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A note on the correlations between maize grain and maize stover quantitative and qualitative traits and the implications for whole maize plant optimization

Y. Ramana Reddy[a,*], D. Ravi[a], Ch. Ramakrishna Reddy[a], K.V.S.V. Prasad[a], P.H. Zaidi[b], M.T. Vinayan[b], M. Blümmel[a]

[a] International Livestock Research Institute (ILRI), c/o ICRISAT, Patancheru 502 324, India
[b] Centro Internacional de Mejoramiento de Maíz Y Trigo (CIMMYT), c/o ICRISAT, Patancheru 502 324, India

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ABSTRACT

The paper explores opportunities and limitations for concomitant improvement of maize grain quantity and quality traits and maize stover quantity and quality traits in 60 parental lines, 30 crosses/local checks and 12 released hybrids. Investigated grain quality traits were protein (CP), fat, metabolizable energy (ME), lysine and tryptophan. Stovers were investigated for nitrogen (N), neutral (NDF) and acid detergent fiber (ADF), acid detergent lignin (ADL), *in vitro* organic matter digestibility (IVOMD) and ME. Quality traits were investigated using near infrared spectroscopy (NIRS) applied to whole and ground maize grain and to ground stover. Application of NIRS to whole maize grain was unsuccessful but CP, fat and ME contents in ground maize grain were well predicted with $R^2 = 0.81$, 0.83 and 0.94, respectively, and predictions of lysine and tryptophan were acceptable ($R^2 = 0.70$). Maize stover quality traits were generally well predicted by NIRS ($R^2 = 0.81$–0.96). Genotype and environment effect was significant on the quality traits of grain, whereas $G \times E$ effect was not significant. Trade-offs between grain and stover quality traits were generally absent or weak and inconsistent but several grain quality traits were incompatible. Thus grain CP was negatively correlated with grain yield. Lysine and tryptophan were consistently significantly negatively correlated with CP. Line and cultivars-dependent variation in grain and stover quality traits were high enough to be of nutritional significance to monogastrics and ruminants.

1. Introduction

Several recent publications investigated opportunities for improving maize stover fodder quality traits in East Africa and South Asia (Ertiro et al., 2013a,b; Anandan et al., 2013; Zaidi et al., 2012). These authors stressed that stover fodder quality improvement should not be achieved at the expense of grain traits but commonly only grain yield was considered while grain quality traits were ignored (Ertiro et al., 2013a,b; Anandan et al., 2013; Zaidi et al., 2012). Where grain quality was considered for example by Melchinger et al. (1986) the comparisons focused on the crude nutrient protein and starch but much of the current interest is on more refined nutrients such as essential amino acids.

Globally maize demand is diversifying from food use to livestock feed but the rate of diversification is different in developed (70% for livestock) and developing (56% for livestock) countries and in the latter countries maize grain is still a staple food (Notenbaert et al., 2012). Like other cereals, maize is deficient in essential amino acids, particularly lysine and tryptophan (NRC, 1994). Humans (as well the mono-gastric animals swine and poultry) are not able to synthesize these amino acids which must be acquired through their diet.

In Ethiopia, Tanzania and Uganda, where the population relies on maize, randomized trials showed significantly improved height and weight of children consuming maize grain with high lysine and tryptophan (QPM) content (Gunaratna et al., 2010). Similarly positive effects of OPM have been reported the case in swine and poultry (Prandini et al., 2011; Burgoon et al., 1992; Sullivan et al., 1989). The multiple usage of the maize plant – grain for human, pig and poultry

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; ANOVA, analysis of variance; AOAC, Association of Official Analytical Chemists; CIMMYT, Centro Internacional de Mejoramiento de Maíz Y Trigo; FAO, Food and Agriculture Organization; ICRISAT, International Crops Research Institute for the Semi Arid Tropics; ILRI, International Livestock Research Institute; IVOMD, *in vitro* organic matter digestibility; LSD, least significant difference; ME, metabolizable energy; N, nitrogen; NDF, neutral detergent fiber; NIRS, near infrared reflectance spectroscopy; NRC, National Research Council; SAS, statistical analysis systems; SEP, standard error of prediction; WHO, World Health Organization.

* Corresponding author. Tel.: +91 40 30713654.
E-mail addresses: r.ramana@cgiar.org, ramanayr19@yahoo.co.in (Y. Ramana Reddy).

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nutrition and stover for ruminant feeding – calls for a concomitant whole plant improvement and optimization approach rather than focusing on improvement of grain or stover traits in isolation. In earlier study NIRS was successfully used to predict some grain and stover quality traits (Melchinger et al., 1986) but the genotypic variations were discussed separately for grain and stover and the relationship between grain and stover traits was not studied which, however would be required for whole plant optimization. This approach requires nutritionally significant genetic variations in the traits of interest, absence or manageability of trade-offs between desirable traits, and quick and cost effective phenotyping facilities for desirable traits.

2. Materials and methods

2.1. Phenotyping for maize grain and stover quality traits

Grain trait phenotyping was based on near infrared spectroscopy (NIRS), with a FOSS Forage Analyzer 5000 and software package WinISI II calibrated for this experiment against conventional wet laboratory analyses at ILRI c/o ICRISAT, Patancheru, India. Maize grain was scanned intact and ground to pass a 1 mm mesh screen while maize stover was only scanned in ground form after grinding through 1 mm mesh screen using cutting mill (Retsch make, model SM 100). NIRS equations for maize grain analyses were based on conventional analysis of 60 samples with protein ($N \times 6.25$) analyzed by Kjeldahl and fat content by Soxhlet methods (AOAC, 1997; procedure nos. 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) and tryptophan was analyzed by colorimetric method of Nurit et al. (2009) using Hitachi U-2001 spectrophotometer. Grain metabolizable energy (ME) content was analyzed according to Menke and Steingass (1988) using an equation developed for concentrate feeds in ruminant feeding (see also below). In the ILRI laboratory in India a total of 690 maize stover samples had been conventionally analyzed for fiber fractions (Van Soest et al., 1991) in addition to nitrogen, *in vitro* organic matter digestibility (IVOMD) and ME following the procedures mentioned above and 345 were selected for calibration and 345 for validation procedures using the WinISI II spectral sample selection programs. Validation procedures were blind-predictions of laboratory measurements by the NIRS equations developed in the calibration procedures.

2.2. Maize parental lines, experimental crosses and release-tested hybrids used

Details of the agronomic trials of parental lines and experimental crosses have been reported elsewhere in the special issue (Zaidi et al., 2012). For grain and stover trait analysis, 10 plants per plot were collected from the parental lines (un-replicated) and experimental crosses (two replications). The 12 advanced hybrids were planted in the *Rabi* season (2011) as advanced multi-location (Patancheru, Doddaballapur, Gowrarum and Phaltan) hybrid trials in two replications. Four plants per hybrid and replication were harvested and sent to the ILRI laboratory for further analysis.

2.3. Statistical analysis

The SAS 9.2 (2008) statistical package was used for descriptive statistics and for analysis of variance (ANOVA). Variance components of the traits (phenotypic/genotypic) estimated by mixed model of restricted maximum likelihood (REML) method using the PROC VARCOMP were used to determine the heritability of traits where multi-location trails were investigated. Correlations among traits were calculated by using linear regressions (PROC CORR).

3. Results

3.1. Near infrared spectroscopy (NIRS) analysis of whole and ground maize grain and of ground maize stover

The accuracy of NIRS predictions of maize grain and stover quality traits is presented in Table 1. Except for tryptophan content ($R^2 = 0.49–0.9$), nutrients in maize grain scanned whole were poorly predicted by NIRS ($R^2 = 0.0–0.34$). In ground maize samples, protein, fat and ME were well predicted ($R^2 = 0.81–0.94$). Predictions of lysine and tryptophan as per cent grain and grain protein were less accurate ($R^2 = 0.60–0.79$) but still adequate to categorize cultivars into several quality classes (see below). Maize stover quality traits were generally well predicted ($R^2 = 0.81–0.96$).

3.2. Variations in grain and stover traits in parental lines, derived experimental crosses and advanced hybrids

Means and ranges in protein, fat, lysine, tryptophan and ME content of maize grain and means and ranges in N, NDF, ADF, ADL, IVOMD and ME content of maize stover in the 60 parental lines are presented in Table 2. Substantial variations of about 70–104% were observed for grain fat, lysine and tryptophan content, about 41% in protein content and about 13% in ME content.

In the experimental crosses, significant differences in all grain traits were observed except for tryptophan content (Table 3). In stover traits significant differences were observed for ADF and stover yield but not for NDF, IVOMD and ME.

In the advanced 12 hybrids tested at four locations significant differences were observed for all grain traits (Table 4). Except for tryptophan as per cent protein ($h^2 = 0.39$) heritabilities for grain traits were quite high ($h^2 = 0.67–0.80$). Significant effect of genotype (G) and environment (E) 0*n* grain quality traits was observed (Table 4). However, $G \times E$ effect on grain quality traits was not significant.

3.3. Correlations among grain and stover traits and between grain and stover traits

A significant negative correlation existed between grain protein content and grain energy related traits (fat and ME) (Table 5). Total grain protein content and grain lysine and tryptophan content were significantly negatively correlated. This negative correlation became stronger ($P < 0.0001$) when lysine and tryptophan content were adjusted for protein content. Grain yield in parental lines was significantly negatively correlated with grain protein content and mostly significantly positively correlated with grain fat, lysine, tryptophan and ME contents. Grain fat contents were significantly positively correlated with grain lysine, tryptophan and ME contents. Grain lysine and tryptophan contents were strongly ($P < 0.0001$) positively correlated.

Grain and stover yield in parental lines were statistically not correlated. Stover yield was significantly negatively ($P < 0.05$) correlated with grain fat and tryptophan content and to a greater degree ($P < 0.0001$) with grain ME content. Stover yield was positively ($P < 0.05$) correlated to grain protein content. Stover constituents N, NDF, ADF and ADL were not correlated ($P > 0.05$) to any of the grain traits. No significant ($P > 0.05$) correlations were observed between stover IVOMD and ME and any of the grain traits. Stover IVOMD and ME were positively ($P < 0.05$) associated with grain fat and ME content.

Correlations among and between grain and stover traits in crosses are reported in Table 6. Grain yield was negatively ($P < 0.01$)