The Fodder Value of Maize Stover vis-à-vis Other Cereals Residues and Opportunities for Improvement through Crop Breeding and Value Addition

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Introduction

In recent decades, maize has emerged as an increasingly important food-feed-fodder crop in India, and its production is increasingly dominated by high-yield potential proprietary hybrids from a wide range of large and small private seed companies (Spielman et al., 2011), principally, to meet the needs of an expanding poultry feed market. Maize is now the third most important crop after rice and wheat in India, and cultivated on over 8.7 m hectares (ha) producing 20.03 million tons (mt) of grain at an average grain yield of 2.3 t/hectare (ha) (Directorate of Maize Research, 2011). Much of the growth took place in non-traditional maize areas where maize is now grown for commercial purposes, including southern India and also as an irrigated crop during the dry season (Joshi et al., 2005). In these areas, maize is largely replacing sorghum, an important dual-purpose crop, the stover of which is highly valued by livestock keeper and fodder traders (Blümmel and Rao 2006; Sharma et al., 2010). Given the prevalent fodder shortage in India, maize stover would need to substitute for the loss in sorghum stover However, perceptions about the inferiority of maize compared to sorghum stover is widespread (Biradar 2004).

To elucidate, address and countermand these negative perceptions, the current work presents data from: 1) investigations of a very wide range of released and widely grown maize hybrids using a demonstration trial of the Indian Directorate of Maize Research (DMR) in *Kharif* (monsoon) season 2013 for variations in maize stover fodder quality traits; 2) analysis of G x E effects on food-fodder traits in 24 pipeline maize hybrids tested across four locations in India; 3) laboratory-based comparisons of stover fodder quality traits of maize stover with that of commercially-traded sorghum stover; 4) feeding maize stover from a superior food-fodder hybrid instead of sorghum stover in a commercial dairy farm and resulting milk potential and economy of dairy production; and 5) substitution of sorghum stover by maize stover in commercially produced total mixed rations.

Variations in maize stover laboratory fodder quality traits in a wide range of popular public and private sector maize hybrids

Phenotyping for maize stover laboratory fodder quality traits

Stover from 10 maize plants per plot replication of the 102 released public and private maize hybrids from the *Kharif* 2013 demonstration plots of the DMR, were sent to the ILRI laboratory in Hyderabad, India, where the stover were dried and ground to pass through a 1 mm mesh. All samples were analyzed by Near Infrared Spectroscopy (NRS) and calibrated against conventional laboratory analyses. The NRS instrument used was a FOSS Forage Analyzer 5000 with software package WinISI II. Out of a total of 690 stover samples, 345 were selected for calibration and 345 for validation procedures using the WinISI II samples selection programs. Validation procedures were based on blind-predictions of laboratory measurements by the NRS equations developed in the calibration procedures. Relationships between blind-predicted and measured variables were described by R^2 and standard error of prediction (SEP). Relationships between laboratory values and NRS blind-predicted values were R^2 = 0.94 (SEP = 0.06) for nitrogen (N) concentration,R^2 = 0.94 (SEP = 1.6) for neutral detergent fibre (NDF), R^2 = 0.96 (SEP = 1.2) for acid detergent fibre (ADF), R^2 = 0.79 (SEP = 1.6),R^2 = 0.82 (SEP = 0.4) for acid detergent lignin (ADL), R^2 = 0.81 (SEP = 2.5) for *in vitro* organic matter digestibility (IVOMD) and R^2 = 0.82 (SEP = 0.4) for metabolizable energy (ME) content.

Means and ranges in maize stover fodder quality traits

Stover N, NDF, ADF, ADL, IVOMD and ME varied substantially in the stover of the 102 released public and private maize hybrids from the demonstration plot of the DMR. Since the demo plot had the hybrids in only two replications, stover from these two replications were only available for NRS analysis yielding the minimum degree of freedom for more than descriptive statistical analysis. Still, key traits such as IVOMD, ME and ADL differed statistically at highly significant rates between the hybrids. For example, IVOMD, a trait discussed in more detail later, varied by about 10 percent units, which has tremendous implications for the productivity of maize stover-fed livestock.

Ravi et al. (2013) related the maize stover fodder quality traits N, NDF, ADF, ADL, IVOMD and ME to digestibility, voluntary dry matter intake (DMI) and digestibility dry matter intake (DDMI the products of DMD and DMI) of 10 maize stover fed to sheep. The associations between N, IVOMD and ME with DMD, DMI and DDMI were positive while NDF, ADF and ADL were negatively associated with the *in vivo* measurements (Ravi et al., 2013). Laboratory-based measurements estimated to be most suitable for prediction of *in vivo* measurements were ADF, IVOMD and ME, since good agreement (r = 0.87 to 0.91) was found particularly between measured DMI and DDMI by cross validation predictions of DMI and DDMI using either ADF, IVOMD or ME (Ravi et al., 2013). Stover N content, often considered the most limiting nutrient in cereal crop residues, did predict DMI and DDMI less (r = 0.67 and 0.73) than ADF, IVOMD and ME (Ravi et al., 2013).

Table 1. Means and ranges in maize stover laboratory fodder quality traits in 102 released public and private maize hybrids in India.

Trait	Mean	Range	P < F
Nitrogen (%)	1.13	1.09 - 1.70	0.07
Neutral detergent fiber (%)	70.5	66.3 - 74.0	0.50
Acid detergent fiber (%)	44.5	40.9 – 74.0	0.13
Acid detergent lignin (%)	5.0	3.8 – 6.0	0.02
In vitro digestibility (%)	50.1	44.6 – 54.3	0.002
Metabolizable energy (MJ/kg)	7.22	6.33 – 7.93	0.0009

The stover IVOMD of the 102 maize hybrids compared favorably with *Kharif* and *Rabi* (winter season) sorghum stover IVOMD investigated in the context of new cultivar release testing by the Directorate of Sorghum Research during 2002 to 2008 (Blümmel et al. 2010). The mean IVOMD for *Kharif* and *Rabi* sorghum stover were 46.5 percent and 51.6 percent, respectively. Thus, the lowest stover IVOMD of the 102 maize hybrids was close to the mean of *Kharif* sorghum stover IVOMD while the highest maize stover IVOMD was quite superior to the mean *Rabi* sorghum stover IVOMD. Clearly maize stover fodder quality is not inherently inferior to that of sorghum stover!

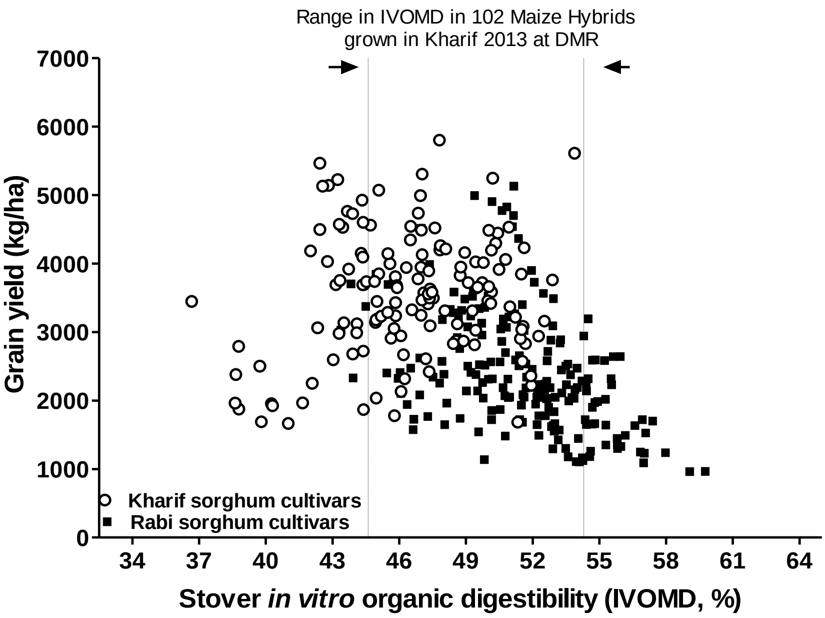

Figure 1: Ranges in stover IVOMD of 102 released maize hybrids overlaid on Kharif and Rabi sorghum stover data tested as part of new sorghum cultivar release procedures in 2002 to 2008

Variations in maize stover laboratory fodder quality traits, GX E effects and grain-stover relationships in 24 pipeline hybrids tested across 4 locations in India

Variations in maize stover traits

Days to anthesis (DA), anthesis silking interval (ASI), grain yield (GY), stover yield (SY), stover N, NDF, ADF, ADL, IVOMD and ME content of the 24 pipeline maize hybrids grown at four locations in India, during *Rabi* season 2013, are presented in Table 2. Morphological/physiological (DA, ASI and PH) and yield traits (GY and SY) varied highly-significantly among the pipeline hybrids. Except for stover N content, stover fodder quality traits differed significantly among the pipeline hybrids (P = 0.007 to P =0.05) or as in the case of ADL at least tended to differ (P = 0.1). While broad sense heritabilities (Table 2) were strongest (h^2 about 0.8) for DA and grain yield, they were still useful and significant for afore mentioned key stover fodder quality ADF, IVOMD and ME and for stover yield (h^2 between 0.45 and 0.48).

While the above reported heritabilities suggest considerable genotypic consistency of key traits across the four environments, location had a strong effect ($P < 0.0001$) on the physiological/morphological (DA, ASI, PH), yield (GY, SY) and stover fodder quality traits. However, while interaction between cultivars and locations was highly significant for DA, ASI, GY and SY, interactions were not significant in the stover fodder quality traits.

Relationship between grain and stover traits

While higher maize stover fodder quantity and quality will have an undoubted advantage in mixed crop livestock systems, this should not be achieved at the expense of grain yield. In the 24 pipeline maize hybrids, a considerable degree of independence existed between grain and stover traits. At the very basic level, grain and stover yield were statistically unrelated (Figure 2), casting doubts on the usefulness of fixed harvest indices (HI) to predict stover from grain yields. Thus, in the present work, stover yields in hybrids with grain yields of about 9 t/ha could vary by about 3 t/ha (Figure 2).

These cultivar-dependent variations in stover yield are important since there are other potential trade-offs – including alternative stover uses, such as the potential use of biomass for soil health, as explored by Valbuena et al. (2012). These trade-offs are not limited to the direct competition between stover for fodder or soil health – and may actually be further entangled by dual-purpose maize varieties. For instance, the higher fodder value of dual-purpose maize may increase stover off take (in situ or ex situ) and thereby exacerbate competition between uses. Furthermore, dual-purpose maize varieties typically have higher digestibility as feed, but this may also have implication for their digestibility by soil biota and susceptibility to weathering vis-à-vis their retention as mulch within conservation agriculture systems (Erenstein, 2002). Some of these trade-offs are inherently complex and may not be limited to maize, this merits further research. Still increasing the overall biomass yield, i.e., grain and stover yield, will remove some of competition between biomass usage for livestock feeding and soil improvement. As an aside, livestock have limited intake capacities for bulky feed such as stover and increasing quantitative availability of a given maize stover above the intake capacity of livestock for this stover, will not improve fodder resources beyond possible making fodder cheaper (Homann-Kee-Tui et al., 2013). Therefore, quantitative and quality aspects of stover work in maize improvement cannot strictly be separated either in the context of livestock feeding or biomass allocation for soil improvement.

There was no relationship between two selected stover quality traits, namely stover N and stover IVOMD, which meet distinctly different digestive needs of livestock (Figure 3a-3d). It is very encouraging to note that the pipeline hybrid with the highest grain yield had the highest stover N and the second highest stover IVOMD (Figure 3a, b).

Table 2. Days to male anthesis (DA), anthesis to silking interval (ASI), grain yield (GY, kg/ha), stover yield (SY, kg/ha), stover nitrogen (N, %), neutral (NDF, %) and acid (ADF, %) detergent fiber, acid detergent lignin (ADL, %), *in vitro* organic matter digestibilities (IVOMD, %) and metabolizble energy (ME; MJ/kg) content of 24 pipeline maize hybrids grown at four locations in India during *Rabi* season 2013.

Hybrids	DA	ASI	PH	GY	SY	N	NDF	ADF	ADL	ME	IVOMD
AH 113948	67.8	2.0	257.6	7766	7860	1.09	69.9	37.8	4.3	7.7	52.9
AH 1216	68.1	1.7	266.8	9370	7527	1.13	70.4	38.4	4.8	7.5	51.5
VH 112037	70.7	2.5	252.7	7484	8252	1.13	71.4	38.4	4.7	7.6	52.1
VH 112649	72.6	1.9	246.3	8229	8925	1.15	68.2	36.3	4.5	7.7	53.0
VH 112650	69.1	1.6	242.4	6237	8188	1.12	68.6	36.3	4.4	8.0	54.7
VH 112655	72.8	1.5	264.0	8916	9600	1.12	70.6	37.5	4.6	7.6	51.8
VH 112667	68.7	1.6	270.0	8224	7000	1.09	70.8	38.7	4.5	7.7	52.8
VH 112670	69.2	2.1	252.6	9503	8625	1.18	68.3	36.6	4.6	7.7	53.1
VH 123949	68.9	2.0	247.1	8281	9658	1.17	69.0	36.6	4.3	7.8	53.2
VH 123950	69.1	2.8	244.1	10230	8474	1.21	69.0	35.8	4.2	7.8	53.6
VH 123951	70.1	3.0	254.7	8882	6959	1.14	71.3	38.6	4.6	7.6	52.1
VH 123952	68.0	2.6	239.7	9356	7942	1.08	72.1	38.6	4.8	7.6	51.6
VH 123953	69.2	2.2	240.7	7548	7378	1.10	70.9	37.9	4.6	7.6	52.2
VH 123954	70.4	1.7	248.1	8056	7141	1.11	70.1	37.6	4.6	7.7	52.5
VH 123955	69.1	1.7	250.4	8519	6555	1.16	71.9	38.5	4.7	7.3	50.2
VH 123956	65.9	1.8	244.7	8362	7844	1.19	69.3	37.1	4.6	7.6	52.3
VH 123957	70.6	2.2	258.4	9232	8928	1.11	69.7	36.7	4.4	7.6	52.0
VH 123958	68.4	2.1	256.7	9242	9672	1.11	71.3	38.9	4.7	7.8	53.1
VH 123959	69.3	2.3	230.0	8930	9216	1.12	69.8	37.0	4.7	7.5	51.6
VH 123960	70.8	1.5	253.3	8257	7304	1.14	71.7	38.7	4.9	7.5	51.3
VH 123961	69.9	2.2	263.0	9296	8301	1.08	71.2	38.8	4.9	7.5	51.5
VH 123962	68.7	1.8	263.0	8170	8172	1.09	70.0	38.6	4.9	7.6	51.8
VH 123963	69.7	1.9	260.0	9523	9243	1.14	70.2	37.6	4.9	7.2	49.9
VH 123964	69.7	2.3	264.2	8354	6948	1.13	71.1	38.9	4.6	7.6	52.4
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.54	0.05	0.01	0.1	0.01	0.007
h^2	0.81	0.0	0.8	0.67	0.47	0.0	0.37	0.45	0.33	0.48	0.47

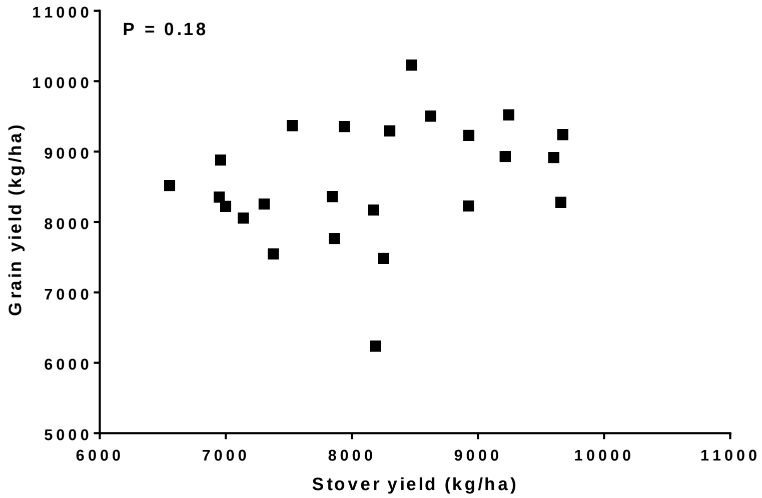

Figure 2: Relationship between stover yield and grain yield in 24 pipeline maize hybrids grown at 4 locations in India

Table 3. Effects of cultivars, locations and their potential interactions on male anthesis date (AD), anthesis-silking interval (ASI), stover nitrogen (N), stover neutral (NDF) and acid (ADF) detergent fiber, acid detergent lignin (ADL), on *in vitro* organic matter digestibilities (IVOMD) and metabolizable energy (ME) content of 24 pipeline maize hybrids grown at four locations in India in 2013.

Source	**F-value**	**P > F**
	DA	
Cultivar	22.9	<0.0001
Location	3136	<0.0001
Cultivar x Location	4.5	<0.0001
	ASI	
Cultivar	2.8	<0.0001
Location	286	<0.0001
Cultivar x Location	2.8	<0.0001
	Plant Height	
Cultivar	6.6	<0.0001
Location	1090	<0.0001
Cultivar x Location	1.3	0.06
	Stover Yield	
Cultivar	3.17	<0.0001
Location	56.2	<0.0001
Cultivar x Location	1.69	0.003
	Grain Yield	
Cultivar	8.75	<0.0001
Location	637	<0.0001
Cultivar x Location	2.89	<0.0001
	Stover N	
Cultivar	0.94	0.54
Location	102.0	<0.0001
Cultivar x Location	0.98	0.53
	Stover NDF	
Cultivar	1.56	0.06
Location	66.2	<0.0001
Cultivar x Location	0.97	0.55
	Stover ADF	
Cultivar	1.85	0.01
Location	96.8	<0.0001
Cultivar x Location	1.0	0.43
	Stover ADL	
Cultivar	1.43	0.1
Location	26.5	<0.0001
Cultivar x Location	0.94	0.6
	Stover IVOMD	
Cultivar	1.98	0.0068
Location	95.8	<0.0001
Cultivar x Location	1.05	0.39
	Stover ME	
Cultivar	1.91	0.01
Location	76.2	<0.0001
Cultivar x Location	0.97	0.55

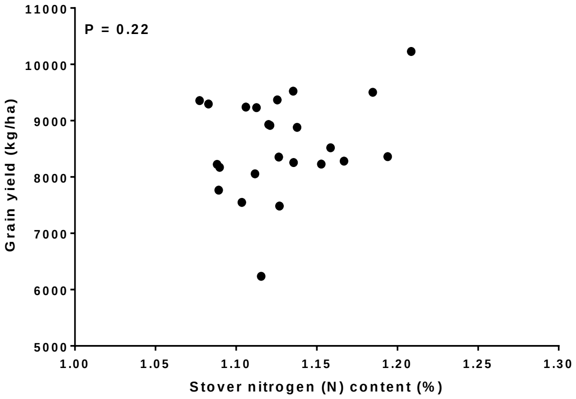

Figure 3a: Relationship between stover N and grain yield in 24 pipeline maize hybrids grown at 4 locations in India

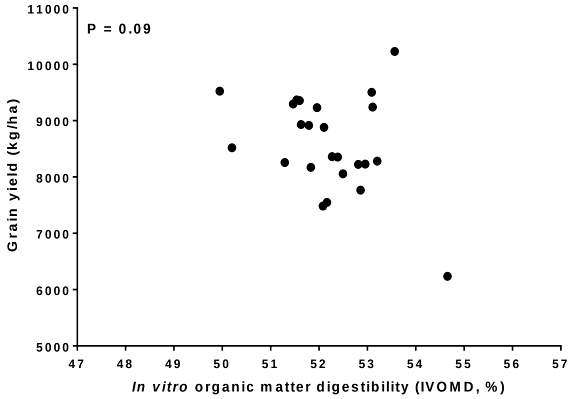

Figure 3b: Relationship between stover IVOMD and grain yield in 24 pipeline maize hybrids grown at 4 locations in India

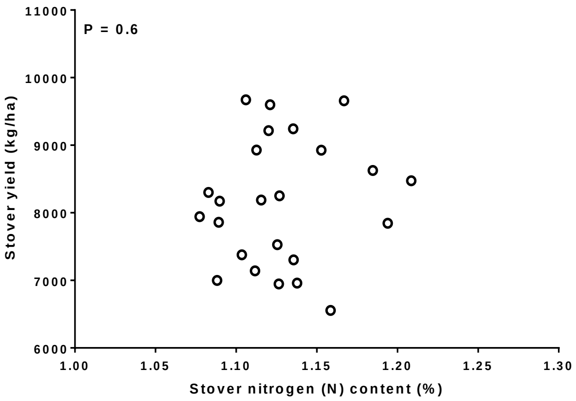

Figure 3c: Relationship between stover N and stover yield in 24 pipeline maize hybrids grown at 4 locations in India

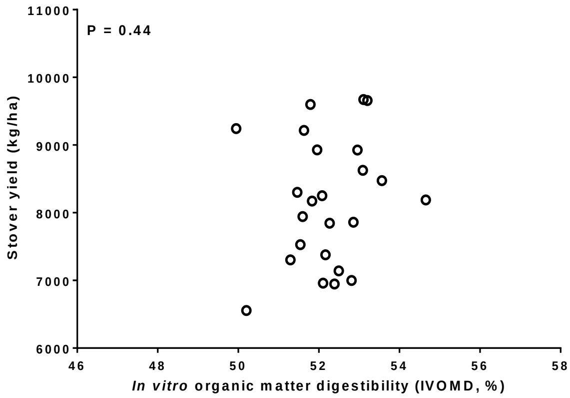

Figure 3d: Relationship between stover IVOMD and stover yield in 24 pipeline maize hybrids grown at 4 locations in India

Targeted genetic enhancement towards concomitant improvement of grain and stover traits

Parental lines and hybridization

Ertiro et al. (2013) investigated the trend in variability and association between grain and stover traits in inbred parents and the hybrids derived from them using 16 inbred lines to generate 60 single cross hybrids which were evaluated for grain and stover yield and stover N, NDF, ADF, ADL, IVOMD and ME across three environments in Ethiopia. Genotypes in both hybrids and inbred trials showed highly significant variations for all the traits studied. The authors reported substantial variations in key stover traits; for example, IVOMD varied by 9.2 percent units among the hybrids and by 11 percent units among the inbred parents. As reported also in Figure 3b, IVOMD and grain yield were quite independent (P = 0.56) and at high grain yields of about 10 to 12 t/ha, IVOMD could range from about 53 percent to 61 percent. The authors noted that grain-stover relationships were less rigid then often assumed. The authors also reported correlation between mid-parent and hybrid values for stover N, NDF, ADF, ADL, ME and IVOMD to range from r = 0.42 for stover ADF to r = 0.79 for stover ME, and argued that the significant positive relationships observed between inbred lines per se and hybrid performances for these fodder quality traits suggest the feasibility of predicting hybrid performance from the performance of the inbred lines. Ertiro et al. (2013) also observed that the general combining abilities (GCA) of both lines and testers and the specific combining ability (SCA) of line by tester interactions were significant for most traits studied. The highly significant GCA effects observed for most traits and the greater relative importance of GCA (lines and testers) as compared to SCA for grain yield and most stover fodder quality traits suggest the importance of additive gene effects in controlling grain and stover yield as well as stover fodder quality.

Zaidi et al. (2013) used cluster analysis to understand the existing variability among elite lines from CIMMYT-Asia with respect to superior stover IVOMD (in addition to good grain and stover yield performance) for initiating high stover fodder quality breeding activities. The authors observed that the IVOMD of the crosses did not significantly deviate from the mid-parental values which also suggests a simple genetic basis with predominant additive effects for IVOMD. The authors further compared the performance of several single crosses targeting stover quality improvement with one of the leading commercial hybrid in India (900M Gold from Monsanto) and all but two crosses showed favorable deviation from the commercial hybrid for stover quality parameters. On the basis this dataset, forage quality breeding had been initiated by combining high quality inbred lines with good grain yield through to extract superior lines for developing good dual-purpose hybrids. Advanced stage lines from these populations are being phenotyped for their stover fodder quality traits and for using them in development of new dual-purpose hybrid. In addition, a population of high fodder quality trait (IVOMD) has also been developed to sustain the fodder quality breeding efforts and for use in marker-assisted breeding programs based on the leads from genome-wide association studies.

Genome-wide association studies (GWAS)

GWAS has the potential to unravel favorable native genetic variations for traits of agronomic and economic importance and is widely used in crops like maize. We studied a panel of 276 inbred lines from CIMMYT's Drought Tolerant Maize for Africa (DTMA) program using their testcross hybrids (each line crossed with a tester CML312) and the single crosses were evaluated for grain and stover yields, plant height (PH), days to 50 percent anthesis (DtA50) and silking, stover N, NDF, ADF, ADL, IVOMD and ME content. GWAS, carried-out using GBS (genotyping by sequencing) and 55K SNPs, revealed several genomic regions of significant association for N, ADF and IVOMD, each explaining 3 percent-to-9 percent of phenotypic variance for these fodder quality traits. SYN7725 from the 55K chip on chromosome 4 explained the largest proportion of phenotypic variance (∼9 percent) for ADF and had a robust minor allele frequency (MAF) of 0.35, which indicated prevalence of the favorable allele in the panel of lines. A specific genomic region on chromosome 3 (132.7–149.2 Mb) was found to be significantly associated with all the three forage quality traits, with the largest effect on IVOMD. This region appears to be a potential region further validation and marker-assisted introgressions. A cellulose-related candidate gene, Xyloglucan endo trans-glucosylase/hydrolase(xth1, GRMZM2G119783) was identified closer to the peak on chr.10 (∼76.9 Mb) for ADF (Vinayan et al., 2013), which has been previously demonstrated to have a significant role in fiber elongation in cotton.

While GWAS is helpful in uncovering genomic regions of interest for target traits, Genomic selection (GS) is a newer approach that helps in the prediction of untested phenotypes based on whole genome information content. Currently, we are training GS models for a suite of fodder quality traits to enable prediction of likely superior lines from the vast collection of Doubled Haploid (DH) lines that the Global Maize Program of CIMMYT has generated, in the recent past, across Latin America, Africa and Asia. Specifically, we are making use of high-density genotypic information as well as fodder quality phenotypes of ~700 lines from two association panels – DTMA and CAAM (CIMMYT-Asia Association Panel) for obtaining marker effects for the fodder quality traits mentioned above.

Maize stover in feeding and fodder value chains

Maize stover as tradable commodity?

In an ex-ante assessment on the genetic enhancement of stover fodder quality in sorghum and pearl millet in India, Kristjanson and Zerbini (1999) calculated that a 1 percent unit improvement in digestibility would result in an increase in livestock output of 6 percent to 8 percent. Surveying sorghum stover fodder trading in urban and peri-urban dairy production in Hyderabad in peninsular India monthly 2005 to 2005, Blümmel and Rao (2006) observed that the cultivars-dependent variations in key traits, such as IVOMD which accounted for about 75 percent of the variation in stover price, were about 5 percent, with units ranging from 47 percent to 52 percent (Figure 4). In other words, a 1 percent unit increase in IVOMD was associated with a price premium of about 5 percent. When feeding total mixed rations for higher yielding dairy buffalo in India, which consisted of 50 percent sorghum stover using stover with 47 percent and 52 percent IVOMD, respectively, differences in daily milk yield potential of about 5 kg resulted (10 vs 15 kg daily, Anandan et al., 2010). The authors explained the differences in milk yield potential – or more generally in livestock performance – by the accumulating effects of higher feed quality per unit of feed and higher feed intake by the livestock. It is interesting to note that this degree (i.e., about 5 percent units in IVOMD) of stover fodder quality difference also exists in the pipeline maize hybrids across four environments (Table 2) without having been targeted specifically through stover improvement. In fact, the overall maize stover fodder quality as reflected by IVOMD compared favorably with the quality of diverse sorghum stover traded and surveyed in 2004 to 2005 by Blümmel and Rao (2006), as reflected in Figure 4.

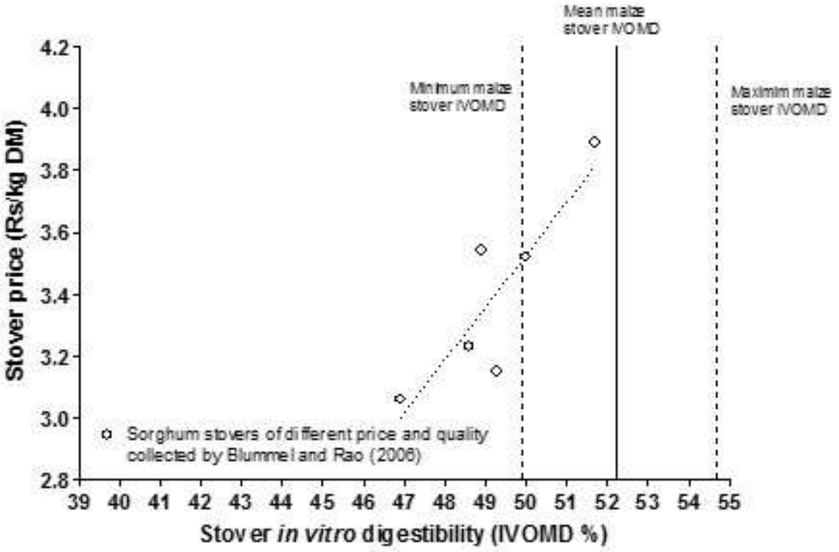

Figure 4: Mean and ranges of maize stover IVOMD in 24 pipeline hybrids overlayed on quality-prize relations in sorghum stovers traded in pensinsular India in 2004 to 2005.

Potential of maize stover use in dairy
Sorghum stover supports much of the urban and per-urban dairy production in peninsular India. For example, about 130 to 200 tons of sorghum stover are daily transacted at the Hyderabad fodder market alone. The stover is transported over distances of several hundred kilometres and commands, on a dry weight basis, about 50 percent of the price of sorghum grains. This ratio used to be about 20 percent to 30 percent a decade and a half back. The present high monetary value of sorghum stover can be explained by the general high-demand for fodder in India, but perhaps also due to a decline in sorghum grown area and replacement of sorghum through maize. There is a general perception among dairy farmers and fodder traders in India, that maize stover is less suitable for their livestock than sorghum stover. Collaboration of CIMMYT and ILRI under the Bill & Melinda Gates Foundation-funded Cereal Systems Initiative South Asia (CSISA) and the CGIAR Research Program on MAIZE tested and challenged the negative perception about maize stover. Stover of a selected hybrid with high grain yield and high stover fodder quality was made available to a commercial dairy producer in Andhra Pradesh. When feeding sorghum stover as the basal diet to his improved 8 Murrah buffaloes, the dairy producer received on average 8.9 kg of milk per buffalo per day. His feeding regimes is quite representative for urban and peri-urban dairy production in peninsular India and consisted of about 60 percent of sorghum stover and about 40 percent of a home-made concentrate mix consisting of 15 percent wheat bran, 54 percent cotton seed cake and 31 percent husks and hulls from threshing of pigeon pea. Each of his buffaloes consumed about 9.5 kg of stover and 6.5 kg of the concentrate mix on any average day. The farmer purchased the sorghum stover at 6.3 Indian Rupees (Rs) per kg and together with costs for concentrates his feed cost per kg of milk were 18.2 (Rs) while his milk sales price was 28 Rs per kg. The farmer was willing to purchase maize stover on a trial basis for 3.8 Rs per kg. Substituting sorghum stover with the maize stover, his average daily milk yield per buffalo increased slightly to 9.4 kg per day while his overall feed costs per kg of milk decreased to 14.5 Rs (Table 4). The study convincingly demonstrated that dual-purpose maize cultivars combining high grain yield with high stover quality have enormous potential in mitigating fodder scarcity and increasing overall benefit from maize cropping in peninsular India.

Pilot testing of maize stover in commercial production of a total mixed ration feed block
Selected superior sorghum stover (for example, higher quality stover as in Figure 4) is the major component (50 percent) of a total mixed ration feed block of Miracle Fodder and Feeds Pvt. Ltd. in Hyderabad, India. In collaboration with this company, experimental feed blocks were produced where the sorghum stover was substituted by maize stover from an identified superior pipeline hybrid from the private sector. Sorghum- and maize-based feed blocks were fed to growing bulls ad libitum and voluntary feed intake and growth rate (live-weight gains) were recorded (Prasad et al., 2007). There was no significant difference in either intake or growth rate between the two feed blocks (Table 5).

Table 5. Maize stover as substitute for sorghum stover in commercial complete mixed ration feed blocks

	Maize stover feed block	Sorghum stover feed block
Dry matter intake (g/kg LW/d)	33	35
Liveweight gain (g/d)	859	820

Conclusions

Contrary to the widespread perception, maize stover fodder quality traits can easily be at par with those of sorghum stover. The probability of having higher quality maize stover available for mixed crop livestock farmers, fodder traders and feed processors can be increased through phenotyping for stover fodder quality traits in the product pipeline and new cultivar release trials. Our work estimates that across environments, on average, about 5 percent unit in IVOMD naturally exists among the pipeline maize hybrids. This magnitude of difference (i.e., 5 percent units in stover IVOMD) resulted in a difference of about 5 kg in daily milk production in dairy buffalo. Using information from the parental lines, similar differences in stover IVOMD can be effected. A disadvantage of maize stover compared to sorghum stover appears to be higher transport costs of the former.

References

Anandan S, Khan AA, Ravi D, Jeethander Reddy and Blümmel M (2010) A Comparison of Sorghum Stover Based Complete Feed Blocks with a Conventional Feeding Practice in a Peri Urban Dairy. *Animal Nutrition and Feed Technology* 10S: 23-28.

Biradar N (2004). Analysis of straw and stover of different crops as a livestock feed by the farmers. *Annals of Agricultural Research* 25:377-380.

Blümmel M and Rao PP (2006).Value of sorghum stover, and stover price to quality relationships in stover trading for urban and peri-urban dairy production. *International Sorghum and Millet Newsletter* 47: 97-100.

Blümmel M, Vishala A, Ravi D, Prasad KVSV, Ramakrishna Reddy and Seetharama N (2010). Multi-environmental investigations of food-feed trait relationships in Kharif and Rabi sorghum (*Sorghum bicolor* (L) Moench) over several years of cultivars testing in India. *Animal Nutrition and Feed Technology* 10S: 11-21.

Directorate of Maize Research (2011). DMR Vision 2030. Directorate of Maize Research, Pusa Campus, New Delhi, India, 24p.

Erenstein O, Samaddar A, Teufel N and Blümmel M (2011). The paradox of limited maize stover use in India's small holder crop-livestock systems. *Experimental Agriculture* 47, 677-704.

Erenstein O (2002). Crop residue mulching in tropical and semi-tropical countries: an evaluation of residue availability and other technological implications. *Soil and Tillage Research*, 67: 115-133.

Ertiro BT, Habtamu Z, Friesen D, Blümmel M, Twumasi-Afriyie S (2013). Relationship between the performance of parental inbred lines and hybrids for food-feed traits in maize (*Zea mays* L.) in Ethiopia. *Field Crops Research* http://dx.doi.org/10.1016/j.fcr.2013.02.008.

Homann-Kee Tui S, Blümmel M, Valbuena D, Chirima A, Masikate P, Van Rooyen A, Girma T. Kassie (2013). Assessing the potential of dual-purpose-maize in southern Africa: a multi-level approach. *Field Crops Research* http://dx.doi.org/10.1016/j.fcr.2013.07.002.

Kristjianson P M and Zerbini E (1999). Genetic enhancement of sorghum and millet residues fed to ruminants ILRI Impact Assessment Series 3, ILRI Nairobi.

Joshi PK, Singh NP, Singh NN, Gerpacio RV and Pingali PL (2005). *Maize in India: Production Systems, Constraints, and Research Priorities*. Mexico, D.F.: CIMMYT.

Prasad KVSV, Gupta MD, Shah L and Blümmel M (2007) Potential of maize stover from a new dual-purpose hybrid in substituting for sorghum stover in a commercially produced feed block. In: International Tropical Animal Nutrition Conference (Eds Bakshi PS and Wadha M), Vol 2: 41-42.

Ravi D, Khan AA, Saibutcha Rao M, Blümmel M (2013). A note on suitable laboratory stover quality traits for multidimensional maize improvement. *Fields Crops Research* http://dx.doi.org/10.1016/j.fcr.2013.01.013.

Sharma K, Pattanaik AK, Anandan S and Blümmel M (2010). Food-feed crop research: a synthesis. *Animal Nutrition and Feed Technology* 10S: 1-10.

Spielman DJ, Kolady D, Cavalieri A and Rao NC (2011) The Seed and Agricultural Biotechnology Industries in India: An Analysis of Industry Structure, Competition, and Policy Options. IFPRI Discussion Paper 01103, International Food Policy Research Institute, Washington DC, USA. 36p.

Valbuena D, Erenstein O, Homann-Kee Tui S, Abdoulaye T, Claessens L, Duncan AJ, Gerard B, Rufino MC, Teufel N, van Rooyen A, van Wijk MT (2012). Conservation agriculture in mixed crop-livestock systems: scoping crop residue trade-offs in sub-Saharan Africa and South Asia. *Field Crops Research* 132: 175-184.

Vinayan MT, Raman Babu, Jyothsna T, Zaidi PH, Blümmel M (2013). A note on potential candidate genomic regions with implications for maize stover fodder quality. *Fields Crops Research* http://dx.doi.org/10.1016/j.fcr.2013.03.018.

Zaidi PH, Vinayan MT, Blümmel M (2012). Genetic variability of tropical maize stover quality and the potential for genetic improvement of food-feed value in India. *Fields Crops Research* http://dx.doi.org./10.1016/j.fcr.2012.11.020.