trial. Prior to the initiation of experimental treatments, growing goats were ear tagged, treated against internal and external parasites (Ivomec, Merck, Rahway, NJ) and vaccinated for protection against various clostridia. Health status (fever, abnormal breathing, icterus, weakness, weight loss, etc.) of the experimental animals was evaluated and recorded daily.

The ingredients of the experimental treatment diets are listed in Table 1. For the evaluation of animal performance parameters, the experimental unit was the individual pen (four pens with two animals each per treatment; response variable was the average performance of the two animals per pen). The trial lasted 84 days. Experimental diets were formulated to meet the requirements for maximum daily gains of growing goats (150 g day^{-1}, 0.92 Mcal NE_g, 45 g DP; NRC, 2007). Feed was offered ad libitum twice daily at 09:00 and 16:00 h as a total mixed ration. Feed refusals were weighed daily to determine daily feed consumption. Although *S. elaeagnifolium* hay was chopped to reduce selection, refusals contained only *S. eleagnifolium*. Average daily gain (ADG), dry mater intake (DMI), and feed conversion ratio (FCR; defined as DMI/ADG) were determined for all goats. Goats were weighed biweekly without withdrawal of feed or water. Both Initial and final weights were determined using the average of weights taken on 2 consecutive days.

2.2. Analytical methods and in vitro incubation

For the chemical determination of nutritional properties, samples of *S. elaeagnifolium* (leaves, stems, and flowers) were collected at the late flower stage. Samples were sun-dried and ground to pass a 5 mm sieve using a cutting mill (Wiley). Chemical analyses were conducted in duplicate. Ash was determined by ignition of dried samples in a muffle furnace at 550 °C for 3 h (AOAC, 1990; method ID 942.05). The crude protein (CP) was determined by the Kjeldahl method (AOAC, 1990, ID 954.01). Ether extract from *S. elaeagnifolium* was analyzed according to procedure 920.39 of AOAC methods (AOAC, 1990). Ash-free neutral detergent fiber (NDF; sodium sulfite was added during neutral detergent extraction) and ash-free acid detergent fiber (ADF) were determined using methods described by Van Soest et al. (1991). Soluble or free-bound condensed tannins fractions in the forage samples were determined according to Terrill et al. (1992), using quebracho tannins as a standard. This procedure was chosen following the recommendations of Hagerman and Butler

Table 1
Ingredient composition (g kg^{-1}) of diets containing 0% (control), 25%, 50%, 75%, and 100% *Solanum elaeagnifolium* of the roughage contained in the diet

	Ingredient				
	T0	T25	T50	T75	T100
Alfalfa hay	300	225	150	75	0.0
S. elaeagnifolium	0	75	150	225	300
Corn grain	455	453	452	450	448
Soybean meal	63	65	67	69	71
Animal fat	50	50	50	50	50
Cane molasses	100	100	100	100	100
Bicarbonate	5	5	5	5	5
Mineral mix[a]	25	25	25	25	25
Sodium chloride	2.5	2.5	2.5	2.5	2.5

[a] Macro- and micro-elements, monensin, and vitamins A, D, E (GANATEC-25; Tecnicas Nutricionales S.A. de C.V., San Nicolas de los Garza, Mexico).

(1989), who recommended standards that are easily replicable. Briefly, duplicate 10 mg samples were extracted with a mixture of 2.5 ml of 70% aqueous acetone containing 0.1% ascorbic acid and 2.5 ml of diethyl ether. Tubes were centrifuged at 2500 rpm for 5 min. The upper phase was discarded and the extraction was repeated one more time. Traces of solvent in the aqueous phase were removed at 38 °C on an evaporator under compressed nitrogen. After centrifugation, the aqueous phase was separated from the pellet, and the latter was dried at 38 °C in an oven. After bringing the volume of the aqueous extract to 5 ml with distilled water, 0.5 ml aliquots were mixed with 3 ml of butanol/HCl (95:5, v/v) and the mixture was heated at 95 °C for 1 h. Tannins still bound to the residue were extracted by adding 4 ml of butanol/HCl to the dry pellet, and tannins were hydrolyzed by heating at 95 °C for 75 min. Standard curves were obtained and equations were generated.

Metabolizable energy (ME) and *in vitro* organic matter digestibility (OMD) were estimated according to an *in vitro* procedure described by Menke and Steingass (1988). Briefly, approximately 200 mg of sample were weighed in duplicate into 100 ml graduated glass syringes with 30 ml buffered rumen fluid. Buffer and mineral solution were prepared and placed in a water bath at 39 °C under continuous flushing with CO_2. Gas produced during the fermentation process moves the piston along a graduated scale. Readings of cumulative gas production were taken from 0 to 72 h. Stochiometric relationships between gas volume and digestibility allows the calculation of digestibility, ME concentration and the determination of digestion kinetics. Rumen fluid was collected before the morning meal from two rumen-fistulated, non-lactating, non-pregnant Holstein cows fed a grass hay diet. Total gas values were corrected for blank incubations, and reported gas values are expressed per g of DM. Volume of gas produced after 24 h of incubation was used as an index of digestibility and energy feed value, using the following equations:

$$\text{OMD (g kg}^{-1}\text{ DM)} = 14.88 + 0.889 \times \text{GV24} + 0.45 \times \text{CP} + 0.0651 \times \text{XA},$$

$$\text{ME (MJ kg}^{-1}\text{ DM)} = 2.2 + 0.136 \times \text{GV24} + 0.057 \times \text{CP} + 0.0029\text{CP}^2,$$

where XA denotes ash g kg^{-1} DM, and GV24 denotes cumulative gas production in ml at 24 h of incubation.

2.3. Statistical analysis

Forage composition data and parameters estimated from the *in vitro* gas production were analyzed statistically using Student's paired *t*-test (SAS, 2000), taking the $P<0.05$ level as significant. The model contained the effects due to forage, and samples ($n = 3$) served as the experimental unit.

Animal performance data were analyzed using the GLM procedures of SAS (2000) for a completely randomized design comparing five treatments. The model included the effect due to diet; initial body weight was included as covariate. Residual mean square was the error term and pens ($n = 4$) were the experimental units. Regression equations and correlations were calculated between levels of *S. elaeagnifolium* in the diet and ADG and FCR.

Parameters of *in vitro* digestion kinetics were determined by non-linear analysis of the gas production profile. For the latter, two models found useful in similar analyses (France et al., 2000; Getachew et al., 1998) were examined. Both models have three parameters (*GAST*, or asymptotic gas production, *beta*, a location parameter, and *gamma,* or intrinsic rate of digestion). In addition to the regression diagnostic R^2, goodness-of-fit of the model used for estimating digestion kinetics was evaluated by calculating the mean squared prediction error (MSPE):

$$\text{MSPE} = \sum_{i=1}^{n} \frac{(O_i - P_i)^2}{n},$$

where $i = 1, 2, \ldots n$ is the number of experimental observations, and O_i and P_i are observed and predicted values, respectively. The square root of this diagnostic was expressed as percentage of the observed overall mean, providing an index of overall error of prediction. The Brody model produced the lowest value (0.82) for this parameter, and was consequently selected to estimate all kinetics parameters.

3. Results and discussion

3.1. Nutritive value of S. elaeagnifolium

The chemical composition of *S. elaeagnifolium* (leaves, stems, and flowers combined) and alfalfa hay is reported in Table 2. CP concentration in *S. elaeagnifolium* was lower ($P<0.05$) than that of alfalfa hay, although it is considerably higher than the 60–120 g kg^{-1} reported for typical grasses of the Chihuahuan desert range (Ramirez et al., 2004). NDF values were higher ($P<0.01$) for *S. elaeagnifolium* than in alfalfa. Both NDF and ADF values of *S. elaeagnifolium* are higher that that reported for other forbs present in this plant community (Schweitzer et al., 1993). Ash content of *S. elaeagnifolium* was lower ($P<0.01$) than that of alfalfa hay, whereas crude fat was 32% higher ($P<0.01$) in alfalfa hay compared to *S. elaeagnifolium*.

Table 2
Nutrients and tannin concentration (g kg^{-1} DM) of *S. elaeagnifolium* and alfalfa hay

Items	*S. elaeagnifolium*	Alfalfa hay
Dry matter	814 ± 8.3	801 ± 7.4
Ash	114 ± 4.7[a]	795 ± 4.3[b]
Crude fat	25 ± 2.3[a]	33 ± 2.3[b]
Crude protein (total $N \times 6.25$)	150 ± 4.3[a]	170 ± 4.4[b]
Nitrogen free extract	389 ± 9.7[a]	486 ± 6.4[a]
Neutral detergent fibre	543 ± 10.6[a]	450 ± 8.6[a]
Acid detergent fibre	337 ± 5.9[a]	356 ± 6.9[b]
Condensed tannins (soluble)	0.0	–
Condensed tannins (insoluble)	15	–

Means in a row not follow by the same superscript letters (a, b) differ ($P<0.05$).
Values are means of three samples ± S.D.

Table 3
Parameters estimated from the *in vitro* gas production, *in vitro* OM digestibility and energy content of *S. elaeagnifolium* and alfalfa hay

Item	*S. elaeagnigolium*	Alfalfa hay
Potential gas production (ml g^{-1} DM)	1.03 ± 0.42[a]	1.60 ± 0.14[b]
Rate of gas accumulation (ml h^{-1})	0.08 ± 0.03[a]	0.11 ± 0.02[b]
Total gas production (ml g^{-1} DM)	216 ± 4.9[a]	223 ± 4.2[b]
In vitro OM digestibility (g kg^{-1})	522 ± 7.2[a]	637 ± 6.2[b]
ME (MJ kg^{-1} DM)	6.52 ± 0.1[a]	9.72 ± 0.1[b]

Values in the same row with different superscript letters (a, b) differ ($P<0.05$).
Values are means of three samples ± S.D.

The energy content of *S. elaeagnifolium* was lower ($P<0.05$) than that of alfalfa (Table 3), or high quality forage grasses, reaching only about half of the values reported for the latter (Moss et al., 1992). Accordingly, *S. elaeagnifolium* may be a suitable source of protein in diets for ruminants, but disqualfies as a high-energy forage. The low-energy concentration of *S. elaeagnifolium* was reflected in a low N-free extract concentration (Table 2), which is indicative of low concentration of soluble carbohydrates. *S. elaeagnifolium* is practically a tannin-free forb (Table 2); accordingly, its intake limiting properties cannot be attributed to these otherwise common plant secondary compounds (PSC).

The *in vitro* OM digestibility of *S. elaeagnifolium* was intermediate at about 53% (Table 3). Similar values have been reported for other forbs prevalent in this ecosystem (Holechek et al., 1989). This moderate digestibility is probably an effect of the high concentration of structural carbohydrates (NDF; Table 2).

Rate of gas accumulation (gamma) was lower ($P<0.05$) for *S. elaeagnifolium* compared to alfalfa hay (Table 3). Likewise, asymptotic gas production was lower for *S. elaeagnifolium* than for alfalfa, but surpassed values reported by Cerrillo et al. (2006) for other forages consumed by grazing goats in the same type of vegetation.

Feed intake is related to the rate of gas production (gamma) which indirectly affects the passage rate of feed through the rumen, whereas the potential asymptotic gas production (GAST) is associated with degradability of feed (Khazaal et al., 1995). In the current study, cumulative gas production was highest with the forage containing the lower fiber fraction (alfalfa) and lowest with *S. elaeagnifolium* (highest fiber fraction). Generally, the differences observed in net gas production reflect the energy value of feeds (Menke and Steingass, 1988), which is consistent with the estimated low ME of *S. elaeagnifolium* (Table 3).

3.2. Feeding trial

Animals fed diets where *S. elaeagnifolium* replaced >250 g kg^{-1} alfalfa hay grew slower ($P<0.01$) and exhibited higher ($P<0.01$) FCR than control animals (T0). The lower ($P<0.01$) DMI of goats fed increasing levels of *S. elaeagnifolium* in their diets (intake of T100 animals was 74% of that of T0 animals) appears to be the most likely explanation for their lower rate of gain. Tannins were virtually absent in *S. elaeagnifolium* and cannot be expected to have negative effects on intake and and animal growth. Reduced intake by goats on *S. elaeagnifolium*-containing diets could be the result of the effect of other PSC like alkaloids. *S. elaeagnifolium* contains toxic alkaloids (Chiale et al., 1991) that combine with sugars to produce glycoalkaloids that can irritate the gastrointestinal tract. Within the GI tract, these compounds may be hydrolyzed to release neurotoxic alkaloids or alkamines (Boyd and Murray, 1982; Porter et al., 2003). Several workers have observed voluntary intake effects of plants containing deleterious PSC's (Baptista and Launchbaugh, 2001; Ben Salem et al., 1999;

Megarrity and Jones, 1983). On the other hand, reduced DMI with increasing levels of *S. elaeagnifolium* in the diet may also be a result of comparatively lower energy concentration and OM digestibility of *S. elaeagnifolium*, compared to alfalfa hay.

However, previous research has shown that, under range conditions, goats readily select and consume *S. elaeagnifolium* (up to one-third of the diet; Mellado et al., 2004). It is possible that selective foraging behavior allows grazing goats to select plant material lower in PSC than encountered on average in the plant biomass. Moreover, goats do not consume the spiny stems of this plant. However, in the current study the pen-fed goats were actually forced to consume this less nutritious part of *S. elaeagnifolium* contained in the total mixed ration.

The regression analysis relating ADG ($y = -0.82x+122.6$; $r^2 = 0.96$) and FCR ($y = 0.001 \times 2-0.027x+5.8$; $r^2 = 0.99$) to treatment level expressed as a linear increase of *S. elaeagnifolium* in the diet presented a close fit for these parameters, which clearly demonstrates the negative effect of substitution of alfalfa by *S. elaeagnifolium* on these two production traits.

Average total concentrations and molar proportions of ruminal volatile fatty acids in rumen fluid of goats fed different levels of *S. elaeagnifolium* are presented in Appendix Table 1 (electronic version). Serum metabolites and minerals for growing goats fed different levels of *S. elaeagnifolium* are presented in Appendix Table 2 (electronic version).

Because *S. elaeagnifolium* can spread by seed, rhizomes, and/or root fragments (Boyd and Murray, 1982), it is considered as one of the most invasive weeds in many arid regions of the world. This deep-rooted perennial forb is also one of the most difficult weeds to eradicate. Mechanical, herbicidal, and biological methods often fail because of its network of creeping horizontal and deep vertical roots (Olckers et al., 1995). The phenotypic plasticity of this plant further allows switiching to prostrate growth under repeated cutting (Mekki, 2007).

Considering the apparently high intake levels of *S. elaeagnifolium* observed in grazing goats, prescribed grazing could be an ''environmentally friendly'' tool for minimizing the spread of *S. elaeagnifolium* arable and pastoral lands. Millions of goats graze arid regions in the world with abundance of *S. elaeagnifolium*, so a precise knowledge of the nutritive value of this forb is important for livestock husbandry. The results in the present study indicate that the use of *S. elaeagnifolium* as feed for confined goats should be avoided, because of its unfavourable chemical composition, low digestibility and acceptance by confined goats that cannot optimize the selection of plant parts. However, selective grazing seems to allow goats to minimize deleterious effects of PSC's and unfavorable nutritional quality of specific plant parts. Accordingly, goat producers can benefit from this plant under range conditions, where this aggressive invader and colonizer forb allows long-term sustainability and productivity of goat production under intensive grazing conditions on impoverished arid grazing lands. Further, prescribed goat grazing with appropriate stocking rates appears to be a promising tool for the control of *S. elaeagnifolium* dominating in severely degraded areas.

4. Conclusions

S. elaeagnifolium is characterized by low-energy concentration and intermediate crude protein levels. On impoverished arid rangelands in northern Mexico, grazing goats can select high proportions of *S. eleagnifolium,* apparently without deleterious effects. However, increasing levels of *S. eleagnifolium* in the diet of confined goats result in decreasing DMI and animal performance. Accordingly, this plant cannot be used to replace high quality roughage in rations fed to confined goats.

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Appendix A. Supplementary materials

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.jaridenv.2008.06.009.

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