A note on prediction of maize stover quality by near-infrared reflectance spectroscopy (NIRS) technique

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ABSTRACT

Near-infrared reflectance spectroscopy (NIRS) technique was investigated as a means of predicting quality parameters in semi-exotic maize stover. These parameters included neutral detergent fibre (NDF) and *in vitro* dry matter (DM) digestibility. Samples of semi-exotic maize stover were formed by crossing the exotic material Across 8443 La Posta with inbred Mo 17.

An InfraAlyzer 450 (Bran + Luebbe) was used for the study. Calibration equations were obtained by multiple linear regression from 162 samples and verified with 18 additional samples. The coeffcients of multiple correlation obtained were 0.92 for NDF and 0.93 for DM digestibility and the standard errors of calibration were 1.30 and 2.56, respectively. The study showed sufficient accuracy in the prediction of NDF and digestible DM content in semi-exotic maize stover for use in the plant breeding programme.

KEY WORDS: NIRS, semi-exotic maize, NDF, DM digestibility

INTRODUCTION

Maize is generally valued as a grain crop, however it has substantial importance as a forage crop in many maize-growing regions where many hectares of maize silage are harvested annually. Whole-plant digestibility is

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influenced by two independent factors: whole-plant grain content and stover digestibility (Deinum and Bakker, 1981; Hunt et al., 1992). Hunt et al. (1992) evaluated commercial maize hybrids to determine the extent of variation for nutritional quality and found differences among commercial hybrids for both stover and whole-plant tissues. Hybrids with equal grain yield can have large differences in nutritive value. Therefore, selection criteria for silage hybrids should include whole-plant grain content and stover fibre content.

Semi-exotic populations of maize with late maturity can be obtained by crossing exotic germplasm with adapted inbred lines. Being very productive, these populations give an appropriate starting point for Mediterranean-type conditions. This material is intended for use as forage maximization of ear yields is still a goal. Therefore selection for high stover digestibility, high cell wall digestibility and low neutral detergent fibre (NDF) are important in a strategy for improving the nutritive value of the plant.

Near-infrared reflectance spectroscopy (NIRS) measurement can be used to predict nutritive quality. The application of this technique to asses quality in forage crops was first described by Norris et al. (1976). In maize (*Zea mays* L.), NIRS has been proposed as a tool for the prediction the nutritive value of the forage in breeding programmes (Melchinger et al., 1986; Pinter et al., 1986; Valdes et al., 1987a; Zimmer et al., 1990), because it is rapid, reliable, non-time consuming and economic, needs no chemical reagents, and multiple analyses can be conducted simultaneously.

The general objectives of this genetic study of the semi-exotic population are to estimate the values of narrow sense hereditability of many forage traits (related to maturity, whole plant production, and nutritive value of the stover) and the additive genetic correlations between them. To obtain the calibration equations of NDF content and DM digestibility of semi-exotic maize stover is the main objective of the present work. Preliminary results on stover quality traits have been published elsewhere (Albanell et al.,1995).

MATERIAL AND METHODS

Sample collection and preparation

The semi-exotic populations were formed by crossing the pure line Mo17 with the exotic Across 8443 La Posta. The semi-exotic population (F3) was studied using a nested mating design (North Carolina I), with 50 half-sibs and 150 full-sibs (three full-sibs into each half-sib familily).

The field experiment was conducted in 1993 under irrigation, using a randomized complete block design with three replications and a density of 60.000

pl/ha. Plants were harvested (separating the stover from the ear) when the mean grain moisture was approximately 400 g/kg. The samples were dried at 60°C for 48 h and ground through a mill fitted with a 1 mm screen.

Chemical analysis

Samples of maize stover were analyzed in duplicate. Dry matter was determined by drying in a forced-draught oven at 103 ± 1°C for 24 h, NDF by the method of Goering and Van Soest (1970) and *in vitro* DM digestibility (IVDMD) was determined using the enzymatic method of Aufrère (1982).

NIRS analysis

The NIRS equipment used in this study consisted of an InfraAlyzer 450 fitted with 19 discrete filters (Bran + Luebbe, Norderstedt, Germany) interfaced to a personal computer. Reflectance data were collected in the form of log (1/R) (where R measures reflectance) and used to perform statistical analysis for developing the NIRS calibrations. The software for scanning, mathematical processing and statistical analysis was supplied with the spectrophotometer (IACAL P01, 1987, Bran + Luebbe, Norderstedt, Germany). The methodology for the development of NIRS equations has been given elsewhere (Albanell et al., 1993, 1995).

Eighty samples of semi-exotic maize stover used in a previous calibration (Albanell et al., 1995), and 82 new samples were used to recalibrate prediction equations. New calibration equations obtained were validated with 18 independent samples not included in the calibration process.

RESULTS AND DISCUSSION

Table 1 shows the characteristics of the sample sets used in the study. Chemical analysis indicated that the calibration and validation sets covered similar ranges for each component, represented the variability that exist in the predicted samples.

The optimal calibration equation for semi-exotic maize stover samples was obtained using seven terms for NDF content and six terms for IVDMD. In this study the calibration equation for NDF content used the reflectance at wavelengths 1759, 1778, 1982, 2100, 2230, 2270 and 2336 nm, and the primary wavelengths selected were 1778 and 1759 and 2336 nm (Table 2). These two wavelengths have been selected previously for the prediction of acid detergent fibre, crude protein and IVDMD in whole-plant maize forage (Valdes et al., 1990). It is also important to try to assign a chemical meaning to the wavelengths

TABLE 1

Chemical composition of the semi-exotic maize stover samples used in NIRS analysis, %

Component	Calibration				Validation			
	n	range	mean	SD	n	range	mean	SD
NDF	162	59.85-76.35	68.17	3.29	18	61.44-74.00	69.00	3.42
IVDMD	162	29.77-60.10	44.73	6.94	18	33.46-55.76	41.08	6.26

TABLE 2

NIRS calibration statistics for neutral detergent fibre (NDF) and *in vitro* dry matter digestibility (IVDMD) in semi-exotic maize stover samples

Component	R[1]	SEC[2]	CCV[3]	Wavelength, nm[4]						
				1	2	3	4	5	6	7
NDF	0.92	1.30	1.89	1778	1759	1982	2100	2336	2270	2230
IVDMD	0.93	2.56	5.72	2230	2208	2310	1778	1759	2336	

[1] R, coefficient of multiple correlation
[2] SEC, standard error of calibration
[3] CCV, calibration coefficient of variation
[4] filters in order of importance according to the size of the T-test

selected by NIRS. Osborne and Fear (1986) reported that the absorption band at 1759 nm was due to the first overtone stretching vibrations of C-H bonds and 1778 nm band to hemicellulose. The 1600-1800 nm area are sensitive to primary and tertiary overtones of C-H deformations and overtones of N-H, C-H, and C=O (Clark and Lamb, 1991).

The other wavelengths selected in the NDF equation were between 2100 and 2300 nm. The 2200-2300 nm area is associated primarily with C-H groups which are related to fibre (Clark and Lamb, 1991).

The calibration equation for IVDMD used the reflectance at wavelengths 1759, 1778, 2208, 2230, 2310 and 2336 nm and the first two wavelengths selected were 2230 and 2208 nm. Some of the wavelengths have been previously selected in the prediction of IVDMD in whole-plant maize forage by the Tilley and Terry method (Valdes et al., 1987b) and by the pepsin-cellulase technique (Valdes et al., 1990). Clark and Lamb (1991) observed the frequency distribution of wavelength selection in studies on legumes, grasses and mixtures to measure digestibility (*in vitro* or *in vivo*) and the predominant wavelengths were 1600-1900 nm and 2200-2300 nm. These regions are related to the more fibrous portion of plant material and the lignin content. Therefore, these regions of the NIRS spectrum are important both in the prediction of lignin content and in the prediction of digestibility (*in vitro, in sacco* or *in vivo*). The 1650-1700 nm region of the spectrum has been widely associated with digestibility equations (Marten et al., 1988).

The values for the multiple correlation coeffcients and the standard error of calibration (SEC) were in general satisfactory and comparable with those reported by other workers using NIRS in maize forage to determine: *in vitro* digestible organic matter (Melchinger et al., 1986; Deinum and Struik, 1989; Zimmer et al., 1990), *in vitro* dry matter digestibility (Valdes et al., 1990) and NDF (Deinum and Struik, 1989; Zimmer et al., 1990).

Another criteria for determining the suitability of a calibration is the calibration coeffcient of variation (CCV) as a percentage, the ratio of the standard error to the mean of the constituent values times 100. Good calibrations have a CCV of 10% or less and the most robust calibrations will have 5% or less (McClure, 1994). The CCV obtain in semi-exotic maize forage was 1.89% for NDF and 5.72% for IVDMD.

The statistical results from linear regression analysis comparing those predicted from NIRS analysis are shown in Table 3. The correlation coefficients obtained were 0.95 for NDF and 0.90 for IVDMD and the mean bias was near zero. The standard error of prediction (SEP) was comparable to SEC or even smaller. This may be explained by the fact that the SEP includes, as well as the error associated with wet chemical analysis, the error associated with the NIRS

TABLE 3

Validation statistics for NIRS determination of chemical composition of semi-exotic maize stover

Component	r[1]	SEP[2]	Bias	Slope
NDF	0.95	1.75	-0.09	1.168
IVDMD	0.90	3.35	-0.69	1.222

[1] r – correlation coefficient

[2] SEP – standard error of prediction

equipment (Holechek et al., 1982). However the SEP did not exceed the SEC by 33% as suggested by Shenk et al. (1981). Melchinger et al. (1986) and Zimmer et al. (1990) also obtained in maize stover SEP comparable to SEC or even smaller than the SEC in some parameters. The standard error, slope and bias values of selected equations indicated that NDF and IVDMD (by the enzymatic method) were estimated acceptably in semi-exotic stover.

CONCLUSIONS

The results obtained showed sufficient accuracy in the predictions of cell-wall content and dry matter digestibility of semi-exotic maize stover, to be used in plant breeding programme.

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STRESZCZENIE

Zastosowanie metody NIRS do prognozowania wartości pokarmowej łodyg kukurydzianych

Badano przydatność metody NIRS do oznaczenia zawartości NDF i strawności *in vitro* SM jako wskaźników jakości łodyg kukurydzianych. Próby kukurydzy pochodziły ze skrzyżowania odmiany Across 8443 La Plata z inbredem Mo 17. Oznaczenia prowadzono na aparaturze InfraAnalyzer 450 (Bran + Luebbe).

Równania kalibracyjne obliczono metodą wielokrotnej regresji liniowej ze 162 próbek i zweryfikowanych na podstawie dodatkowych 18 prób. Współczynniki wielokrotnej korelacji wynosiły 0,92 dla zawartości NDF i 0,93 dla strawności SM, a błąd standardowy kalibracji wynosił odpowiednio 1,30 i 2,56.

Otrzymane wyniki wskazują, że dokładność określania zawartości NDF i strawnej SM w łodygach kukurydzianych jest wystarczająca dla hodowli roślin.