Effect of drying method on chemical composition and *in vitro* digestibility of multi-purpose tree and shrub fodders

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Abstract

Methods of drying fodder (sun-air- vs oven-drying) from 8 multi-purpose trees and shrubs were compared with freeze-drying in one experiment. Twelve-month-old coppice foliage (leaf and petioles) was separated from browseable stem components. The samples were either sun-air-dried for 3 days at 25°C maximum day temperature or oven-dried at 65°C for 48 hours. These dried samples were compared with freshly cut samples that were freeze-dried in liquid nitrogen. In a second experiment, both leaf and browseable stem components of the fodder were either sun-air- or oven-dried as in Experiment 1 above. Dry matter, acid and neutral detergent fibre (ADF; NDF), lignin, soluble polyphenolics, NDF insoluble condensed tannins, total N and NDF-N concentrations were determined. The *in vitro* digestibilities of both organic and dry matter (IVOMD, IVDMD) were also determined.

Major differences were recorded in fibre and nutrient concentrations between multi-purpose tree species, fodder components and drying methods. *Flemingia macrophylla* and *Acacia angustissima* had the lowest overall IVDMD, probably on account of their high ADF, NDF and lignin concentrations.

Oven-drying resulted in an overall increase in ADF, NDF and lignin concentrations compared with sun-drying and freeze-drying. However, oven-drying resulted in an overall reduction in soluble polyphenolics, total N, NDF-N and IVOMD.

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The implications of the effects of drying method on *in vitro* digestibility values are discussed in the context of preservation of the fodders for dry season use.

Introduction

Fodder production profiles in the unimodal rainfall plateau of Southern Africa are characterised by large amounts of foliage production at the end of the 4-to 5-month-long rainy season. Up to 8–15 t/ha forage dry matter production can be realised. When left uncut, this foliage biomass would be lost during the long dry season due to leaf fall, frost damage or decomposition. This is particularly true in Zimbabwe where frosts are experienced in the June–July period. Consequently, at the height of the dry season, most trees become deciduous in response to climatic stress. Forage conservation strategies are necessary and include cutting and drying before leaf drop sets in. Once cut, the fodder, usually made up of leaves, browseable twigs and small stems (≤8–10mm diameter), is dried, mostly by spreading the material on a concrete floor until it can be easily crushed in the hand, usually after 2–3 days. At this stage, the material is still green in colour, but drying for longer periods results in a brown coloration associated with loss of quality.

Alternatively, the drying could be done using an artificial heating source such as a temperature-regulated, forced-draft oven. Both drying methods conserve the forage for use in the dry season. However, depending on temperatures used, drying causes losses in water-soluble carbohydrates due to respiration and possibly decomposition (Smith 1973; van Soest 1982; Abdalla *et al.* 1988; Ahn *et al.* 1989; Deinum and Maassen 1994) and Maillard reaction (Schnickels *et al.* 1976). These complexes are poorly soluble in acid and neutral detergents (van Soest 1982) and their formation increases with heat input during the drying process.

Other reports by Smith *et al.* (1967), Goering and van Soest (1970), Grant and Campbell (1978), Burritt *et al.* (1988) and Papachristou and Nastis (1994) indicate that oven-drying increases the neutral detergent fibre (NDF) and lignin concentrations and depresses the *in vitro* dry matter digestibility (IVDMD). The solubility of N could also be affected by the drying method, thus lowering the nutritive value of fodder (van Soest 1982). Information is needed on the effects of drying forages derived from woody species in smallholder farming systems. The present study was designed to determine the most suitable drying method for tropical multi-purpose leguminous tree/shrub foliages (MPTs) under subhumid conditions in Zimbabwe.

Materials and methods

The study was conducted at Domboshawa Training Centre (31° 13'E, 17° 30'S, altitude 1530m), 30km north-east of Harare, Zimbabwe. Long-term annual rainfall is 895mm, falling predominantly from November - March. Summer temperatures rise to a maximum monthly mean of 27.9°C in October and fall to a minimum winter mean of 5.5°C in July. Evapotranspiration is highest (224mm/week) in October and lowest (100mm/week) in June. Ground frosts are experienced in the June - July period.

Soils are classified as Ferrallic cumbisols (Nyamapfene 1991), derived *in situ* from granodiorite, of relatively low fertility, and predominantly of a sandy loam texture.

Eight MPTs (*Acacia angustissima*, *Cajanus cajan*, *Calliandra calothyrsus*, *Flemingia macrophylla*, *Gliricidia sepium*, *Leucaena leucocephala*, *Sesbania macrantha* and *S. sesban* var. *nubica*) were planted out in the 1990–91 growing season in a randomised complete block layout with 3 replicates. Plot size was 8 × 8m with trees spaced on a 2m × 2m grid.

At the end of the 1992–93 growing season (in April), 12-month regrowth plants were cut back to a 20cm stubble and the leaf components (including the petiole) were separated from the stems. They were then sun-air-dried for 3 days on an open concrete floor. Ambient maximum sunny-day temperature averaged 25°C. The other drying treatment involved oven-drying at 65°C for 48 hours. Samples dried by these methods were compared with other samples freshly cut and freeze-dried at the liquid nitrogen temperature of −46°C in Experiment 1.

In Experiment 2, both the leaf component and the browseable twigs (≤ 10mm in diameter) were either sun-dried or oven-dried under similar temperature conditions as above. For the leaf component, the following analyses were done: dry matter (DM) concentration by drying at 105°C; acid and neutral detergent fibre (ADF; NDF) and lignin concentrations (Goering and van Soest 1970); soluble polyphenolics concentration by precipitating with trivalent ytterbium (Reed *et al.* 1985); insoluble condensed tannins (proanthocyanidins and other related flavonoids) on NDF using the vanillin-HCl assay of Broadhurst and Jones (1978); and *in vitro* organic matter digestibility according to Goering and van Soest (1970). Nitrogen was estimated using the modified Kjeldahl method (Davidson *et al.* 1970). Organic matter concentration was determined by combustion in a muffle furnace at 600°C for 4 hours, and *in vitro* organic matter digestibility (IVOMD) by the method of Goering and van Soest (1970). *In vitro* dry matter digestibility (IVDMD) was determined by the Tilley and Terry method (1963). For all chemical analyses, the samples were dried at 65°C for 48 hours. This was done to standardise moisture levels of all samples before analyses.

All data were subjected to an analysis of variance procedure (Steel and Torrie 1980).

Results

In Experiment 1, ADF, NDF and IVDMD values were affected by MPT species, drying method and plant component (Table 1). Lowest ADF values occurred in the leaves of *Sesbania sesban*, *Sesbania macrantha* and *Gliricidia sepium*. Similarly, *S. sesban* and *S. macrantha* had the lowest NDF values in their leaf components. There was much less variation in the ADF and NDF values for stem material, but stems consistently had higher NDF and ADF than leaves. Highest IVDMD occurred in leaves of *S. sesban* and *S. macrantha*. Overall, leaves were much more digestible than stems (44 vs 26%).

Overall, oven-drying produced the highest ADF and NDF concentrations in both leaf and stem material and freeze-drying the lowest. IVDMD levels followed the reverse pattern, being

Table 1. Effect of drying method on fibre (ADF and NDF) composition and *in vitro* dry matter digestibility (IVDMD) of leaf and stem forage components of different multi-purpose trees (MPT) in Experiment 1.

MPT species	Drying methods	Fibre composition and IVDMD					
		ADF		NDF		IVDMD	
		Leaf	Stem	Leaf	Stem	Leaf	Stem
		(%)		(%)		(%)	
Acacia angustissima	Freeze-dried	44.4	46.0	53.9	55.6	24.8	35.0
	Oven-dried	59.9	67.4	82.9	70.6	23.2	30.1
	Sun-dried	55.0	59.1	61.8	63.9	40.1	17.2
Cajanus cajan	Freeze-dried	28.5	57.5	35.0	60.6	44.7	30.8
	Oven-dried	57.1	68.2	60.0	80.3	30.3	10.9
	Sun-dried	36.2	62.4	41.1	73.6	35.6	23.2
Calliandra calothyrsus	Freeze-dried	35.7	61.7	46.2	71.8	40.2	23.3
	Oven-dried	69.4	58.5	79.5	70.5	19.5	31.5
	Sun-dried	32.6	64.5	48.0	69.3	35.8	22.0
Flemingia macrophylla	Freeze-dried	41.4	44.1	48.7	57.1	31.5	28.0
	Oven-dried	70.3	74.0	71.8	81.3	27.6	14.7
	Sun-dried	50.6	58.4	58.7	60.3	27.7	16.8
Gliricidia sepium	Freeze-dried	26.4	44.3	49.4	56.9	52.3	45.7
	Oven-dried	36.7	63.4	56.6	87.7	57.7	20.0
	Sun-dried	31.6	56.0	43.8	63.8	51.0	36.5
Leucaena leucocephala	Freeze-dried	21.3	20.5	27.6	66.4	63.4	35.8
	Oven-dried	55.9	77.6	59.8	77.8	29.7	20.8
	Sun-dried	49.2	60.1	54.3	63.4	43.7	22.7
Sesbania macrantha	Freeze-dried	23.3	58.8	28.2	65.6	66.3	25.2
	Oven-dried	39.6	67.4	50.9	83.5	62.7	30.1
	Sun-dried	30.6	64.5	36.9	70.7	54.0	22.0
Sesbania sesban	Freeze-dried	15.5	39.9	24.1	40.8	76.1	39.6
	Oven-dried	24.1	69.7	71.8	72.5	60.5	20.0
	Sun-dried	17.7	59.7	24.1	73.8	66.3	19.1
Means:	MPT species	39.7	58.5	50.6	68.2	44.4	25.9
	Drying methods:						
	Freeze-dried	29.6	46.6	39.1	59.4	49.9	32.9
	Oven-dried	51.6	68.3	66.7	78.3	38.9	22.3
	Sun-dried	37.9	60.6	46.0	67.4	44.3	22.4
LSD (P<0.05)	MPT means	11.8		11.4		7.3	
	Drying methods	7.3		6.9		6.6	
	Forage components	5.8		5.5		5.2	
	CV (%)	16.8		13.6		21.2	

highest in freeze-dried and lowest in oven-dried material.

In Experiment 2, MPT species and method of drying had significant effects on most parameters studied (Table 2). Although ADF levels did not differ significantly between species, *Sesbania sesban* and *Gliricidia sepium* had lower NDF and lignin concentrations than other species. Levels of soluble phenolics ranged from 1.9–11.2% in different MPT species, the lowest levels being in *Gliricidia sepium* and *Cajanus cajan* and the highest in *Calliandra calothyrsus*. While total N ranged from 1.9–3.4%, about 65% of this on average was bound to the neutral detergent fibre. However, *Leucaena leucocephala* was atypical in that only 28% of its total N of 3.25% was bound to NDF. In general, sun-drying increased the level of total N which was bound to the NDF fraction. Overall, sun-drying reduced NDF, ADF and lignin concentrations but increased total N and NDF–N as well as the level of soluble phenolics. IVOMD was unaffected by drying method.

ADF, NDF and lignin levels were all positively and significantly related, but were significantly

Table 2. Effect of drying methods on chemical composition and *in vitro* digestibility of organic matter (IVOMD) for different multi-purpose trees (MPT) in Experiment 2.

MPT species	Drying methods	ADF	NDF	Lignin	Soluble polyphenols	Total N	NDF (N)	IVOMD
		(%)	(%)	(%)	(%)	(%)	(%)	(%)
Acacia angustissima	Sun-dried	36.7	50.8	14.3	12.2	3.1	2.1	34.8
	Oven-dried	48.9	58.4	17.1	8.0	2.5	1.2	32.1
Cajanus cajan	Sun-dried	42.0	56.6	16.5	4.2	3.3	2.7	44.3
	Oven-dried	47.9	62.3	18.9	1.4	3.5	1.2	45.8
Calliandra calothyrsus	Sun-dried	35.8	46.3	11.4	6.9	2.0	1.8	33.4
	Oven-dried	51.6	54.3	20.9	15.4	1.8	1.1	30.2
Flemingia macrophylla	Sun-dried	44.0	59.4	19.3	10.5	2.4	1.9	25.4
	Oven-dried	49.9	62.8	22.5	5.5	1.9	0.9	29.2
Gliricidia sepium	Sun-dried	33.7	38.2	11.1	2.3	3.1	2.5	53.1
	Oven-dried	42.7	36.2	14.8	1.5	2.4	1.1	51.8
Leucaena leucocephala	Sun-dried	33.0	45.8	12.2	12.2	3.2	1.3	45.5
	Oven-dried	51.5	62.5	18.6	2.7	3.3	0.5	33.2
Sesbania sesban	Sun-dried	31.7	38.2	6.7	11.2	2.9	2.1	64.2
	Oven-dried	28.2	36.2	6.5	9.2	2.8	1.1	69.9
Means	Sun-dried	30.4	47.9	13.1	8.5	2.8	2.1	42.8
	Oven-dried	38.0	53.2	17.0	6.2	2.1	1.1	41.7
LSD (P<0.05)	MPT spp.	12.8	9.7	5.5	5.5	0.6	0.5	9.7
	Drying methods	6.6	5.2	2.8	3.1	0.3	0.3	5.2
	CV (%)	12.6	7.6	14.7	31.1	9.4	12.4	9.4

Table 3. Correlation coefficients (r) of the relationship between IVOMD, ADF, NDF, lignin, soluble polyphenolics, total N and NDF-N concentrations of 7 multi-purpose tree (MPT) fodders.

Variable	ADF	NDF	Lignin	Sol. phen	Tot-N	NDF-N	IVOMD
ADF	—						
NDF	0.95***	—					
Lignin	0.93***	0.94***	—				
Sol. phen	–0.14	0.11	–0.03	—			
Tot-N	–0.18	–0.13	–0.06	0.06	—		
NDF-N	0.29	0.08	0.11	–0.71***	0.33	—	
IVOMD	–0.71**	–0.78**	–0.80***	–0.16	0.51**	0.25	—

and negatively correlated with IVOMD. The significant negative correlation between IVOMD and NDF and ADF concentrations was strongest (P<0.001) for freeze-dried and oven-dried leaf and still significant (P<0.05) for sun-dried leaf (Table 3; Table 4).

There were large variations in N, NDF-N, lignin and tannin contents of the fodders (Table 5). However, there was no consistency in the relationship between levels of extractable condensed tannins in NDF-N and lignin contents. For instance, *A. angustissima* and *C. calothyrsus* had

Table 4. Correlation coefficients (r) of IVOMD versus fibre components (ADF and NDF) for multi-purpose tree fodders freeze-dried, oven-dried and sun-dried.

Drying method	ADF	NDF
Freeze-dried leaf	–0.98 ***	–0.89 ***
Oven-dried leaf	–0.92 ***	–0.62 ***
Sun-dried leaf	–0.72 *	–0.79 *
Freeze-dried stem	–0.57 NS	–0.61 NS
Oven-dried stem	–0.49 NS	–0.43 NS
Sun-dried stem	–0.34 NS	–0.06 NS

Table 5. Chemical quality factors of foliage (leaflets and petioles) of 12-week-old regrowth of multi-purpose trees.

MPT species	Total N	NDF-N	Lignin	Soluble polyphenolics	Condensed tannins (550nm/g NDF)
	(%)	(%)	(%)	(%)	
Acacia angustissima	2.5	1.9	14.3	12.2	15.8
Cajanus cajan	3.1	1.2	14.0	4.2	88.9
Calliandra calothyrsus	2.7	1.2	11.4	15.4	53.3
Gliricidia sepium	1.8	0.9	11.1	2.3	208.6
Flemingia macrophylla	1.8	1.1	19.3	10.5	102.6
Leucaena leucocephala	3.1	1.1	12.0	12.2	49.7
Sesbania sesban	2.8	0.5	6.7	11.2	16.4

soluble polyphenolics levels above 10% of the DM and high lignin levels above 10% of the DM. However, they contained lower levels of bound condensed tannins than *F. macrophylla* and *G. sepium.*

Discussion

The fact that oven-drying resulted in increases in the fibre components and lignin, thereby decreasing IVDMD and IVOMD, is consistent with results obtained by other workers (Goering and van Soest 1970; Burritt *et al.* 1988; Nastis and Malechek 1988; Papachristou and Nastis 1994) and thought to be due to formation of artefact lignin. Differences between oven-dried and freeze-dried samples are particularly attributed to non-enzymatic browning effect and the formation of insoluble polymers (van Soest 1982). Alternatively, the differences may simply be due to loss of organic matter (Acosta-Gonzalez and Kothman 1978). This latter explanation is consistent with the studies of Mahyuddin *et al.* (1988) especially with respect to *F. macrophylla.* Freeze-drying, on the other hand, gives results that are closest to the ideal because enzyme activity is low and ice crystals may not disrupt membranes and cell walls (Deinum and Maassen 1994). Sun-air-drying exposes the material to ultra-violet radiation, which reacts with forage constituents to increase ADF and NDF and reduce digestibility. This was particularly evident in the present study in both *A. angustissima* and *F. macrophylla* in which their low digestibility values could be attributed to their exceedingly high ADF, NDF, and lignin contents (Table 5). Ultra-violet radiation could, to some extent, cause the browning or Maillard effects. It is possible to avoid direct ultra-violet radiation by air-drying under a thatched shade. This is an area that needs to be investigated.

While sun-air-drying is practicable under farm situations in Zimbabwe's smallholder and large-scale commercial farming systems, the other methods, freeze-drying and oven-drying, were used merely for purposes of comparison. However, when one considers the large-scale commercial farming sub-sector only, the threat of imminent frost damage on standing herbage within a month after the cessation of rains in April could make oven-drying feasible for fast drying of large amounts of herbage.

G. sepium has been shown elsewhere to have one of the highest rumen degradability coefficients of DM (Dzowela *et al.* 1995). The low and apparently non-significant relationship between phenolics, the condensed tannin content and *in vitro* degradability of DM (e.g. in *G. sepium*) agrees with reports of Nastis and Malechek (1981) and Nunez-Hernandez *et al.* (1989). The result of the present trial may mean that the phenolic assays used failed to measure some phenolic compounds which have a negative effect on the nutritive value of some tree/shrub fodders (Khazaal *et al.* 1994). For instance, certain soluble phenolics are not precipitated in the ytterbium precipitation method (Lowry and Sumpter 1990). Mueller-Harvey and McAllan (1992) have reported that many new compounds have been identified within the last decade, which, while not fitting into the categories of either condensed or hydrolysable tannins, show tannin-like properties.

The stem component, being woody, is generally considered to be higher in fibre than leaf (Brown and Pitman 1991); it usually has high ADF and NDF, resulting in lower dry matter digestibility (Table 1). An exception to this was *A. angustissima* in which freeze-dried and oven-dried stem material had higher IVDMD (7-10 percentage units) than the leaf. This is attributed to the condensed tannin levels of the leaf (Dzowela *et al.* 1995). In certain woody plants, leaves are generally higher in tannins than stems or woody parts (Zucker 1983; Robbins *et al.* 1987), thereby potentially depressing leaf digestibility (Bassala *et al.* 1991). Elevated levels of polyphenolics and condensed tannins have been reported in *A. angustissima* by Ahn *et al.* (1989). Oven-drying of this species will result in the formation of tannin-cell wall complexes which could lower digestibility (Reed 1986).

Conclusion

This research has important practical implications in the mixed farming systems of the unimodal rainfall plateau of Southern Africa, where the 7-month dry season can be aggravated by severe frosty winters, calling for the need to conserve high-protein supplementary feedstuffs such as leguminous tree and shrub fodders. The influences of drying methods on nutritional factors of the fodders must be considered in the context of the data presented above. For instance, if sun-air-drying results in the reduction of digestibility as reported above, then air-drying in the shade could be done. This method, however, could lengthen the drying periods.

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