BARD Final Scientific Report

Date of Submission of the report: 17 April 2000

Evaluating Panel:

Project Title: Consumption of Tannin-Rich Forage by Ruminants: From Mechanisms to Improved Performance

BARD Project Number: US-2625-95

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Continuation of (Related to) Previous BARD Project: □Yes □No

Number:

Keywords not appearing in the title and in order of importance. Avoid abbreviations.
Polyethylene glycol, nutrition, livestock, cattle, sheep, goats

Abbreviations used in the report, in alphabetical order:
PEG (polyethylene glycol)

Budget: IS: $124,800          US: $175,200          Total: $300,000

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Signature                                      Signature
Principal Investigator                       Research Authority, Principal Institution
## Publication Summary (numbers)

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- Cooperation, briefly explain whether synergistic, complementary or supportive.
Abstract

Trees and shrubs are potentially important sources of food for livestock in many parts of the world, but their use is limited by tannins. Tannins reduce food intake by decreasing digestibility or by causing illness. Supplementing cattle, sheep, and goats with polyethylene glycol (PEG), which has a high affinity for binding tannins and thus attenuating their aversive effects, increases intake of high-tannin foods and improves weight gains and wool growth. The objectives of this proposal were:

**Objective 1**: To further delineate the conditions under which PEG affects intake of high-tannin foods.

**Objective 2**: To ascertain if animals self-regulate intake of PEG in accord with the tannin content of their diet under pen, paddock, and field conditions.

**Objective 3**: To determine how nutritional status and PEG supplementation affect preference for foods varying in nutrients and tannins.

**Objective 4**: To assess the effects of PEG on food selection, intake, and livestock performance in different production systems.

The results from this research show that supplementing livestock with low doses of PEG increases intake of high-tannin foods and improves performance of cattle, sheep, and goats. Neutralizing the effects of tannins with supplemental PEG promotes the use of woody species usually considered useless as forage resources. Supplementing animals with PEG has the potential to improve the profitability - mainly milk production - of high-yielding dairy goats fed high-quality foods and supplemented with browse in Mediterranean areas. However, its contribution to production systems utilizing low-yielding goats is limited. Our findings also support the notion that supplemental PEG enhances the ability of livestock to control shrub encroachment and to maintain firebreaks. However, our work also suggests that the effectiveness of supplemental PEG may be low if alternative forages are equal or superior in nutritional quality and contain fewer metabolites with adverse effects.
Achievements

Tannins reduce food intake by decreasing the digestibility of macronutrients — energy and protein — in food or by causing illness. Tannins bind to proteins and carbohydrates under conditions prevailing in the gut of mammals and birds. Thus, tannins can reduce digestibility of cell walls, cell solubles, organic matter, and protein. Tannins also cause rapid (< 1 h) and dramatic decreases intake of foods high in tannins that are best accounted for by oral astringency, lesions of the gut mucosa, and toxicity.

The capacity of polyethylene glycol (PEG) to bind tannins has been known for almost 30 years. Only recently, however, has PEG been considered an environmentally safe, effective, and inexpensive means to inactivate tannins. The results from our research show that supplemental PEG increases intake of high-tannin foods and improves performance of cattle, sheep, and goats grazing under diverse conditions (Objective 1).

The labor required to supplement animals is a disadvantage of using PEG, particularly on extensive areas of rangeland. One solution to such problems is to let animals regulate intake of PEG. We also have shown that animals learn to consume foods and solutions that attenuate aversive effects of food ingestion, and applied this principle to show how animals self-regulate intake of PEG to attenuate the aversive effects of tannins in confinement and under field conditions (Objective 2).

Supplemental PEG increases intake when animals eat foods high in tannins, but little is known about how PEG affects preference for foods that vary in concentrations of macronutrients and tannin. The outcome of this study provides novel and basic information on the interactions between macronutrients and tannins (Objective 3). In the absence of added tannins, animals prefer high energy/low protein > medium energy/medium protein > low energy/high protein. As tannin levels increase, preference for the high- and medium-energy foods decrease, and animals prefer foods that are lower in tannins and higher in protein. Animals supplemented with PEG eat more macronutrients and tannins than unsupplemented, and the effect becomes increasingly apparent as tannin levels increase. Nutritional status also influences the ability of animals to eat foods high in tannins. Animals on a higher plane of macronutrient nutrition are better able to ingest foods high in tannins. As regards management of lands with mixtures of different plant species, we draw two conclusions. (1) The effectiveness of supplemental PEG to enhance intake of tannin-
rich foods may be low if alternative forages are equal or superior in nutritional quality and contain fewer metabolites with aversive effects. In such cases, animals may prefer alternatives to the high-tannin foods. (2) Supplemental PEG and macronutrients both enhance the abilities of livestock to ingest forages high in tannins. In combination, they further enable animals to eat foods high in tannins.

In grazing systems throughout the world, ruminants are used to convert forages that are high in tannins and lignin, and otherwise unusable by humans, into food for people. In the Old World, a thousand years of adaptation have resulted in animals that can effectively utilize plant resources of low nutritional quality. On the eve of the third millennium, income from ruminants in traditional systems must be compatible with modern standards of living to be sustainable. Research from this study suggests that supplemental PEG can enhance productivity and improve sustainability of grazing systems (Objective 4). In Israel, PEG is currently being used on 8 dairy-goats farm raising 1000 goats - a direct short-term consequence of this research program. It is estimated that the annual increase in income from PEG application per 100 goats under conditions in Israel is 20000 NIS (5000 US$).

Finally, use of supplemental PEG to increase intake of woody plants is emerging as an important tool in land management (Objectives 1-4). Supplemental PEG enables sheep and goats to eat thick stands of shrubs and trees, thus lowering fire hazard and increasing amenity value of lands for recreation. The high economic and environmental costs of herbicides mandate the development of less expensive and more ecologically sound alternatives. Range management by livestock is a viable and effective alternative, and our research on PEG supplementation has improved this capacity substantially.
Consumption of Tannin-Rich Forage by Ruminants: From Mechanisms to Improved Performance

1. Background

Trees and shrubs are potentially important sources of food in arid areas (Devendra, 1990), but their use is often limited by tannins (Waterman et al., 1980, 1984; Cooper and Owen-Smith, 1985; Owen-Smith, 1993), which can adversely affect intake (Nastis and Malechek, 1981; Reed et al., 1990; Furstenburg and van Hoven, 1994). Use of livestock to reduce woody biomass in areas prone to fire (Davis et al., 1975; Tsiouvaras et al., 1989; Severson and Debano, 1991) depends on how tannins affect intake. Attempts to use rangelands dominated by shrubs and trees must overcome problems caused by tannins.

Our objective was to explore the relationship between polyethylene glycol (PEG), tannin content in food, and food preferences of ruminants, and to use this information to increase intake of tannin-containing forages. We hypothesized that tannins decrease preference by altering postingestive effects, either by reducing digestion of food or by causing illness, both of which decrease food intake. Supplementing with PEG, which has a high affinity for binding tannins and thus attenuating their aversive effects, increases intake of high-tannin foods and improves weight gains and wool growth (Barry, 1985; Pritchard et al., 1988; Kumar and Vaithiyanathan, 1990; Silanikove et al., 1994, 1995). Thus, PEG may provide an efficient way to increase performance of animals foraging on rangelands.

2. Methods and materials

We used a variety of animals - sheep goats, dairy heifers and beef cattle - and methods, under confined and field conditions, in this research. These methodologies are consistent with the original proposal, and briefly described in what follows.

3. Results

3.1. Preliminary experiments

To achieve the degree of control needed in some of the proposed studies, we used commercially available quebracho tannin, which is a complex of tannins, flavonoids, and other phenolic compounds (the commercial product varies from 50-75% tannins; Asquith
and Butler, 1985; Mole and Waterman, 1987). Before beginning work with quebracho tannin, we conducted trials to determine if lambs responded differently to unpurified and purified tannin and if molecular weight and dose of PEG affected intake of quebracho tannin. In both trials, we fed lambs a basal ration of alfalfa pellets (which are high in protein but low in energy) and then offered them for 1 h/d a meal of food high in energy (grain), but containing quebracho tannin. An animal's nutritional needs change depending on the nutrient content of the foods it ingests and macronutrients (energy and protein) play a primary role in food preference. Lambs fed a ration high in protein (alfalfa) prefer food high in energy (grain) (Wang and Provenza, 1996; Villalba and Provenza, 1997).

3.1.1 Unpurified vs. Purified Quebracho Tannin

We determined intake (from 08:00 to 09:00 h daily for 7 d) of a mix of ground foods (barley and alfalfa) by lambs in three treatments (8 lambs/treatment): (1) controls - 40% barley/60% alfalfa; (2) unpurified quebracho - 80% barley/20% tannin; (3) purified quebracho - 80% barley/20% tannin. The diets for the controls and the two treatments were formulated such that their energy contents were approximately the same. The quebracho we used contained 84% tannin; we added unpurified quebracho such that the food was 20% tannin. Lambs were fed a basal ration of alfalfa pellets ad libitum from 09:00 to 17:00 h daily. Lambs in the control group ate more (P<0.01) barley (353 g) than lambs fed barley with unpurified (211 g) or purified (210 g) tannin. Because lambs in treatments 2 and 3 ate similar amounts of food containing unpurified and purified tannin, we used unpurified quebracho tannin in subsequent trials with PEG.

3.1.2 Molecular Weight of PEG

We determined if molecular weight of PEG affected intake of ground food (40% barley + 60% alfalfa) to which we added 20% tannin. We compared three molecular weights of PEG (3,350, 4,600 and 8,000; 8 lambs/treatment) because studies in vivo have used MW 4,000 and work in vitro suggests higher molecular weights (e.g., 6,000) may be better (Makkar et al., 1995). Lambs were supplemented with 50 g of ground barley mixed with PEG from 08:00 to 08:15 h as follows: d 1 to 7, no PEG; d 8 to 13, 50 g PEG; d 14 to 20, 25 g PEG; d 21 to 25, 12 g PEG. Lambs were fed the barley-alfalfa-tannin mix from
0830 to 0930 h daily. Lambs were fed a basal ration of alfalfa pellets ad libitum from 09:30 to 17:00 h daily. Intake increased when lambs were supplemented with PEG (P<0.01), but molecular weight did not affect intake at any dose of PEG (PEG 3,350 = 172 g; PEG 4,600 = 168 g; PEG 8,000 = 168 g; P>0.10).

We conducted another trial, which was similar to Trial 1, except the test food contained 80% barley + 20% alfalfa. During days 1 to 3, lambs were offered food containing 20% tannin, but without PEG; on days 4 to 11 lambs were supplemented with PEG; and on days 12 to 14 lambs did not receive PEG. Lambs ingested more food when they were supplemented with PEG (days 4 to 11) than when they were not supplemented (P<0.01), but again molecular weight of PEG did not affect intake (PEG 3,350 = 329 g; PEG 4,600 = 341 g; PEG 8,000 = 323 g; P>0.10). Based on these trials, we concluded that molecular weights of PEG in the range we studied did not affect intake of quebracho tannin-containing foods of varying nutritional qualities.

3.2. Preferences for Foods Varying in Macronutrients and Tannins

PEG increases intake when animals eat foods high in tannins, but little is known about how PEG affects preference for foods that vary in concentrations of macronutrients and tannin. We investigated how varying macronutrients and tannins (commercially available extracts from quebracho trees) affected food intake, and we assessed the degree to which PEG (MW 3350) affected intake of tannin-rich foods by sheep (Titus et al. 2000a).

From 0715 to 1800 daily, lambs were offered diets that varied in concentrations of macronutrients: high energy/low protein (75% barley/25% alfalfa), medium energy/medium protein (35% barley/65% alfalfa), and low energy/high protein (100% alfalfa). Preference for these diets was determined in the absence of tannin, and then in Trials 1 to 3, tannin was added in increasing concentrations (from 5 to 20%) to the diets with high and medium levels of energy. In Trial 4, tannin (10%) also was added to the low-energy diet. Lambs were supplemented with either 50 g of PEG mixed with 50 g of ground barley or 50 g of ground barley alone from 0700 to 1715 daily; lambs always consumed all of these supplements. In the absence of added tannins, all lambs preferred high energy/low protein > medium energy/medium protein > low energy/high protein. As tannin levels increased, preference for the high- and medium-energy foods decreased, and all lambs...
preferred foods that were lower in tannins and higher in protein. Lambs supplemented with PEG ate more macronutrients and tannins than unsupplemented lambs, and the effect became increasingly apparent as tannin levels increased from Trials 1 to 4. We conclude that the effectiveness of supplemental PEG may be low if alternative forages are equal or superior in nutritional quality and contain fewer metabolites with adverse effects. In such cases, animals would likely prefer alternatives to high-tannin foods.

3.3. Effects of Condensed Tannins on Short-term Changes in Eating Patterns

Ingestion of condensed tannins decreases food intake in ruminants. PEG forms high-affinity complexes with tannins. In two experiments carried out on Holstein heifers naive to tannins, quebracho tannin from the Aspidosperma quebracho served as source of tannin. The aims of the study were i) to quantify the effect of tannin on intake and eating behavior in cattle fed complete mixed diets; ii) to clarify if changes in ingestive behavior and intake due to tannin could be reversed by feeding PEG; and iii) to clarify if the decrease in intake is associated with short-term (astringency, post-ingestive malaise) or longer-term effects (Landau et al. 2000). In Experiment 1, tannin was given in increments of 50-100 g/d, and 500 g/d of tannin was the minimum dose that decreased food intake in heifers. A ratio of PEG to tannin equal to 1:12.5 did not fully restore intake. In experiment 2, four heifers received a random sequence of four rations ad libitum in a Latin-square design with feeding cycles of approximately 7 days: complete mixed diet (CMD) containing no supplements (C), CMD containing 625 g/d of tannin without 250 g/d of PEG (Q), CMD containing 250 g/d of PEG (Q-PEG), or CMD without tannin with 250 g/d of PEG (PEG). Individual rations were continuously weighed in the trough and the behavior of heifers was observed for 180 min after distribution of CMD. Overall, feeding Q reduced food intake and resulted in shorter duration eating bouts, mainly the first eating bout, immediately after offering the diet. A larger portion of the diet was consumed 180 min after food distribution in Q-fed heifers. PEG attenuated the effects of quebracho tannin on food intake. Heifers adapted to the tannin-rich CMD by increasing the number eating bouts and the portion of diet consumed posterior to 180 min after food distribution, so that no differences in food intake were noted on the last day of each feeding cycle. Data are interpreted to show that: (i) negative effects of quebracho tannin on food intake derive from...
astringency of the tannin and short-term post-ingestive malaise; (ii) the increased number of eating bouts and their wider partition during the day preserve the rumen environment in Q-fed heifers; (iii) PEG can neutralize the negative effects of quebracho tannin.

3.4. Effect of PEG on Browsing Preferences of Goats

Our objectives were to investigate how macronutrients, tannins, and PEG (MW 3350) affected ingestion of the shrub blackbrush by goats. Browsing of blackbrush during winter stimulates production of current season’s growth (CSG) during the following spring. CSG is higher than older growth (OG) from unbrowsed plants in energy and protein, but goats prefer OG to CSG because high levels of condensed tannins in CSG decrease preference (Titus et al. 2000b). We conducted two trials, one with goats on a paddock and one with goats in pens. During the paddock trial, goats grazed a 1-ha area that contained an equal interspersion of CSG and OG, with scattered juniper trees, from about 0730 to 1700 daily for 17 d. We determined preference by observing goats and recording, at 3-min intervals from 0800 to 0900 daily, which of the three foods (CSG, OG, juniper) individual goats were eating. One group of 10 goats was supplemented with 50 g PEG mixed with ground alfalfa/barley; the other group of 10 goats was supplemented with ground alfalfa/barley only. Supplement was provided at 0700 daily. PEG-supplemented goats preferred CSG to OG, whereas PEG-unsupplemented goats preferred OG to CSG throughout the trial. Goats in both groups had equal preference for juniper. During the pen trial, goats were fed CSG and OG throughout the day and we measured the amount ingested daily during the 7-d trial. One group of 8 goats was supplemented with 20 g PEG mixed with 100 g ground alfalfa pellets; the other group of 8 goats was supplemented with 100 g ground alfalfa pellets only. Goats supplemented with PEG ingested more CSG than goats that did not receive PEG. Collectively, our results indicate that supplemental PEG changed food preferences, and greater intake of CSG likely enabled PEG-supplemented goats maintain a diet higher in macronutrients than PEG-unsupplemented goats.

3.5. Effect of PEG on Browsing Preferences of Cattle

The aim of this research was to determine if supplementing beef cattle with PEG would increase use of shrubs by cattle grazing Mediterranean scrubland (Israel, in
preparation for publication). In the first experiment, 19 cows were placed in each of two experimental plots of ~13 ha for a period of 3 months. Both groups were provided with a protein-rich supplement (prolix) ad lib. One Kg of 4000 MW PEG was added each morning to the water tank of one group, providing at least 50 g of PEG/cow/day. Supplemental PEG allowed cows to feed for longer periods throughout the day and to use more tannin-rich woody vegetation. The disappearance of Pistacia lentiscus, a shrub notorious for its aggressive growth and high concentration of tannins, was greater in the PEG-supplemented plot than in the control plot. The second experiment showed that 50 g PEG/cow/day provided in the water reduced the consumption of supplemented feed (poultry manure) by 20-30%. PEG also increased foraging time by 30% and daily foraging distance by 15%. However, PEG supplementation did not affect average cow body weight, weaning weight, or water consumption. Neutralizing the effects of tannins with PEG promotes the use of woody species usually considered useless as forages. This study shows that diet composition is affected by the content of tannins in the available shrubs in Mediterranean scrubland. PEG also encouraged cattle to spend more time in the woodland. These findings may be applied for controlling shrub encroachment or maintaining fire breaks using PEG-supplemented cattle.

3.6 Self-regulation of Intake of Polyethylene Glycol by Sheep

Given the strong response to supplemental PEG, we speculated that animals might self-regulate their intake of PEG when offered foods high in tannins (Provenza et al. 2000). The objective of the first experiment was to determine if the amount of supplemental PEG (0, 25, 50, 75, 100 g; MW 3350) affected intake of a food (milo-tannin mix) containing 20% quebracho tannin by lambs. There was a linear relationship (Y = 272 + 1.2X; R² = .86; P = .023) between the amount of supplemental PEG ingested and the subsequent intake of milo-tannin food by lambs. The objective of the second experiment was to determine if lambs self-regulated intake of PEG (MW 3350) when fed a ration that contained 5, 10, 15, or 20% quebracho tannin, and if they adjusted their intake of PEG when tannin was removed from the diet. There was a positive relationship between the amount of PEG ingested and intake of food and tannin. Lambs fed high-tannin diets ate more PEG than controls. Lambs fed the 20% tannin diet ate the most PEG and controls ate the least PEG.
Tannin limited intake of the diets, but PEG attenuated the response to a great degree. Immediately after tannin was removed from the ration, lambs formerly fed the 20% tannin ration ate more PEG than lambs fed the other rations. Ten of the lambs (5 from the 20% tannin group, 1 from the 15% tannin, and 2 each from the 10 and 5% groups) continued to eat PEG for 7 d after tannin was removed from their ration. When they were tested again 6 wk after the trial, and offered tannin-free diets, their intake of PEG had decreased.

3.7. Self-regulation of Intake of Polyethylene Glycol by Goats

The aim of the first phase of this experiment, was to clarify (i) if PEG-supplementation modifies the feeding behavior of goats feeding on Mediterranean scrubland; (ii) if goats modulate PEG-intake according to the frequency of tannin-rich species in their diet and; (iii) if free self-feeding of PEG has potential to be used in the management of goats feeding on tannin-rich browse (Israel, in preparation for publication). Goats supplemented with PEG spent more time foraging on tannin-rich lentisk, and less time on vegetation of low (herbage) or medium (carob) tannin content. This has important implications if goats are to be used to prevent encroachment of tannin-rich vegetation. Feeding on the tannin-rich lentisk represented 74% and 40% of feeding observations in the PEG-supplemented and control groups, respectively. We assume that the intake rate of lentisk is similar for supplemented and unsupplemented goats. If so, then PEG-supplemented goats consumed, on average, 1.54 kg of fresh plant material while foraging and 100 g/d of condensed tannins. Using a similar calculation, control goats that consumed nearly 1 kg of fresh plant material consumed less than 40 g/d of condensed tannins.

3.8. Increasing Productivity with Supplemental PEG

The aim of this study was to quantify the effect of supplementing 10 g/d 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 x Anglo-Nubian goats raised mainly for milk (experiment 3). In Mamber goats, PEG supplementation was associated with higher live weight gain during pregnancy, higher kid birth weight and daily body weight
gain until weaning, and modest increase of milk for one month post-weaning. In contrast, the response of Damascus x Anglo-Nubian goats to PEG was a 43% increase in milk yield, 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 reproduction in harsh environment. In contrast, Damascus x Anglo-Nubians responded to increased available nutrients by increasing 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.

4. Discussion

4.1 Food Preference and Eating Patterns

Macronutrients, quebracho tannins, and PEG interacted along a continuum to affect food intake of lambs. As tannin concentrations increased in the preferred foods containing high and medium concentrations of barley, or when all available foods contained tannin, lambs supplemented with 50 g of PEG ingested more macronutrients and tannins than unsupplemented lambs. Supplemented lambs did not prefer tannin-rich foods, even though the high-tannin foods were also high in energy, unless the available alternatives all contained tannin. Thus, our results suggest that supplemental PEG will not lead inevitably to greater use of high-tannin plants when animals have a variety of alternatives from which to choose. Unless the alternatives are equal to or lower in nutritional quality than the high-tannin plants, animals may eat the alternatives, regardless of supplemental PEG. When alternatives are of equal or lower value, then supplemental PEG is likely to affect food preference. Such conditions are common in shrub-dominated rangelands worldwide.

It seems that novelty cannot be claimed the cause of depressed intake in tannin-fed heifers. Effects of tannins on food intake can be classified as oral sensations exerted at very short time after ingestion (a few minutes), post-ingestive malaise felt within less than one hour, longer-term effects due to digestion inhibition, or possible associations between them. An effect exerted in the mouth, such as astringency was probably associated with lower duration of the first eating bout, which is the major eating bout in stall-fed ruminants.
4.2 PEG and Browsing Preferences

It has been hypothesized that supplemental PEG might dramatically increase preferences of herbivores for tannin-rich forages. This could lead to better animal production in areas dominated by tannin-containing species, and allow herbivores to more evenly use rangeland biomass. It has also been suggested that animals supplemented with PEG could graze and thereby maintain fire breaks in areas dominated by plants high in tannins. Our findings are generally consistent with these hypotheses. The results from the paddock trial establish that PEG-supplemented goats preferred high-tannin food, whereas PEG-unsupplemented goats did not. The findings from the pen trial indicate that PEG-supplemented goats ate more tannin-rich food than PEG-unsupplemented goats.

The studies in Israel show that it is possible to overcome the inherent repulsion of cattle for tannin-rich vegetation with supplemental PEG. Thus, it is suggested that PEG may help the livestock industry to take advantage of the vast, poorly exploited areas with plants high in tannins. Moreover, cattle supplemented with PEG may also help in managing areas with dense cover of woody vegetation that is prone to develop wildfires.

4.3 Self-regulation of PEG and Applicative Aspects

Supplementing PEG may be practical under many farm conditions (Silanikove et al., 1994). However, the labor required to supplement PEG is a disadvantage, particularly on extensive areas of rangeland. The amount and frequency of dosing PEG depends on the tannin content of the diet, which varies with environment and season (Cooper et al., 1988). One solution to such problems is to let animals self-regulate intake of PEG. Since PEG is costly, it may not be feasible to offer loose PEG as a supplement to free-ranging livestock. However, it may be possible to formulate "range" blocks that contain PEG, along with other compounds - charcoal, macronutrients (Banner et al., 1999; Villalba and Provenza, unpublished data) - that increase use of forages high in potentially harmful plant metabolites. PEG must be administered to livestock daily prior to grazing, and it often is mixed with grain. These costs associated with PEG supplementation might be reduced if livestock would consume PEG without grain and if they would only consume as much
PEG as needed to counter the effects of tannins. In general, the studies in Israel supported this concept suggesting that PEG self-regulation is applicable under field conditions.

Furthermore, 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 is PEG-feeding likely to be economical.

**Scientific Implications**

We have shown that tannins affect individual animal eating bouts and grazing behavior. The results from this research show that supplementing animals with low doses of PEG increases intake of high-tannin foods and improves performance in a variety of species – cattle, sheep, goats – under a variety of conditions in the U.S. and in Israel.

We also have shown that animals learn to consume foods and solutions that attenuate aversive effects of food ingestion, and applied this principle to show how animals self-regulate intake of PEG to attenuate the aversive effects of tannins.

Finally, this study provides basic information on the interactions between macronutrients and tannins. Animals supplemented with PEG eat more macronutrients and tannins than unsupplemented animals, and the effect becomes increasingly apparent as tannin levels increase. Moreover, animals on a higher plane of macronutrient nutrition are better able to ingest foods high in tannins. Thus, PEG supplementation and nutrient status both influence the amount of high-tannin food an animal can ingest.

**Potential Impact on Agriculture and Environment**

Our research shows that supplementing livestock with PEG increases intake of high-tannin foods, which can influence animal production and improve the sustainability of systems. Use of supplemental PEG to increase intake of woody plants is emerging as an important tool in land management. Supplemental PEG enables sheep and goats to eat thick stands of shrubs and trees, thus lowering fire hazard and increasing amenity value of lands for recreation. The high economic and environmental costs of herbicides mandate the development of less expensive and more ecologically sound alternatives. Range management by livestock is a viable and effective alternative, and our research on PEG supplementation has improved this capacity substantially.
References


List of Publications

Refereed Papers

In addition to the papers listed below, we have five papers – three from the U.S. and two from Israel – that are in preparation and will be submitted this year.


Invited Review Papers


Book Chapters

