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Variations in the nutritive value of soybean straw and their use with agronomic traits for breeding assays

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1 SUMMARY

To make full use of soybean [*Glycine max* (L.) Merr.] straw (SBS) as roughage, the SBS nutritive values with agronomic traits of 35 varieties were evaluated for breeding. The plant height of all soybeans ranged from 47.2 to 175.5 cm, and grain yield ranged from 2030.6 to 5059.7 kg ha^{-1}. The contents of crude protein, crude fibre, crude ash, nitrogen-free extract (NFE), neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) of SBS were 31.8–63.6 g kg^{-1}, 447.5–566.9 g kg^{-1}, 45.7–67.8 g kg^{-1}, 284.3–427.1 g kg^{-1}, 722.1–808.5 g kg^{-1}, 491.2–572.2 g kg^{-1}, and 128.3–195.8 g kg^{-1}, respectively. *In vitro* dry matter digestibility (IVDMD) and relative feed value (RFV) were 31.68–43.86% and 52.14–65.38%, respectively. The straw composition, excluding crude ash, hemicelluloses and cellulose, was significantly different among varieties ($P < 0.05$). The plant height and contents of NDF, ADF, and ADL had negative correlations with IVDMD ($P < 0.01$), and IVDMD was positively correlated with grain yield, NFE content and RFV ($P < 0.01$). Considering the straw quality and grain yield, varieties with short plants and high grain yield should be selected as soybean breeding materials.

2 INTRODUCTION

The global grain crisis of 2008 reminded us of the importance of changing agriculture to address worldwide challenges such as farmland decline and population growth (Fedoroff *et al.,* 2010; Godfray *et al.,* 2010; Lusser *et al.,* 2012). In order to meet the food supply, farmers will have to hit high targets to increase grain supply to people and livestock (Ainsworth *et al.,* 2012). There is an increasing tendency, although technological problems still need to be solved, for feeding livestock (particularly ruminant animals) with crop residue (Tester and Langridge, 2010; Bromley, 2010). The soybean [*Glycine max* (L.) Merr.], as grain feed, is a high-protein component of animal diets. In 2011, soybean production was about 15.1 million tons, and the straw (SBS) yield was about 1.6-fold that of grain in China (Bi, 2010). However, almost 75% of soybean consumption still relied on imported soybean (Yang *et al.,* 2012). Few efforts have been devoted to developing soybean for dual-purpose use as grain and straw, although there have been some studies on SBS as feed (Khorvash *et al.,* 2010; Maheri-Sis *et al.,* 2011; Chang *et al.,* 2012). To bridge the gap, in this study we collected many soybean germplasms and investigated the characteristics of 35 soybean varieties as feed. Digestibility is an important characteristic of roughages, including SBS, that affects ruminant intake, growth rate, and beef and dairy production

(Jung and Allen, 1995). Soybean producers usually only plant varieties with high potential grain-yield because grain is highly digestible, while SBS is often cast off or burned. In fact, grain makes up less than half of the total aboveground dry matter (DM) production. Improving straw quality and increasing its digestibility are major objectives in forage breeding improvement programs (Howarth and Goplen, 1983; Barrière *et al.,* 2003). The aim of this study was to compare the agronomic traits of soybean and the chemical composition, *in vitro* dry matter digestibility (IVDMD), and relative feed value (RFV) of SBS. Finally, the correlations among the agronomic characteristics of soybean and the chemical components, IVDMD, and RFV of SBS were analyzed.

3 MATERIALS AND METHODS

Materials: 35 late-maturing summer or autumn-sown soybean germplasms collected from Southern China were planted in Zengcheng Experimental Field of South China Agricultural University in June 2011. The experimental field is located in Guangzhou at 23°26"N and 113°15"E and an altitude of 11 m above sea level, and it has a subtropical monsoon climate. The mean annual rainfall of the area was 1869.5 mm. The average annual air temperature was 22°C. Soybeans were arranged in a randomized complete block with 3 replicates. All of the plots were 2.5 m wide by 2.5 m long, with soybean planted at 200 000 seeds ha^{-1}. The plots contained 5 rows spaced 50 cm apart. Standard cultivation techniques were used.

3.1 Measurement methods: Ten consecutive plants in the mid-row of each plot were sampled to measure plant height (PHT). Grain yield was calculated through measuring the grain yield of the middle 3 rows from 5 rows. The materials were dried at 70°C for 48 hours in an oven, ground to pass through a 0.45-mm screen and stored for chemical analyses. Moisture content was determined by drying at 105±2°C for 4 hours in an oven. Crude protein (CP), Crude fibre (CF) and crude fat (EE) were analyzed according to AOAC methods (1990). Crude ash contents were measured after incineration for 3h at 550°C. Nitrogen-free extract (NFE) was determined by subtracting the sum of crude protein, crude fibre, crude fat and crude ash from 100. Neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) contents were measured according to the procedures of Van Soest *et al.* (1991). Cellulose content was calculated as the difference between ADF and ADL. Hemicellulose content was calculated as the difference between NDF and ADF. *In vitro* dry matter digestibility (IVDMD) was measured using two-stage methods (Tilley and Terry, 1963). Relative feed value (RFV) was calculated using the following formula (Redfearn *et al.,* 2004):

RFV (%) = 93 × (88.9 – 0.779ADF) / NDF (% DM).

3.2 Statistical analysis: Data on plant height, grain yield, chemical compositions, IVDMD and RFV of SBS were subjected to one-way analysis of variance. The means were then compared for significance by using Duncan's multiple range method. All statistical procedures were performed using the statistical packages for the social sciences (IBM SPSS 20).

4 RESULTS

Table 1 shows that PHT ranged from 47.2–175.5 cm; grain yield, 2030.6–5802.9 kg ha^{-1}; CP content, 31.8–63.6 g kg^{-1}; CF content, 447.5–566.9 g kg^{-1}; EE content, 9.7–16.6 g kg^{-1}; crude ash content, 45.7–67.8 g kg^{-1}; NFE content, 284.3–427.1 g kg^{-1}. The mean values of PHT, grain yield, CP, CF, EE, ash and NFE were 87.93 cm, 3193.43 kg ha^{-1}, 41.4 g kg^{-1}, 510.8 g kg^{-1}, 13.3 g kg^{-1}, 57.4 g kg^{-1}, and 345.7 g kg^{-1}, respectively. Table 2 shows that NDF content ranged from 722.1–808.5 g kg^{-1}; ADF content, 491.2–572.2 g kg^{-1}; ADL content, 128.3–195.8 g kg^{-1}; HEC content, 181.7–248.5 g kg^{-1}; cellulose content, 338.6–414.5 g kg^{-1}; IVDMD, 31.7–43.7%; and RFV, 52.1–65.4%, while the means of NDF, ADF, ADL, HEC, CEL, IVDMD, and RFV were 758.1 g kg^{-1}, 530.9 g kg^{-1}, 161.9 g kg^{-1}, 226.9 g kg^{-1}, 369.0 g kg^{-1}, 37.02%, and 58.46%, respectively. There were significant differences among the 35 SBS with respect to the contents of CP, CF, ash, NFE, ADF, IVDMD, and RFV ($P < 0.01$); the agronomic traits of PHT and grain yield ($P < 0.01$); and in NDF and ADL contents ($P < 0.05$), while there were no differences in EE, HEC, or CEL content ($P > 0.05$).

Table 1: Traits of different soybean varieties and nutritive compositions of their straw

Varieties	Plant height (cm)	Grain yield (kg ha^{-1})	Crude protein (g kg^{-1} DM)	Crude fibre (g kg^{-1} DM)	Crude fat (g kg^{-1} DM)	Crude ash (g kg^{-1} DM)	NFE (g kg^{-1} DM)
ASND	91.2	2385.2	36.9	566.9	13.4	66.2	284.3
BZD	60.4	2778.1	31.8	488.8	13.8	59.2	370.0
BJD	107.0	3237.4	43.3	539.4	13.8	56.1	314.3
CDGJHHQ	85.8	3932.7	44.1	488.0	13.0	52.8	376.6
CNWZD	112.0	2743.7	34.6	503.9	13.6	51.8	371.6
CXDHD	61.1	3072.3	42.1	528.4	14.1	67.8	304.9
DQD2	59.8	4469.8	42.6	499.5	13.3	57.4	351.2
DXD	79.6	2752.0	37.2	537.3	13.9	57.4	310.1
GHD4	51.9	4215.7	41.2	483.6	13.8	57.4	372.2
GX1	70.1	3748.8	36.1	512.5	12.8	55.4	345.8
GX3	69.3	3915.1	43.9	481.8	11.5	64.3	366.1
H16	92.7	3371.4	39.9	526.5	11.8	49.3	343.4
H17	94.2	3117.5	35.0	519.8	12.7	49.7	350.8
H51	96.2	2608.0	40.3	549.5	15.0	58.9	315.1
HTYD	175.5	2030.6	35.4	553.9	12.9	61.1	311.4
HKWD	96.1	2660.6	32.9	526.6	11.0	56.5	334.7
HX1	51.1	3059.7	42.7	522.3	14.5	56.4	323.0
HX3	99.3	3303.5	63.6	463.9	14.3	52.8	368.6
LYH2	81.4	2173.3	36.0	509.1	13.4	59.5	344.6
LSZD	70.3	5802.9	38.3	453.6	15.4	59.9	408.2
MSRFHD	131.7	3005.1	40.4	524.3	9.7	62.3	327.8
NHHHQ	100.3	2593.9	37.6	501.7	16.6	56.7	359.1
SXWD	90.4	2936.2	50.8	519.2	15.5	56.5	328.2
SRAZW	70.5	4195.0	51.4	476.8	12.5	64.6	364.8
SSHD	122.0	3053.7	41.8	526.0	11.2	57.1	331.6
SYH	115.7	3336.5	37.1	550.2	15.2	45.7	322.0
SYQ	143.9	2594.1	46.4	503.7	11.6	60.1	349.6
TWHD	78.2	3403.0	33.1	447.5	14.2	51.4	427.1
XPLDX	53.0	3780.7	39.0	485.6	14.8	64.8	370.8
XSHD	119.4	3075.0	37.1	502.0	13.9	64.1	351.0
YGB	47.3	3270.9	55.1	521.8	13.5	53.7	321.8
YX106	64.8	3034.8	44.4	498.8	11.4	66.8	335.7
YX107	56.2	3696.2	47.4	530.4	10.1	55.6	326.9
YX120	107.1	2979.2	53.3	517.3	15.4	47.0	329.8
ZHDHD	72.2	2803.3	41.4	523.1	11.4	52.3	342.8
Average	87.9	3232.4	41.4	510.8	13.3	57.4	345.7
CV(%)	35.7	26.8	24.8	6.5	20.7	13.2	14.3
Significance	**	**	**	**	NS	**	**

NS, not significant ($P > 0.05$).
**significant at the 0.01 probability level.

Table 2: Fibre compositions, IVDMD and RFV of straw from different soybean varieties

Varieties	NDF (g kg^{-1} DM)	ADF (g kg^{-1} DM)	ADL (g kg^{-1} DM)	HC (g kg^{-1} DM)	Cellulose (g kg^{-1} DM)	IVDMD (%)	RFV (%)
ASND	760.8	554.8	195.8	206.0	359.1	36.21	55.86
BZD	751.8	514.6	144.0	237.1	370.6	38.19	60.50
BJD	753.9	572.2	177.9	181.7	394.3	34.60	54.81
CDGJHHQ	770.6	529.4	159.4	241.2	370.0	36.82	57.54
CNWZD	808.5	560.4	176.8	248.1	383.6	31.68	52.14
CXDHD	733.0	511.0	156.2	218.7	354.9	39.03	61.99
DQD2	751.7	510.1	171.5	241.6	338.6	39.06	60.85
DXD	747.9	556.7	179.4	191.3	377.2	36.65	56.67
GHD4	760.8	519.7	166.5	241.1	353.2	35.54	59.21
GX1	755.0	534.9	158.3	220.2	376.5	36.71	58.22
GX3	752.2	516.4	166.4	235.7	350.0	39.29	60.25
H16	778.2	547.7	182.0	230.4	365.8	33.98	55.29
H17	781.6	551.5	162.9	230.1	388.6	35.40	55.08
H51	777.3	538.1	172.0	239.2	366.1	34.16	56.35
HTYD	779.8	550.0	181.3	229.8	368.8	33.67	54.94
HKWD	800.6	552.1	164.8	248.5	387.3	38.13	53.45
HX1	753.3	533.8	172.8	219.5	361.0	35.11	58.46
HX3	763.1	526.6	167.0	236.5	359.5	37.93	58.40
LYH2	755.9	527.4	164.3	228.5	363.1	37.63	58.91
LSZD	722.1	491.2	144.2	230.9	347.0	43.86	65.38
MSRFHD	740.2	520.1	144.9	220.2	375.2	35.16	60.85
NHHHQ	797.0	549.8	164.0	247.2	385.8	34.02	53.79
SXWD	734.7	511.5	170.5	223.2	340.9	38.84	62.15
SRAZW	724.9	501.6	142.3	223.3	359.4	38.36	63.93
SSHD	770.2	525.0	152.1	245.1	373.0	37.32	58.14
SYH	744.7	521.4	149.0	223.3	372.4	34.13	60.38
SYQ	776.3	564.1	149.6	212.2	414.5	34.30	53.88
TWHD	741.5	503.4	149.1	238.0	354.3	41.30	62.33
XPLDX	751.0	536.1	150.3	215.0	385.8	39.23	58.44
XSHD	765.3	550.3	157.0	215.0	393.4	36.56	55.97
YGB	760.5	525.1	169.9	235.4	355.3	38.60	58.71
YX106	735.7	493.3	128.3	242.4	365.0	40.30	63.95
YX107	755.5	524.2	152.1	231.5	372.0	37.77	59.29
YX120	734.8	526.0	158.8	208.8	367.2	37.10	60.83
ZHDHD	737.0	523.5	169.2	213.5	354.4	37.55	60.78
Average	758.1	530.9	161.9	226.9	369.0	37.02	58.46
CV (%)	3.7	5.4	12.2	10.2	6.7	7.7	7.6
Significance	**	**	*	NS	NS	**	**

* significant at the 0.05 probability level, **significant at the 0.01 probability level, NS, not significant ($P > 0.05$).

IVDMD was negatively correlated with PHT and the contents of CF, NDF, ADF, ADL, and CEL ($P < 0.01$), but positively correlated with grain yield, contents of ash and HEC ($P < 0.05$) and NFE and RFV ($P < 0.01$). According to the absolute sizes of the correlation coefficients (Table 3), IVDMD was affected in order from the greatest to the least by ADF > CF > PHT > NDF > CEL > ADL and NFE > Ash > HEC. Combined with agronomic characteristics, the top 5 varieties with respect to comprehensive performance were LSZD, TWHD2, YX106, GX3, and XPLDX, and the worst 5 were CNWZD, HTYD, H16, NHHHQ, and H51.

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Table 3. Correlation between traits of straw nutrients and agronomic traits of soybean

Items	Plant height	Grain yield	Crude protein	Crude fibre	Crude fat	Crude ash	NFE	NDF	ADF	ADL	Hemi-cellulose	Cellulose	IVDMD	RFV
Plant height	1													
Grain yield	–0.264**	1												
Crude protein	–0.046	0.207*	1											
Crude fibre	0.301**	–0.270**	–0.227*	1										
Crude fat	–0.126	–0.108	0.021	–0.085	1									
Crude ash	–0.158	–0.046	–0.072	–0.082	–0.060	1								
NFE	–0.213*	0.247*	–0.035	–0.909**	0.057	–0.093	1							
NDF	0.315**	–0.240*	–0.238*	0.248*	–0.074	–0.279**	–0.098	1						
ADF	0.387**	–0.253*	–0.260*	0.478**	–0.087	–0.225*	–0.347**	0.666**	1					
ADL	0.109	–0.212*	–0.092	0.315**	0.091	–0.287**	–0.231*	0.393**	0.531**	1				
Hemicellulose	–0.085	0.017	0.018	–0.285**	0.008	–0.072	0.320**	0.405**	–0.412**	–0.170	1			
Cellulose	0.360**	–0.117	–0.228*	0.299**	–0.174	–0.029	–0.215*	0.452**	0.729**	–0.193	–0.339**	1		
IVDMD	–0.500**	0.248*	0.194	–0.546**	0.095	0.258*	0.380**	–0.476**	–0.642**	–0.344**	0.201*	–0.466**	1	
RFV	–0.384**	0.277**	0.264**	–0.419**	0.085	0.260*	0.274**	–0.886**	–0.933**	–0.521**	0.061	–0.658**	0.621**	1

* significant at the 0.05 probability level.
**significant at the 0.01 probability level.

DISUSSION

The experiments verified that genetic differences in the forage quality of 35 varieties did exist just as corn plants vary with respect to the contents of CP, NDF, lignin, ash, and fat (Barrière *et al.*, 2003; Owens, 2005), and the results were consistent with those of Cheng (2008), Qiao (2008), and Yang (2010), who reported that soybean cultivars differed with respect to PHT, stem diameter, and contents of CF, CP, and lignin due to genetic and numerous environmental factors. This provides the possibility of breeding soybean with a dual function as food and fodder. The average CP content was 41.4 g kg^{-1}, which was higher than 34 g kg^{-1} reported by Cheng *et al.* (2008) and lower than the 49–51 g kg^{-1} reported by Minor *et al.* (1973), Sruamsiri and Silman (2008) and Maheri-Sis *et al.* (2011). Compared to wheat straw, soybean straw had more CP and ADL and less NFE (Yadav and Tripathi, 1991; Kakkar and Dhanda, 1998). In addition, this study showed 8that the average content of ADL was 161.9 g kg^{-1}, similar to that reported by Gupta *et al.* (1978) and Maheri-Sis *et al.* (2011). Soybean straw contained similar contents of CP, cellulose, hemicelluloses, and lignin to rice straw, but its ash content was lower (Yang and Chang, 1998). The IVDMD of SBS averaged 37.0%, which was lower than of the approximately 47.1% of corn stems near physiological maturity (Lundvall *et al.,* 1994). The IVDMD showed negative relationships with the content of NDF, ADF, ADL, CF, and CEL. This finding was consistent with Datt *et al.* (2009). There were only 3 varieties (LSZD, TWHD2 and YX106) with an IVDMD higher than 40%, accounting for about 8.57% of the total varieties. This also reflected the fact that in China soybean breeders do not currently pay attention to improving the forage quality of SBS. This study shows that choosing varieties with high SBS IVDMD would not affect grain-yield and improve the perspective of conventional breeding programs.

Of course, the soybean straw quality would be affected by cultivation measures and environmental factors (climate, soil properties.) (Lu and Li, 2010; Maheri-Sis *et al.,* 2011). However, selective plant breeding should pay attention to improving the chemical composition of SBS to obtain materials with high IVDMD and less lignin (Howarth and Goplen, 1983; Jung and Allen, 1995; Barrière *et al.,* 2003). Screening the high-yield soybean germplasm resources could meet the demands for good straw quality for animal production. IVDMD had a very significantly negative correlation with PHT, NDF, ADF, ADL, CF, and CEL content. However, it was significantly and positively correlated with grain yield, ash, NFE, HEC, and RFV, while there was no significant correlation with CP and EE content. In general, the fibre fractions of NDF, ADF, ADL, CF and CEL are difficult to be digested, while NFE and HEC are easy to be digested. In addition, SBS contained less CP and EE, which might not affect the IVDMD of SBS. Since PHT was positively correlated with NDF, ADF, ADL, CF and CEL, possibly indicated that the higher plants needed more fibre to support. This research preliminarily determined the correlation of major agronomic traits and forage quality. Namely breeding grain-soybean is not contradictory with fodder-soybean, raising the grain yield can also benefit to improving the quality of SBS. The experiments verified the genetic differences in the forage quality among 35 varieties, and a part of SBS had relatively good quality, but the rests were poor. This requires further improvement by breeding. The strategy for soybean breeding is to produce plants with a low height and large grain yield, which will increase IVDMD at the same time.

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