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Nutritive evaluations of some browse tree foliages during the dry season: Secondary compounds, feed intake and *in vivo* digestibility in sheep and goats

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Abstract

Four browse tree foliages (*Cassia fistula*, *Schinus molle*, *Chorisia speciosa* and *Eucalyptus camaldulensis*), native to the semi-arid region of north Egypt, were harvested during the dry season and evaluated for nutritional quality by determination of levels of nutrient and secondary compounds, as well as feed intake and apparent digestibility in sheep and goats. The study consisted of four experiments conducted in sequential 28-day periods that were the same in all respects, except that a different foliage was evaluated in each experiment which used six adult male Rhmani sheep (35 ± 2.3 kg body weight (BW) at the start of the study) and six crossbred goats (30 ± 1.56 kg BW). Sheep and goats were randomly divided into two groups of three and offered foliage at a level equal to 1.3 of the previous days voluntary intake of fresh matter and a commercial concentrate, with or without 10 g/animal/d of PEG, at 10 g/kg of BW to meet 0.7 of maintenance metabolizable energy requirements. Foliage crude protein (CP) content ranged from 124 (*S. molle*) and 128 (*C. speciosa*) to 185 g/kg DM (*C. fistula*). Ether extract was highest (97 g/kg) in *S. molle*. *C. fistula* had the lowest neutral detergent fiber

Abbreviations: BW, body weight; ADFom, acid detergent fiber; NDFom, neutral detergent fiber; Lignin(sa), acid detergent lignin; CP, crude protein; DM, dry matter; PEG, polyethylene glycol; TP, total phenolics; CT, condensed tannins; SAP, saponins; ALKA, alkaloids; AF, the aqueous fraction

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(NDFom), acid detergent fiber (ADFom) and acid detergent lignin (lignin(sa)), while *E. camaldulensis* had the highest values. Total phenolics (TP), condensed tannins (CT), saponins (SAP), alkaloids (ALKA), the aqueous fraction (AF) of lectins, polypeptides and starch, and essential oils (EO) were lowest in *C. speciosa* (29, 21, 3, 0, 4 g/kg DM and 0.40 ml/kg DM, respectively) and highest in *E. camaldulensis* (102, 68, 15, 5, 3 g/kg DM and 15 ml/kg DM, respectively). Levels of TP, CT, SAP, ALKA and EO were highly positively intercorrelated among foliages, although AF was weakly negatively correlated to all others. Goats consumed 3.9% more foliage dry matter (DM) than sheep per kg $BW^{0.75}$, and their digestibility was about 8% higher, probably reflecting their better capacity to detoxify secondary compounds in the rumen than sheep. Levels of CT (and due to its correlations, also TP, SAP, ALKA and EO) was a strong predictor of DM intake of PEG unsupplemented foliages within both sheep and goats. PEG increased ($P<0.05$) intake of DM and its components in sheep and goats. Digestion of DM and NDFom were not affected by feeding PEG, although digestion of OM, EE and CP were higher ($P<0.05$). TP in tree foliages (and due to its correlations, also CT, SAP, ALKA and EO) was not a predictor of the proportional increase in DM with PEG feeding, which was best predicted by level of CP within foliage. Overall, *C. speciosa*, had the highest nutrient value for both sheep and goats, both without and with PEG feeding, *S. molle* and *C. fistula* were intermediate and *E. camaldulensis* had the lowest nutritive value.

Keywords: Foliage; Secondary compounds; Feed intake; Digestibility; Sheep; Goats

1. Introduction

A major cause of low productivity of livestock in tropical regions, such as Egypt, is inadequate amounts, and poor nutritional quality, of many locally available feeds. Browse fodder is a potentially inexpensive locally produced protein supplement for ruminants, particularly during the critical periods of the year when the quantity and quality of herbage is limited. However, most tropical browse species contain substantial amounts of phenolic compounds, mainly tannins (Makkar and Becker, 1998; Salem, 2005) as well as other secondary compounds (Salem et al., 2004b). This can reduce their nutritional value, as most tannins bind to feed proteins thereby making them unavailable to ruminal microorganisms. Thus, the use of high tannin browse species as supplements to crop residue-based diets may not increase the productivity of animals, as ruminally available N frequently limits ruminal microbial growth and subsequent degradation of structural carbohydrates.

However, several fodder shrubs and trees have been shown to be able to partially or totally replace concentrate feeds without decreasing digestion or growth of sheep and goats. For example, Ondiek et al. (2000) concluded that *Leucaena leucocephala* and *Gliricidia sepium* foliage could contribute N in diet supplements without detrimental effects on production of dairy goats. Liu et al. (2001) showed that mulberry (*Morus alba*) leaves could be used as a protein supplement in an ammoniated rice straw diet to fully substitute for rapeseed meal.

Goats are effective browsers, have the ability to utilize woody species and low-quality forages better than cattle and sheep, and can adapt to harsh environments (Tisserand et al., 1991; Silanikove, 2000a, 2000b; Salem et al., 2004a). Extensive shrub-lands of evergreens

and small trees, known as garrigue or maquis, that are often high in tannins and other secondary compounds are the basic component of diets of goats in the Mediterranean area.

Attempts have been made to deactivate tannins, and other secondary compounds, in temperate and tropical forages. These attempts include use of polyethylene glycol (PEG), a synthetic polymer for which tannins have a greater binding affinity than proteins (Makkar, 2003a). Therefore, PEG releases forage proteins from tannin–protein complexes and improves their nutritional value. Degen et al. (1998, 2000) used *Acacia saligna*, a tannin-rich leguminous shrub species, and suggested that effects of PEG may persist for up to 14 days in sheep and goats after PEG feeding is terminated.

This study was designed to determine the nutritive value of four browse tree species in terms of nutrient and secondary compounds, and to assess the capability of PEG added to the diet to mitigate adverse effects of secondary compounds on feed intake and nutrient digestibility in sheep and goats.

2. Materials and methods

The study was completed at the experimental station of the Faculty of Agriculture of Alexandria University in northern Egypt during May–August 2004.

2.1. Tree foliage species

Consumable parts (*i.e.*, leaves and twigs of about 1 year of age) of each foliage species used (*i.e.*, *Cassia fistula*; *Schinus molle*; *Chorisia speciosa*; *Eucalyptus camaldulensis*) were randomly harvested, by hand plucking from 8 to 10 trees of each species, every second day.

2.2. Animals, management and feeding

This study consisted of four experiments completed in sequential 28 day periods that were the same in all respects, except that a different tree foliage was evaluated in each experiment which used six adult male Rahmani sheeps and six crossbred goats weighing 35 ± 2.3 and 30 ± 1.56 kg body weight (BW), respectively, at the start of the study.

Sheep and goats were randomly divided into two groups of three to create the two experimental groups. All were offered foliage at a level equal to 1.3 of the previous days voluntary intake of fresh matter, and a commercial concentrate (with or without 10 g of PEG/animal/d; MW 4000, Analytical grade, Sigma®–Aldrich, El-Safua Co., Alexandria, Egypt) at 10 g/kg of BW to meet 0.7 of their calculated maintenance metabolizable energy (ME) requirements (NRC, 1985). The concentrate used was formulated to contain undecorticated cotton seed meal (300 g/kg), ground yellow corn (355 g/kg), wheat bran (300 g/kg), limestone (30 g/kg), salt (10 g/kg) and 5 g/kg of a trace mineral/vitamin premix (all values/kg of DM: Vitamin A, 2,000,000 IU; Vitamin D_3, 150,000 IU; Vitamin K, 0.33 mg; Vitamin B_1, 0.33 g; Vitamin B_2, 1.0 g; Vitamin B_6, 0.33 g; Vitamin B_{12}, 1.7 mg; pantathenic acid, 3.33 g; biotin, 33.0 mg; Folic acid, 0.83 g; choline chloride, 200 mg; Zn, 11.7 g; Mn, 5.0 g; Fe, 12.5 g; Mg, 66.7 mg;

Se, 16.6 mg; Co, 1.33 mg; Cu, 0.5 g; I, 16.6 mg; antioxidant, 10.0 g). The concentrate was fed at 9.00 h and animals were fed the foliage 10.00 h and allowed access to it until 2 h before the next feeding of concentrate, at which time uneaten foliage was removed and weighed. All offered concentrate was consumed by all sheep and goats within 60 min of offer on all occasions, and so orts were assumed to be foliage.

Sheep and goats were housed in individual pens during the adaptation period (*i.e.*, the first 15 days of each experiment) to the dietary treatments and had free access to clean water.

2.3. Metabolism trial (feed intake and apparent digestibility determinations)

During each experiment, after the 15 day adaptation to dietary treatments, a digestion study of 10 days duration, involving quantitative collection of feeds, refusals and faeces was conducted to determine the apparent digestibility of the diets. Animals were acclimatized to the metabolism cages for 3 days after the 15 day adaptation period and prior to the 10 day collection period. Faeces voided during each successive 24 h period were collected and weighed. Representative samples of foliage, concentrate, refusals and faeces were collected daily and dried at 105 °C to determine daily intake of DM for each animal. Other representative samples of each material, by animal for refusals and faeces, were collected daily over the 10 day collection period, bulked, mixed, sub-sampled and ground to pass a 1 mm sieve for subsequent laboratory analysis.

2.4. Analytical methods

Ground samples of feeds, refusals and faeces were analyzed for dry matter (DM) by drying samples at 105 °C for 24 h in forced air oven. Ash content was measured after igniting samples in a muffle furnace at 550 °C for 4 h. The crude protein (CP) was determined by Kjeldahl method (AOAC, 1990; ID 954.01). Ether extract (EE) was determined by Soxhlet method (AOAC, 1990; ID 920.39). Neutral detergent fiber (NDFom), acid detergent fiber (ADFom) and acid detergent lignin (lignin(sa)) were determined by methods of Van Soest et al. (1991). NDFom was assayed without the use of an alpha amylase but with use of sodium sulfite. Both NDFom and ADFom are expressed without residual ash.

Samples of each tree foliage were dried at 40 °C for 72 h and ground to pass a 1 mm sieve. All samples were thoroughly mixed and sub-sampled into four representative bulk samples of each foliage for further analysis of secondary compounds.

Approximately 200 mg (DM) of ground samples of each foliage were extracted in 10 ml of aqueous acetone (7:3 v/v) in a water bath maintained at 39–40 °C for 90 min (Makkar, 2000). Total extractable phenolics (TP) were assayed by Folin-Ciocalteu-reagent 2N (Sigma®–Aldrich, El-Safua Co., Alexandria, Egypt) based on known concentrations of tannic acid as the calibration curve (Sigma®–Aldrich) according to Makkar and Becker (1993). Condensed tannins (CT) were determined according to Porter et al. (1986) with the modification of Makkar (2000, 2003b) using butanol/HCl (95:5 v/v) and ferric ammonium sulfate (20 g/l 2 M HCl) as reagents, and a solution of purified quebracho tannin (1 mg/ml aqueous acetone, 700 ml/l) as the standard. Absorbance was measured against a blank at 550 nm.

Saponins (SAP) were extracted and isolated according to Ahmad et al. (1990), wherein dried samples are extracted with methanol several times. The combined methanol extract was evaporated and partitioned between ethanol acetate and H_2O. For the alkaloid (ALKA) extract, dried samples were first extracted with ethanol and then dissolved in dilute HCl. This solution was filtered and extracted with petroleum ether to remove fat (Arambewela and Ranatunge, 1991).

The aqueous fraction (AF) of lectins, polypeptides and starch (see review of Cowan, 1999) was determined according to Hussein et al. (1999) using fractionation by column chromatography of extracted samples by saturating the extract with distilled H_2O and 500 g/l methanol. For essential oil (EO) analysis, fresh leaves of tree foliage were cut into small pieces (0.2–0.4 cm length) with a small chopper and steam distilled. The distillate was then extracted with petroleum ether, and the resulting extract was dried on anhydrous sodium sulfate. Petroleum ether was removed carefully and EO was obtained as the liquid.

2.5. Statistical analysis

Tree foliage nutrient and secondary compound contents were statistically analyzed using the 'PROC GLM' procedure of SAS (1999), with methods of Steel and Torrie (1980), and differences among foliage species were determined using Duncan's multiple-range test (Duncan, 1955). Data on nutrient components of total feed intake, foliage consumed and digestibility were analyzed as 2×2 factorial experiments (2 animal species (sheep and goats) $\times$ 2 treatments (with or without PEG)) within each tree foliage for each experiment using 'PROC GLM' (SAS, 1999), with methods of Steel and Torrie (1980), to determine differences due to animal species and PEG. In the case of significant interactions (*i.e.*, $P<0.05$), Duncan's multiple-range test (Duncan, 1955) was used to separate means within animal species. Correlations between foliage secondary compounds (Table 6) used simple linear regression (SAS, 1999), whereas multiple regressions (Table 7) used the 'PROC STEPWISE' procedure of SAS (1999).

3. Results

3.1. Chemical composition and secondary compounds of the tree foliages

The crude protein (CP) content of the foliages (Table 1) ranged from 124 (*S. molle*) and 128 (*C. speciosa*) to 185 g/kg DM (*C. fistula*), with *E. camaldulensis* intermediate (154 g/kg). Ether extract was highest (97 g/kg) in *S. molle*, with the others containing less than half that level. *C. fistula* had the lowest NDFom, ADFom and lignin(sa), *E. camaldulensis* had the highest values, and *S. molle* and *C. speciosa* were intermediate.

Total phenolics, condensed tannins, saponins, alkaloids, the aqueous fraction of lectins, polypeptides and starch, and essential oils were lowest in *C. speciosa* (29, 21, 3, 0, 4 g/kg DM and 0.40 ml/kg DM, respectively) and highest in *E. camaldulensis* (102, 68, 15, 5, 3 and 15). *C. fistula* and *S. molle* had intermediate values, although *S. molle* had higher levels of TP and CT. Tannins (*i.e.*, TP and CT) were higher than 50 g/kg of DM in *S. molle* (70

Table 1
Nutrient and secondary compound levels (g/kg DM) of foliages and the concentrate

	Tree species				S.E.M.	Concentrate[a]
	C. fistula	*S. molle*	*C. speciosa*	*E. camaldulensis*		
Chemical composition[b]						
OM	923 b	909 d	916 c	945 a	0.88	965 (0.6)
CP	185 a	124 d	128 c	154 b	0.95	147 (2.3)
EE	39 c	97 a	47 b	41 bc	2.64	83 (1.2)
NDFom	368 d	515 b	435 c	615 a	4.47	289 (3.4)
ADFom	200 d	327 c	356 b	542 a	5.56	186 (2.1)
Lignin(sa)	101 c	160 b	102 c	192 a	2.82	110 (1.8)
Secondary compounds[c]						
TP	44.3 c	67.7 b	29.0 d	102.3 a	2.76	12.4 (1.6)
CT	31.6 c	49.2 b	20.8 d	68.1 a	0.96	ND[d]
SAP	8.3 b	10.3 b	3.0 c	14.6 a	0.73	ND
ALKA	1.3 b	1.9 b	0.0 c	5.0 a	0.20	ND
AF	8.6 a	6.6 b	3.9 c	2.4 d	0.28	ND
EO	0.8 c	5.3 b	0.4 c	15.5 a	0.27	ND

In the same row with different online letters (a, b, c, d) differ (P<0.05).

[a] Mean value ± S.D.

[b] OM, organic matter; CP, crude protein; EE, ether extract; NDFom, neutral detergent fiber; ADFom, acid detergent fiber; lignin(sa), acid detergent lignin.

[c] TP, total extractable phenolic components; CT, condensed tannins (as quebracho equivalent); SAP, saponins; ALKA, alkaloids; AF, aqueous fraction (lectins, polypeptides, starch; Cowan, 1999); EO, essential oils (ml/kg DM).

[d] Assumed to be zero (<0.01 g/kg DM).

and 50) and *E. camaldulensis* (110 and 70), which is considered to be their upper beneficial level in ruminant nutrition (Mangan, 1988).

3.2. Effects of tree foliage species on intake and digestion

3.2.1. C. fistula

Water consumption was higher (P<0.05) in sheep, although the actual values are not convincing. Sheep also consumed more (P<0.01) total and foliage DM (absolutely and relative to BW) than goats (Table 2), as well as all measured nutrients, although their digestion of nutrients, except NDFom, was lower (P<0.05).

Addition of PEG had no impact on water intake, but increased (P<0.05) intake of DM and its components in sheep and goats. Digestion of DM and NDFom were not affected by feeding PEG, although digestion of OM, EE and CP were higher (P<0.05).

3.2.2. S. molle

Water consumption was higher (P<0.05) in sheep, which consumed more (P<0.01) total, but not foliage, DM (absolute and relative to BW) than goats (Table 3), as well as all measured nutrients, although their digestion of nutrients, except NDFom, was lower (P<0.05).

Addition of PEG had no impact on water intake, but increased (P<0.05) intake of DM and its components absolutely, although relative to BW the increase in DM intake and digestibility was greater within goats (P=0.04). Digestion of DM and NDFom were not

Table 2
Water intake (l/d), feed intake (g/d) and digestion (g/kg) in sheep and goats fed *C. fistula* in the absence (−) or presence (+) of PEG

Species (Sp)	Sheep		Goats		S.E.M.	Significance (P)		
PEG	−	+	−	+		Sp	PEG	Sp × PEG
Water intake (l/d)	2.3	3.0	2.5	2.5	0.08	0.01	0.40	0.65
Dry matter (DM) intake								
Foliage (g/d)	309	329	262	272	4.2	<0.01	0.03	0.41
Foliage (g/kg$^{0.75}$)	21.4	22.9	20.4	21.2	0.31	0.02	0.03	0.48
Concentrate[a]	320	320	274	274				
Total (g/d)	629	649	536	546	4.2	<0.01	0.03	0.41
Total (g/kg$^{0.75}$)	43.8	45.2	41.9	42.6	0.31	<0.01	0.03	0.48
DM digestion	502	525	549	565	4.6	0.01	0.25	0.06
Organic matter								
Intake	594	613	507	516	3.9	<0.01	0.03	0.41
Digestion	531	547	579	595	4.0	<0.01	0.02	0.98
Ether extract								
Intake	26	27	22	23	0.2	<0.01	0.03	0.41
Digestion	527	556	556	570	6.1	0.04	0.04	0.41
Crude protein								
Intake	104	108	89	91	0.8	<0.01	0.03	0.41
Digestion	521	536	565	606	7.2	<0.01	0.02	0.23
Neutral detergent fiber								
Intake	206 b	214 a	132 b	179 a	1.4	<0.01	<0.01	<0.01
Digestion	448	468	464	482	7.3	0.20	0.10	0.92

In the same row (within animal species) with different letters (a, b) differ (P<0.05).
[a] Concentrate intake was not statistically analyzed as it was offered at a flat rate.

affected by feeding PEG, although digestion of OM, EE and CP were higher (P<0.05) with PEG feeding.

3.2.3. *C. speciosa*

Water consumption was higher (P=0.02) in sheep, which consumed more (P<0.01) total and foliage DM than goats absolutely (but less (P<0.01) foliage than goats relative to BW) (Table 4), as well as all measured nutrients, although their digestion of nutrients, except CP and NDFom, was lower (P<0.05 except OM P=0.06).

Addition of PEG had no impact on water intake, but increased (P<0.05) intake of DM and its components both absolutely and relative to BW, although relative to BW the increase in total DM intake was greater within goats (P=0.01). Digestion of CP and NDFom were not affected by feeding PEG, although digestion of DM, OM and EE were higher (P<0.05) with PEG feeding.

3.2.4. *E. camaldulensis*

Water consumption was unaffected by animal species, but sheep consumed more (P<0.01) total, but not foliage, DM than goats absolutely (although goats consumed more

Table 3
Water intake (l/d), feed intake (g/d) and digestion (g/kg) in sheep and goats fed *S. molle* in the absence (−) or presence (+) of PEG

	Sheep		Goats		S.E.M.	Significance (P)		
	−	+	−	+		Sp	PEG	Sp × PEG
Water intake (l/d)	3.6	3.1	2.9	2.8	0.1	0.04	0.25	0.90
Dry matter (DM) intake								
Foliage (g/d)	269	316	259	331	4.9	0.75	<0.01	0.11
Foliage (g/kg$^{0.75}$)	18.7 b	22.0 a	20.2 b	25.8 a	0.35	<0.01	<0.01	0.04
Concentrate[a]	320	320	274	274				
Total (g/d)	589	636	533	605	4.9	0.02	0.01	0.11
Total (g/kg$^{0.75}$)	41.0 b	44.3 a	41.6 b	47.2 a	0.35	0.01	<0.01	0.04
DM digestion	505	506	529	544	4.3	<0.01	0.19	0.13
Organic matter								
Intake	554	596	500	566	4.5	<0.01	<0.01	0.11
Digestion	538	544	567 b	605 a	6.2	<0.01	0.02	0.04
Ether extract								
Intake	40	44	37	44	0.5	0.03	<0.01	0.11
Digestion	511	536	544	559	5.8	0.01	0.04	0.54
Crude protein								
Intake	80	86	72	81	0.6	<0.01	<0.01	0.11
Digestion	496	528	544	608	6.2	<0.01	<0.01	0.10
Neutral detergent fiber								
Intake	231 b	225 a	164 b	250 a	2.5	<0.01	<0.01	<0.01
Digestion	491	503	496	522	7.5	0.29	0.11	0.52

In the same row (within animal species) with different letters (a, b) differ (P<0.05).
[a] Concentrate intake was not statistically analyzed as it was offered at a flat rate.

(P=0.01) foliage DM relative to BW) (Table 5), as well as all measured nutrients, although their digestion of nutrients was lower (P<0.05 except EE P=0.06).

Addition of PEG tended (P=0.06) to increase water consumption, although the actual values are not convincing. Addition of PEG only increased (P<0.05) intake of NDFom, although intake of DM and all other measured components tended (P<0.10) to be higher. Digestion of EE and NDFom were not affected by PEG, although digestion of DM, OM and CP were higher (P<0.05 except DM P=0.07) with PEG.

4. Discussion

4.1. Composition of the tree foliages

High CP, and low NDFom and ADFom levels, suggest browse with potential as N supplements to ruminants fed low quality forages during the dry season in semi-arid regions. Use of multipurpose trees and shrubs has become a useful alternative ruminant feed in harsh semi-arid environments (FAO, 1992; Topps, 1992). Differences in CP con-

Table 4
Water intake (l/d), feed intake (g/d) and digestion (g/kg) in sheep and goats fed *C. speciosa* in the absence (−) or presence (+) of PEG

	Sheep		Goats		S.E.M.	Significance (P)		
	−	+	−	+		Sp	PEG	Sp × PEG
Water intake (l/d)	2.6	2.8	2.3	2.3	0.09	0.02	0.77	0.59
Dry matter (DM) intake								
Foliage (g/d)	439	484	400	468	5.9	0.01	<0.01	0.20
Foliage (g/kg$^{0.75}$)	30.5	33.6	31.3	36.6	0.45	0.02	<0.01	0.12
Concentrate[a]	320	320	274	274				
Total (g/d)	760	804	675	743	5.9	<0.01	<0.01	0.20
Total (g/kg$^{0.75}$)	52.9 b	56.0 a	52.7 b	58.0 a	0.44	0.21	<0.01	0.01
DM digestion	524	556	609	624	5.9	<0.01	0.02	0.30
Organic matter								
Intake	711	752	631	694	5.4	<0.01	<0.01	0.20
Digestion	552	578	573	596	6.3	0.06	0.03	0.89
Ether extract								
Intake	35	37	31	34	0.3	<0.01	<0.01	0.20
Digestion	503	515	515	548	4.5	0.01	0.01	0.12
Crude protein								
Intake	103	109	92	100	0.8	<0.01	<0.01	0.20
Digestion	516	536	538	544	6.5	0.14	0.19	0.46
Neutral detergent fiber								
Intake	284 b	303 a	222 b	283 a	2.5	<0.01	<0.01	<0.01
Digestion	509	519	516	523	6.5	0.57	0.35	0.88

In the same row (within animal species) with different letters (a, b) differ (P<0.05).
[a] Concentrate intake was not statistically analyzed as it was offered at a flat rate.

tents between these browses are probably due to differences in protein accumulation in them during growth. The reported nutrient levels are comparable to those found by Le Houérou (1980), Topps (1992) and Rubanza et al. (2003), although some inconsistencies (*e.g.*, Rubanza et al. reported values ranging from 115 to 205, 52 to 126, 182 to 619, 68 to 196 and 44 to 130 g/kg DM for CP, ash, NDFom, ADFom, and lignin(sa), respectively, in browse legume tree leaves native to Tanzania) are likely due to differences in the stage of growth and type (*i.e.*, twigs, leaves or soft stem) of foliage sampled. Inconsistencies could also be due to sampling site and climatic influences on foliage growth and plant nutrient accumulation.

High secondary compound contents in foliages are mainly a property of plant genotypic factors controlling physiological synthesis and accumulation of secondary compounds (Okuda et al., 1993; Kelman et al., 1997). Other factors associated with high rates of polyphenolic synthesis include high environmental temperatures, drought stress, and plant defensive mechanisms against pests, pathogens and predators (Mangan, 1988). Shayo and Uden (1999) and Abdulrazak et al. (2000) also reported high phenolic and tannin levels in some East African browses. High polyphenolic components were also reported in semi-arid of north Egypt (Salem, 2005) and arid regions of Sudan (Fadel Elseed et al., 2002).

Table 5
Water intake (l/d), feed intake (g/d) and digestion (g/kg) in sheep and goats fed *E. camaldulensis* in the absence (−) or presence (+) of PEG

	Sheep		Goats		S.E.M.	Significance (P)		
	−	+	−	+		Sp	PEG	Sp × PEG
Water intake (l/d)	2.3	3.1	3.4	2.9	0.13	0.67	0.06	0.37
Dry matter (DM) intake								
Foliage (g/d)	222	239	233	244	5.2	0.29	0.09	0.70
Foliage (g/kg$^{0.75}$)	15.4	16.6	18.2	19.1	0.37	0.01	0.09	0.78
Concentrate[a]	320	320	274	274				
Total (g/d)	542	559	508	519	5.2	0.01	0.09	0.70
Total (g/kg$^{0.75}$)	37.8	39.0	36.6	40.5	0.38	0.01	0.09	0.78
DM digestion	506	506	518	560	6.9	0.01	0.07	0.07
Organic matter								
Intake	519	535	485	496	4.9	<0.01	0.09	0.71
Digestion	513	531	557	588	6.5	<0.01	0.03	0.47
Ether extract								
Intake	23	24	21	22	0.2	<0.01	0.09	0.70
Digestion	503	526	533	555	9.6	0.06	0.15	0.92
Crude protein								
Intake	81	84	76	78	0.8	0.01	0.09	0.70
Digestion	492 b	520 a	505 b	600 a	7.0	<0.01	<0.01	0.01
Neutral detergent fiber								
Intake	229	240	205	230	3.2	0.01	0.01	0.17
Digestion	431	437	453	456	5.7	0.04	0.62	0.92

Means in the same row (within animal species) with different letters (a, b) differ (P<0.05).
[a] Concentrate intake was not statistically analyzed as it was offered at a flat rate.

There were differences between levels of TP and CT in the tree foliages studied compared to similar tree foliages reported by others (*e.g.*, Rubanza et al. (2003) reported TP and CT were between 65–237 and 6–74 g/kg DM, respectively). This may, at least partly, be due to different assays and assay standards, although variability in chemical composition of polyphenolics among foliages (Makkar and Becker, 1993; Pino et al., 2005) may also be a factor. Some differences might also have been due to stage of plant growth and/or season of collection (Salem, 2005), site of sampling (Makkar and Becker, 1998), and/or proportions of foliage materials sampled (Salem, 2005).

In the current study, the secondary compounds SAP, ALKA, AF and EO were determined for the first time in these tree foliage species. However, their interpretive value relative to prediction of negative impacts of plant secondary compound levels on voluntary DM intake and animal performance may be modest, particularly for SAP, ALKA and EO, which were very strongly positively correlated to TP and CT in these tree foliages (Table 6). In contrast, AF was weakly negatively correlated to TP and CT, as well as SAP, ALKA and EO, suggesting that it may have value in predicting voluntary DM intake and performance of animals fed tree foliages.

Table 6
Intercorrelations (r) of plant secondary compounds[a]

	TP	CT	SAP	ALKA	AF
CT	0.997				
SAP	0.963	0.968			
ALKA	0.980	0.964	0.952		
AF	−0.458	−0.413	−0.212	−0.475	
EO	0.971	0.953	0.883	0.973	−0.646

[a] TP, total phenolics; CT, condensed tannins; SAP, saponins; Alka, alkaloids; AF, aqueous fraction.

4.2. *Effect of animal species*

Inter-animal species differences in voluntary intake of these foliages, without addition of PEG, were inconsistent among the foliages. While sheep ate more grams per day of *C. fistula*, *S. Molle* and *C. speciosa* than goats, intake of *E. camaldulensis* was slightly higher in goats. In contrast, sheep ate more *C. fistula* than goats relative to BW, but goats ate more of the other three foliages. Over all PEG unsupplemented foliages, goats consumed 3.9% more foliage DM than sheep per kg of $BW^{0.75}$ (Fig. 1), a finding consistent with Gilboa et al. (1995) who found that goats were able to consume larger amounts of tannin-rich browse than sheep under similar conditions, probably due, at least partially, to the ability of goats to detoxify higher amounts of tannins or secondary compounds *versus* other ruminants (Silanikove et al., 1996). In addition, goats, as browsers, may have selected the parts of the foliage with a higher proportion of CP, and lower proportion of fiber and/or secondary compounds, *versus* sheep as grazers (Kababya et al., 1998; Salem, 2002; Salem et al., 2003). However, this is speculatory, as the composition of the uneaten feed was not determined.

Salem et al. (2004a) observed an increase in the number of eating bouts of short duration in goats fed alfalfa hay treated with 50 g quebracho/kg DM, *versus* sheep fed the same hay, and suggested that this may be a mechanism used by goats to minimize negative effects of secondary compounds in foliages. The mobile upper lip of goats allows them to browse

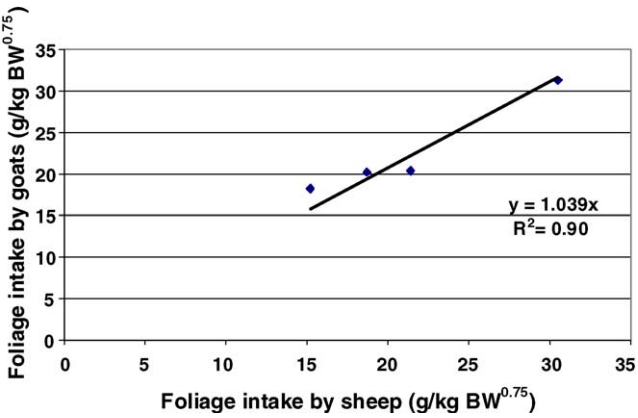

Fig. 1. Relationship between PEG unsupplemented foliage intake by goats and sheep (the intercept was 0).

a variety of plants to obtain nutrients under harsh conditions. In many studies (Tisserand et al., 1991; Silanikove, 2000a, 2000b; Salem et al., 2004a), goats had the ability to utilize woody species and low quality forages better than cattle and sheep, and were able to adapt better to harsh environments, such as the extensive shrub lands of evergreen shrubs and small trees, that are the basic component of the diets of goats raised in the Mediterranean basin.

In spite of the higher PEG unsupplemented foliage DM intake relative to BW of goats *versus* sheep in three of the four foliages, an event that would be expected to suppress digestibility (NRC, 2001), digestion of DM, and its measured components (except NDFom which was only numerically higher in three of the four foliages) were consistently higher in goats. For example, average DM digestibility was 509 g/kg in sheep and 551 g/kg in goats unsupplemented with PEG, suggesting an approximate increase of 8% in the energetic value of these foliages to goats *versus* sheep. In addition to the advantages of goats *versus* sheep noted above, their ability to consume larger amounts of tannin-rich browse (Gilboa et al., 1995) and ability detoxify higher amounts of tannins (or other secondary compounds) *versus* other ruminants (Silanikove et al., 1996), may occur by development of adaptive mechanisms in response to the presence of secondary compounds in the diet (Provenza and Malechek, 1984; Silanikove et al., 1996; Kababya et al., 1998; Salem et al., 2004a). Such an adaptive mechanism may be due to the existence of ruminal bacteria, such as *Streptococcus caprins*, in goats that has the ability to degrade tannin–protein complexes (Brooker et al., 1994). In addition, goats, as browsers, may have selected the parts of the foliage with a lower proportion of secondary compounds, *versus* sheep as grazers (Kababya et al., 1998; Salem, 2002; Salem et al., 2003).

4.3. *Effect of PEG supply*

Polyethylene glycol is widely used to neutralize tannins and other secondary compounds in foliages. Formation of complexes between PEG and secondary compounds, particularly tannins, from leaves of trees and shrubs was investigated by Makkar et al. (1995a), and the affinity of tannins for PEG at various pH's was demonstrated. Positive effects of PEG feeding on feed intake, digestibility, rumen fermentation, microbial synthesis, daily gain and wool growth by sheep and goats fed tannin rich forages have been widely demonstrated (Pritchard et al., 1992; Miller et al., 1997; Silanikove et al., 1997; Degen et al., 1998; Ben Salem et al., 2000; Decandia et al., 2000; Barry et al., 2001), but the nature and magnitude of the positive impact is thought to depend on factors such as tannin structure, level of tannin in the foliage, PEG dose level and means of administration, animal species and diet composition.

In the current study, the level of CT (as well as the levels of TP, SAP and ALKA due to their high correlations to CT levels as shown in Table 6) was a strong predictor of foliage DM intake (g/d), explaining 0.81 and 0.60 of the variation (*i.e.*, r^2) in sheep and goat DM intake, respectively (Table 7). Levels of AF and CP in the foliages were poor predictors (r^2 from <0.01 to 0.20) of DM intake, but when CP was added to CT, 0.87 and 0.78 of the variation in sheep and goat DM intake, respectively, was explained and if AF was added to CT, predictions were essentially perfect. Clearly four foliage observations are insufficient to support firm conclusions, but it suggests that negative effects of CT on DM intake can

Table 7
Power (r^2) of CT, AF and CP to predict foliage DM intake (g/d) by sheep and goats fed foliages not supplemented with PEG, and to predict the percentage increase in foliage DM intake due to feeding PEG

Predictor[a]	DM intake		DM intake increase (%)	
	Sheep	Goats	Sheep	Goats
CT	0.81	0.60	<0.01	0.04
AF	<0.01	0.04	0.01	<0.01
CP	0.08	0.20	0.62	0.64
CT + CP	0.87	0.78	0.62	0.76
AF + CP	0.10	0.20	0.87	0.99
CT + AF	0.99	0.99	0.02	0.04

[a] CT, condensed tannins; AF, aqueous fraction; CP, crude protein.

be counteracted to only a slight degree by lower levels of CP, but to a substantive extent by higher levels of AF.

In general, these results are consistent with findings of others. For example, secondary compounds, particularly phenolics, could act by lowering foliage palatability by their negative effects in the mouth, such as by astringent bitterness (Jackson et al., 1996), binding to salivary proteins in the mouth (Wong, 1973; Salem et al., 2000), or by negative effects on gustative receptors (McLeod, 1974). Higher levels of secondary compounds in foliages, particularly in *E. camaldulensis*, during eating could have negatively affected salivation rate, which could have increased the astringent taste and so decreased feed intake (Salem et al., 2000, 2001). Reduced salivation might also have negatively affected ruminal microbial activity (Salem et al., 2002) and inhibited enzyme production (Dawson et al., 1999; Barry and McNabb, 1999; Salem et al., 2002). In addition, secondary compounds perturb intestinal wall permeability through reactions with intestinal membrane proteins (McLeod, 1974; Zimmer and Cordesse, 1996; Fondevila et al., 2002).

Studies on tannin–saponin interactions which suggested that effects of both tannins and saponins to decrease *in vitro* digestibilities and gas production were additive (Makkar et al., 1995b; Makkar, 2003a), do not support the hypothesis that simultaneous presence of tannins and saponins might alleviate the adverse effect of each other. For example, Johnson et al. (1986) found that some saponins increase the permeability of intestinal mucosal cells *in vitro*, inhibit active mucosal transport and facilitate intestinal absorption of compounds that are normally not absorbed.

The EO, which are the volatile components responsible for some of the characteristic aroma of foliage species, may also have negative effects on DM intake. EO appear to have selective antibacterial activity (Janssen et al., 1986; Demetzos et al., 1997; Newbold et al., 2004), and Nagy and Tengerdy (1968) found that addition of EO extracted from Sagebush (*Atemisa tridentate*) altered the rumen bacterial population composition.

Feeding PEG has been shown to improve intake of foliage containing secondary compounds in goats (Silanikove et al., 1997; Decandia et al., 2000) and sheep (Silanikove et al., 1994; Salawu et al., 1997). It has also been shown to increase availability of nutrients in the gastrointestinal tract and so increase digestibility (Ben Salem et al., 2005). However, the actual chemical linkages between tannins and PEG that neutralize the negative effects of secondary compounds of foliages to allow increased feed intake and digestibility are not

clear. Consistent with results of others, supplementation of PEG to sheep and goats in the current study increased foliage DM intake and digestion to variable extents in both animal species fed all foliages.

The foliages used in the current study had very different levels of secondary compounds (*e.g.*, the CT of *E. camaldulensis* was 3.27 times that of *C. speciosa*), and it might have been expected that PEG feeding would have a larger positive impact on DM intake in foliages with higher level of secondary compounds. However, this was not the case. The level of CT (as well as the levels of TP, SAP and ALKA due to their high correlations to CT levels as shown in Table 6) was not a predictor of the percentage increase in foliage DM intake due to feeding PEG in either sheep or goats, explaining only <0.01 and 0.04 of the variation for sheep and goats, respectively, increase in foliage DM intake due to PEG (Table 7). The best single (negative) predictor of the percentage increase in foliage DM intake due to PEG feeding was the CP level of the foliage, explaining 0.62 and 0.64 of the variation for sheep and goats, respectively. If CT was added to CP as a predictor, the variation explained did not change (*i.e.*, 0.62 and 0.76), however addition of AF (positive) to CP increased the variation explained to 0.87 and 0.99, respectively, for sheep and goats.

The inability of CT (and by correlation the other secondary compounds) to explain the percentage increase in DM due to PEG feeding contrasts to the ability of CT to predict the absolute DM intake of these foliages. However, as previously noted, four foliage observations are insufficient for firm conclusions, although it does suggest that the positive effects of PEG on DM intake may not be related to its levels of CT, or other secondary compounds, but due to associations with CP and AF that overcome the negative affects of secondary compounds on DM intake and digestion.

5. Conclusions

The nutritional quality of the browse tree foliages *C. fistula*, *S. molle*, *C. speciosa* and *E. camaldulensis*, native to the semi-arid region of north Egypt, were evaluated by determining levels of nutrients and secondary compounds, as well as feed intake and apparent digestibility in sheep and goats. Goats consumed 3.9% more DM than sheep per kg $BW^{0.75}$, and their digestibility was about 8% higher. Levels of CT (and due to its correlations, also TP, SAP, ALKA and EO) was a strong predictor of DM intake of PEG unsupplemented foliages in both sheep and goats. PEG increased intake of DM and its components in both sheep and goats, but levels of TP (and due to its correlations, also CT, SAP, ALKA and EO) was not a predictor of the proportional increase in DM with PEG feeding, which was best predicted by the level of CP within foliage (negative), which was improved by adding AF (positive) to the prediction. *C. speciosa*, had the highest nutrient value for both sheep and goats, both without and with PEG feeding, *S. molle* and *C. fistula* were intermediate and *E. camaldulensis* had the lowest nutritive value.

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