Morphological, chemical and in vitro stover quality traits to predict the livestock productivity potential of pearl millet stover

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Introduction

Pearl millet (*Pennisetum glaucum*) is one of the important coarse cereals in the smallholder crop livestock systems of the semi-arid tropics of Asia and Africa. Pearl millet provides grains for human consumption and stover for the livestock and perceptions about stover fodder quality traits were actually shown to influence farmers' decision about adoption of new pearl millet cultivars (Kelly et al. 1996). In response, new pearl millet improvement programs started to explore the feasibility of including pearl millet stover fodder quality traits into the breeding and selection work. These new programs need stover quality indicators that are: (1) closely related to actual livestock productivity; (2) easy to measure in large numbers of plant samples; and (3) simple to interpret also by non-livestock nutritionist. The work presented here relates to a wide array of morphological, chemical and in vitro measurements to the organic matter digestibility (OMD), organic matter intake (OMI), digestible organic matter intake (DOMI) and nitrogen balance (accretion or loss of nitrogen) of 34 pearl millet genotypes in relation to livestock productivity involving sheep.

Materials and methods

Pearl millet stover investigated. The stovers originated from eight pearl millet cultivars (GB 8735, Guerinari, Jakhrana, Sadore Local, Sosat C-88, Wrajpop, ICMV 155 and ICMV 221) and were grown for the livestock trials on the research fields of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India in 2002, 2005 and 2006. The total number of 34 treatments from eight cultivars is accounted for by varying soil condition (black versus red soil), stage of harvest (physiological versus full maturity) and design of experimental varieties (dual purpose-, high grain yield-, high stover digestibility-, and high stover nitrogen variety) from cultivar ICMV 221 through two cycles of recurrent selections.

Morphological measurements. The morphological traits measured were plant height, stem diameter, leaf blade : leaf sheath : stem ratio and residual green leaf area (using Li-Core Area Counter Instrument).

Chemical stover quality traits. The traits analyzed were nitrogen content by auto analyzer and the cell wall constituents, neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL), according to Goering and Van Soest (1970).

In vitro rumen digestibility, metabolizable energy content, and rate and extent of digestion. In vitro rumen organic matter digestibility (IVOMD) and metabolizable energy (ME) content were analyzed according to Menke and Steingass (1988). Rate and extent of in vitro digestion were estimated according to Blümmel and Ørskov (1993).

Livestock productivity trials. Each pearl millet stover was chopped and fed *ad libitum* (allowing for refusal of about 15% of the stover offered) to six growing male Deccani sheep (average body weight approximately 20 kg) kept in metabolic cages. Measurements on OMD, OMI, DOMI and nitrogen balance were recorded during a 10-day period after a minimum of 14-day preliminary feed adjustment periods.

Statistical analysis. The computer software package Statistical Analysis System (1988) was used for analysis of variance (Proc. GLM) to assess statistical difference in the stover treatments during the feeding trials. Simple correlations between morphological, chemical and in vitro measurements and livestock productivity measurements were analyzed using SAS Proc. Corr. and stepwise multiple regressions.

Results and discussion

Livestock productivity measurements. The ranges in OMD, OMI, the product of the two, ie, DOMI and nitrogen balance observed in the sheep fed on 34 pearl millet stovers are reported in Table 1. The differences in these measurements were highly ($P < 0.0001$) significant. Although it was not the objective of the present work to investigate differences between pearl millet cultivars in stover quality, these differences were consistently observed within comparable trial layouts (soils, harvest dates and experimental varieties). Of the recorded in vivo measurements, DOMI and nitrogen balance are of higher importance for actual livestock productivity than OMD and OMI. The DOMI combines the information on both OMD and OMI and nitrogen balance estimates changes in the animal itself, ie, accretion or loss of tissue nitrogen. Accurate prediction of these two measurements is therefore important for assessing the livestock productivity potential of feeds and fodder.

How individual laboratory stover quality traits relate to the livestock productivity measurements. The laboratory quality traits investigated for their potential in predicting OMD, OMI, DOMI and nitrogen balance fell into three categories, morphological, chemical and in vitro measurements. The requirements in terms of laboratory infrastructure increase in the order of morphological > chemical analysis > in vitro measurements. Simple correlations between these traits and OMD, OMI, DOMI and nitrogen balance are reported in Table 2. Except for green leaf area, morphological measurements are rather easily obtained even in the field without much need for equipment. They would therefore be very convenient fodder quality traits. However, only plant height and stem diameter showed consistent significant (negative) relationships with the in vivo measurement. They accounted for a maximum of 55% (plant height) and 50% (stem diameter) of the variation in DOMI and 50% (plant height) and 40% (stem diameter) of the variation in nitrogen balance (Table 2). At this point, we do not have an explanation for the negative association between plant height and livestock productivity potential; so more research is required. As to stem diameter, it is quite plausible that thick stem/stem pieces are harder to consume than thin stems, which would account for the rather strong inverse relationship between stem diameter and OMI and DOMI. Interestingly, leafiness, as reflected in leaf blade proportions and leaf quality as reflected in green leaf area, were not well correlated to any of the in vivo measurements.

In contrast, chemical constituents were highly (P <0.0001) correlated with the in vivo measurements, positively in the case of nitrogen and negatively in the case of the cell wall constituents: NDF, ADF and ADL (Table 2). The estimate of cell wall content NDF accounted for 69 and 74% of the variation in DOMI and nitrogen balance, respectively, confirming the important role of this plant fraction in ranking for fodder quality (Van Soest 1994). The NDF (and ADF) measurement is a single step fractionation analysis in contrast to ADL analysis, that requires several steps making the analysis time consuming and prone to additive errors. In other words, NDF estimation is a simple and convenient chemical analysis and high correlation between NDF and in vivo measurements makes NDF an important laboratory quality trait for ranking pearl millet stover.

Close relationships were also observed between in vitro digestibility, and ME content and in vivo measurements (Table 2). These in vitro measurements are based on inoculation of feed samples with microorganisms from the rumen, and put in a simplified manner, define the proportion of the feed useful to the animal. In particular ME measurements can be used for feed ration design and calculation of potential meat and milk production. In vitro measurements yield an immediate description of feed quality than, for example, cell wall constituents such as NDF, which entail a correlative relationship with feed quality. Unfortunately, in vitro measurements also require rumen cannulated animals as donor for rumen microorganisms, which can be a drawback for pure crop improvement institutions. However, collaborations such as the one between ICRISAT and International Livestock Research Institute (ILRI) can easily overcome such constraints. Rate and extent of digestion, which include a kinetic element of feed digestion, while highly correlated with the in vivo measurements, did not provide more accuracy than the simpler in vitro digestibility and ME measurements (Table 2). Since considerable laboratory input is involved in the former two than the latter, we do not recommend rate and extent measurements for assessments of pearl millet stover. Similar observations were reported for fine cereal straws (Blümmel and Ørskov 1993).

Combination of morphological, chemical and in vitro measurements in the prediction of livestock

Table 1. Variations in organic matter digestibility (OMD), organic matter intake (OMI), digestible organic matter intake (DOMI) and nitrogen balance in sheep fed pearl millet stovers *ad libitum* (n = 34).

Variable	Range	Mean	LSD	P
OMD (%)	47.7–60.1	54.4	2.6	<0.0001
OMI (g/kg $LW^{0.75}$/d)	36.9–59.6	49.0	6.2	<0.0001
DOMI (g/kg $LW^{0.75}$/d)	18.7–35.1	26.7	3.1	<0.0001
Nitrogen balance (g/kg $LW^{0.75}$/d)	–0.23–0.28	–0.02	0.08	<0.0001

productivity associated measurements. A combination of morphological, chemical and/or in vitro measurements, using stepwise multiple regression procedures, did improve the prediction of OMI, DOMI and nitrogen balance (Table 3) compared to the use of a single laboratory trait. A combination of NDF and stem diameter, for example, accounted for 78 and 83% of the variation in OMI and DOMI, respectively. These findings suggest that morphological and chemical measurements convey complementary information about feed value and livestock productivity potential. Chemical (and in vitro) analysis uses dried feed samples milled to pass through a 1 mm mesh. Important information related to structure of the feed can be lost in this way. After all, livestock does not eat finely ground stover but stover chopped to various lengths and livestock has to cope with plant structure while eating. Eighty-two percent of the variations in nitrogen accretion/losses were accounted for by a combination of IVOMD, ADF and nitrogen with ADF and nitrogen both contributing 4% to the variation explained by IVOMD (74%).

Table 2. Correlations (r) between diverse laboratory fodder quality traits and OMD (%), OMI (g/kg $LW^{0.75}$/d), DOMI (g/kg $LW^{0.75}$/d) and nitrogen balance (g/kg $LW^{0.75}$/d)[1].

Trait	OMD	OMI	DOMI	Nitrogen balance
Morphological/physical measurements				
Plant height (cm)	–0.68***	–0.70***	–0.74***	–0.70***
Stem diameter (mm)	–0.57**	–0.71***	–0.71***	–0.63***
Stem proportion	–0.36*	–0.29	–0.34	–0.47**
Sheath proportion	0.03	0.28	0.21	0.07
Leaf blade proportion	0.35*	0.23	0.30	0.46**
Green leaf area (cm^2)	0.20	0.26	0.27	0.27
Chemical analysis				
Nitrogen (%)	0.43*	0.65***	0.62***	0.67***
NDF (%)	–0.75***	–0.81***	–0.86***	–0.83***
ADF (%)	–0.74***	–0.67***	–0.76***	–0.83***
ADL (%)	–0.76***	–0.58***	–0.69***	–0.76***
In vitro measurements				
IVOMD (%)	0.85***	0.72***	0.82***	0.86***
ME (MJ kg^{-1})	0.86***	0.71***	0.82***	0.85***
Extent (ml)	0.78***	0.64***	0.75***	0.76***
Rate (ml h^{-1})	0.69***	0.55**	0.64***	0.69***

1. Abbreviations as in the text.
   * = P <0.05; ** = P <0.01; *** = P <0.0001.

Table 3. Stepwise multiple regressions between laboratory fodder quality traits and OMI (g/kg $LW^{0.75}$/d), DOMI (g/kg $LW^{0.75}$/d) and nitrogen balance (g/kg $LW^{0.75}$/d)[1].

Laboratory traits (x)	In vivo variables (y)	R^2	*P*
Model: NDF + stem diameter	OMI	0.78	<0.0001
Step 1: NDF (–0.82)[2]		0.66[3]	<0.0001
Step 2: Stem diameter (–2.27)		0.12	0.0004
Model: NDF + stem diameter	DOMI	0.83	<0.0001
Step 1: NDF (–0.64)		0.73	<0.0001
Step 2: Stem diameter (–1.52)		0.10	0.0001
Model: IVOMD + ADF + nitrogen	Nitrogen balance	0.82	<0.0001
Step 1: IVOMD (0.009)		0.74	<0.0001
Step 2: ADF (–0.013)		0.04	0.025
Step 3: Nitrogen (0.17)		0.04	0.013

1. Abbreviations as in the text.
2. Regression coefficients.
3. Partial R^2.

The livestock productivity potential of pearl millet stover as reflected by DOMI and nitrogen balance can be predicted accurately based on simple morphological (stem diameter), chemical (nitrogen, NDF, ADF) and in vitro (IVOMD, ME) measurements.

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