Animal Feed Science and Technology 222 (2016) 122–131

Contents lists available at ScienceDirect

Animal Feed Science and Technology

journal homepage: www.elsevier.com/locate/anifeedsci

Variation in the straw traits of morphological fractions of faba bean (*Vicia faba* L.) and implications for selecting for food-feed varieties

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ARTICLE INFO

Article history:
Received 29 January 2016
Received in revised form 15 October 2016
Accepted 17 October 2016

Keywords:
Faba bean straw
Nutritive value
Food-feed traits

ABSTRACT

Five varieties of faba beans, 4 improved and released variety and one local variety, were investigated for varietal variation in straw yield, nutritive value of straw morphological fractions and grain yield. Samples of the whole plant biomass were collected and separated into grain and straw. The straw was further divided into leaves, stems and pods. Straw samples were analyzed for their chemical composition, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME). The potential utility index (PUI) was employed to rank the varieties. The results demonstrated significant varietal variation in grain yield, straw yield and proportions of botanical fractions of straw. The improved varieties were superior to the local variety in grain yield, straw yield and PUI. The local variety had the highest proportion of stem and lowest proportion of leaf and pods. Significant varietal variations ($P < 0.001$) were detected in dry matter (DM), organic matter (OM), ash, IVOMD, ME but not in crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) of whole straw. The leaves showed the highest IVOMD and content of crude protein, while pods were highest in ME. Canonical correlation analysis showed significant ($P < 0.001$) correlations between the nutritive value of whole straw and nutritive value and proportions of its botanical fractions. Grain and straw yields were positively, strongly and significantly ($P < 0.001$) correlated. Weak correlations were detected between grain yield and straw quality traits. Ranking the varieties differed when grain yield, straw quality scores and PUI were considered. However the weak correlation existed between grain yield and straw quality, including straw quality index or PUI to select food-feed varieties of faba bean is still necessary. These findings indicate the possibility of selecting faba bean varieties which combine superior grain and straw traits.

1. Introduction

In the tropics (latitudes 30°N to 30°S), 40 to 80% of livestock are found in mixed crop-livestock farming systems. The reduction in feeding value of crop residues from improved crops has often resulted in low adoption of new varieties by

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; DM, dry matter; IVOMD, *in vitro* organic matter digestibility using gas production technique; ME, metabolizable energy; NDF, neutral detergent fiber; PUI, potential utility index.

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http://dx.doi.org/10.1016/j.anifeedsci.2016.10.006
0377-8401/

Table 1
Agronomic characters of faba bean varieties.

Agronomic traits	Mosisa	Walki	Degaga	Shallo	Local
Days to flower	55	59	55	55	57
Days to mature	142	140	140	118	139
100 seeds weight (g)	43.4	63.6	60.7	55.8	70.8
Plant height	122	95.9	82.7	118	76.1
Altitude (m.a.s.l)	2300–2600	1900–2800	1800–3000	2300–2600	2300–3000
Year of release	2013	2008	2002	2000	–

Source: Sinana Agricultural Research Center, Robe, Ethiopia.

smallholders. Due to the close relationship between crop and livestock production, animal scientists are partnering with plant breeders in efforts to ensure that the focus to improve grain yield for human consumption is not detrimental to the nutritive value of crop residues fed to livestock. In Ethiopia, faba bean (*Vicia faba)* is grown by approximately 20% of farmers in the mixed crop-livestock systems over an area of 538,000 ha yielding 485,000 tons of grains annually (CSA, 2014). It is a primary source of protein and cash income for farmers (Mulualem et al., 2012). The production of one kg of faba bean grain generates approximately two kg of straw (Gebremeskel et al., 2011). Therefore, more than one million tons of faba bean straw is available in Ethiopia annually. Faba bean production is predominant in highland regions where mixed crop-livestock systems prevail (Mulualem et al., 2012). Studies have reported a relatively high nutritive value of faba bean straw is relatively high, containing on average, an average of 7.4 g/kg crude protein (CP) and 46.9 g/kg organic matter digestibility (Hadjipanayiotou et al., 1985; Abreu and Bruno-Soares, 1988; Alibes and Tisserand, 1990; Nsahlai and Umunna, 1996; Bruno-Soares et al., 2000; Asar et al., 2010). Faba bean is not only an important source of food for households, it is also an important source of nutrients for livestock. However, studies on the utilization of faba bean straw as livestock feed are limited. Studies on the varietal variation of faba beans have mainly focused on agronomic traits (Ricciardi et al., 2001; Keneni et al., 2005; Alghamdi, 2009; Mulualem et al., 2012). These studies reported high genetic variation in plant height, number of pods per plant, seeds per pod, branches per plant and the duration of vegetation and maturity, which may lead to exploitable variation in straw yields and quality. Gebremeskel et al. (2011) reported that location and variety have an effect on cell wall components and digestibility of faba bean straw. The selection of faba bean varieties that combine superior food-feed traits could lead to enhanced food and feed security in mixed crop-livestock systems. Therefore, this study was undertaken to: (1) evaluate the nutritive value of straws from five varieties of faba bean grown under similar climatic conditions and (2) examine the relationship between grain yield and corresponding straw yield and quality.

2. Materials and methods

2.1. Plant material

Four improved varieties, namely Degaga, Mosisa, Shallo, Walki and one local variety were obtained from Sinana Agricultural Research Center, Oromia, Ethiopia. The germplasm of the improved varieties was obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA). Germplasm was initially tested by the Ethiopian Institute of Agricultural Research (EIAR) for adaptability to the local environment and crossbred with local varieties. The selected varieties are among those released based on their high yield potential. Faba bean was grown on one ha plots during the main rainy season between August 2014 to January 2015 at the Sinana Agricultural Research Center (7°N latitude and 40°E longitude; 2400 masl). Agronomic characteristics of the varieties are presented in Table 1. The experimental plots were hand planted and received optimal crop management as per recommended practices for faba bean. The plots were manually seeded at a rate of 200 kg/ha. Chemical fertilizer was applied at a rate of 100 kg/ha diammonium phosphate on all plots. Hand weeding was undertaken at 30 and 45 days post-emergence. The average temperature and precipitation during the experimental period were 14.5 °C and 627.5 mm respectively. Thirty plots of one-square-meter quadrates (1×1 m) of each variety were manually harvested. Grains of each sample were separated from the total biomass and weighed. Half of the straw from each sample was fractionated into leaves, stems and pods. The remaining half represented the whole straw.

2.2. Straw quality analysis

Straw samples were ground to pass through a 1-mm sieve and analyzed for dry matter (DM), ash, CP, neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent lignin (ADL) and *in vitro* organic matter digestibility (IVOMD) using a combination of conventional nutritional laboratory analyses and Near Infrared Reflectance Spectroscopy (NIRS; Instrument FOSS 5000 Forage Analyzer with WINSI II software package). For conventional analysis, DM, OM, CP were analyzed according to AOAC (2000). Dry matter was determined by oven drying at 105 °C overnight (method 934.01). Ash was determined by burning in a muffle furnace at 500 °C overnight (method 942.05). Nitrogen content was determined by Kjeldahl method using Kjeldahl (protein/nitrogen) Model 1026 (Foss Technology Corp.) (method 954.01). Crude protein was calculated by multiplying the nitrogen content by 6.25. Neutral detergent fiber, ADF and ADL were determined as described by Van Soest and Robertson (1985). Amylase was not used in NDF determination and the result was expressed exclusive of residual ash.

Acid detergent fiber was expressed exclusive of residual ash. Lignin was determined by solubilization of cellulose with sulphuric acid. *In vitro* organic matter digestibility and ME were measured in rumen microbial inoculum using the *in vitro* gas production technique described by Menke and Steingass (1988). Briefly, approximately 0.2 g of sample was weighed and placed into 100 ml graduated glass syringes. Buffer mineral solution medium was prepared and placed in a water bath at 39 °C under constant flushing with CO_2. Rumen fluid was collected after morning feeding from three ruminally fistulated male cattle using a manually operated vacuum pump. It was filtered through four layers of cheesecloth, flushed with CO_2, mixed with buffered mineral solution (1:2 v/v) and pipetted into 30 ml syringes, which were immediately placed in a water bath at 39 °C. Gas production was recorded after 24 h of incubation and used to calculate IVOMD and ME according to Menke and Steingass (1988) equations. A basal NIRS calibration was developed and validated using conventional laboratory analysis of 20% of the samples. All chemical analyses were undertaken at the International Livestock Research Institute (ILRI) Animal Nutrition Laboratory in Addis Ababa, Ethiopia.

2.3. Calculations and statistical analysis

2.3.1. Analysis of variance

A general linear model was used to test the effect of variety on grain yield, straw yield, potential utility index and proportion of botanical fractions of straw. To compare straw quality traits, two models were applied. The first model included the effect of variety, straw fraction (pods, leaves and stems) and variety-fraction interaction. The second model analyzed the effect of variety on nutritive value of whole straw. Means were separated using least significant difference (LSD). Potential utility index, which estimates the proportion of utilizable portion of total faba bean biomass for food and feed regardless of the economic value was calculated according to the following equation:

$$PUI\left(w/w\right) = \frac{grain\ \ yield\ \ \ (t\ \ per\ \ ha) + 0.01 \times IVOMD\,(\%) \times straw\ \ yield\ \ \ (t\ \ per\ \ ha)}{total\ \ biomass\ \ production\ \ \ (t\ \ per\ \ ha)}$$

2.3.2. Pearson and canonical correlations

Canonical correlation is a multivariate analysis used to assess the correlation between two sets of variables at the same time. Canonical correlation analysis was conducted to explain the relationship between (a) quality traits (CP, NDF, ADL and ME) of the whole straw and each straw fraction and (b) the correlation between quality traits of whole straw and the relative proportion of the three straw fractions. Pearson correlations were calculated between grain yield and straw traits. The correlation between grain yield and straw yield was tested. Correlations for whole straw were tested for the following: grain yield and CP, grain yield and ME, straw yield and CP, straw yield and ME.

2.3.3. Principle component analysis

Principal component analysis is a multivariate statistical procedure which allows several variables to be used simultaneously in evaluating mean differences. Principal component analysis of data of nutritive quality of whole straw was carried out with objectives to: (1) quantify the contribution of each constituent to the variation in nutritive value of straw and (2) compute a single variable (principle component score) which summarizes the nutritive value of straw. All eigenvectors were standardized to unite the variance. Eigenvectors were used to calculate the index of the nutritive value of straw according to Langyintuo (2008):

$$W_i = \sum_{i=1}^{k} \left[b_i \left(a_{ij} - x_i \right) \right] / S_i$$

where: W_j is a standardized straw quality index for each variety; *bi* is the eigenvector assigned to (k) variables on the first principal component; a_{ji} is the value of each variety on each of k variables; x_i is the mean of each of k variables; and S_i is the standard deviation.

3. Results

3.1. Grain yield, straw yield and potential utility index

Variety had a significant (P < 0.001) effect on grain and straw yields (Table 2). The mean of grain yield was 3.95 t/ha and straw yield was 4.61 t/ha. The local variety showed significantly lower grain yields than improved varieties (P < 0.001). Similarly, straw yield of improved varieties was significantly higher than that of the local variety (P < 0.001). There were significant differences among improved varieties. The range between the highest (Mosisa) and lowest yielding (local) variety was 1.49 t/ha in grain yield and 2.03 t/ha in straw yield. Variety had a significant effect on PUI. Harvest index in Walki and Degaga was significantly higher than Shallo, Mosisa and local variety. The varietal range in harvest index was 0.059 units. The varietal range in harvest index was 0.121 units.

Table 2
Effect of the variety on grain yield, straw yield, potential utility index (PUI) and the proportions of the straw fractions (n = 150).

	Mosisa	Walki	Degaga	Shallo	Local	Mean	SEM
Grain yield (t/ha)	4.38[a]	4.21[a]	4.20[a]	4.06[a]	2.89[b]	3.95	0.170
Straw yield (t/ha)	5.68[a]	4.42[c]	4.31[c]	4.98[b]	3.65[d]	4.61	0.181
Harvest index	0.44[b]	0.487[a]	0.492[a]	0.442[b]	0.433[b]	0.459	0.001
PUI (w/w)	0.681[bc]	0.791[a]	0.697[ab]	0.686[abc]	0.670[c]	0.705	0.007
Rank*	4	1	2	3	5		
Straw fractions (w/w)							
Leaf	0.093[a]	0.076[a]	0.048[b]	0.095[a]	0.042[b]	0.074	0.007
Stem	0.687[b]	0.68[b]	0.733[a]	0.702[b]	0.764[a]	0.701	0.012
Pod	0.224[bc]	0.258[a]	0.226[bc]	0.245[ab]	0.201[c]	0.231	0.011

PUI: potential utility index, [a–c]Means within a raw with different superscripts differ ($P < 0.05$).
* Varieties were ranked according to PUI value.

3.2. Straw fractions

The effect of variety on proportion of straw fractions was significant ($P < 0.001$; Table 2). Straw mainly consisted of stems and pods. The proportion of leaf to whole straw was less than 0.10. The proportion of leaves tended to be higher in Shallo, Mosisa and Walki compared to Degaga and the local variety. The local variety and Degaga had significantly higher proportions of stems compared to Shallo, Walki and Mosisa. The proportion of pods in Walki tended to be higher than in Shallo. The differences in pod proportion among Shallo, Degaga and Mosisa were insignificant. Among the varieties, the ranges between the highest and the lowest proportions in leaves, stems and pods were 0.053 units, 0.084 units and 0.057 units respectively.

3.3. Straw quality

Table 3 shows that there is a significant effect of variety ($P < 0.001$), botanical fraction ($P < 0.001$) and the variety-fraction interaction ($P < 0.001$) on the chemical composition, IVOMD and ME of the straw samples. That means the effect of the variety on the chemical composition, IVOMD and ME depended on the botanical fraction of the straw.

3.3.1. Effect of variety

Ash content among varieties ranged from 108 g/kg in Degaga to 116 g/kg in Walki. Ash content of the local variety was similar to Degaga and Shallo but lesser than that of Mosisa and Walki. Crude protein content ranged from 80.5 g/kg in Shallo to 86 g/kg in Mosisa. Crude protein content of the local variety was not significantly different from improved varieties. Neutral detergent fiber ranged from 488 g/kg in Walki to 518 g/kg in Degaga. Acid detergent fiber ranged from 465 g/kg in Shallo to 473 g/kg in the local variety. Acid detergent lignin content of varieties ranged from 93.1 g/kg in Shallo to 98.1 g/kg in the local variety. *In vitro* organic matter digestibility ranged from 509 g/kg in Degaga to 550 g/kg in Mosisa and Shallo. The local variety had higher IVOMD compared to Degaga but lower than that of other varieties. Mosisa, Shallo and Walki had similar IVOMD and ME. Metabolizable energy content of varieties ranged from 8.12 MJ/kg in Shallo to 7.82 MJ/kg in Degaga. Metabolizable energy content of local variety was similar to that of Degaga but higher than that of other varieties.

3.3.2. Effect of botanical fraction

Straw fractions were significantly different ($P < 0.001$) from each other in chemical composition, IVOMD and ME. Leaf had the highest content of ash, CP and IVOMD followed by pod and stem while pod had the highest value of ME followed by leaf and stem. The stem contained the highest content of NDF, ADF and ADL followed by pod and leaf.

3.3.3. Leaf

Ash content of leaf ranged from 136 g/kg in local variety to 169 g/kg in Walki. The local variety had significantly lesser ash content compared to improved varieties which were different from each other. Crude protein ranged from 120 g/kg in the local variety to 140 g/kg in Mosisa. The local variety had higher CP compared to Mosisa and Walki but similar to Degaga and Shallo. Neutral detergent fiber ranged from 294 g/kg in Walki to 388 g/kg in local variety. NDF of local variety was similar to that of Degaga and Shallo but higher than that of other improved varieties. Acid detergent fiber ranged from 266 g/kg in Walki to 357 g/kg in local variety. All improve varieties had lesser ADF compared to the local variety. Acid detergent lignin content ranged from 68.1 g/kg in Walki to 79.2 g/kg in local variety. Degaga was similar to the local variety in ADL while other improved varieties were lesser. *In vitro* organic matter digestibility ranged from 601 g/kg in Degaga to 694 g/kg in Walki. Metabolizable energy ranged from 8.63 MJ/kg in local variety to 9.06 MJ/kg in Walki. The local variety had similar IVOMD and ME compared to Degaga but lesser than Mosisa, Shallo and Walki. Improved varieties varied in chemical composition, IVOMD and ME.

3.3.4. Pod

Ash content of pod ranged from 115 g/kg in Degaga, Mosisa and Shallo to 120 g/kg in the local variety. Crude protein content ranged from 76.3 g/kg in Walki to 89 g/kg in local variety. Crude protein content of local variety was higher than that

Table 3
Least square means of chemical composition and nutritive value of variety-botanical fraction interaction of faba bean straw.

		DM	Ash	CP	NDF	ADF	ADL	IVOMD	ME
Straw fraction									
Leaf		892^{b}	155^{a}	130^{a}	338^{c}	303^{c}	73.1^{c}	653^{a}	8.85^{b}
Pod		890^{c}	116^{b}	80.4^{b}	432^{b}	383^{b}	77.8^{b}	558^{b}	9.35^{a}
Stem		904^{a}	62.8^{c}	39.1^{c}	734^{a}	680^{a}	137^{a}	398^{c}	5.76^{c}
SEM		0.122	0.718	0.887	2.61	2.36	0.524	2.94	0.029
P value		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Variety									
Local		896	107^{b}	82.9^{ab}	514^{a}	473^{a}	98.1^{a}	527^{b}	7.87^{b}
Degaga		896	108^{b}	82.7^{b}	518^{a}	466^{a}	97.6^{ab}	509^{c}	7.82^{b}
Mosisa		895	114^{a}	86^{a}	496^{b}	448^{b}	95.9^{bc}	550^{a}	8.04^{a}
Shallo		895	110^{b}	80.5^{b}	493^{b}	445^{b}	93.1^{c}	550^{a}	8.12^{a}
Walki		895	116^{a}	82.8^{ab}	488^{b}	446^{b}	95.2^{d}	543^{a}	8.07^{a}
SEM		0.157	0.927	1.14	3.37	3.05	0.676	3.80	0.037
P value		0.42	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Fraction-variety interaction									
Fraction	Variety								
Leaf	Local	893^{c}	136^{d}	120^{b}	388^{e}	357^{d}	79.2^{c}	610^{c}	8.63^{e}
Leaf	Degaga	893^{c}	143^{c}	126^{b}	375^{e}	332^{e}	77.1^{cde}	601^{c}	8.65^{e}
Leaf	Mosisa	893^{c}	166^{a}	140^{a}	321^{f}	282^{f}	73.4^{f}	683^{ab}	8.9^{d}
Leaf	Shallo	892^{d}	156^{b}	126^{b}	321^{f}	284^{f}	68.6^{g}	672^{b}	8.96^{cd}
Leaf	Walki	891^{d}	169^{a}	135^{a}	294^{g}	266^{g}	68.1^{g}	694^{a}	9.06^{cd}
Pod	Local	889^{e}	120^{e}	89^{c}	417^{d}	370^{d}	75.6^{def}	581^{d}	9.41^{ab}
Pod	Degaga	891^{d}	115^{f}	81.1^{d}	444^{b}	388^{c}	80.1^{c}	527^{f}	9.1^{c}
Pod	Mosisa	889^{e}	115^{f}	77.7^{d}	442^{b}	392^{c}	78.5^{cd}	563^{ed}	9.39^{ab}
Pod	Shallo	889^{e}	115^{f}	78^{d}	420^{cd}	372^{d}	74.7^{ef}	567^{ed}	9.53^{a}
Pod	Walki	889^{e}	118^{ef}	76.3^{d}	435^{cb}	391^{c}	79.9^{c}	550^{e}	9.33^{b}
Stem	Local	905^{ab}	65.9^{g}	39.4^{e}	738^{a}	693^{a}	139^{a}	391^{h}	5.57^{h}
Stem	Degaga	905^{a}	65.2^{g}	41.3^{e}	737^{a}	680^{ab}	136^{b}	397^{gh}	5.69^{gh}
Stem	Mosisa	905^{ab}	62.4^{gh}	49.7^{e}	724^{a}	671^{b}	136^{b}	404^{gh}	5.83^{gf}
Stem	Shallo	904^{ab}	58.7^{h}	37.8^{e}	737^{a}	677^{b}	136^{b}	410^{g}	5.88^{f}
Stem	Walki	904^{b}	61.6^{gh}	37^{e}	736^{a}	680^{ab}	137^{ab}	387^{h}	5.82^{gf}
SEM		0.310	1.61	1.98	5.83	5.32	1.17	6.61	0.648
P of value for V × F		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

DM: dry matter (g/kg), Ash: g/kg DM), CP: crude protein (g/kg DM), NDF: neutral detergent fibers (g/kg), ADF: acid detergent fiber (g/kg), ADL: acid detergent lignin (g/kg DM), IVOMD: *in vitro* organic matter digestibility (g/kg), ME: metabolizable energy (MJ/kg DM), $^{a–h}$means within a column with different superscripts differ ($P < 0.05$), V × F: the interaction between variety and botanical fraction.

of improved varieties. Neutral detergent fiber ranged from 417 g/kg in local variety to 444 g/kg in Degaga. Acid detergent fiber ranged from 370 g/kg in the local variety to 392 g/kg in Mosisa. The local variety had lesser NDF and ADF content compared to Degaga, Mosisa and Walki but similar to Shallo. Acid detergent lignin ranged from 74.7 g/kg in Shallo to 80.1 g/kg in Degaga. Acid detergent fiber of local variety was similar to that of Mosisa and Shallo but lesser than that of Degaga and Walki. *In vitro* organic matter digestibility of pod ranged from 527 g/kg in Degaga to 581 g/kg in the local variety. Metabolizable energy ranged from 9.1 MJ/kg in Degaga to 9.53 MJ/kg in Shallo. *In vitro* organic matter digestibility and ME of the local variety were higher than these of Degaga and Walki but similar to these of Mosisa and Shallo. All nutritive value parameters except ash varied among improved varieties.

3.3.5. Stem

Ash content ranged from 58.7 g/kg in Shallo to 65 g/kg in the local variety. Ash of the local variety was higher than that of Shallo but similar to that of Degaga, Mosisa and Walki. Crude protein and NDF were similar among varieties. Acid detergent fiber ranged from 671 g/kg in Mosisa to 693 g/kg in the local variety. Acid detergent fiber of the local variety was similar to that of Degaga and Walki but higher than that of Mosisa and Shallo. Acid detergent lignin ranged from 136 g/kg in Degaga, Mosisa and Shallo to 139 g/kg in the local variety. Acid detergent lignin in the local variety was similar to Walki, but higher than Degaga, Mosisa and Shallo. *In vitro* organic matter digestibility ranged from 387 g/kg in Walki to 410 g/kg in Shallo. The local variety had higher IVOMD than Shallo but similar to other improved varieties. Metabolizable energy ranged from 5.57 MJ/kg in local variety to 5.88 MJ/kg in Shallo. The local variety had ME similar to Degaga but lesser than other improved varieties. Improved varieties varied in ash, IVOMD and ME but not in CP, NDF ADF and ADL.

3.3.6. Whole straw

Whole straw of all varieties had similar content of CP, NDF, ADF and ADL. Ash content ranged from 70.5 g/kg in Shallo to 79.1 g/kg in the local variety. The local variety did not differ from improved varieties in ash. *In vitro* organic matter digestibility ranged from 404 g/kg in Degaga to 437 g/kg in Shallo. The local variety had the same IVOMD as Degaga, Mosisa and Walki

Table 4
Effect of variety on chemical composition and nutritive value of whole straw of faba bean (n = 150).

	Variety						
	Local	Degaga	Mosisa	Shallo	Walki	Mean	SEM
DM	901[ab]	902[a]	901[bc]	901[bc]	900[c]	901	0.316
Ash	79.1[ab]	76.3[a]	75.3[a]	70.5[b]	76.5[a]	75.5	1.43
CP	53.7	52.7	52.2	50.5	51.3	52.1	1.54
NDF	671	679	665	671	661	669	7.43
ADF	619	617	602	599	599	608	7.46
ADL	126	126	123	122	123	124	1.68
IVOMD	418[bc]	404[c]	429[ab]	437[a]	417[bc]	421	6.60
ME	6.31[b]	6.33[b]	6.61[a]	6.69[a]	6.65[a]	6.51	0.090

DM: dry matter (g/kg), Ash: g/kg DM), CP: crude protein (g/kg DM), NDF: neutral detergent fibers (g/kg), ADF: acid detergent fiber (g/kg), ADL: acid detergent lignin (g/kg DM), IVOMD*: in vitro* organic matter digestibility (g/kg), ME: metabolizable energy (MJ/kg DM), [a–c]means within a raw with different superscripts differ ($P<0.05$).

but lesser than Shallo. Metabolizable energy ranged from 6.31 g/kg in local variety to 6.69 MJ/kg in Shallo. The local variety had lesser ME compared to Mosisa, Shallo and Walki. Whole straw of the improved varieties varied in ash, IVOMD and ME but not in CP and fiber constituents (Table 4).

3.4. Pearson and canonical correlations

The canonical correlations procedure generated four (4) canonical correlations for each fraction. However, only the coefficients of the first two significant correlations are shown in Tables 5 and 6 because they cumulatively accounted for 97.9% of the variance in leaves, 86.9% in stems and 91.6% in pods. The first canonical represented majority of the variance (85.6%), thus, it was used in the interpretation. The first canonical correlation between the nutritive value of whole straw and the nutritive value of leaves, stems and pods were strong and significant (r 0.671, $P<0.001$ in leaf; r 0.734, $P<0.001$ in stem, r 0.606 in pod; $P<0.001$). There was significant correlation between the nutritive value of the whole straw and proportion of its fractions (Can1: r 0.479, $P<0.001$). Pearson correlation between the grain and straw yield was positive, strong and significant (r 0.661, R^2 0.437, $P<0.001$) while the correlation between grain yield and CP of the whole straw was weak, negative and significant (r −0.162, R^2 0.026, $P=0.042$). There was a weak association (r 0.164, R^2 0.027, $P=0.050$)

Table 5
Canonical correlations analysis: Correlations between the nutritive value of the whole straw and the nutritive value of each straw fraction.

	Leaf		Stem		Pod	
	Can1	Can2	Can1	Can2	Can1	Can2
r	0.671(<0.001)	0.503(<0.001)	0.734(<0.001)	0.453(<0.001)	0.606(<0.001)	0.483(<0.001)
Variance (%)	70.0	27.9	71.1	15.8	60.9	30.7
Pillai's Trace	7.71(<0.001)		11.0(<0.001)		7.25(<0.001)	
Coefficients						
CP	0.221	0.343	0.213	−0.242	0.507	−0.201
NDF	0.428	−0.352	0.242	0.174	0.036	0.022
ADL	0.501	−0.201	0.291	0.339	0.051	−0.023
ME	−0.364	0.389	−0.551	−0.165	0.052	0.334

Can: canonical, CP: crude protein (g/kg DM), NDF: neutral detergent fibers (g/kg), ADL: acid detergent lignin (g/kg DM), ME: metabolizable energy (MJ/kg DM), values in parentheses are noted to *P* values, first two canonical correlations are shown as they are accounted for more than 90% of variance.

Table 6
Canonical correlations analysis: Correlations between the nutritive value of the whole straw and the relative proportion of the three straw fractions.

	Nutritive value of whole straw	
	Can1	Can2
r	0.479(<0.001)	0.179(<0.001)
Variance (%)	85.6	9.56
Pillai's Trace	3.72(<0.001)	
Coefficients		
Leaf	0.349	0.113
Stem	−0.478	−0.014
Pod	0.337	−0.107

Can: canonical. Values in parentheses are noted to *P* values, first two canonical correlations are shown as they are accounted for more than 90% of variance in the data of the nutritive value of the whole straw.

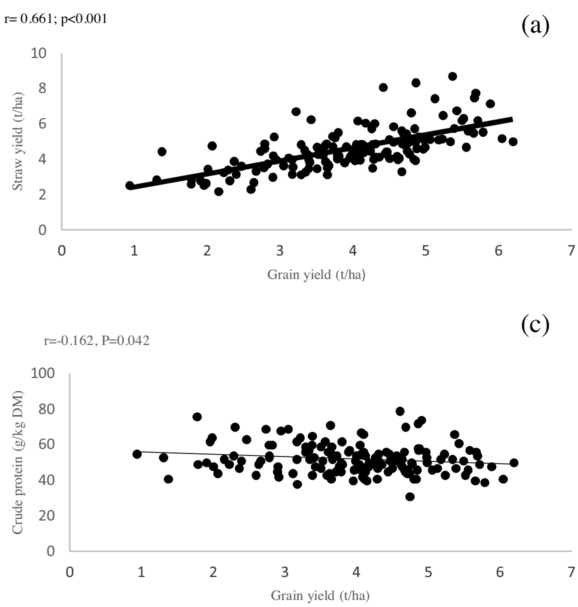

Fig. 1. Relationship between grain and straw traits.

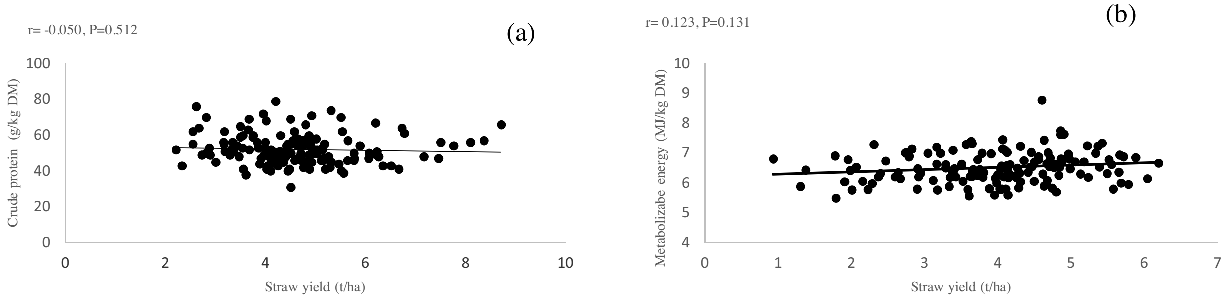

Fig. 2. Correlation between straw yield and the crude protein and metabolizable content of straw.

between grain yield and ME of the straw. The straw yield was weakly and insignificantly correlated to CP (r −0.050, R^2 0.003, P = 0.512) and ME (r 0.123, R^2 0.015, P = 0.131) (Figs. 1 and 2).

3.5. Principle component analysis

Principle component analysis generated five principle components: PC1, PC2, PC3, PC4 and PC5. PC1 and PC2 accumulatively accounted for 92% of the variance (Table 7). An examination of the eigenvectors showed that PC1 best explained the nutritive value of straw. Crude protein, ash and ME eigenvectors were positive, suggesting that they would contribute positively to the nutritive value of straw. Neutral detergent fiber and ADL were negative suggesting that they would con-

Table 7
Principle component analysis of the chemical composition and nutritive value of the whole straw of faba bean.

	PC1[a]	PC2
Eigenvalues	3.88	0.695
Variance (%)	77.8	139
Eigenvectors		
Ash	0.351	0.835
CP	0.445	0.123
NDF	−0.496	0.002
ADL	−0.481	0.326
ME	0.449	−0.427

[a] PC: principle component, Ash: g/kg DM, CP: crude protein (g/kg DM), NDF: neutral detergent fibers (g/kg), ADL: acid detergent lignin (g/kg DM), ME: metabolizable energy (MJ/kg DM).

tribute negatively to the nutritive value of straw. The scores of the varieties which were generated from the eigenvectors of PC1 according to the Langyintuo (2008) equation, were used to rank the varieties according to the nutritive value of their straw. The varieties ranked from best to the poorest in terms of nutritive value as follows: Degaga (0.010) > the local variety (−0.710) > Shallo (−1.60) > Walki (−3.20) > Mosisa (−14.5).

4. Discussion

4.1. Grain and straw yields

The significant varietal variation in grain and straw yields was consistent with results reported for chickpea (Kafilzadeh and Maleki, 2012) and lentil (Tullu et al., 2001) in Ethiopia. The wide range in grain and straw yields confirms the potential to increase yields through selection. Mosisa had the highest grain and straw yields, indicating the opportunity to increase both yields at the same time. This was confirmed by the strong, positive and significant correlation between grain and straw yields. Positive and strong correlations have been reported in lentils (Erskine, 1993) and maize (Tolera et al., 1999). The local variety had significantly inferior grain and straw yields compared to the improved varieties. In line with our findings, improved varieties had better grain and straw yields than the local varieties in wheat (Tolera et al., 2008) and maize (Tolera et al., 1999). The potential utility index in improved varieties was significantly larger than the local variety. Contrary to our findings, Tolera et al. (2008) found that the PUI of the local varieties were higher than that of the improved varieties. The high variation in grain and straw yields on the one hand, and the positive and strong correlation between them on the other, shows potential for selection of faba bean varieties with high biomass. Plant breeders and animal nutritionists, in association with the farmers, need to work together to achieve an optimal utilization of whole crop by improving grain yield, straw yields and improving the nutritive value of straw. Although the potential utility index is based on grain and digestible straw yields, other considerations such as the nutritive value of grain for human consumption, the price of grain and straw as well as the palatability of straw for livestock might change the index values and subsequent ranking order of the varieties. Moreover, for a better understanding of the interaction between varietal and environmental factors affecting grain and straw traits of faba bean, further research in various locations and seasons is required. The prediction of the straw yield using the harvest index is not accurate. That is because there is a significant varietal variation in the harvest index. Moreover, the R^2 of the correlation between the grain and straw yields shows that the variation in the grain yield accounts for only 43.7% of the variation in the straw yield.

4.2. Botanical fractions of the straw

The significant varietal variation in the relative proportions of straw fractions is in line with results reported in rice, maize and chickpea (Vadiveloo, 1995; Tolera et al., 1999; Kafilzadeh and Maleki, 2012). At harvest, faba bean comprises 70% stem and 23% of pods. This is because leaves of faba bean are fine and are lost during harvesting and threshing. The botanical structure of faba bean straw is different from the botanical structure of maize stover, which contains higher proportion of leaves (Tolera et al., 1999). The proportion of the pod in the whole straw was higher in this study than in that of Kafilzadeh and Maleki (2012) for chickpea. The proportions of the pods and leaves in the local variety were lower than those in the improved varieties. This finding differs with those of Tolera et al. (2008) on durum wheat which demonstrated that the straw of the local varieties contains a higher proportion of leaves than the improved varieties.

4.3. Straw quality

The effect of variety, botanical fractions and the interaction between the variety and the botanical fraction were highly significant. The variance component analysis results showed that the straw fractions had the highest estimates, regardless of their signs, which means that for all straw quality parameters, the variance between the botanical fractions was higher than the variance between the varieties. Within each straw fraction, variety affects significantly the quality parameters of the straw. Similar results were reported in chick pea straw (Kafilzadeh and Maleki, 2012) and barley straw (Thomson et al., 1993). Faba bean leaves contained the highest content of ash, CP and IVOMD, while the stems contained the highest content of NDF, ADF and ADL. Compared to the other straw fractions, pods have the best value of ME. The higher content of total ash in leaves could explain the low ME content compared to the pods. Faba bean pods contained higher amounts of CP and lower amounts of NDF, ADF and ADL compared to pods of chickpea (Kafilzadeh and Maleki, 2012). Faba bean pods in our results contained higher content of CP the lower content of NDF, ADF and ADL compared to the results on the pods of chickpea (Kafilzadeh and Maleki, 2012). The CP content of faba bean straw had an average value of 52.1 g/kg DM. However, this is still lower than the 7% of DM which is required for optimum activity of rumen microorganisms (Belachew et al., 2013). According to our results, local and improved varieties had the same content of CP. The whole straw of the local variety had equal ME content compared to Degaga but lesser content compared to Mosisa, Shalo and Walki. Chowdhury et al. (1995) noticed similar results in rice varieties. When the faba bean straw constitutes the whole diet, protein supplementation could be necessary in a diet of ruminants that consists of faba bean straw as the basal diet. Crude protein in the whole straw comes mainly from the leaves and pods, however, pods are the most important source as most faba bean leaves fall down during harvesting and threshing. The varietal variation in the ME content of the whole straw offers an opportunity to increase the straw content of ME throughout selection and lessen the need for alkaline treatments. Constituting 23.08% of the whole straw biomass, with relatively good feeding value, pods could be used alone as livestock feed.

4.4. Canonical correlation

Canonical correlation analysis showed that there was a strong and significant correlation between the nutritive value of the whole straw and the nutritive value of its botanical fractions Our results resemble the results of the studies of (Vadiveloo, 1995) and (Vadiveloo and Phang, 1996) on rice straw. Acid detergent lignin, ME and CP of the botanical fractions with coefficients of 0.50, −0.55 and 0.51 respectively were the most important parameters affecting the chemical composition and ME of the whole straw. Furthermore, significant associations were detected between the proportions of the botanical fraction and the chemical composition and ME of the whole straw. The coefficient of the proportion of the stem is higher than the coefficients of the proportion of the leaf and pods. This suggests that the proportion of the stem contributes more to the chemical composition and ME of the straw compared to leaf and pod proportions. However, lack of such correlation was observed by Vadiveloo (1995) in rice straw. These results enable the use of proportion of pods and stems to quickly and cheaply evaluate the nutritive value of faba bean straw.

4.5. Principle component analysis

Principle component analysis was applied, although the analytic procedure is not mathematically accurate (Vadiveloo, 1995). However, the analysis allows for unbiased identification of the best varieties from their component scores. The score generated for the nutritive value of faba bean straw using ash, CP, NDF, ADL and ME content simultaneously accounted for 77.8% of the variation in the nutritive value. Therefore, this score can be used to rank varieties of faba bean depending on the nutritive value of the straw. Similar to these results have been reported by Vadiveloo (1995) in rice straw.

4.6. Pearson correlations

The strong and positive association between grain yield and straw yields suggests the possibility to increase grain yield of faba bean without affecting straw yields. The correlations between the grain yield and the CP and ME content of the whole faba bean straw were weak. Similarly, no such correlation was reported by Ertiro et al. (2013) in maize, Blümmel et al. (2007) in pearl millet and Blümmel et al. (2010) in Sorghum. No correlations between straw yields and quality traits of the straw present a good opportunity to increase the total biomass of faba bean without affecting straw quality.

5. Conclusions

The study confirmed varietal variation in grain and straw yields and the nutritive value of faba bean straw in the faba bean varieties. Moreover, it indicates that selecting varieties of faba bean with high grain and straw yields will not negatively affect most of the parameters for straw quality.

Acknowledgements

The authors would like to acknowledge the financial support from the USAID-funded Africa RISING project, the Collaborative Research Program (CRP), Livestock and Fish and council of at-risk academics. Gratitude to the Sinana Agricultural Research Institute, Ethiopia for facilitating the cultivation of faba bean varieties. Appreciation goes to the Animal Nutrition Laboratory of the International Livestock Research Institute (ILRI) in Addis Ababa, Ethiopia for the analysis of the samples.

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