Quality estimation of intact and ground maize (*Zea mays*) grain and stover by near-infrared spectroscopy.

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Introduction

Globally, maize is the most preferred cereal grain component in poultry diets (60-70%) due to its high energy content, good palatability, presence of desirable pigments and essential fatty acids besides being a staple food for human populations in eastern and southern Africa. However, maize, like other cereals, is deficient in certain essential amino acids, particularly lysine and tryptophan. Man and mono-gastric animals such as pig and poultry are not able to synthesize essential amino acids found in proteins, including lysine and tryptophan, which must therefore be acquired through the diet. Cereal proteins contain on average about 2 per cent lysine, which is less than one-half of the concentration recommended for human nutrition by the WHO (1985). Increasing demand for maize grain for swine and poultry production is, at least regionally (Asia and Africa), matched by increasing demand for maize stover as a ruminant feedstuff (Erenstein et al., 2011; Berhanu et al., 2013). Hence, both grain and stover quantity and quality are important particularly in smallholder, mixed crop-livestock farming systems existing in Asia and Africa. In fact, in earlier studies, nutritionally significant variation in stover/haulms traits in existing cultivars of cereals/legumes was identified without affecting the grain/pod yields which positively and significantly influenced the performance of milk- and meat-producing animals (Anandan et al., 2010; Rao and Blümmel, 2010; Nigam and Blümmel, 2010).

In view of this, plant breeders are attempting to improve both grain (amino acids, metabolisable energy content) and stover quality (IVOMD, ME) traits so as to optimise whole maize plant utilisation. However, in large breeding programmes, it is tedious to analyse the grain/stover samples for quality traits by laboratory analysis but near infrared (NIR) spectroscopy appears to be attractive for quick assessment of grain and stover quality traits in large numbers of samples because NIRS analysis is time-saving, requires less labour, saves consumables cost and does not use hazardous chemicals. In the case of grain, the other factor which makes NIR laborious, costly and slow is grinding of grain samples before scanning. Studies on small cereals (Choudhary et al., 2010) have demonstrated that NIR models have been developed with reasonable accuracy to predict the quality of intact grain samples. Hence, we focused this study on non-destructive assessment of maize grain quality traits as well as stover quality traits by NIR.

Materials and methods

Grain and stover quality assessment was based on near infrared (NIR) spectroscopy calibrated for this experiment against conventional wet laboratory analyses. The NIR instrument used was a FOSS Forage Analyzer 5000 with software package WinISI II. Thirty samples of maize grain in whole and in ground form (1 mm mesh size) and 690 samples of maize stover were scanned using small circular cups (36 mm diameter). NIR calibration equations for maize grain were based on conventional analysis of 60 samples with protein (N x 6.25) analysed by Kjeldahl and fat content by Soxhlet methods (AOAC 1997; procedure no.s 4.2.02 and 4.5.01). Lysine content in maize grain was determined by the colorimetric method described by Tsai et al. (1972) and Galicia et al. (2009) while tryptophan was analysed by the colorimetric method of Nurit et al. (2009) using a Hitachi U-2001 spectrophotometer. Grain metabolisable energy (ME) content was analysed according to Menke and Steingass (1988) using an equation developed for concentrates in ruminant feeding. Similarly, NIR equations for stover analysis were based on laboratory traits of 690 samples. Traits analysed were nitrogen (N) by the method described above , neutral (NDF) and acid detergent fibre (ADF) and acid detergent lignin (ADL) according to Van Soest et al. (1991). *In vitro* organic matter digestibility (IVOMD) and ME content of stover samples were determined by the method described above for grain ME but an equation developed for roughages was used for ME calculation. Validation procedures were blind-predictions of laboratory measurements by the NIR equations developed in the calibration procedures. Relationships between blind-predicted and measured variables were described by R^2 and standard error of prediction (SEP) values.

Results and discussion

The accuracy of NIR blind predictions of protein, fat, lysine, tryptophan and ME content of intact and ground maize grain are presented in Table 1 and 2. Except for tryptophan content, nutrients in maize grain scanned whole, i.e. un-ground, were poorly correlated to NIR predictions (R^2 = 0.0 to 0.34).

Table 1. Coefficient of determination (R^2) and standard errors of prediction (SEP) and calibration (SEC) of near infrared prediction from scans of whole maize grain.

Trait	NIR validation			NIR calibration		
	n	R^2	SEP	n	R^2	SEC
Protein (%)	30	0.23	1.2	60	0.65	0.73
Fat (%)	30	0.06	1.2	60	0.40	0.94
Lysine (%)	30	0.06	0.08	60	0.67	0.04
Lysine (% protein)	30	0.34	0.72	60	0.67	0.45
Tryptophan (%)	30	0.90	0.004	60	0.96	0.002
Tryptophan (% protein)	30	0.49	0.082	60	0.88	0.03
ME (MJ/kg)	30	0.0	0.33	60	0.41	0.17

ME, metabolisable energy

In ground maize samples, protein, fat and ME were well-correlated (R^2 = 0.81 to 0.94). Predictions of lysine and tryptophan were less highly-correlated (R^2 = 0.60 to 0.79) but still adequate to categorise cultivars into three or four quality classes. Both standard error of calibration (SEC) and standard error of validation (SEP) values were lower for quality traits in ground maize grain than intact grain with the exception of tryptophan.

The possibility of scanning intact whole grain would substantially reduce sample processing needs particularly in terms of time and labour. Several workers have shown that in smaller grains such as pearl millet (Choudhary et al., 2010), rice (Zhang et al., 2011) and rape seed (Velasco et al., 1999) scanning of intact grain samples resulted in similar accuracy of prediction of key nutritional quality traits as scanning of ground samples. However, this was not the case for maize grains (Table 1). Except for tryptophan content, nutritive grain quality traits were very poorly predicted when based on scanning of intact maize grains due to the sheath covering the grain, diversity of surface area and size of the material in the intact grain samples and/or due to vacant space(s) in the NIR scanning cups.

In contrast, quality traits based on scanning of ground maize grains were well-predicted for protein, fat and ME content, while predictions of lysine and tryptophan succeed reasonably well (Table 2).

Table 2. Coefficient of determination (R^2) and standard errors of prediction (SEP) and calibration (SEC) of near infrared prediction from scans of ground maize grain.

Trait	NIR validation			NIR calibration		
	n	R^2	SEP	n	R^2	SEC
Protein (%)	30	0.81	0.59	60	0.91	0.34
Fat (%)	30	0.83	0.50	60	0.88	0.41
Lysine (%)	30	0.69	0.05	60	0.91	0.02
Lysine (% protein)	30	0.79	0.42	60	0.88	0.28
Tryptophan (%)	30	0.70	0.005	60	0.70	0.005
Tryptophan (% protein)	30	0.60	0.08	60	0.77	0.05
ME (MJ/kg)	30	0.94	0.13	60	0.94	0.03

ME, metabolisable energy

The R^2 for comparisons of blind predicted and actually measured lysine and tryptophan content was about 0.70 with a SEP of 0.05 and 0.005 for lysine and tryptophan, respectively; these are similar to validation statistics obtained by Rosales et al. (2011). Delwiche (2004) reported that traditional NIR (diffuse reflectance spectroscopy) region (1000-2500 nm) better predicted the quality of ground cereals whereas shorter wave length light (800-1000 nm) is better suited for predicting the quality of intact seeds because of its higher inherent penetration.

Stover quality traits analysed by single step chemical digestive processes such as N (Kjeldahl), NDF
and ADF (Van Soest, 1994) were very well correlated to NIR predicted results with R^2 values ranging from 0.94 to 0.96 (Table 3); multi-step chemical digestive process such as ADL or biological tests (IVOMD and ME) were well correlated (R^2 = 0.81 to 0.82). This is not unexpected since NIR was successfully used to predict these traits in maize stover (Melchinger et al., 1986) and a wide range of forages (Deaville et al., 2000).

Table 3: Coefficient of determination (R^2) and standard errors of prediction (SEP) and calibration (SEC) of near infrared prediction from scans of maize stover.

Trait	NIR validation			NIR calibration		
	n	R^2	SEP	n	R^2	SEC
Nitrogen (%)	345	0.94	0.06	345	0.97	0.04
NDF (%)	345	0.94	1.6	345	0.97	1.1
ADF (%)	345	0.96	1.2	345	0.97	0.9
ADL (%)	345	0.82	0.4	345	0.84	0.4
IVOMD (%)	345	0.81	0.4	345	0.92	0.3
ME (MJ/kg)	345	0.81	2.5	345	0.92	1.6

Abbreviation: ME, metabolisable energy; NDF, neutral detergent fibre; ADF, acid detergent fibre; ADL, acid detergent lignin; IVOMD, *in vitro* organic matter digestibility

Conclusion

Both grain and stover quality traits of maize cultivars were well predicted by NIR. However, maize grain quality traits such as content of protein, fat, energy and amino acids (lysine and tryptophan) were better predicted by NIR when the samples were in the ground form. Based on protein, energy and amino acid content, maize grain can be classified and superior samples can be traded for a premium price in the market; use of the same material in livestock and poultry rations reduces the need for other costlier protein sources.

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