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Increasing productivity in goats grazing Mediterranean woodland and scrubland by supplementation of polyethylene glycol

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Abstract

A single daily oral dose of polyethylene glycol (PEG) — a tannin-binding agent — has been shown to substantially improve feed intake and efficiency of utilization by sheep and goats consuming tannin-rich forage. The aim of this study was to quantify the effect of supplementing 10 g/day of PEG on the performance of does grazing on Mediterranean woodland and scrubland. The experiments were carried out in production systems based on Mamber goats raised only for the production of slaughter kids (Experiment 1), dual-purpose Mamber goats raised for slaughter kids and milk (Experiment 2) or Damascus×Anglo-Nubian goats raised mainly for milk (Experiment 3). In Mamber goats, PEG supplementation was associated with higher body weight (BW) gain during pregnancy ($p<0.01$), higher kid birth-weight ($p<0.05$) and daily BW gain until weaning ($p<0.10$ and $p<0.05$ in Experiments 1 and 2, respectively), and no difference in milk yield. In contrast, the response of Damascus×Anglo-Nubian goats to PEG was a 43% increase in milk yield ($p<0.001$) but no response in kid weight at birth. These responses are consistent with previous findings that show the resilience of Mamber goats to practices aimed at increasing their milk production while these goats respond well to practices that improve the probability of successful reproduction in harsh environments. In contrast, Damascus×Anglo-Nubians respond to increased available nutrients by increasing their milk production. Supplementation with PEG has the potential to improve the profitability of systems in which liberally supplemented and high-yielding dairy goats feed on Mediterranean browse. However, its contribution to production systems exploiting well adapted but low-yielding local goats is limited. © 2000 Published by Elsevier Science B.V.

Keywords: Goats; Tannins; Mediterranean browse; PEG

1. Introduction

Browse species represent more than 60% of food intake by ranging goats in circum-Mediterranean woodlands and scrublands (Kababya et al., 1998; Perevolotsky et al., 1998), where few or no agricultural alternatives are available (Meuret et al., 1990). Woody species constitute the majority of natural vegetation in these areas. However, their use as browse by ruminants is restricted by the high content of tannins in foliage (Kumar and Vaithiyanathan, 1990; Leinmuller et al., 1991). High levels of tannins negatively affect voluntary feed intake, and the digestibility and nitrogen retention of browse (Robbins et al., 1987; Silanikove et al., 1994, 1996) and of supplementary food (Silanikove et al., 1997a). It seems, therefore, that any attempt to improve performance of ruminants ranging on woody rangelands, or to

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increase their control of shrub growth by increased intake of browse, must first overcome the negative effects posed by high tannin content.

Polyethylene glycol (PEG) is a polymer that binds tannins irreversibly over a wide range of pH, and its presence reduces the formation of protein–tannin complex (Jones and Mangan, 1977). PEG has been supplied experimentally to grazing ruminants by using different procedures, e.g. sprayed on leaves in aqueous solution (Kumar and Vaithiyanathan, 1990), mixed as dry powder with harvested leaves (Kumar and Vaithiyanathan, 1990), or drenched orally (Pritchard et al., 1992; Terril et al., 1992). These methods are time-consuming and are generally impractical under field conditions (drenching) or uneconomical (spraying, and mixing with harvested leaves). Recently, a more practical field application has been proposed. PEG is mixed with a small amount of concentrate and provided to animals once daily (Silanikove et al., 1994, 1996), before turning them to pasture (Decandia et al., 1998). The rationale behind this approach relates to the finding that a considerable portion of the antinutritional effects of tannins is exerted in the intestine by depressing the activity of pancreatic enzymes (Silanikove et al., 1994, 1996). Thus, despite the rapid washout of PEG from the rumen as a water-soluble molecule, the typical slow mean retention time of fluid in the entire gastrointestinal tract — $\approx$35–40 h according to Silanikove et al. (1993) and Aharoni et al. (1998) — allows effective neutralization of ruminal and post ruminal effects of tannins by PEG. In fact, provision of PEG twice a day was not more effective than a single administration in terms of positive impact on intake and digestibility (Silanikove et al., 1994).

Once-daily supplementation of 10 g PEG to goats consuming common oak leaves (6.5% crude protein and 5% condensed tannins), the main native woody species in the eastern Mediterranean woodland, yielded the best cost–benefit response in terms of improvements in intake and organic matter digestibility (Silanikove et al., 1996). In addition, this dose prevented the negative interaction between high-carbohydrate concentrate supplementation and leaf intake, and allowed to spare the use of costly high-protein supplements due to greater efficiency of protein utilization (Silanikove et al., 1997a). However, these results were obtained in goats fed a pre-determined-one-component-experimental diet, whereas diets selected by ranging goats in heterogeneous environments contain 8–20 ingredients (Kababya et al., 1998; Perevolotsky et al., 1998). These diets are characterized (Kababya et al., 1998) by a relatively steady level of non-ADF linked protein (9–12.5%) and condensed tannins (3.5–4.7%). Barry et al. (1986) contended that protein utilization is optimized in sheep when dietary condensed tannins constitute approximately 4% of dietary dry matter. If so, PEG supplementation is not likely to be beneficial to ranging goats, because they select diets that are optimal in terms of protein utilization. Indeed, a short-term (60 days) experiment carried out with Sarda dairy goats feeding on a coppice dominated by *Pistacia lentiscus* (25% condensed tannins in DM) showed that the effect of PEG on milk production was significant, but relatively small (Decandia et al., 1998).

The aim of this study was to evaluate the effect of PEG on the productive traits of range-fed goats in Mediterranean woodland and scrubland. The experiments were carried out in three locations representing three types of management systems that are typical to the Mediterranean region (Landau et al., 1995).

2. Materials and methods

2.1. Experiment 1

Experiment 1 was conducted for one year, commencing in August, at Michmanim, in lower Galilee (32.5°N, 35.3°E, elevation 700 m a.s.l., 600 mm of rainfall mostly occuring during November–March). The herd management in this location, in which goats are raised mainly for slaughter kids, represents the lowest-input type production system. No feed supplementation is provided except for the last stage of pregnancy (Landau et al., 1995).

During the experimental period, a group of 50 adult (>2 years old) Mamber goats were randomly allocated into two equal groups (PEG and C-control) before exposure to bucks. Both groups grazed on a 90 ha fenced paddock from 05:30 to 16:00 hours and spent the night in a roofed, dust-floor building. The main plant species in the range were *Quercus calliprinos*, *P. lentiscus*, *Sarcopoterium spinosa* and *Rhamnus palestina*. Lush green annuals and perennial grasses were abundant between January and April, but dried-up in early May. A supplement consisting of 10 g of PEG 4000 (MW) mixed with 100 g of pelleted concentrate was distributed to the PEG group, whereas the goats in the C groups received concentrate only. During the last 2 months of pregnancy, does were given daily 450 g of the same pellets containing, on dry matter basis, 16% CP, 18.7% NDF, and 1.7 Mcal/kg of net energy. There were two kidding periods, the main one during January, and the second one during March. During these periods, goats were turned out in a smaller (20 ha) fenced paddock, which enabled better animal control. The kids were weaned at the age of 30–45 days. After weaning, the goats were usually hand-milked twice daily at 05:00 and 16:30 hours, but occasionally, they were milked only once daily or not at all. During mid-pregnancy, between August and October, does were weighed monthly by using a portable electronic scale (Shekel Merav 2001, Rosh Haain, Israel; accuracy $\pm$100 g). The scale was equipped with an algorithm allowing it to perform three weighings per second and to keep weighing until residual fluctuations did not exceed the standard error of previous weighings. After parturition, both goats and kids were weighed monthly. Milk was sampled every 3 weeks after parturition, and was analyzed within 24 h for protein, fat and lactose using a Near Infra-Red Milk-O-Scan (Foss Electric, A/S, Denmark).

2.2. Experiment 2

Experiment 2 was carried out between January and May at Matat in the upper Galilee (33.1°N, 35.2°E, elevation 820 m a.s.l., 800 mm of annual rainfall mostly concentrated during November–March). The experimental site was described previously (Kababya et al., 1998). Goats at Matat were machine-milked once daily until weaning and twice-daily after weaning of the kids.

A group of 102 adult (>2 years old) Mamber goats, that gave birth between 10 December and 25 December were randomly allocated into three groups of 34 goats on 28 December. All goats in the three groups were individually supplemented with 200 g/day of pelleted concentrate in the milking parlour. In addition, goats in the PEG group were supplemented with 10 g/day of PEG, and the goats of the Soybean group (S) received 200 g/day of soybean meal. The group that received only concentrates served as the control (C). The supplementation was provided in two meals, half during the morning milking (05:00 hours), and half in the evening milking (16:30 hours). The composition of concentrate was the same as described for Experiment 1. The soybean meal contained, on a DM basis, 50% CP, 8.2% NDF and 1.88 Mcal/kg of net energy for lactation. The goats were released each morning at 06:00 hours to a 200 ha fenced range, and were gathered back to the shed at 16.00 hours. Therefore, they could nurse their kids from 16:00 to 06:00 hours. The kids were weaned on 1 February and machine-milking of the does was initiated. Milking was performed twice daily, before and after the grazing session. The body weight (BW) of the goats and kids were recorded every 3 weeks as described in Experiment 1. Milk volume was determined with $\pm$2% precision (Goat Milk Meter, Vicato, NZ) on the same days as BW. Milk samples were analyzed within 24 h for protein, fat and lactose, as described for Experiment 1. Vegetation on the range has already been described in detail (Kababya et al., 1998). The main species were *Q. calliprinos*, *Quercus boisserii* (*Reuter*), *Pistacia palestina*, *S. spinosa* and *Rhamnus palaestina*. The length of the green season was about the same as described for Experiment 1 (lower Galilee), but it started about 1 month later due to higher altitude and lower temperatures.

2.3. Experiment 3

Experiment 3 was conducted between July and May of the subsequent year in the vicinity of Sataf springs, in the Judean mountains, 5 km west of Jerusalem (31.7°N, 35.3°E, 550 m a.s.l., 600 mm of annual rainfall mostly concentrated during October–April). The site and animals have been described before (Landau et al., 1993; Perevolotsky et al., 1998). Briefly, the production system is characterized by highly productive Anglo-Nubian$\times$Damascus goats, machine-milked twice daily. Kids are separated from dams immediately after birth, hand-suckled colostrum and reared to weaning on milk replacer.

Fifty adult ($\geq$2 years old) does were randomly allocated into two equal groups toward the end of the lactation period, and just before the mating season. Each goat was given individually, in the milking parlour, 350 and 450 g of a commercial pelleted concentrate during the morning (06:00 hours) and the evening milking (17:00 hours), respectively. Goats in the PEG group received in addition 10 g/day of PEG during the morning milking. The composition of the pelleted concentrate was as in Experiments 1 and 2.

The BW of the goats and kids were assessed every 3 weeks. Milk volume was determined on these occasions as in Experiment 2. Similarly, milk samples were analyzed within 24 h for protein, fat, and lactose. The main plant species on the range were *Q. calliprinos*, *P. palestina*, *P. lentiscus*, *S. spinosa*, *Rhamnus palatina* and *Calicitome villosa*.

Herbaceous vegetation was scarce and restricted to the few patches of soil and abandoned terraces. Sparsely planted Cypress (*Cupressus sempervirens*) and Aleppo Pine (*Pinus halepensis*) trees were disseminated on the range. Total biomass was ≈1500 kg DM/ha/year. The growing season of vegetation was from the end of January to the end of April.

2.4. Statistical analysis

Analysis of variance was carried out using GLM procedures (SAS, 1982). For analysis of milk yield, milk composition, BW of does, procedures for repeated measurements were used. The model included treatment and goat (treatment). The error term (Type 3) for treatment was goat (treatment). When possible (Experiment 3), the pre-treatment milk yield and composition were used as co-variants. After parturition, the prepartum BW of the does, and the birth weight of the kids served as co-variants in the analyses of BW changes. The sources of variation for comparing the birth weight and daily gain rate of kids were treatment, sex (male, female), season (in the case of two kidding seasons) and the season×treatment interaction.

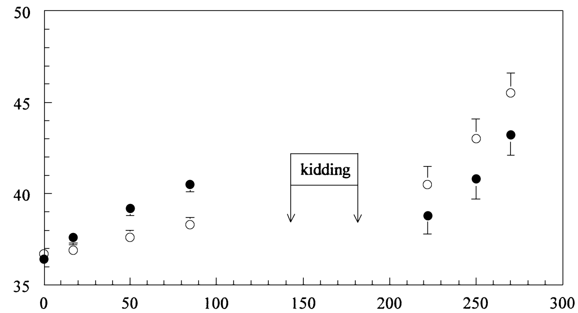

Fig. 1. Body weights of Mamber goats that were supplemented with (●) or without (○) PEG (Experiment 1): average of 25 goats±S.E.

3. Results

3.1. Experiment 1

At mid-pregnancy, goats in the PEG group weighed 2.2 kg more than their counterparts in the control group (40.5±1.0 and 38.3±0.9, $p<0.01$; Fig. 1). Corresponding average daily gains were 46.4±5 versus 17.8±5.5 g/day ($p<0.01$). After parturition, the goats in the PEG group gained BW at 76 g/day, compared with 62 g/day in the controls (NS; Fig. 1).

In both groups, the pregnancy rate was 88% and prolificacy was one kid/goat kidding. The birth weight of kids in the PEG group was higher ($p<0.05$) than in the control group in the two parturition periods (Table 1). Growth rate of the male and female kids in the PEG group tended to be higher than in the control group ($p<0.10$; Table 1). Although BW means were higher in C than in PEG goats during the second pregnancy period, no statistical significance was found between them.

Table 1
The body weight (kg) and average daily gain (g/day) of kids born in January or March–April (Experiment 1) to Mamber goats that were supplemented with or without 10 g/day of PEG during pregnancy: least square means±S.E.

	Birth weight		Daily weight gain	
	January*	March–April**	Males***	Females
PEG	3.81±0.19 (n=15) [a]	4.58±0.44 (n=7) [a]	248±19[a]	175±16
Control	3.45±0.11 (n=14) [b]	3.93±0.15 (n=8) [b]	215±27[b]	152±21

[a,b] Within a column, values with no common superscript differ.
* $p<0.05$; ** $p<0.01$; *** $p<0.10$.

3.2. Experiment 2

No dietary effect was noted on BW at Day 7 *post-partum* (41.3 kg in S-fed goats, compared to 40.0 kg in the other groups) and throughout all the experiment. Goats lost 1.5–2.0 kg of BW from mid-December (parturition) to the end of March.

Milk yields were higher ($p<0.05$) in S than in C goats, with the treatment PEG being intermediate (Table 2). There were no differences among the three groups in milk protein (3.45%) and lactose concentration (4.59%). The concentration of fat was consistently higher in goats from the S group than in their counterparts from the C and PEG groups (4.41, 4.20 and 4.04%, respectively, $p<0.05$). The average daily yield of milk fat was higher ($p<0.05$) in S (41.2±1.6 g) than in the other two groups (average: 36.0±1.4 g). Overall, the protein and lactose concentrations in milk were not affected by treatments, but the daily yields of protein and of lactose were 10% higher in S than in the average of the two other groups: 34.2 versus 31.3 g/day for protein and 45.6 versus 41.8 g/day for lactose ($p<0.05$).

The birth weight of kids was similar in the three groups (Table 3). From day 23 *post-partum* and onward, the weight of kids in group C became significantly lower ($p<0.05$), compared with counterparts from the S and PEG groups (Table 3).

3.3. Experiment 3

At the beginning of the experiment in July, about 140 days before parturition, milk yield was quite similar in the two groups (Fig. 2). One month later, the milk yield dropped ($p<0.05$) in the C group, whereas it remained steady in the PEG group. Milk yield declined in both groups, thereafter, but it remained consistently higher ($p<0.05$) in the PEG group until the end of lactation. After parturition, daily milk yield was 0.5 kg higher in the PEG than in the C group ($p<0.02$), and this advantage increased to 0.8 kg ($p<0.001$) at the peak of lactation. On average, milk yield was 1.46±0.06 in the PEG group and 1.00±0.06 kg/day in the C group ($p<0.001$). The fat and protein contents in milk ranged from 4.2 to 6.1% and 3.7 to 4.1%, respectively, and did not differ

Table 2
Milk yield (g/day) and composition (%) in Mamber goats (Experiment 2) grazing Mediterranean woodland and supplemented with concentrates (C) only, or with concentrates and 10 g/day of PEG (PEG), or with 200 g/day of soybean meal (S): means of 34 goats±S.E.M.

	21 January (Day 35 *post-partum*)	25 February (Day 70 *post-partum*)	29 March (Day 102 *post-partum*)	3 May (Day 139 *post-partum*)	1 June (Day 166 *post-partum*)	Average
Milk yield						
C	795^{a}	887^{b}	1106	971	741	890^{b}
PEG	$922^{a,b}$	891^{b}	1057	971	736	$915^{a,b}$
S	982^{a}	1048^{a}	1101	1003	779	980^{a}
S.E.M.	38	33	38	39	31	36
Milk composition						
C	2.55	3.99	3.76^{b}	5.34	5.34	$4.20^{a,b}$
PEG	2.88	3.88	3.65^{b}	4.90	4.90	4.04^{b}
S	2.96	4.17	4.10^{a}	5.41	5.41	4.41^{a}
Protein						
C	3.46	3.45	3.31	3.59	3.29	3.42
PEG	3.48	3.53	3.44	3.50	3.34	3.46
S	3.57	3.45	3.46	3.59	3.27	3.47
Lactose						
C	5.00^{a}	4.57	4.52	4.76	4.35	4.64
PEG	4.88^{b}	4.53	4.53	4.48	4.29	4.54
S	$4.97^{a,b}$	4.51	4.59	4.71	4.30	4.62

[a,b] Within days, values with no common superscript differ at $p<0.05$.

Table 3
Body weight of kids born to Mamber goats (Experiment 2) grazing Mediterranean woodland and supplemented with concentrates (C) only, or with concentrates and with 10 g/day of PEG (PEG), or with 200 g/day of soybean meal (S)

	Date	Age (±1 day)	C	PEG	S
Males	Birth	1	3.50±0.08	3.43±0.08	3.46±0.10
	28 December	10	4.99±0.12	5.30±0.18	4.89±0.24
	11 January	23	7.05±0.09[b]	7.34±0.11[a]	7.39±0.12[a]
	24 January	35	8.67±0.11[b]	9.12±0.13[a]	9.22±0.22[a]
Females	Birth	1	3.13±0.09	3.20±0.10	3.24±0.12
	28 December	10	3.98±0.16	4.79±0.27	4.50±0.22
	11 January	23	5.87±0.11[b]	6.85±0.29[a]	6.86±0.24[a]
	24 January	35	7.07±0.15[b]	8.30±0.36[a]	8.50±0.23[a]

[a,b] Values in a row with no common superscript differ at $p<0.05$.

between treatments. Yields of organic matter, protein and fat were significantly higher in the PEG than in the C group: 189, 53.2 and 71.5 g/day, compared with 141, 40.2 and 53.5 g/day, respectively ($p<0.001$).

No differences between the two groups were noted in pregnancy rate (91±3%) prolificacy (1.8±0.1 kids/goat) or in the average weight of kids at birth (3.05±0.05 kg).

4. Discussion

Overall, providing goats with PEG was beneficial for their productivity, as was also found by Decandia et al. (1998) in Sarda goats grazing in a similar environment. The most prominent effect of tannins on feed intake and digestibility is due to the production of tannin–protein complexes (Jones and Mangan, 1977). This effect of tannins was found to be negative (i.e. tannin-complexed protein were not digested) by some authors (Silanikove et al., 1994, 1996, 1997a, 1997b; Ben Salem et al., 2000). Other authors (Barry et al., 1986; Terril et al., 1992) estimated that tannins had a positive effect (i.e. tannins protected dietary proteins from ruminal hydrolysis, hence improving their biological value for animals). In our study, preventing the formation of protein–tannin complexes by PEG improved goat performance, suggesting that the formation of protein–tannin complex has more negative than positive effects for goats feeding on Mediterranean browse. This may be related to the much higher levels of tannins found in Mediterranean browse (Khazaal et al., 1993; Khazaal and Orskov, 1994) than in the forages in which the positive effects of tannins were demonstrated (Barry et al., 1986; Terril et al., 1992). Our results on the positive effect of PEG on productivity are consistent with the findings of Silanikove et al. (1994, 1996, 1997a) and Ben Salem et al. (2000) who reported higher feed intake and digestibility in PEG-supplemented small ruminants feeding on tannin-rich browse.

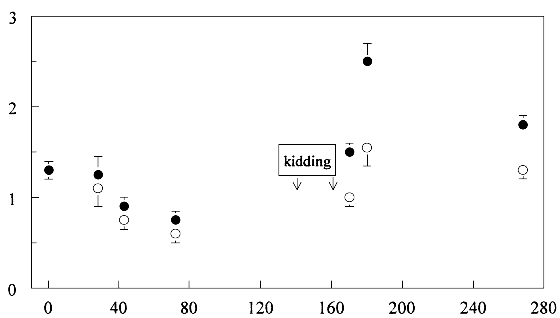

Fig. 2. Daily milk yield (kg/day) of Damascus×Anglo-Nubiam goats that were supplemented with (●) or without (○) PEG (Experiment 3): average of 25 goats±S.E.

Previous data by Kababya (1994) showed that lactating Mamber goats feeding on Mediterranean woodland do not select the highest possible dietary protein concentration, in spite of high physiological demand, even though protein availability is the first constraint on their milk production. The improved milking performance of S-fed goats suggest that supplementation of exogenous protein above that available on range, and above that needed for the alleviation of the protein-binding effect of tannins, may be what is needed for sustained improvement of milk production. In stall-fed goats fed with tannin-rich browse, the best supplement to increase feed intake and digestibility was a combination of protein-rich concentrate and PEG (Silanikove et al., 1997a). Such combination not only increases the availability of proteins from browse but also decreases the binding of dietary protein supplied in concentrates by tannins originating from browse (Silanikove et al., 1997a). It should be worth testing under grazing conditions.

Although geographically coincident, Mamber and Anglo-Nubian (or their crosses with Damascus) goats are exploited in distinct production systems. Both breeds of goats are found where natural resources are scarce and seasonal fluctuations in resource quality are great. However, Mamber goats usually receive little food supplementation, whereas Anglo-Nubian and Damascus goats receive liberal supplementation (Landau et al., 1995). Experiments 1, 2 and 3 feature a positive gradient in the intensification of goat farming in typical Mediterranean environments. The effects of PEG on production traits varied in the three experiments reported herein. When given to Mamber goats, PEG was associated with more rapid growth of the litter (Tables 1 and 3), most likely resulting from increased milk yield at the onset of lactation. This PEG effect on milk production ended shortly after kids weaning at 35 days *post-partum*, when milking was initiated (Table 2). The production cycle of Mamber goats is characterized by a relatively short lactation, moderate utilization of body depots and rapid recovery of body condition in spring. This means that at a time when nutrient-rich feed resources could be exploited to enhance lactation, they are directed, instead, to body tissue accretion. Mamber goats manage feed and body resources in a way that improves the probability of reproductive success, that privileges embryo development and milk production only for a short period after parturition (Kababya et al., 1998). In Anglo-Nubian goats, a breed selected for milk production, that is able to utilize body depots for lactation to a great extent (Landau et al., 1993), PEG greatly enhanced milk production throughout a long lactation, independently of kid survival and growth.

Providing 10 g PEG daily (US$ 0.09 under Israeli conditions) to Mamber goats was associated with an average of 26 and 22 g/day higher daily weight gain of kids in Experiments 1 and 2, respectively (calculated from Tables 1 and 3). Assuming that 1 g of gain is achieved by 1 g DM of milk (Economides, 1982), this is equivalent to 171 g of milk, worth US$ 0.09. In Experiment 2 (Mamber goats), milk yield was 127 g/day higher in PEG-fed goats than in the controls. This relatively modest increase in milk yield is similar to that reported by Decandia et al. (1998), i.e. 110 g/day, for Sarda goats. This additional production of milk contributes US$ 0.06 during 35 days. It is clear that feeding PEG all year round for such a low return during 35 days is uneconomical. In contrast, in Anglo-Nubian goats, the difference in milk yield between PEG-fed and control groups averaged 0.46 kg/day, priced US$ 0.23. Assessing an average lactation length of 210 days, the return on 365 days feeding PEG (cost US$ 33) is US$ 48. If an increase of milk yield is anticipated as a result of PEG-feeding, it is clear that the production system exploiting Mamber goats is more resilient to this new practice (as it is to concentrate supplementation; Landau et al., 1995) than the system that exploits Damascus or Anglo-Nubian goats. However, PEG-feeding may improve the odds of successful reproduction of Mamber goats in the long-term, maximising their career crop of kids, which has not been taken into account in this brief calculation.

To summarize, it seems that PEG-feeding, which improves the utilization of Mediterranean browse, results in an elevation in milk production that parallels the production potential in goats. The more productive the goat, the more PEG-feeding is likely to be economical.

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References

Aharoni, Y., Gilboa, N., Silanikove, N., 1998. Analysis of the suppressive effect of tannins on ruminal degradation by compartmental models. Anim. Feed Sci. Technol. 71, 251–267.

Barry, N.T., Manley, T.R., Duncan, S.J., 1986. The role of condensed tannins in the nutritional value of *Lotus pedunculatus* for sheep 4 — sites of carbohydrate and protein digestion as influenced by dietary reactive tannin concentration. Br. J. Nutr. 55, 123–137.

Ben Salem, H., Nefzaoui, A., Ben Salem, L., Tisserand, J.L., 2000. Deactivation of condensed tannins in *Acacia cyanophylla* Lindl. foliage by PEG in feed blocks. Effect on feed intake, diet digestibility, nitrogen balance, microbial synthesis and growth by sheep. Livest. Prod. Sci. 64, 51–64.

Decandia, M., Molle, G., Sitzia, M., Cabiddu, A., Ruiu, P.A., Pampiro, F., Pintus, A., 1998. Effect of PEG on browsing behavior and performance of late lactating goats. In: Proceedings of FAO/CIHEAM meeting on the Nutrition of Sheep and Goats, Grignon, France, 3–5 September 1998.

Economides, S., 1982. Factors affecting growth of milk fed kids and fattening of kids for meat production. In: Proceedings of FAO meeting on Goat Nutrition, Reading, UK, 9–10 Novrmber 1982.

Jones, W.T., Mangan, J.L., 1977. Complexes of the condensed tannins of sainfoin (*Onobrychis viciaefolia Scop*) with fraction 1 leaf protein and with submaxillary mucoprotein and their reversal by PEG and pH. J. Sci. Food Agric. 28, 26–36.

Kababya, D., 1994. Grazing behavior and nutrition in Mediterranean woodland. M.Sc. Thesis, The Hebrew University of Jerusalem.

Kababya, D., Perevolotsky, A., Bruckental, I., Landau, S., 1998. Selection of diets by dual-purpose Mamber goats in Mediterranean woodland. J. Agric. Sci. (Camb.) 131, 221–228.

Khazaal, K., Orskov, E.R., 1994. The in vitro gas production technique: an investigation on its potential use with insoluble polyvinylpolypyrrolidone for the assessment of phenolic-related antinutritive factors in browse species. Anim. Feed Sci. Technol. 47, 305–320.

Khazaal, K., Markantonatos, X., Orskov, E.R., 1993. Changes with maturity in fiber composition and levels of extractable polyphenols in Greek browse: effects on in vitro gas production and in sacco dry matter degradation. J. Sci. Food Agric. 63, 237–244.

Kumar, R., Vaithiyanathan, S., 1990. Occurrence, nutritional significance and effect on animal productivity of tannins in tree leaves. Anim. Feed Sci. Technol. 30, 21–38.

Landau, S., Vecht, J., Perevolotsky, A., 1993. Effects of two levels of concentrate supplementation on milk production of dairy goats browsing Mediterranean scrubland. Small Rumin. Res. 11, 227–237.

Landau, S., Perevolotsky, A., Carasso, Y., Rattner, D., 1995. Goat production systems in Israel. In: El-Aich, A., Landau, S., Bourbouze, A., Rubino, R., Morand-Fehr, P. (Eds.), Goat Production Systems in the Mediterranean. Wageningen Pers., Wageningen, The Netherlands, pp. 136–159.

Leinmuller, E., Steingass, I., Menke, K.H., 1991. Tannins in ruminant feedstuffs. Anim. Res. 321, 1–56.

Meuret, M., Boza, J., Narjisse, H., Nastis, A. 1990. Evaluation and utilization of rangelands feeds by goats. In: Morand-Fehr, P. (Ed.), Goat Nutrition, PUDOC. Wageningen, The Netherlands, pp. 161–170.

Perevolotsky, A., Landau, S., Kababya, D., Ungar, E.D., 1998. Diet selection in dairy goats grazing woody Mediterranean rangeland. Appl. Anim. Behav. Sci. 57, 117–131.

Pritchard, P.H., Martin, P.R., O'Rourke, P.K., 1992. The role of condensed tannins in the nutritional value of mulga (*Acacia aneura*) for sheep. Aust. J. Agric. Sci. 43, 1739–1756.

Robbins, H., Hagerman, A.E., Hajeljord, O., Baker, D.L., Schwartz, C.C., Moutz, W.W., 1987. Role of tannins in defending plants against ruminants: reduction in protein availability. Ecology 68, 98–107.

SAS, 1982. SAS User's Guide: Statistics. SAS Inst. Inc., Cary, NC.

Silanikove, N., Tagari, H., Shkolnik, A., 1993. Comparison of rate passage and efficiency of fermentation of high fiber diets in desert black Bedouin goats as compared to Swiss Saanen goats. Small Rumin. Res. 12, 45–60.

Silanikove, N., Nitsan, Z., Perevolotsky, A., 1994. Effect of polyethylene glycol supplementation on intake and digestion of tannin-containing leaves (*Ceratonia siliqua*) by sheep. J. Agric. Food Chem. 42, 2844–2847.

Silanikove, N., Gilboa, A., Nir, I., Perevolotzky, A., Nitsan, Z., 1996. Effect of a daily supplementation of polyethylene glycol on intake and digestion of tannin-containing leaves (*Quercus calliprinos*, *Pistacia lentiscus* and *Ceratonia siliqua*) by goats. J. Agric. Food Chem. 44, 199–205.

Silanikove, N., Gilboa, N., Nitsan, Z., 1997a. Interactions among tannins, supplementation and polyethylene glycol in goats fed oak leaves. Anim. Sci. 64, 479–483.

Silanikove, N., Shinder, D., Gilboa, N., Eyal, M., Nitsan, Z., 1997b. Binding of poly (ethylene glycol) to samples of forages as an assay of tannins and their negative action on ruminal degradation. J. Agric. Chem. Food Sci. 44, 3230–3234.

Terril, T.H., Douglas, G.B., Foote, A.G., Purchas, R.W., Wilson, G.F., Barry, T.N., 1992. Effect of condensed tannins upon body growth, wool growth and rumen metabolism in sheep grazing sulla (*Hedysarum coronarium*) and perennial pasture. J. Agric. Sci. (Cambridge) 119, 265–274.