is to grow resistant varieties. All the test composites were resistant to Jalna pathotype. Some composites exhibited resistance to more than one pathotypes; eg, DRSB-6 (Jalna, Patancheru), DRSB-7 (Jalna, Patancheru and Jodhpur), DRSB-10 (Jalna, Patancheru), and DRSB-3 (Jalna and Jodhpur). Thus these can be safely recommended to farmers of different regions, especially Karnataka, Maharashtra, Andhra Pradesh and Rajasthan. Further, they could form useful source material for developing pearl millet varieties resistant to multiple pathotypes.

These superior populations with high yield potential and good fodder quality could be extensively tested for commercial release and are potential sources of new germplasm for use in breeding programs. All these composites are at various levels of testing in the All India Coordinated Research Project and Regional Multi-Location Trials. The composite DRSB-2 was released in 2002 in Karnataka for northern transitional zone. The open-pollinated varieties are better suited than hybrids for forage purpose owing to technically easy and cost-effective seed production by the farmer. Because of diverse genetic base, they maintain growth and vigor and ensure the crop against diseases and pests.

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Stover Quality and Grain Yield Relationships and Heterosis Effects in Pearl Millet

M Blummel[1,*] and KN Rai[2] (1. International Livestock Research Institute - South Asia Project, Patancheru 502 324, Andhra Pradesh, India; 2. ICRISAT, Patancheru 502 324, Andhra Pradesh, India)
*Corresponding author: m.blummel@cgiar.org

Introduction

Pearl millet (*Pennisetum glaucum*) is the most drought tolerant of all domesticated cereals and can yield grain under rainfall as low as 200 to 250 mm (Bidinger and Hash, in press) making it the only reliably productive cereal in the driest rainfed regions of the arid and semi-arid tropics. In these regions, crop-livestock production systems are highly integrated and the stover from pearl millet plays a very crucial role in feeding the livestock. Kelley et al. (1996) observed that farmers rejected several pearl millet cultivars (improved only for grain yield) because of too poor fodder value of the stover. Considering the growing demand for more and better quality fodder for livestock, crop improvement programs have now become multidimensional, targeting the whole plant rather than one single trait. Nearly 70% of the Indian pearl millet area (>9 million ha) is sown to more than 72 hybrids and improvement in the quantity and/or the nutritional quality of the stover of these hybrids could make tremendous impact on livestock productivity in the region. The objective of the current research was to assess heterosis in top-cross hybrids for stover quality traits and to investigate genotypic variability in stover quality traits and their relationships with grain and stover yield.

Material and Methods

Field trial. Forty-two top-cross hybrids developed by crossing seven populations of diverse origin on each of six fodder-type male-sterile lines, plus the respective parental populations and three released dual-purpose cultivars (2 open-pollinated varieties and a hybrid) as checks, were evaluated at ICRISAT, Patancheru, India during the 2002 rainy season at a high fertility level [120 kg nitrogen (N) and 18 kg phosphorus (P) ha^{-1}]. The trial was planted in 4-row plots of 4 m length in randomized complete block design replicated three times with 75 cm spacing between the rows and 10 cm spacing between plants within the rows. Panicles were harvested at maturity and dried at 55°C for 24 h and threshed to determine grain yield. For stover yield, plants were

Table 1. Grain yield (GY) (t ha^{-1}), stover yield (SY) (t ha^{-1}), stover crude protein (CP) (%), stover in vitro digestibility (IVD) (%) and heterosis effects (A) (%) in 42 top-cross hybrids of pearl millet and GY, SY, CP and IVD in 7 pollinator populations used in producing these hybrids.

Genotype	GY	ΔGY	SY	Δ SY	CP	Δ CP	IVD	Δ IVD
ICMA 01222 x HHVBC Tall	3.36	-8.4	3.86	-10.7	4.8	-21.6	41.1	-7.3
ICMA 01222 x RC-B-2	3.52	24.4	4.14	11.3	4.8	1.3	41.8	4.2
ICMA 01222 x ICMV 91059	3.64	0	3.86	-25.2	4.5	-21.2	43.4	-6.2
ICMA 01222 x SDMV 93032	3.61	19.5	4.77	18.4	5.9	8.5	45.9	2.1
ICMA 01222 x MC 94	3.60	9.4	3.45	3.0	4.7	-6.2	41.1	-4.8
ICMA 01222 x ICMS 7704	3.65	18.9	4.43	-19.9	4.2	6.0	44.1	-1.6
ICMA 01222 x ICMV-IS 94206	3.72	1.9	4.29	-3.2	4.3	29.6	40.8	2.2
Mean	3.59	9.4	4.6	-3.8	4.6	-0.5	42.6	-1.6
ICMA 98555 x HHVBC Tall	3.53	-3.8	4.31	-0.2	6.3	3.0	43.5	-1.9
ICMA 98555 x RC-B-2	3.35	18.4	3.64	-2.2	5.2	8.2	39.1	-2.6
ICMA 98555 x ICMV 91059	3.91	7.4	3.74	-27.5	5.7	-0.5	43.1	-6.9
ICMA 98555 x SDMV 93032	3.45	14.2	4.11	2.0	5.1	11.1	45.0	0.1
ICMA 98555 x MC 94	3.59	9.1	3.47	3.6	5.2	2.6	41.3	-4.3
ICMA 98555 x ICMS 7704	3.65	18.9	4.05	-26.8	4.0	1.8	41.8	-6.8
ICMA 98555 x ICMV-IS 94206	3.89	6.6	4.78	7.9	4.5	35.5	42.8	7.1
Mean	3.62	10.1	4.01	-6.2	5.1	8.8	42.4	-2.2
ICMA 91777 x HHVBC Tall	3.54	-3.5	4.09	-5.3	4.4	-26.9	40.0	-9.7
ICMA 91777 x RC-B-2	3.20	13.1	4.37	17.5	4.9	2.5	40.9	2.0
ICMA 91777 x ICMV 91059	3.20	-12.1	4.44	-14.0	5.2	-1.3	43.7	-5.5
ICMA 91777 x SDMV 93032	3.31	9.6	4.58	13.7	4.2	-7.9	42.8	-4.8
ICMA 91777 x MC94	3.65	10.9	5.29	57.9	4.8	-4.0	39.6	-8.2
ICMA 91777 x ICMS 7704	3.72	21.2	4.37	-21.0	4.3	8.1	40.7	-9.2
ICMA 91777 x ICMV-IS 94206	3.43	-6.0	3.97	-10.4	3.9	17.0	38.5	-3.6
Mean	3.43	4.7	4.44	5.5	4.5	-1.8	40.9	-5.6
ICMA 98333 x HHVBC Tall	3.75	2.2	3.18	-26.4	6.0	-1.0	42.1	-5.0
ICMA 98333 x RC-B-2	3.27	15.6	3.10	-16.7	4.6	-2.5	40.5	1.0
ICMA 98333 x ICMV 91059	3.82	5.0	3.53	-31.6	5.8	0	41.5	-10.3
ICMA 98333 x SDMV 93032	3.44	13.9	3.62	-10.2	4.4	-3.5	42.4	-5.6
ICMA 98333 x MC 94	3.66	11.3	3.12	-6.9	5.2	3.8	42.9	-0.7
ICMA 98333 x ICMS 7704	3.83	24.8	3.38	-38.9	4.9	22.7	41.7	-7.1
ICMA 98333 x ICMV-IS 94206	3.96	8.5	3.89	-12.2	4.1	23.0	42.0	5.2
Mean	3.68	11.6	3.40	-20.4	5.0	6.1	41.9	-3.2
ICMA 00888 x HHVBC Tall	2.85	-22.3	3.24	-25.0	5.2	-13.7	43.3	-2.3
ICMA 00888 x RC-B-2	3.15	11.3	3.40	-8.6	5.1	6.5	43.0	7.1
ICMA 00888 x ICMV 91059	3.10	-14.5	3.77	-26.9	6.0	4.9	46.0	-0.6
ICMA 00888 x SDMV 93032	3.01	-0.3	3.56	-11.7	5.9	29.7	43.5	-3.3
ICMA 00888 x MC 94	3.50	6.4	3.53	5.4	5.4	6.2	44.4	2.9
ICMA 00888 x ICMS 7704	3.92	27.8	3.72	-32.7	5.6	41.8	42.4	-5.6
ICMA 00888 x ICMV-IS 94206	3.50	-4.1	3.65	-17.6	4.4	32.5	43.3	8.3
Mean	3.29	0.6	3.55	-16.7	5.4	15.4	43.7	0.9
ICMA 01777 x HHVBC Tall	3.66	-0.3	3.71	-14.1	4.1	-32.5	41.6	-6.1
ICMA 01777 x RC-B-2	3.91	38.2	4.18	12.4	4.9	3.6	41.7	3.7
ICMA 01777 x ICMV 91059	3.70	1.7	3.89	-24.6	3.9	-31.5	44.8	-3.2
ICMA 01777 x SDMV 93032	3.46	14.6	3.87	-4.0	5.6	22.1	46.7	4.0
ICMA 01777 x MC 94	3.78	14.9	3.59	7.2	4.7	-6.4	42.5	-1.5
ICMA 01777 x ICMS 7704	3.84	25.1	4.74	-14.3	4.0	1.8	45.5	1.4
ICMA 01777 x ICMV-IS 94206	3.91	7.1	2.93	-33.9	3.6	8.4	39.9	-0.2
Mean	3.75	14.5	3.84	-10.2	4.4	-4.9	43.2	-0.3

continued

Table 1. ***continuted.***

Genotype	GY	Δ GY	SY	Δ SY	CP	Δ CP	IVD	Δ IVD
HHVBC Tall	3.67		4.32		6.1		44.3	
RC-B-2	2.83		3.72		4.8		40.2	
ICMV 91059	3.64		5.16		5.8		46.3	
SDMV 93032	3.02		4.03		4.6		44.9	
MC 94	3.29		3.35		5.0		43.1	
ICMS 7704	3.07		5.53		4.0		44.9	
ICMV-IS 94206	3.65		4.43		3.4		40.0	
Pollinator mean	3.31		4.36		4.8		43.4	
JBV2 9 (check)	3.27		3.76		6.0		42.3	
JBV3 (check)	3.27		3.68		4.0		44.3	
ICMH 451 (check)	3.54		4.16		5.2		42.2	
SED[1]	0.24		0.54		0.6		1.8	
SEm±	0.17		0.38		0.4		1.3	
Mean	3.51		3.96		4.9		42.6	
CV (%)	8		17		14		5	
LSD	0.47		1.06		1.1		3.6	

1. Statistical variables relate to overall ANOVA on all treatments.

harvested at soil level and a sample of 5 plants from each plot was oven-dried at 50°C for three days (8 h a day) to determine dry stover yield and quality. Heterosis effects were estimated as value of the top-cross hybrid minus value of the pollinator divided by value of the pollinator. Significant heterosis effects were assumed with differences between lop-cross hybrid and pollinator greater than the least significant difference value from overall analysis of variance.

Stover analysis. Stover quality assessments were based on a combination of conventional laboratory analysis and Near Infrared Spectroscopy (NIRS) using a FOSS 5000 Forage Analyzer with WINSI II software package. Seventy-two stover samples from the total of 165 were selected for NIRS calibration-validation procedures using WINSI II software features and analyzed for protein and in vitro digestibility by conventional laboratory techniques. Thirty-six of these stover samples were used to develop NIRS calibration equations for protein and in vitro digestibility to blind-predict these measurements for the remaining 36-stover samples. Agreement between conventionally analyzed crude protein and in vitro digestibility and NIRS-predicled values were R^2 = 0.92 and 0.89, respectively. Calibration equations were then developed based on all 72 samples and used for the prediction of crude protein and stover digestibility of the entire set of stover samples.

Conventional in vitro digestibility measurements were based on incubation of stover in an in vitro gas production test as described by Menke and Steingass (1988). Rumen microbial inoculum for in vitro incubation was collected from two rumen-cannulated bullocks (local Indian breed) kept on a diet based on stover. Accumulating gas volumes were recorded after 24 h of incubation and in vitro digestibility was calculated as 15.38 + [0.8453 x gas (ml) produced after 24 h] + [0.595 x crude protein (%)] + (0.181 *% ash) as described by Menke and Steingass (1988). Conventional crude protein measurements were obtained by N determinations by Technicon Auto Analyzer and multiplication of N% by 6.25.

Results and Discussions

Grain yield, stover yield, stover crude protein content and in vitro digestibility of stover of the 42 top-cross hybrids, the 7 pollinators and the 3 checks of pearl millet and heterosis for traits are presented in Table 1. Significant genotypic differences (P <0.05) were observed for all the traits. Grain yield ranged from 2.83 to 3.96 t ha^{-1} and stover yield ranged from 2.93 to 5.53 t ha^{-1}. Stover crude protein content and stover in vitro digestibility ranged from 3.4 to 6.3% and from 38.5 to 46.7%, respectively. Significant (P <0.05) positive as well as negative heterosis effects were observed for grain yield, stover yield and stover crude protein content but not for in vitro digestibility where only negative heterosis effects were significant. As pointed out by Bidinger et al. (2003) selection history played a large role in heterosis effects on grain and stover yields in pearl millet. Parental material selected for grain yield through increasing harvest index resulted in heterosis for higher grain yield but lower stover yields while lines which were selected

for increased biomass yields/growth rates and neutral effects on harvest index resulted in hybrids with higher grain and stover yields (Bidinger et al. 2003). We observed positive (although rarely significant) heterosis trends in 32 hybrids for grain yield, in 12 hybrids for stover yield, in 27 hybrids for crude protein and in 14 hybrids for in vitro digestibility (Table 1).

Ruminants need a minimum of 7% of crude protein in their diet (Van Soest 1994) to utilize the potentially digestible organic matter. Cereal crop residues are deficient in crude protein since their mean protein content is approximately only half of that required. The response in livestock productivity to incremental increases of 3.5 to 7% in protein content of the diet is substantial. The observed genotypic variation in stover crude protein (3.4 to 6.3%) is therefore nutritionally relevant, and increasing crude protein content of stover by crop improvement could be a very relevant option to pursue. However, this option would require absence of strong competitive associations between stover crude protein content and grain yield and other desirable traits. Stover crude protein content and grain and stover yield tended to be inversely associated but the relationships did not attain (nor approach) significance levels (Figs. Ia and Ib). These findings suggest that stover with high crude protein content can be selected without sacrificing the grain yield. Crude protein content in pearl millet stover is also affected by N fertilizer application; Blummel et al. (2003) observed mean stover crude protein content of 3 and 4.4% under low (9 kg N ha^{-1}) and high (90 kg N ha^{-1}) fertilizer application, respectively. The N application rate in our work was even higher (120 kg N ha^{-1}) which might explain the very large range in crude protein values observed. More work appears to be warranted to investigate the variation in protein content and the relationships between stover protein content and grain and stover yield under low input systems.

Stover organic matter digestibility - besides stover intake - will determine livestock productivity in stover-fed animals. Organic matter digestibility in the animals is an estimate of how much of the fodder can be used (digested) by the animal for productive purposes and is

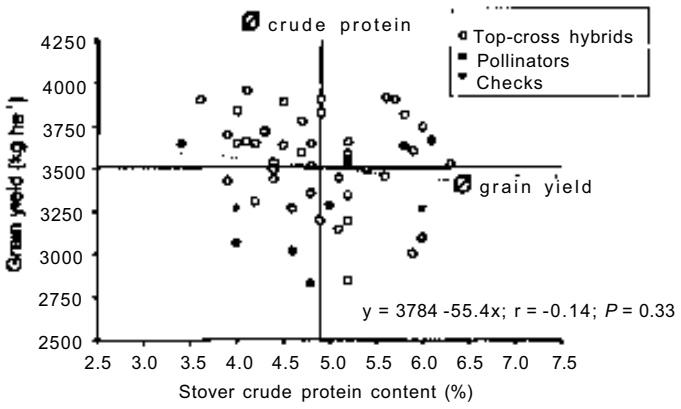

Figure Ia. Relation between stover crude protein content and grain yield in 52 genotypes of pearl millet.

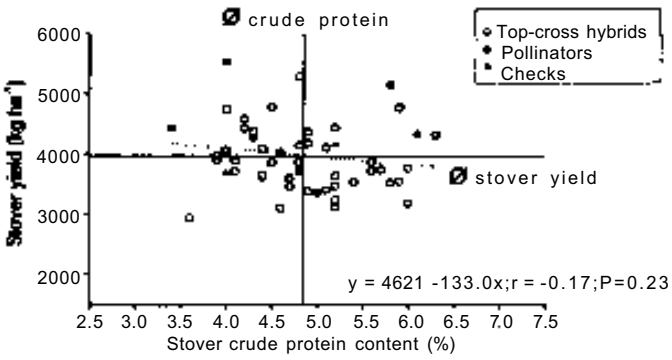

Figure Ib. Relation between stover crude protein content and stover yield in 52 genotypes of pearl millet.

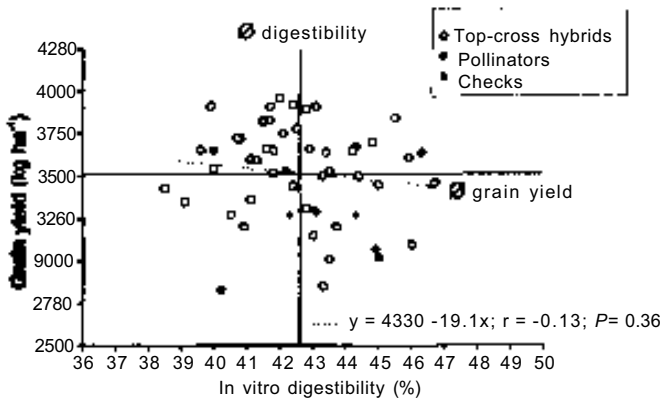

Figure 2a. Relation between in vitro digestibility and grain yield in 52 genotypes of pearl millet.

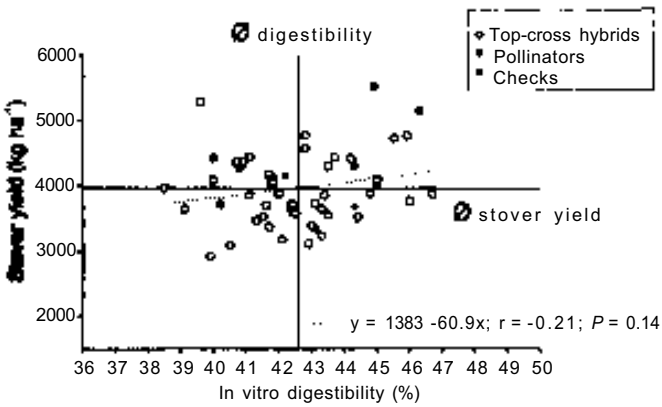

Figure 2b. Relation between in vitro digestibility and stover yield in 52 genotypes of pearl millet.

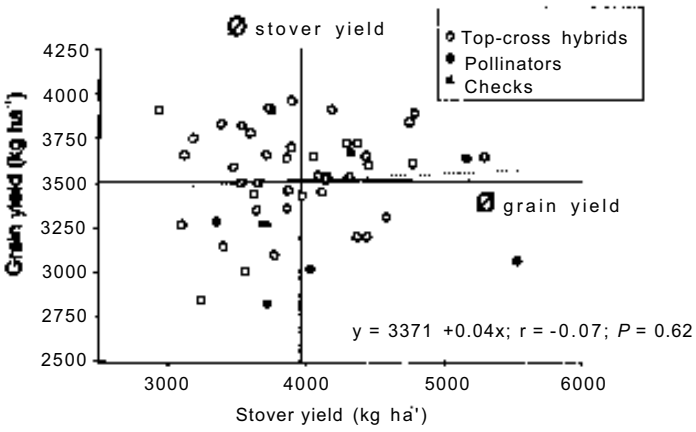

Figure 3a. Relations between stover yield and grain yield in 52 genotypes of pearl millet.

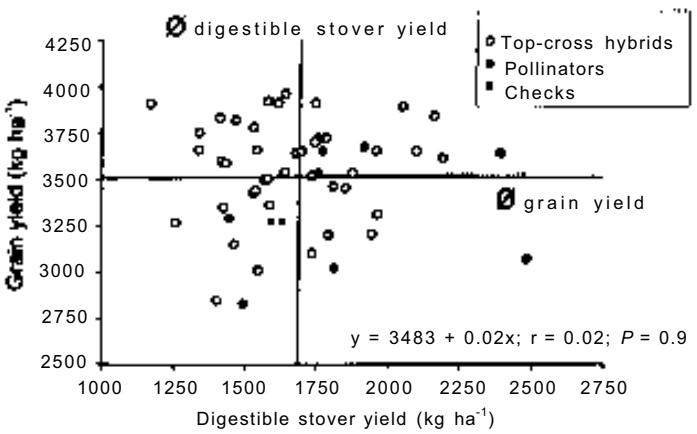

Figure 3b. Relations between digestible stover yield and grain yield in 52 genotypes of pearl millet.

commonly predicted by in vitro incubation in rumen inoculum in the laboratory. We observed genotypic differences of about 8 units in in vitro digestibility of stover. Differences of this magnitude will have substantial effects on livestock productivity (Van Soest 1994). In vitro digestibility of stover and grain and stover yield seem to be compatible traits, ie, stover in vitro digestibility and grain and stover yields were not significantly associated (Figs. 2a and 2b).

Mixed crop-livestock farmers in the semi-arid tropics require stover of good quality but they also need stover quantity. Stover yield and grain yield were not related (Fig. 3a) and improvement for grain yield will not automatically affect stover yield in either positive or negative way. Stover yield measurements should, therefore, be included in genotype evaluations. Overall stover value will be a product of stover quantity and stover quality. Digestible stover yield was calculated as the product of total stover yield and its in vitro digestibility and was found to vary from 1.3 to 2.5 t ha^{-1}. No relationship was observed between these two variables (Fig. 3b) suggesting that high stover value and high grain yield are not mutually exclusive traits.

Conclusions

Significant and nutritionally relevant cultivar differences exist in pearl millet stover quality and these were largely independent of grain and stover yield. Highest grain yields were observed for top-cross hybrids but some open-pollinated cultivars were superior in dual-purpose usage in that they provided excellent stover value and good grain yield at the same time.

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