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Monitoring diet composition and quality of ranging goats by faecal NIRS

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SUMMARY –The present study tested the ability of faecal NIRS to predict quantitative and qualitative attributes of the diets of goats grazing Mediterranean scrubland in the Carmel mountain ridge of Israel. This landscape is dominated by the shrubs *Pistacia lentiscus* and *Phillyrea latifolia*, with interspersed patches of herbaceous vegetation. A group of 12 goats foraged in the study area for four hours daily and were supplemented with 100-300 g/d of concentrate feed. During two observation days, one randomly-selected focal goat was observed continuously, and the species foraged, the number and size category of bites removed were recorded by dictation into a tape-recorder. Periodically, bites of each selected species and size category were sampled by clipping and collected for estimation of bite weight and quality. Following suitable preparation, faecal samples were scanned by NIRS, and clipped samples were dried, weighed and analysed for chemical attributes by standard procedures. Calibrations were based on 23 pairs of faeces and diets of the observed goats. Equation quality was evaluated by R2 and the standard error of cross validation (SECV). The R^2 values obtained for the dietary percentage (on a DM basis) of *Pistacia lentiscus*, *Phillyrea latifolia*, CP, ADF, NDF, IVDMD and PEG-binding tannins were 0.88, 0.92, 0.80, 0.93, 0.87, 0.75 and 0.80, respectively. The corresponding SECV values were 6.77, 8.15, 0.81, 1.73, 2.96, 2.44 and 0.97, respectively. The equations for *P. lentiscus, P. latifolia* and PEG-binding tannins were applied to a set of 83 samples from a previous experiment for external validation. R^2 values were 0.78, 0.80, 0.78 and standard error of prediction (SEP) values were 16.78, 13.88 and 2.62, respectively. Results suggest that faecal NIRS can be calibrated under free-grazing conditions but larger calibration datasets will need to be gathered in order to secure the robustness of this technology.

Keywords: goat, feeding behaviour, Near Infrared, Mediterranean pasture, browsing.

RESUME – *"Suivi par NIRS fécal de la composition et de la qualité du régime chez des chèvres sur parcours". La présente étude a examiné l'aptitude du NIRS fécal à prédire les attributs quantitatifs et qualitatifs des régimes pour caprins en pâturage sur des zones broussailleuses méditerranéennes dans la cordillère montagneuse de Carmel en Israël. Ce paysage est dominé par les espèces arbustives Pistacia lentiscus et Phillyrea latifolia, et parsemé de végétation herbacée. Un groupe de 12 caprins a pâturé dans la zone d'étude tous les jours pendant quatre heures, et a reçu une supplémentation de 100-300 g/j de concentré. Pendant deux journées d'observation, un caprin choisi au hasard comme objet d'étude a été observé continuellement, en dictant sur magnétophone les espèces broutées, le nombre et la catégorie par taille des coups de dents portés. Périodiquement, les coups de dents de chaque espèce sélectionnée ainsi que la catégorie par taille étaient échantillonnés par coupure et collectés pour estimation du poids et de la qualité du coup de dent. Après une préparation adéquate, des échantillons fécaux étaient scannés par NIRS, et les échantillons coupes étaient séchés, pesés et analysés pour connaître les attributs chimiques par des procédures standardisées. Les calibrations étaient basées sur 23 paires de fèces et sur les régimes des caprins observés. La qualité des équations était évaluée par R^2 et erreur standard de validation croisée (SECV). Les valeurs de R^2 obtenues pour le pourcentage dans le régime (sur la base de la MS) de Pistacia lentiscus, Phillyrea latifolia, CP, ADF, NDF, IVDMD et tannins liés par PEG étaient de 0,88, 0,92, 0,80, 0,93, 0,87, 0,75 et 0,80, respectivement. Les valeurs correspondantes de SECV étaient de 6,77, 8,15, 0,81, 1,73, 2,96, 2,44 et 0,97, respectivement. Les équations pour P. lentiscus, P. latifolia et tannins liés par PEG étaient appliquées à un ensemble de 83 échantillons d'une expérience préalable pour validation externe. Les valeurs de R^2 étaient de 0,78, 0,80, 0,78 et les valeurs de l'erreur standard de prédiction (SEP) étaient de 16,78, 13,88 et 2,62, respectivement. Les résultats suggèrent que le NIRS fécal peut être calibré en conditions de libre pâturage mais il sera nécessaire de rassembler des séries plus vastes de données de calibration afin de s'assurer de la rigueur de cette technologie.*

Mots-clés : *Caprin, comportement alimentaire, proche infrarouge, pâturage méditerranéen, broutage.*

Introduction

Since the pioneering work of Lyons and Stuth (1992) that established the feasibility of predicting

dietary chemical attributes by analyzing near infrared spectra of the feces, termed "fecal NIRS", this technology has been used for predicting the chemical (Leite and Stuth, 1995; Landau *et al*., 2004a) and botanical composition of diets (Walker *et al*., 2002; Landau *et al.*, 2004a) ingested by goats. Most of research has assessed that this technique has a good ability to predict a variety of diet attributes. Nevertheless, it has been shown that the robustness of many fecal NIRS equations is low when less spectral variety is found in feces used for calibrations established in controlled conditions than in validations carried out under free-grazing conditions, where diet variability is extremely high (Landau *et al.*, 2005). Goats are known to be very selective while grazing on heterogeneous plant species (Mill, 1990). Therefore, the main problem with free-ranging goats is obtaining accurate reference values of the diet consumed by the goats while grazing. This fact is clearly observable under conditions of grazing Mediterranean shrubland, which has great variability in plant structure and secondary compound concentrations. One of the most important factors (if not the most important) in calibrating robust NIRS equations is obtaining the most accurate reference values as possible, as representative as possible of the conditions under which fecal NIRS calibrations will be utilized.

The current research attempted to extend the use of the fecal NIRS technology by developing equations derived from the spectra of free-ranging goats while employing direct focal observations to quantify diets and overcome the problem of questionable reference values when predicting diets of free ranging animals.

Material and methods

Two herds of goats were used for field observations during February-December, 2004. The first herd included 14 Damascus goats (10 observations) and the second included 36 goats: 12 Damascus (5 observations), 12 Mamber (4 observations) and 12 Boer goats (4 observations). All 23 observations and fecal spectra were used as a calibration set. Candidates for observation were not used if the continuous presence of the observer at a distance of approximately 1 m interfered visibly with normal foraging behaviour. Goats grazed for four hours daily in a 0.1 hectare paddock. Paddocks are part of a Long Term Ecological Research (LTER) station and were chosen to be representative of the Mediterranean shrubland that covers the Carmel region in Israel. After a five-day period of acclimation to a new paddock and presence of the observer. Observations were recorded using a voice-activated tape-recorder. In brief, when a focal goat started to eat, the observer recorded the time, the species grazed or browsed, the number of bites removed and their size and anatomical category (small, medium or large, leaf, stem or fruit). In order to estimate the quality of the diet selected by the goats, a hand-simulated grazing technique was employed in which bite-like samples were clipped from the bushes previously grazed by the observed animal. A composite (morning, noon, evening) sample of feces was grab collected directly from the animal for two days, commencing 48 h after observations.

Diets were "re-constructed" by computer from recordings, in order to obtain botanical and chemical diet composition. The reconstituted bites were weighed and analyzed for crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) (as per AOAC, 1984). In vitro digestibility of dry matter (IVDMD) was determined according to Tilley and Terry (1963). PEG-binding tannins were assessed by a NIRS equation developed by Landau *et al*. (2004b).

Fecal matter was dried in a ventilated oven at 60^{o}C for 48 hours and ground to pass through a 1 mm sieve. Samples were scanned between 1104-2492 nm in 2 nm increments using a Foss NIRSystems 5000 NIR reflectance monochromator spectrometer (Foss Tecator, Hoganas, Sweden). Raw spectra were transformed using Standard Normal Variance (SNV), detrend and derivatized by first or second derivative (Barnes *et al.,* 1989). Outliers were identified and excluded from the calibration set. Spectral data was analyzed with WinISI software (ISI, 1999).

In the first stage, fecal spectra from observed goats were used for equation development. No resident (goats grazing together with the observed goat) goats' feces were used for developing the calibration equations. Calibrations were set for predicting the dietary percentage and daily intake of *P. lentiscus, P. latifolia,* CP, ADF, NDF, IVDMD, and PEG-binding tannins. Validation was carried out by the cross-validation method in which the variability in the difference between predicted and reference values when the equation is applied sequentially to subsets of data from the calibration data set (ISI, 1999). In some cases SECV was divided by the mean in order to make comparisons of errors with different constituents more meaningful. In a second stage, external validation was attempted by using

the equations in predicting 83 diets of hand-fed goats from a previous experiment in which dietary data and fecal samples had been collected (Landau *et al*., 2004a). External validation shows the quality of predictive model when operated on data that has no temporal or spatial connection to the calibration data. This was done because cross-validation is justified in situations with calibration samples that are randomly selected from a natural population but may give over-optimistic results, in particular if data are replicated (Naes *et al*., 2002).

Results and discussion

High R^2 values were obtained for the prediction of dietary percentages of ADF, NDF, *P. lentiscus* and *P. latifolia* using data from observed animals (Table 1). Globally, the R^2 were lower, and SECV values higher with freely-grazing (Table 1, upper part) than browse-hand-fed goats (Table 1, lower part), probably because higher accuracy can be reached in reference values in more controlled conditions. However, the SECV for CP (0.81%) and IVDMD (2.44%) was still relevant for field predictions. From Table 1 (upper part) it is apparent that predictions of botanical components are less accurate than those of chemical components. Range of SECV/mean for the former is 0.05-0.7, while that of the latter is 0.3-0.5. The same trend was exhibited in hand-fed animals (Table 1, lower part). This is expected, due to the fact that botanical composition derives from chemo-spectral data, i.e., it is "second hand" information. Thus, predicted botanical components, are directly affected by the chemo-spectral data, whereas chemical composition is less affected by the botanical components from which it originates. This lower level of accuracy is expressed by the high SECV.

Table 1. Calibration and cross-validation statistics for observed and hand fed goats

	Range (%)	Mean (%)	R^2	SEC	SECV	SECV/mean
Observed goats						
CP *(n=22)*	7.3-10.9	8.7	0.80	0.39	0.81	0.09
ADF *(n=21)*	22.9-32.2	27.6	0.93	0.66	1.73	0.06
NDF *(n=23)*	37.0-54.6	4.2	0.87	1.51	2.96	0.70
IVDMD *(n=20)*	40.3-60.6	45.8	0.75	1.35	2.44	0.05
Tannins *(n=23)*	2.9- 8.7	5.5	0.80	0.74	0.97	0.17
P. lentiscus *(n=23)*	0.4-40.4	13.1	0.88	4.00	6.77	0.52
P. latifolia *(n=22)*	1.3- 50.8	25.6	0.92	3.77	8.15	0.32
Hand-fed goats (Landau *et al*., 2004a)						
CP *(n=79)*	7.7-12.2	10	0.89	0.29	0.44	0.04
ADF *(n=80)*	15.4-28.4	22.8	0.94	3.6	1.38	0.06
NDF *(n=79)*	28.5-41.2	36	0.95	0.85	1.2	0.03
IVDMD *(n=80)*	41.3-67.2	52	0.85	2.07	2.2	0.04
Tannins *(n=81)*	0.29-15.6	6.15	0.96	0.85	1.07	0.17
P. lentiscus *(n=65)*	0-76.5	32.7	0.95	5.4	7.1	0.22
P. latifolia *(n=49)*	0-81.4	45.2	0.94	5.6	7.0	0.15

Max 3 outliers eliminated (upper part) ; - max 4 outliers eliminated (lower part).

External validation was done only for botanical composition and tannin concentration in diets. All other chemical data presented a very narrow range of reference values that did not allow for acceptable statistical analysis. In contrast with this study, Leith and Stuth (1995) have validated equations from free ranging goats with fecal samples sourcing from different experiments, but with goats using the same paddocks for calibration and for validation. Their results presented very high quality equations with values of R^2 for CP and IVOMD of 0.94 and 0.93 and standard errors of validation corrected for bias (SEV-C) of 1.28 and 2.12%, respectively. It is important to mention that size of their calibration sets was 163 and 86 for CP and DOM, respectively, compared with 23 in the current study. As well, external validation in the present study was carried out with spectra from feeding trials and not from goats grazing the same grazing area.

Results for botanical predictions are presented graphically in Fig. 1. External validation results of botanical components and PEG-binding tannins (Table 2) exhibit high SEP values that make the practical value of these equations questionable at this stage. Despite that, R^2 values show that most of the variation in reference values is explained by the calibration model. This leaves place for optimism that with a larger calibration set, the SEP values will decrease significantly and allow practical use through higher robustness of these equations. It is interesting to note that in the tannin prediction there is a trend of lower accuracy as the percent of tannins in the diet increases (Fig. 2). A constant trend such as this can be corrected in order to achieve higher prediction accuracy.

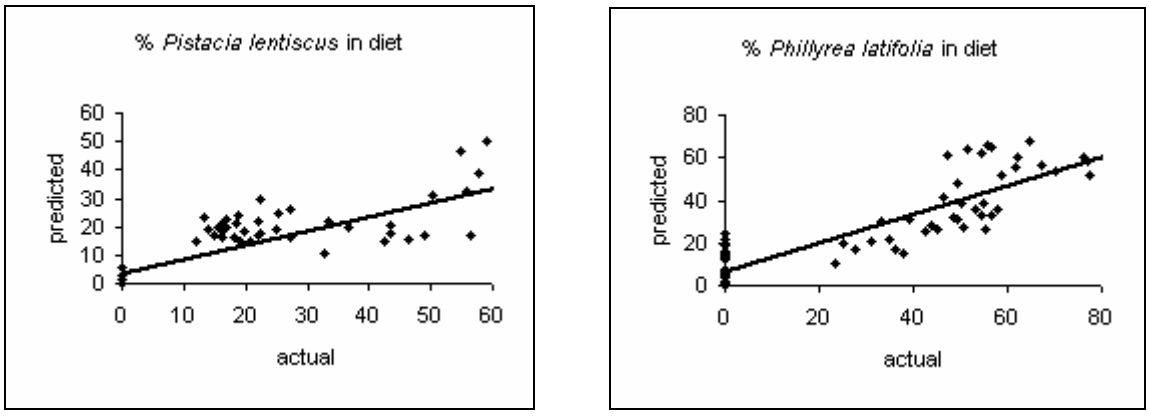

Fig. 1. External validation of botanical dietary components.

Table 2. Equations from free grazing goats validated by data from feeding trials

	Range (%)	Mean (%)	R^2	SEP	Slope	Bias
Tannins *(n=81)*	2.9-8.7	6.2	0.81	2.62	1.5	-0.65
P. lentiscus (n=81)	0.4-40.4	24.6	0.78	16.78	1.2	8.63
P. latifolia (n=80)	1.3-50.8	26.8	0.80	13.88	0.7	2.21

Max 3 outliers eliminated.

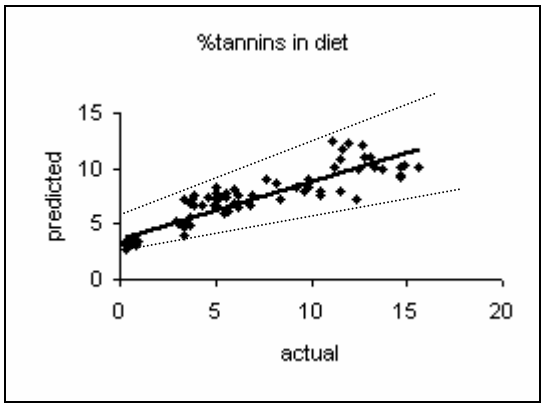

Fig. 2. External validation for prediction of percent of PEG-binding tannins in diet.

Table 3 presents the results of validating equations established in the hand-feeding trial on data derived from freely grazing goats. Despite the high accuracy obtained by using the cross-validation procedure, these calibration equations featured low R^2 and high SEP, and were unsuccessful in

predicting the diet of free ranging goats. This was probably due to the low variation of spectral data of the feeding trial goats' feces *vs* free grazing goats' feces, as evidenced in the graph of feces scattering across a 3-dimension graph where the axes are the best components (Fig. 3). Even though Walker *et al.* (1998) validated equations for percentage of leafy spurge in sheep and goats diets when feeding different concentrations of leafy spurge to the animals with relative success (R^2 of 0.91 and 0.93, and SEP of 4.6% and 4.8%, respectively), our data do not support the idea that calibrations established in feeding trials may be robust under grazing conditions.

Table 3. Equations from feeding trials validated by data from free grazing goats

	Range (%)	Mean (%)	R^2	SEP	Slope	Bias
Tannins *(n=23)*	2.9-8.7	5.5	0.1	2.07	0.30	0.68
P. lentiscus *(n=23)*	0.4-40.4	32.7	0.12	12.3	0.43	3.66
P. latifolia *(n=23)*	1.3-50.8	26.6	0.35	25.5	0.48	-21

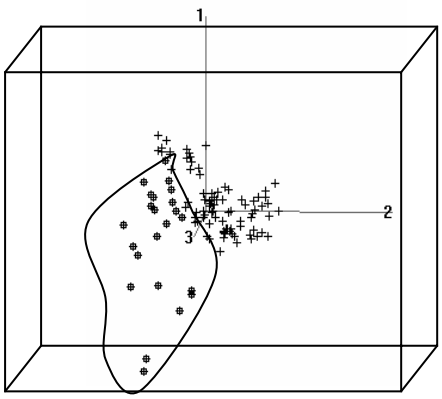

Fig. 3. 3-d graph of scores of spectra from 23 observations (round dots circled with line) vs. spectra from 83 samples of feeding trial (crosses).

Conclusions

We present here one of the first attempts to predict goats' diets under free-grazing conditions in Mediterranean shrubland by fecal NIRS, including external validation. The results exhibit a clear trend that encourages the continuation of developing fecal NIRS equations and attempting to stretch the capability of this tool for day to day practical use. These results suggest that with a larger and broader calibration set there is a good chance of achieving robust calibrations that can be practical for a wide variation of diets.

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