INFLUENCE OF VARIETAL SELECTION AND TREATMENTS ON THE NUTRITIVE VALUE OF SELECTED PULSE CROP RESIDUE

PhD DISSERTATION

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INFLUENCE OF VARIETAL SELECTION AND TREATMENTS ON THE NUTRITIVE VALUE OF SELECTED PULSE CROP RESIDUE

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by

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DEDICATION

I dedicate this dissertation to my wife, family, friends, supervisors, my country Syria and to every Syrian who remains true to peace. I dedicate my work to every individual and organization that supported me through goodwill or prayer. My dedication goes to my teachers in Syria who taught me how to be faithful to my goals, who taught me that the bigger the goal, the bigger the sacrifice. I dedicate this work to persons who help those in need regardless of color, nationality, creed and sex.

STATEMENT OF THE AUTHOR

I declare that this Dissertation is my work and that all sources of materials used for this Dissertation have been duly acknowledged. This Dissertation has been submitted in partial fulfillment of the requirements for the PhD degree at Jimma University and is deposited at the University library to be made available to readers under the rules of the Library. I truly declare that this Dissertation is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate. Brief quotations from this Dissertation are acceptable without special permission on conditions that accurate acknowledgement of the source is made. Requests for permission for extended quotation from or reproduction of this Dissertation in whole or in part may be approved by the head of the Department of Animal Sciences or the Dean of the School of Graduate Studies when in his or her judgment the proposed use of the material is in the interest of scholarship. In all other circumstances, permission must be obtained from the author.

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BIOGRAPHICAL SKETCH

The author was born in Syria, *Hama* district, *Taybet El-Imam* town in 1983, the son of Saber Alkhtib and Fatimah Alkhtib. He attended primary school in *Mohammad Jeran* school and secondary school at *Salah Eldin* school from 1988 - 2000. He joined Aleppo University, Faculty of Agriculture in 2000 and graduated with Bsc. in Animal Production (Ruminants Production) in 2005. After graduation, he worked at the General Commission of Scientific Agricultural Research, *Gedrin* Station for *Awassi* sheep research. He obtained MSc. in Animal Nutrition from Aleppo University, Faculty of Agriculture in 2008. He worked intensively on crop residues, agro-industrial by-products and animal nutrition technologies during his career in Syria for 7 years. The author is married. The author has published the articles listed below:

Articles published from the Ph.D. dissertation

1. Alkhtib, A., Wamatu, J., Kassie, G., Rischkowsky, B. 2016. Analysis of crop residue use in small holder mixed farms in Ethiopia. Renewable Agriculture and Food Systems, DOI: https://doi.org/10.1017/S1742170516000399
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5. Alkhtib, A., Wamatu, J., Ejeta, T., Rischkowsky, B. 2017. Integrating the straw yield and quality into multi-dimensional improvement of lentil (*Lens culinaris*). Journal of the Science of Food and Agriculture DOI:10.1002/jsfa.8282.
6. Alkhtib, A., Wamatu, J., Ejeta, T., Rischkowsky, B. 2017. Genetic variability in straw traits and food-feed relations for multi-dimensional improvement in chickpea

(*cicer arietinum*). Manuscript ready to be submitted to Animal Nutrition and Feed Technology.

7. Alkhtib, A., Wamatu, J., Ejeta, T., Rischkowsky, B. 2017.Improving the nutritive value of pulse straws using dung and wood ash treatment. Manuscript ready to be submitted to Animal Nutrition and Feed Technology.

Other articles and activities

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5. Kiflay, S., Wamatu, J., Mekuriaw, Y., Animut, G., Alkhtib, A., Rischkowsky, B., Participation of Female-headed Households in Sheep Fattening in Ethiopia. Tropentag, September 18-21, 2016, Vienna, Austria.
6. Wamatu, J., Mersha, A., Alkhtib, A., Million Eshete, Kemal, S., Tolera, A., Beyan, M., and Barbara. Rischkowsky, B. 2016. Cultivar-dependent variation in lentil (*Lens culinaris L.*) and implications for selecting food-feed varieties. International Conference on Pulses, Marrakesh, Morocco, 18-20 April, 2016. p. 158-159.
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ABBREVIATIONS

ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
Ca	Calcium
CP	Crude Protein
CPI	Crude Protein Intake
Cu	Copper
DM	Dry Matter
DMI	Dry Matter Intake
FAO	Food And Agriculture Organization of the United Nations
Fe	Iron
GLM	General Linear Model
IVOMD	*In Vitro* Organic Matter Digestibility
LSD	Least Significant Difference
m.a.s.l	Meter Above Sea Level
ME	Metabolizable Energy
MEI	Metabolizable Energy Intake
Mg	Magnesium
MJ	Mega Joule
Mn	Manganese
Na	Sodium
NDF	Neutral Detergent Fiber
NIRS	Near Infrared Reflectance Spectroscopy
P	Phosphorus
SAS	Statistical Analysis System
SD	Standard Deviation
TLU	Tropical Livestock Unit
Zn	Zinc

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ABSTRACT

The current study was aimed to analyze the utilization of crop residue in the mixed farming systems of Ethiopia, to explore the possibility of improving straw yield and nutritive value of chickpea, faba bean and lentil without compromising grain yield and to identify the effect of dung and wood ash treatments on the nutritive value of chickpea, faba bean and lentil straw.

Data on crop residue production and utilization was collected in two highland regions of Ethiopia from 160 households. To assay the varietal variation and food-feed relation in faba bean, 4 improved and released variety and one local variety were planted at the Sinana Agricultural Research Center, Ethiopia during 2014-2015 cropping season. To evaluate the variability in grain yield and straw traits in chickpea and lentil, 24 improved varieties and one local variety of each crop were replicated four times in a randomized complete block trial in two locations of Debre Zeit Research Center during the 2013-2014 cropping season. Straw from plots of the local varieties of the trials was used to determine the effect of 4% urea treatment, dung ash treatment (0g ash/L, 100 g ash/L, 200 g ash/L 300 g ash/L) and wood ash treatment (0 g ash/L, 150 g ash/L, 200 g ash/L) on the nutritional value. All straw samples were analyzed for proximate analysis, *in vitro* organic matter digestibility and metabolizable energy using a combination of Near Infrared Reflectance Spectroscopy and conventional feed analyses methods.

Results showed that farmers prefer using crop residue from pulses over crop residue from cereals for livestock feeding purposes. Proportions of cereal and pulse residue used for soil mulch was positively affected by education level of the farmer, distance between homestead and cultivated land, extension service, awareness about soil mulch, slope of cultivated land, participation in farmer-to-farmer extension and crop residue generated in the preceding season. The proportion of crop residue from pulses that was used as feed was positively affected by education level of the farmer, livestock extension service, number of small ruminants and crop residue stack from the previous season. The effect of the variety, location and variety-location interaction on grain yield, straw yield and straw nutritive value was significant in chickpea and lentil. The correlation between grain yield and straw traits of chickpea was weak in all locations. Grain yield of lentil correlated weakly to crude protein and ME in Chefe Donsa while it correlated moderately to crude protein in Zebre Zeit. Grain and straw yields were positively, strongly and significantly correlated in faba bean. Grain yield of faba bean correlated weakly to the nutritive value parameters of straw. Varietal variations in grain yield, straw yield and straw quality traits within its fractions were significant. The botanical structure of faba bean straw can be used as a reliable method for screening faba bean genotypes for straw quality. Urea treatment showed potential to improve the nutritive value of chickpea, faba bean and lentil straw. Dung ash treatment up to 300 g ash/L and wood ash treatment up to 200 g ash/L did not improve the nutritive value of chickpea, faba bean and lentil straw.

Integrating straw yield and nutritive value into improvement programs of chickpea, faba bean and lentil could improve the nutrients supply for livestock and increase the amount of cereal straws allocated to soil mulching.

KEYWORDS: Genetic variation; pulse straw; ash extract; urea treatment

1. INTRODUCTION

Crop-livestock mixed farming systems are the mainstay of smallholder livelihoods in the developing world (Herrero et al., 2010; Ryschawy et al., 2012). Population growth, increase in livestock population, increased income and rate of urbanization in the developing countries tend to increase the pressure on these systems (Herrero et al., 2010). These challenges also tend to increase intensity of land use which leads to continuous cultivation of farmlands without fallowing (Collier and Dercon, 2009; Drechsel et al., 2001). Without adequate investment in agricultural land management, this may contribute to land degradation and low agricultural productivity (Lal, 2009). Scientific reports on the use and importance of crop residue have shown that leaving 30% of the residue on crop farm plots reduces soil erosion by up to 80% (Rockström et al., 2009). In mixed crop-livestock farming systems, the use of crop residue for livestock feeding is becoming increasingly important due to the expansion of cropland and low productivity of natural pastures (Alkemade et al., 2012). The contribution of crop residue to the total dry matter intake of the livestock in Ethiopia ranges from 10% to 70% (Alemayehu, 2003; Zinash et al., 2001). The crop residue from cereals and pulses has different nutritive values as livestock feed. According to Keftasa (1988), one kg of residue dry matter (DM) from cereal (pulse) contains on average 47 (69) g of crude protein (CP), 6.50 (6.95) MJ of metabolizable energy (ME) and 0.75 (0.55) g of phosphorus (P) and 2.5 (9.2) g of calcium (Ca), indicating that crop residue from pulses have better nutritive value compared to crop residue from cereals. Utilizing one kg of pulse residue as mulch would deprive the livestock of 22 gram of CP, 0.4 MJ of ME, and 6.7 gram of Ca. This is equivalent to a loss of 0.25 kg of cow milk of 4% fat (estimation from Kearl (1982)). Under such situations, better utilization of crop residue could be achieved by maximizing the use of pulse crop residue for livestock feeding and optimizing the use of cereal crop residue for both mulching and livestock feeding. Studies on the utilization of crop residue are limited and have mainly focused on maize residue (Jaleta et al., 2015, Jaleta et al., 2013). Thus, identifying the determinants of crop residue utilization considering the difference in nutritional value between cereal and pulse straws will contribute improve livestock production by increasing the utilization of crop residue. That will also help to direct the possible interventions by livestock scientists which can lead to improving the utilization of crop residue in the mixed farming systems.

In Ethiopia, chickpea (*Cicer arietinum*), faba bean (*Vicia faba)* and lentil (*Lens culinaris*) are grown over an area of 877000 ha and yields 1100000 t annually (CSA, 2014) and their grains are a primary source of protein and cash for the farmers (Mulualem et al., 2012). Growing chickpea, faba bean and lentil is accompanied by large amounts of straw which is nutritionally superior to cereal straws (López et al., 2005). Chickpea straw contains on average 65 g/kg DM of CP, 694g/kg DM and 7.7 MJ/kg DM of ME (Bampidisa and Christodoulou, 2011). It has been reported that chickpea straw has moderate nutritive value as ruminant feed (Aghajanzadeh-Golshani et al., 2012, Maheri-Sis et al., 2011). The nutritive value of faba bean straw is relatively higher, containing an average 74 g/kg DM CP and 469 g/kg DM organic matter digestibility (Abreu and Bruno-Soares, 1988, Alibes and Tisserand, 1990, Asar et al., 2010, Bruno-Soares et al., 2000, Hadjipanayiotou et al., 1985, Nsahlai and Umunna, 1996). Lentil straw has been reported to have better degradation in the rumen as compared to cereal straws (López et al., 2005, Singh et al., 2011). Therefore, chickpea, faba bean and lentil are not only an important source of food for households, but also an important source of nutrients for livestock. Although better quality of chickpea, faba bean and lentil straws compared to cereal straw is documented, there is still need to improve their nutritive value to allow for their use as a sole livestock feed.

In rural areas of Ethiopia where dung and wood are used extensively as a major fuel source of domestic usage (Duguma et al., 2014), ash is available in considerable quantities. Wood ash solutions are alkaline (pH>10) and were successfully used to improve the nutritive value of wheat straw (Nolte et al., 1987), corn stover (Ramirez et al., 1992),sorghum straw (Ramirez et al., 1991) and native Andean grass (Genin et al., 2002). On the contrary, Genin et al. (2007) reported a low effectiveness of dung ash treatment in improving roughages. The effect of dung and wood ash treatment on the nutritive value of chickpea, faba bean and lentil straw has not been reported. Varietal selection to increase the nutritive value of chickpea faba bean and lentil straw holds promising. Genetic variation in straw traits of chickpea, faba bean and lentil have been reported by Kafilzadeh and Maleki, (2012), Gebremeskel et al. (2011) and Erskine et al., (1990) respectively.

Studies showed the possibility of improving crop residue traits by exploiting the genetic variability in several crops including pearl millet (Bidinger et al., 2010), maize (Ertiro et al., 2013), sorghum (Blümmel et al., 2010) and Groundnut (Prasad et al., 2010). Marsha et al.,

(2016) studied the genetic variability in lentil genotypes. However, his study did not consider the differences in lentil populations of varieties. It also ignored the effect of location on food-feed correlation profile. The same comment could be applied for the study conducted by Alemu et al. (2016).

1.2. Objectives

No/or few reports are available on the varietal variability in grain and straw traits and the possibility of breeding food-feed verities of chickpea, faba bean and lentil. Accordingly, this dissertation specifically aimed:

1) To analyze the use of cereal and pulse residue utilization in the mixed farming system of Ethiopia (paper 1).
2) To investigate the possibility of introducing straw traits into multi-trait improvement of chickpea, faba bean and lentil (paper 3 and 4).
3) To determine the possibility of increasing the nutritive value of chickpea, faba bean and lentil straw using dung ash and wood ash treatments (paper 5).

2. GENERAL BACKGROUND

2.1. Crop residue utilization in Ethiopia

Crop residue is defined as the non-edible biomass of crop left after harvesting and threshing grains of cereal and pulse crops. These residues are generally characterized by low content CP and ME. Crop residue is a multi-purpose resource in the farm. It is used for livestock feeding, inputs for soil preservation, domestic energy and construction. However, livestock feeding and soil mulching are the most important uses of crop residue in Ethiopia highlands. Expansion of cropping land area, shrinkage in quality and productivity of grazing lands combined with the increase in land use intensity will put more pressure on crop residue.

Very few studies analyzed the factors affecting the utilization of crop residue for different alternatives. Strong competition between the alternative uses of maize stover was reported (Jaleta et al., 2015, Jaleta et al., 2013). Trade-offs in maize stover were affected by several biophysical and socio-economic factors. Profile of maize stover utilization in the household was affected by season (Jaleta et al., 2013). Extension and training on crop residue use as soil mulch affected positively the use of maize stover as mulch and decrease their use as feed. (Jaleta et al., 2015, Jaleta et al., 2013). Jaleta et al. (2015) reported that households in high maize potential areas used more maize stover for soil mulching and less for livestock feeding compared to households in low maize. That could reflect the positive effect of maize stover production in high potential areas. Larger farmsteads are likely to be richer, have lower discount rates, and have more biomass production and more alternative sources of feed and energy, which may facilitate stover use as soil mulch (Jaleta et al., 2015). The size of livestock herd affected positively the use of maize stover for feeding and decreased the use of it for soil mulching (Jaleta et al., 2015). Farmhouses growing exclusively maize use more maize stover as fodder and less amount as soil mulch; the amount of maize stover used as feed also increases with the increase in labor availability for collecting and storing crop residue (Jaleta et al., 2015). The distance between maize plots and homestead affects negatively the use of the stover as feed and positively the use of stover as soil mulch (Jaleta et al., 2013). Population density affects the availability of open spaces for communal grazing lands to decrease the pressure on crop residue use as livestock feed (Jaleta et al., 2013).

2.2. Nutritive value of chickpea, faba bean and lentil straw

Chickpea straw can be used as a ruminant feed (Bampidisa and Christodoulou, 2011). Heuzé et al. (2015a) summarized the nutritive value of chickpea straw according to several studies. Crude protein content of chickpea ranged between 28 and 88 g/kg DM, OM digestibility by ruminants ranged between 427 to 607 g/kg and ME ranged between 6.2-7.2 MJ/kg DM. Abdel-Magid et al. (2008) reported that chickpea straw has lesser nutritive value compared to pea straw and berseem hay when fed to growing sheep. Chickpea straw has been reported to have high oxalic acid content and to be unpalatable and possibly toxic, however, that is not well confirmed (Heuzé et al., 2015a). Chickpea pod husks contain a high amount of tannins ranging between 60 to 80 g/kg DM (Heuzé et al., 2015a). However, the type and the biological effectiveness of these tannins are not studied yet.

The nutritive value of faba bean straw is relatively high, containing in average 7.4 g/kg CP and 46.9 g/kg organic matter digestibility (Abreu and Bruno-Soares, 1988, Alibes and Tisserand, 1990, Asar et al., 2010, Bruno-Soares et al., 2000, Hadjipanayiotou et al., 1985, Nsahlai and Umunna, 1996).

Lentil straw has been reported to have better degradation in the rumen as compared to cereal straws (López et al., 2005, Singh et al., 2011). High acceptability and digestibility of lentil straw in the ration of livestock was reported by Abbeddou et al. (2011). Heuzé et al. (2015b) reported that CP content of lentil straw ranged between 58 -111 g/kg DM and ME ranged between 6.7 and 8.3 MJ/kg DM. Heuzé et al. (2015b) reported that the dry matter intake of sheep from lentil straw was 46.6 g DM/kg$^{0.75}$.

2.3. Effect of urea, dung and wood ash treatments on the nutritive value of crop residue

Although crop residue contains considerable quantities of cellulose and hemicellulose, the utilization of those components as an energy source by ruminant animals is restricted by lignin-carbohydrates complexes, which hinder the digestion of cellulose and hemicellulose by rumen microbes (Graminha et al., 2008). Nevertheless, crop residue have considerable prospective and any treatment which could increase their energy content by even 20% would be an important attainment (Chaudhry and Miller, 1996). The potential of physical, chemical and biological treatments to upgrade the nutritive value of crop residues have been extensively researched (Sarnklong et al., 2010).

Urea treatment is one of the most effective treatments used to improve the nutritive value of crop residue (Van Soest, 2006). The improvement of crop residue digestibility by urea treatment ranged between 11-52% (Fadel-Elseed et al., 2003, Hart and Wanapat, 1992, Liu et al., 2002, Mgheni et al., 1993, Vadivelloo, 2000). This variability is maybe due to the the variations in the substrate and the process of the treatment. It has been reported that ammonium produced by urea decomposition could link to cell carbohydrates leading to an increase in straw nitrogen content (Bogoro et al., 2006). The increase in CP content of treated substrates ranged between 30 g/kg DM reported by (Saadullah et al., 1981) using rice straw to 80 g/kg DM reported by McDonald (1998) using barley straw. However, most of this protein nitrogen claimed to be excreted in the feces because it bounds to the indigestible carbohydrates and thus it is inefficiently utilized by ruminal bacteria (Ribeiro, 1994).

Many reviews discussed the studies on improving the fibrous roughages by alkaline treatments (Wanapat, 1985, Jackson, 1978). Sodium hydroxide, calcium hydroxide and ammonia were the most common alkalis used. In rural areas of Ethiopia where dung and wood are used extensively as major energy source of domestic usage (Duguma et al., 2014), ash is available in considerable quantities. Wood ash solutions are alkaline ($pH>10$) and were used successfully to improve the nutritive value of wheat straw (Nolte et al., 1987) and corn stover (Ramirez et al., 1992) and sorghum straw (Ramirez et al., 1991). Dung ash was successfully used to improve the nutritive value of native Andean grass (Genin et al., 2002) and *Stipa tenacissima* (Genin et al., 2007).

Although wood ash treated straw contained high levels of ash, feeding for short time did not have negative consequences on the health of steers (Laswai et al., 2007).

2.4 Genetic variation in straw and grain traits and food-feed relations in crops

Integrating the nutritive value of crop residue into multi-trait improvement of crops is a recent direction in both animal nutrition and crop breeding. However, the awareness of the farmers about the variability in the nutritive value of crop residue in the released varieties can be traced to the eightieth of the 20th century (Reed et al., 1988). Rejecting the improved varieties by farmers due to the low yield and quality of crop residue were documented and confirmed by *in situ* trials (Reed et al., 1988). In addition to that, Blümmel and Rao (2006) reported that the variation in *in vitro* organic matter digestibility of the sorghum stover accounts for 75% of the variation in sorghum stover price. Other study showed that the farmers were aware of the cultivar-dependent differences in the nutritive value of sorghum stover and theire pricing of the stover is strongly correlated to the favourable fodder quality traits (Rama Devi et al., 2000). Inclusion of straw quality in multi-dimensional crop improvement requires wide genotypic variation in crop residue traits, reliable method for phenotyping huge number of straw samples for quality traits in short time and a sufficient description of the relation between grain yield and crop residue traits (Sharma et al., 2010). Table 1 present results of studies on the genetic variation in the grain and crop residue traits in several crops. Beyond of variation in fodder quality, variety of crop residue affected intake and performance of livestock. Dry matter intake, milk yield and quality of buffaloes fed on sorghum-based ration were affected by sorghum variety (Anandan et al., 2010). The variety affected dry matter intake (DMI) and organic matter digestibility intake of pearl millet straw by sheep (Ravi et al., 2010). Rao and Blümmel (2010) reported that feeding stover from different varieties of sorghum to the cattle affected organic matter intake, milk yield, milk composition and economic of milk production. Organic matter intake of groundnut straw and daily weight gain of sheep was affected by groundnut variety (Prasad et al., 2010). Nutritive value of crop residue is the potential intake of DM, CP and ME. Conventional lab analysis and *in situ* trials to evaluate CP, ME and DMI of crop residue are costly, time consuming and do not cope with phenotyping large number of crop residue samples. Near infrared spectroscopy proved to be fast, accurate and low-cost method to predict chemical composition, *in vitro* organic matter digestibility and metaboilzable energy of feeds. Recently, the International Livestock Research Institute feed analysis lab have several accurate NIRS prediction equations for wide range of cereal and legume residues. However, ranking crop residue quality based on the botanical structure offers a reliable option. Studies shows existence of botanical–based variation in crop residue quality traits. Tolera et al. (1999) indicated that leaf of maze had better CP and digestibility compared to other botanical fractions. In chickpea, pods have lesser CP content and lesser OM digestibility compared to the rest of the biomass (Kafilzadeh and Maleki, 2012). Vadiveloo (1995) reported that the nutritive value of the whole rice straw was strongly correlated with the nutritive value of each fraction and the digestibility of stems was higher than the digestibility of leaves. With the botanicl fraction, varietal variation in the nutritive value was found in rice (Vadiveloo, 1995), maze (Tolera et al., 1999) and chickpea (Kafilzadeh and Maleki, 2012). Varietal variation in DMI of the crop residue was observed (Table 1). The intake of the digestible organic matter of sorghum can be predicted using plant height and the diameter of stem (for plant height: $r=-0.71$, $P<0.001$; for stem diameter: $r= -0.67$, $P<0.001$) (Ravi et al., 2010). Organic matter intake of sorghum by sheep can be predicted using ADF and CP content ($R^2=0.73$) (Reddy et al., 2010).

Table 2 summarize the correlation between grain yield and straw traits in several crops. Moderate and positive correlations between grain yield and straw yield was found in groundnut while no correlation was found in durum wheat, kharif sorghum, rabi sorghum and pearl millet. Moderate and negative correlation was found between grain yield and CP of crop residue in in pearl millet and durum wheat wheras no correlation was reported in kharif sorghum, rabi sorghum and groundnut. Week and negative correlation between grain yield and IVOMD of crop residue was found in in kharif sorghum, rabi sorghum while no correlation was found in durum wheat, groundnut and pearl millet. The correlation beteen grain yield and me of cr in durum wheat, kharif sorghum, rabi sorghum, pearl millet and groundnut.

Table 1. Genetic variation in grain and crop residue traits in some crops

Reference	Crop	Trait	Genotypic range	N of genotypes
(Blümmel et al., 2010)	Pearl millet	grain yield (t/ha)	2.9-4.2	10
		crop residue yield (t/ha)	3.8-4.9	
		CP (g/kg DM)	3.9-7.9	
		IVOMD	37.6-46.7	
		ME (MJ/kg DM)	5.3-6.9	
(Nigam and Blümmel, 2010)	Groundnut	CP (g/kg DM)	7.5-14.4	860
		IVOMD	51.7-61.1	
		ME (MJ/kg DM)	6.9-8.8	
(Ravi et al., 2010)	Pearl millet	IVOMD	47.7-62.5	40
		Organic matter intake (g/kg$^{0.75}$) by sheep	36.9-59.6	
(Bidinger et al., 2010)	Pearl millet	Grain yield (t/ha)	2.7-4.2	256
		crop residue yield (t/ha)	2.8-5.5	
		CP (g/kg DM)	4.3-8.6	
		IVOMD	40.7-46.1	
		Digestible crop residue yield (t/ha)	40.7-46.1	256
(Singh and Shukla, 2010)	sorghum	CP (g/kg DM)	6.12-17.1	23
		Net energy for maintenance (MJ/kg)	4.4-7.0	
(Reddy et al., 2010)	Groundnut	Organic matter intake (g/kg$^{0.75}$) by sheep	83.7-100.7	10
		Daily weight gain of sheep (g)	65-137	10
(Kafilzadeh and Maleki, 2012)	chickpea	Grain yield (t/ha)	0.688-0.975	4
		crop residue yield (t/ha)	1-1.2	
		CP (g/kg DM)	3.1-3.6	
		IVOMD	47.1-53.6	
		ME (MJ/kg)	5.59-6.21	
(Ertiro et al., 2013)	Maize	Grain yield (t/ha)	6.7 (range)	335 genotypes vs. 3 locations
		crop residue yield (t/ha)	13.8 (range)	
		True IVOMD	62.9-70.4	
		CP (g/kg DM)	4.5-7.4	
(Vadiveloo and Fadel, 2009)	Rice	CP (g/kg DM)	3.3-6.6	16
		IVOMD	42.2-58.0	
(Habib et al., 1998)	wheat	DMI by cattle (%live weight)	1.8-2.3	15
(Erskine, 1983)	lentil	*In vitro* DM digestibility	40.2-48.9	6
		CP (g/kg DM)	5.8-6.9	
(Tolera et al., 1999)	Durum wheat	CP (g/kg DM)	3.2-3.6	4 genotypes vs. 2 years
		In sacco DM digestibility for 24 h	32.1-37.5	
		Gain yield (t/ha)	1.01-1.91	
		crop residue yield (t/ha)	2.33-5.03	

CP: crude protein; DM: dry matter; DMI: DM intake; IVOMD: in vitro organic matter digestibility; ME: metabolizable energy.

Table 2. Relationship between grain and crop residue traits in some crops

Reference	Crop	Yield	CP	IVOMD	ME
(Tolera et al., 1999)	Durum wheat	-0.15	-0.46*	-0.09	Na
(Blümmel et al., 2010)	Kharif sorghum	Na	-0.05	-0.25*	Na
(Blümmel et al., 2010)	Rabi sorghum	Na	-0.13*	-0.29*	Na
(Bidinger et al., 2010)	Pearl millet	Na	-0.56*	Na	Na
(Nigam and Blümmel, 2010)	Groundnut	0.46*	0.28*	0.05	0.13

*: significant at P value of 0.05; Na: not available; CP: crude protein; IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy

3. SUMMARY OF MATERIALS AND METHODS

This section aims to summarize the materials and methods used in the current study. The current study analyzed 3 types of data. The first data was on the use of cereal and pulse residue in mixed farming systems of Ethiopia. The second data was on genetic variability in grain yield and straw yield and nutritive value. The third data was on the effect of dung and wood ash on the nutritive value of chickpea, faba bean and lentil straw. However, further details are presented in the materials and methods of the individual papers.

3.1. Determinants of the use of cereal and pulse residue for livestock feeding and soil mulching among smallholder farmers in the mixed farming system in Ethiopia

A survey was conducted in 6 districts across 2 regions of Ethiopia. Data included use of crop residue, biophysical and socioeconomic information from 160 households. This survey aimed to identify the determinant of use pulse and cereal straw in the mixed farming systems of Ethiopia.

The interest of farmers in a given use of crop residue was expressed as a percentage of total production of crop residue. Which means the dependent variable is latent. Accordingly, many farmers did not report uses of some crop residue. That means the dependent variable is censored to the left side. The proportion of a given crop residue used for depends of the uses of other crop residue. To simplify the model used in analyzing the survey data, 4 equations were constructed as follow:

Y (Cereal residue_feeding) = x1 + x2 + …..+ xn
Y (Cereal residue_mulching) = x1 + x2 + …..+ xn
Y (Pulse residue_feeding) = x1 + x2 + …..+ xn
Y (Pulse residue_mulching) = x1 + x2 + …..+ xn

The explanatory variables in each equation were included according to the relevance. Using general linear model to analyze such data is not appropriate. However, solving the 4 equations at the same time using multivariate tobit model will give more robust results.

3.2. Genetic variability in straw traits and food-feed relations in chickpea and lentil

Two trials were conducted to analyse the possibility of increasing straw yield and straw nutritive value without decreasing grain yield by exploiting the natural variation in early maturing genotypes of Desi chickpea and late maturing genotypes of lentil.

The trials included growing 25 varieties of chickpea and lentil released manly for high grain yield in 2 locations in Ethiopia, namely Debre Zeit and Chefe Donsa. The trials were laid out using a randomized complete block design. At the physiological maturity, the biomass of the experimental plots were harvested and the yield of grain and straw was recorded. Representative samples of straw were collected form each plot for further feed analysis.

Urea treatment is a practical method to improve the nutritive value of crop residue. It has the advantage of improving CP and ME content of crop residue. Therefore, it was used as a baseline to ascertain whether the varietal variation in the nutritive value of pulse straw could be exploited to achieve an important improvement. The straw collected form the plots of the local variety were bulked and used to determine the effect of urea treatment on the nutritive value of straw.

All straw samples were analyzed using a combination of wet chemistry and near infrared reflectance spectroscopy according the guidelines of the international livestock research institute feed lab.

General linear model was used to analyze the effect of variety-location interaction according to the following model:

$$Y_{ijk} = M + G_i + L_j + B_k(L_i) + GL_{ij} + E_{ijk}$$

Where Y_{ij} is the response variable, M is the mean, G_i is the effect of variety i, L_j is the effect of the location j, $B_k(Li)$ is the effect of the block k within location i, GL_{ij} is the interaction between the variety and the location and E_{ijk} is the random error.

The performance of the genotypes for grain yield and straw traits in each location was analyzed separately according to the following model:

$Y_{ij} = M + G_i + B_j + E_{ij}$.

Where Y_{ij} is the response variable, M is the mean, G_i is the effect of variety i, B_j is the effect of the block j and E_{ij} is the random error

In both trials, means were separated using the least significant difference method at a 0.05 level of probability. Stepwise multiple regression analysis was used to identify the best model which describe the relation between IVOMD and ME and the chemical analysis of chickpea straw for each site. Linear relationships among straw quality traits were investigated to minimize the number of the variables which express the nutritive value of chickpea straw. Likewise, linear relationships between grain and straw traits were calculated using Pearson's correlation.

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

Five varieties of faba bean (one local and 4 improved were planted in 5 plots 1 ha each in Sinana agricultural research center. The biomass of 30 plots 1*1 m each were harvested from each variety. Grain yield and straw yield were recorded for each plot.

The straw was divided into two parts. The first part was fractionated into leaves, stem and pods while the second part was left intact to represent the whole straw.

All straw samples were analyzed using a combination of wet chemistry and near infrared reflectance spectroscopy according the guidelines of the international livestock research institute feed lab.

The effect of variety, fraction and variety-fraction interaction was identified using general linear model. The varietal variation in grain yield, straw yield, straw nutritive value and the relative proportions of the fractions was analyzed using one way analysis of variance. The canonical correlation was used to determine the correlation between the nutritive value of the whole straw and the nutritive value of leaf, stem and pods. Likewise, the correlation between the nutritive value of the whole straw and the relative botanical proportions was identified using the canonical correlation. The principle component analysis was used to produce scores for the nutritive value of the straw of the varieties. Simple correlation was used to identify the correlation between grain yield and CP and ME of the straw.

4. SUMMARY OF RESULTS

4.1. Determinants of the use of cereal and pulse residue for livestock feeding and soil mulching among smallholder farmers in the mixed farming system in Ethiopia

Results of the study showed that farmers prefer using crop residue from pulses over crop residue from cereals for livestock feeding purposes. The use of crop residue from pulses as feed was positively affected by education level of the farmer, livestock extension service, number of small ruminants and crop residue production from the previous season. Distance of farm plots from residences of the farm households decreased the proportions of cereal and pulse residue used for feed. The use of pulse residue affected positively significantly when the women participated in decision making on crop residue utilization. The use of cereal and pulse residue as soil mulch was positively affected by the education level of the farmer, the distance between the homestead and the cultivated land, extension service, awareness about soil mulch, the slope of cultivated land, participation in farmer-to-farmer extension and crop residue generated in the preceding season.

In light of that pulse crop residue have better nutritive value compared to cereal crop residue, better utilization of crop residue could be achieved by maximizing the use of pulse residue as livestock feed and optimizing the use of cereal residue as soil mulch.

4.2. Genetic variability in straw traits and food-feed relations for multi-dimensional improvement in chickpea and lentil

The Effect of the variety, location and variety-location interaction on grain yield, straw yield and straw nutritive value of chickpea and lentil was significant. Urea treatment significantly ($P<0.001$) improved CP and ME of chickpea and lentil straw.

The exploitable genotypic range in CP and ME of chickpea and lentil straw was higher than the increase caused by urea treatment.

The ADF straw correlated strongly with the other nutritive value parameter regardless of the location ($r> 0.65$) in chickpea but not in lentil. The IVOMD and ME of chickpea straw can be predicted by the chemical composition (R^2= 0.9 for IVOMD and 0.904 for ME). In the case of lentil, predicting IVOMD and ME of straw using chemical composition depended on location.

In chickpea, the correlation between grain yield and straw traits was weak in all locations. In lentil, the relation between grain yield and straw traits was different across locations.

4.3. Variation in the Straw Traits of Morphological Fractions of Faba bean (*Vicia faba l.*) and Implications for selecting for Food-Feed Varieties

There was a significant genetic variation in grain yield, straw yield and proportions of botanical fractions of straw. The improved varieties were better than the local variety in grain yield, straw yield and PUI. The local variety showed the highest proportion of stem and lowest proportion of leaf and pods. Significant varietal variations (P<0.001) were detected in ash, IVOMD, ME but not in CP), NDF, ADF and ADL of whole straw. The leaves had 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 found between grain yield and straw quality traits. Ranking the varieties differed when grain yield, straw quality scores and PUI were considered. Urea treatment improved significantly CP, IVOMD and ME of faba bean straw by 53%, 6% and 8% respectively.

5. OVERALL DISCUSSION

Crop-livestock mixed farming systems are the backbone of smallholder livelihoods in the developing countries (Ryschawy et al., 2012). The pressure on these systems is increasing due to the increase in human and livestock population, the increase of urbanization and the increase in the income (Herrero et al., 2010). That led to increase the intensity of land use (Collier and Dercon, 2009). Without adequate land management, this may contribute to land degradation and low agricultural productivity (Lal, 2009).

This study showed that the amount of crop residue left on the land as mulch met only 50% of the recommendation for soil mulching. Cereal and pulse residue could cover only 53.5, 75.6 and 94.2% of the maintenance requirement of the household's livestock from dry matter, CP and ME, respectively. This study proved that improving the biomass and nutritive value of pulse straw will supply the livestock in the farm with additional CP and ME.

Urea treatment improved the nutritive value of chickpea, faba bean and lentil straw mainly by increasing CP content. Chenost and Kayouli (1997) stated that only some of 30% of the fixed nitrogen in the straw by urea treatment could be utilized by the rumen microorganisms. Ribeiro (1994) argued that the fixed nitrogen due to urea treatment could be linked to the indigestible portion of cell walls. Yang et al. (2010) stated that an important amount of the fixed CP due to urea treatment could be lost because of the lack of synchrony of nutrients at ruminal and cellular levels. Lack of nitrogen fertilization is an important reason behind the low productivity of crops in Ethiopia (Tena et al., 2016). Fertilizing chickpea at a rate of 100 kg urea/ha increased grain yield by 55% (Namvar and Sharifi, 2011). Applying nitrogen fertilization ata rate of 30 kg N/ha (68.2 kg urea/ha) increased grain yield of faba bean by 35% in average (Aguilera-Diaz and Recalde-Manrique, 1995). An application of urea fertilization at a rate of 50 kg urea/ha increased grain yield of lentil by 40% and straw yield by 60% (Tena et al., 2016). According to our study, the trial average of straw yield was 5 t/ha in chickpea, 4.6 t/ha in faba bean and 5.1 t/ha in lentil. Thus treating straw of chickpea, faba bean and lentil harvested from one ha needs 200 kg, 184 kg and 204 kg of urea fertilizer respectively. These amounts are enough to provide 2 h, 2.7 ha and 4.08 ha planted by chickpea, faba bean and lentil respectively. Thus, the use of urea to upgrade the nutritive value of crop residue should consider the availability and tradeoff of urea at the farming unit level in the mixed farming systems of Ethiopia.

Pulse straws had high content of lignocellulose. Thus, it is expected that they would respond positively to alkaline solutions (Genin et al., 2007). Dung and wood ash contain high amounts of minerals, therefore, they could increase the growth of rumen microbes provided ashes were absorbed during the treatment. However, dung and wood ash treatment did not improve the ash content nor IVOMD of chickpea, faba bean and lentil straw. Our results showed a possibility of improving grain and straw traits in chickpea, faba bean and lentil.

That is in agreement with studies on pearl millet (Bidinger et al., 2010, Blümmel et al., 2007), sorghum (Blümmel et al., 2010), and maize (Ertiro et al., 2013). Breeding new varieties of chickpea, faba bean and lentil for superior grain yield and straw traits has multiple benefits. It will increase the food security of farmers in mixed farming systems. It will increase the straw biomass and quality which will increase the production of milk and meat. Furthermore, it will improve the amounts of crop residue allotted for soil mulching.

Thus, crop breeders and livestock scientists should work closely to design improvement programs which improve simultaneously the food and feed traits of chickpea, faba bean and lentil.

6. CONCLUSIONS

The study pinpointed that there is high demand for crop residue biomass in mixed farming systems of Ethiopia. Under limited biomass production in the households, better utilization of crop residue could be achieved by maximizing the use of pulse residue as feed and optimizing the use of cereal residue as soil mulch.

That could be achieved by providing proper extension and training services on soil mulching and the superiority of pulse residue over cereal residue as livestock feed. Increasing the biomass and nutritive value of pulse residue will improve the supply of nutrients to livestock. That will encourage farmers to leave more quantities of cereal residue in farms. Encouraging informal group discussion among farmers would improve information flow to enhance better utilization of crop residue. Introducing food-feed varieties of chickpea, faba bean and lentil will be practical option which will increase dry matter and nutrients supply in mixed farming systems of Ethiopia.

Dung ash and wood ash treatment failed to improve the nutritive value of chickpea, faba bean and lentil straw. Urea treatment improved the nutritive value of chickpea, faba bean and lentil straw. However, using urea for as a fertilizer to increase grain and straw yield in mixed farming systems of Ethiopia will make the adoption of urea treatment of straw questionable.

Food-feed varieties of chickpea, faba bean and lentil in mixed farming systems of Ethiopia could be a strategic option to increase residue biomass for livestock feeding and soil mulching.

7. RECOMMENDATIONS

In view of the results of the current study, genetic variability of grain and straw traits and food feed relations in faba bean should be studied using larger number of genotypes in multi-environmental trials.

Screening chickpea and lentil genotypes for straw quality depending on the botanical structure should be studied. The genetic variation in straw quality trait of chickpea, faba bean and lentil should by confirmed in *in situ* studies.

Modification on ash treatment in order to improve the activity including adding weak alkaline and increasing soaking duration should be studied. Further levels of ash treatment to the current study is also other potential area of future work.

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9. APPENDIX

Questionnaire

Instrument for data collection on crop residue utilization in Ethiopia highlands. The information collected from this interview will be used only for academic purpose. Personal data will be kept confidential. Total number of question in the current instrument is (7). Thus, we kindly ask you to answer the following questions.

Date of interview: (/ /). **Time of interview**: ( ). **Place of interview**: ( ).

1. Household characteristics	
1.1. Household head name	
1.2. GPS information	Longitude ( ) Latitude ( )
1.3. Household head mobile number	
1.4. Household head age	( ) Year
1.5. Household head sex	( ) Male ( ) female
1.6. Household head education	( ) Years at school
1.7. household size	( ) Members
2. Cultivated land	
2.1. Size	( ) ha
2.2. Slop (the largest plot is considered)	( ) Flat ( ) Mild ( ) Steep
2.3. How much is the distance from between the farmland and the homestead?	( ) Hours
3. Livestock kept	
3.1. Small ruminants	( ) Heads
3.2. Large ruminants kept in the household	( ) Heads
4. Crop yields profile	
Crop1 Name: ( ) Yield: ( ) t	Crop3 Name: ( ) Yield: ( ) t
Crop2 Name: ( ) Yield: ( ) t	Crop4: Name: ( ) Yield: ( ) t
Crop 5 Name: ( ) Yield: ( ) t	Crop 6 Name: ( ) Yield: ( ) t
5. How does make decision about crop residue utilization?	( )Male ( ) Female ( )Joint
6. Perception and extension	
6.1. Have you heard about crop residue mulching?	Yes, No
6.2. Have you got:	
6.2.1. Farmer-to-farmer extension on mulching crop residue?	Yes, No
6.2.2. State extension about mulching crop residue?	Yes, No
6.3. Have you got:	
6.3.1. Farmer-to-farmer Extension on livestock production?	( ) Yes ( )No
6.3.2. State extension on livestock production?	( ) Yes ( ) No
7. Profile of crop residue use (% of total crop residue)	
Crop 1: feed ( ), mulch ( )	Crop 2: feed ( ), mulch ( )
Crop 3: feed ( ), mulch ( )	Crop 4: feed ( ), mulch ( )
Crop 5: feed ( ), mulch ( )	Crop 6: feed ( ), mulch ( )

End of questionnaire

Thank you so much for cooperation

LIST OF PAPERS

PAPER 1

DETERMINANTS OF THE USE OF CEREAL AND PULSE RESIDUE FOR LIVESTOCK FEEDING AND SOIL MULCHING AMONG SMALLHOLDER FARMERS IN THE MIXED FARMING SYSTEM IN ETHIOPIA

Abstract

Crop residue is dual purpose resources in the mixed crop-livestock systems of the Ethiopian highlands. They serve as livestock feed and inputs for soil and water conservation. Furthermore, crop residues are useful as fuel and for house construction where the selection of such use depends on the source of the crop residue itself. They are generated predominantly from cereals and pulses. However, in view of the allocation of crop residue, soil conservation and livestock are two competing enterprises. Identifying the determinants of the intensity of use of cereal and pulse residue may help in designing strategies for more efficient crop residue utilization.

Data on crop residue was generated and its utilization was collected in two highland regions in Ethiopia from 160 households using a structured questionnaire. The data was analyzed using the multivariate Tobit model.

Results of the study showed that farmers prefer using crop residue from pulses over crop residue from cereals for livestock feeding purposes. The proportion of crop residue from pulses that was used as feed was positively affected by education level of the farmer, livestock extension service, number of small ruminants and crop residue production from the previous season.

Distance of farm plots from residences of the farm households negatively affected the proportions of cereal and pulse residue used for feed. The use of pulse residue increased significantly when the women participated in decision making on crop residue utilization. The proportion of cereal and pulse residue used for soil mulch was positively affected by the education level of the farmer, the distance between the homestead and the cultivated land, extension service, awareness about soil mulch, the slope of cultivated land, participation in farmer-to-farmer extension and crop residue generated in the preceding season. In view that pulse crop residue have better nutritive value compared to cereal crop residue, better utilization of crop residue could be achieved by maximizing the use of pulse residue as livestock feed and optimizing the use of cereal residue as soil mulch.

More livestock extension on the nutritive value of pulse residue should be provided to the farmers who cultivate sloppy plots. Encouraging the culture of labor exchange among the farmers could result in increased labor availability in the farms that would facilitate the transport and storage of pulse residue and increase its use as livestock feed. Increasing the awareness among farmers about the superiority of the pulse residue over cereal residue as feed and encouraging use of cereal residue as soil mulch could optimize the utilization of crop residue in the household.

Keywords: Cereals, pulses, residue, mixed crop-livestock farming system.

Introduction

Crop-livestock mixed farming systems are the mainstay of smallholder livelihoods in the developing world (Herrero et al., 2010, Ryschawy et al., 2012). Population growth, increase in livestock population, increased income and rate of urbanization in the developing countries tend to increase the pressure on these systems (Herrero et al., 2009, Herrero et al., 2010). These challenges also tend to increase intensity of land use which leads to continuous cultivation of farmlands without fallowing (Collier and Dercon, 2009, Drechsel et al., 2001). Without adequate investment in agricultural land management, this may contribute to land degradation and low agricultural productivity (Lal, 2009). Scientific reports on the use and importance of crop residue have shown that leaving 30% of the residue on crop farm plots reduces soil erosion by up to 80% (Rockström et al., 2009).

In mixed crop-livestock farming systems, the use of crop residue for livestock feeding is becoming increasingly important due to the expansion of cropland and low productivity of natural pastures (Alkemade et al., 2012). The contribution of crop residue to the total dry mater intake of the livestock in Ethiopia ranges from 10% to 70% (Alemayehu, 2003, Zinash et al., 2001). The crop residue from cereals and pulses has different nutritive values as livestock feed. According to Keftasa (1988), one kg of residue from cereal (pulse) contains on average 47 (69) g of crude protein (CP), 6.50 (6.95) MJ of metabolizable energy (ME) and 0.75 (0.55) g of phosphorus (P) and 2.5 (9.2) g of calcium (Ca), indicating that crop residue from pulses have better nutritive value compared to crop residue from cereals. Using pulse residue for soil mulching would therefore deprive livestock of valuable nutrients that could be used to improve dairy and meat production. Utilizing one kg of pulse residue as mulch would deprive the livestock of 22 gram of CP, 0.4 MJ of ME, and 6.7 gram of Ca. This is equivalent to a loss of 0.25 kg of cow milk of 4% fat (estimation from Kearl (1982)). Under such situations, better utilization of crop residue could be achieved by maximizing the use of pulse crop residue for livestock feeding and optimizing the use of cereal crop residue for both mulching and livestock feeding.

Studies on the utilization of crop residue in Ethiopia are limited and have mainly focused on maize residue (Jaleta et al., 2015, Jaleta et al., 2013). Therefore, this study aimed at identifying the determinants of the utilization of cereal and pulse crop residue as livestock feed and soil mulch considering that crop residue from cereals and pulses is one of the major contributors to livestock feed and soil fertility in the highlands of Ethiopia.

Materials and methods

Study sites and data

The study was carried out in cereal-based farming systems in two regions of Ethiopia, Oromia and Amhara where smallholder mixed crop-livestock systems prevail. These regions represent highlands which have potential for both cereal and pulse production. The average minimum temperature ranges between 8-9°C and the average maximum temperature between 20-22°C. The mean annual rainfall ranges between 750-1200 mm (Table 3). There are two cropping seasons, between January and March and between June and September. Crop harvest takes place between June and July and between October and December. The dominant soil types are vertisols, nitisols and camisols. The source and provision mechanism of agricultural extension services are similar across districts varying only in the skills of the extension agents. Data was drawn across six districts. Two peasant associations were randomly selected within each district (Table 3). Farmers within each peasant association were selected using a proportionate to size sampling method. The total number of the farmers participated in the study was 160 farmers (Table 3). Data was collected using a structured questionnaire. The data collected included household characteristics, resource ownership by the households, and crop residue production and utilization. The crop residue production (t/household) was estimated from the grain production of each crop using conversion factors (Table 4).

Table 3. General information about the studied areas (N=160)

District	Village	N of households interviewed	Altitude (m.a.s.l)	Average Temp. (°C) Min	Max	Precipitation (mm)	Agroecology
Agafra	Illani	11	2606	8-9	21-22	750-1475	Highland
	Elabdu	12	2467	8-9	21-22	750-1475	Highland
Gasera	Ballo Amenga	12	2395	8-9	21-22	750-1475	Highland
	Nake Negaaso	12	2385	8-9	21-22	750-1475	Highland
Goba	Alloshe Tillo	14	2566	8-9	21-22	750-1475	Highland
	Sinja	10	2603	8-9	21-22	750-1475	Highland
Goro	Chefaa Mana	14	2038	8-9	21-22	750-1475	Highland
	Dayu	9	2150	8-9	21-22	750-1475	Highland
Sinana	Sanbitu	14	2454	8-9	21-22	750-1475	Highland
	Selka	12	2457	8-9	21-22	750-1475	Highland
Basona	Goshe bado	20	2790	8-9	20-22	900-1200	Highland
Worena	Godo Beret	20	3084	8-9	20-22	900-1200	Highland

Table 4. Multipliers used to estimation crop residue production

Crop	Residue	Residue multiplier	Reference
Wheat	straw	1.5	(Smil, 1983)
Barley	straw	1.2	(Smil, 1983)
Sorghum	straw	1.2	(Smil, 1983)
Corn	stover	1.2	(Smil, 1983)
Lentil	straw	2.4	(Tullu et al., 2001)
Faba bean	straw	1.3	(Gebremeskel et al., 2011)
Field pea	straw	5.1	(Keftasa, 1988)
Teff	straw	2.3	(Gebretsadik et al., 2009)

Calculations and statistical analysis

The extent of utilization of cereal and pulse residue per household was measured in terms of percentage. In this particular case, our formulation presumes that there will be limited farmers who do not account for any crop residue utilization. The implication is that our latent dependent variable (y^*), which denotes interest in a specific crop residue, is not observed until the interest in the crop residueutilization exceeds some known constant threshold (L); i.e., we observe y^* only when $y^* > L$. Using ordinary least squares method to regress the intensity of use on the explanatory variables will generate inconsistent estimates because the censored nature of the variable. Therefore, Tobit model censored only from the left side (L=0) was employed in this study. Our model is specified as an unobserved latent variable, y^*. The observed y was defined by the following measurement equation:

$$y = \begin{pmatrix} y^* & if & y^* > L \\ L & if & y^* \le L \end{pmatrix} \qquad (1)$$

Each type of residue is used as feed or mulch which leads to joint decision about the utilization of cereal and pulse residue. The allocation functions of crop residueare inter-related and hence our estimation needs to take simultaneity into account. There is also efficiency gain in estimating these equations simultaneously. This study therefore employs multivariate Tobit model (Arias and Cox, 2001, Cornick et al., 1994, Lee, 1981) as specified below. Following the discussion above, let Y_j^* be a (G x 1) vector of latent allocation of the j^{th} consumption of cereal (*c*) or pulse (*l*) residue for feed (*f*) or mulching (*m*) [this implies that '*j'* takes four values] , related to a (G × K) matrix of explanatory variables X_j by [suppressing observation indices]:

$$Y_j^* = X_j \beta_j + \xi_j, \quad j = 1,...,N \qquad (2)$$

where ξ_j is an (G × 1) vector of error terms and $\xi_j \sim N(0, \sigma_j^2)$, β is a (K × 1) vector of estimated coefficients, K is the number of explanatory variables, G is the number of households, and N is the number of allocations (N=4). The relationship between latent (Y_j^*) and observed (Y_j) allocation can be represented by:

$$Y_j = Max(f_j(X;\beta) + \xi_j, 0) \qquad (3)$$

Since the four types of allocation of the crop residue are determined simultaneously, the error terms of the models are likely to be correlated. If that is the case, efficiency gains can be achieved by estimating the equations in Equation (3) as a system. Formally, the likelihood function of the system of equations for an observation in which the first *m* allocation equations are censored out of the 4 equations is given by:

$$\boldsymbol{L} = \int_{-\infty}^{-X_1\beta_1} \dots \int_{-\infty}^{-X_m\beta_m} f(\xi_1,....,\xi_4) d\xi_1 ... d\xi_m . \qquad (4)$$

Here f is the multivariate normal probability density function. Since there are four kinds of allocations we are dealing with, we have to evaluate definite integrals in up to four dimensions to work out the likelihood function of the system. As Equation (4) does not have a closed form solution, we have to evaluate it numerically. Approximating the integral with a weighted sum of integrand values at a finite number of sample points in the interval integration, numerical quadrature serves as an alternative to calculating multi-dimensional integrals. Although quadrature works well for small-dimensional integrals, it is not as effective with higher dimensions (Train, 2003). Actually, if the dimension of integrals is greater than two, quadrature techniques cannot compute the integrals with sufficient speed and precision (Hajivassiliou and Ruud, 1994, Revelt and Train, 1998). As the integral to be calculated in this paper has a dimension of four, we employ the Geweke–Hajivassiliou–Keane simulator in the estimation reported in the paper (Geweke, 1989, Hajivassiliou and McFadden, 1998, Keane, 1994). Suppose the value of the following integral with dimension N (N=4 in our case) needs to be calculated by the GHK:

$$Pr(\boldsymbol{a} < \xi < \mathbf{b}) = \int_a^b g(\xi) d\xi \tag{5}$$

where ξ is a random vector with $\xi \sim N(0, \Sigma)$ and g is the density function of ξ. The idea of the GHK simulator is to draw u from a univariate normal distribution and recursively compute multivariate probability values using Choleski factorization (Cappellari and Jenkins, 2006). Let **L** be the lower triangular Choleski factor of ξ satisfying $\boldsymbol{L}'\boldsymbol{L} = \boldsymbol{\Sigma}$ and $\boldsymbol{e}$ is a vector of independent standard normal random draws, then:

$$Pr(\boldsymbol{a} < \xi < \boldsymbol{b}) = Pr(\boldsymbol{a} < \boldsymbol{Le} < \boldsymbol{b}) = Pr(A_1)Pr(A_2 \mid A_1)...Pr(A_N \mid A_1,...,A_{N-1}) \tag{6}$$

where Ai represents the event in the right hand side of Equation (5), $i= 1,2, \ldots, 4$..

Table 5: Brief description of the explanatory variables used in the Tobit model

Explanatory variables	Description
Household characters	
Age of the head	Continues, years
Sex of the head	Dummy, takes the value of 1 if female and 0 otherwise
Education of the head	Continues, years
Size	Continues, persons
Decision maker on crop residue	
Male	Dummy, takes the value of 1 if male and 0 otherwise
Female	Dummy, takes the value of 1 if female and 0 otherwise
Joint	Dummy, takes the value of 1 if joint and 0 otherwise
Cultivated land	
Area	Continues, ha/household
Slop	
Flat	Dummy, takes the value of 1 if flat and 0 otherwise
Mild	Dummy, takes the value of 1 if mild and 0 otherwise
Steep	Dummy, takes the value of 1 if steep and 0 otherwise
Distance from the homestead	Continues, hours
Extension and perception	
Farmer-to-farmer	Dummy, takes the value of 1 if there is and 0 otherwise
Extension	Dummy, takes the value of 1 if there is and 0 otherwise
Perception about crop reside mulching	Dummy, takes the value of 1 if there is and 0 otherwise
Livestock kept by the household	
Livestock units density	Continues, tropical livestock units/ha of cultivated land
Small ruminants	Continues, head/ha of the cultivated land
Large ruminants	Continues, head/ha of the cultivated land
Crop residue stock from earlier harvests	Continues, t/household

$$
\begin{aligned}
A_1 &= \left(\frac{a_1}{l_{11}} < e_1 < \frac{b_1}{l_{11}} \right) \\
A_2 &= \left(\frac{a_2 - l_{12}e_1}{l_{22}} < e_1 < \frac{b_2 - l_{12}e_1}{l_{22}} \right) \\
&\ldots. \\
A_N &= \left(\frac{a_N - l_{1N}e_1 - \ldots - l_{N-1,N}e_{N-1}}{l_{NN}} < e_N < \frac{b_N - l_{1N}e_1 - \ldots - l_{N-1,N}e_{N-1}}{l_{NN}} \right)
\end{aligned}
\qquad (6)
$$

By taking draws of e_i recursively and repeating the process for R times, we can get the simulated value of $Pr(\boldsymbol{a} < \xi < \boldsymbol{b})$ and then the likelihood function. The explanatory variables included in the model were household characters, farmland characters, extension and awareness, livestock wealth and crop residue stock from earlier harvests (Table 5).

Results

Descriptive analysis

The summary of the descriptive statistics of the variables used in the regression model is presented in Table 6. The result showed that 14.5% of the sample households were female headed. The average age (years) and the education level (years in school) of sample household heads were 45.1 and 4.48, respectively. The average family size was six persons. The average farmland size was 3.68 ha.

The walking distance between the cropping land and the homestead was 0.93 hours. It was observed that 52.2%, 40.25% and 7.55% of the households cultivated flat, mild slope and steep slope plots, respectively. Manure was the main input used for land fertilization by the sample households. The studied households kept 2.09 tropical livestock units/ha of cultivated land.

The households kept on average 5.26 heads of small ruminants, 7.64 heads of large ruminants and 7.64 tropical livestock units. On the decision to undertake crop residue utilization, the men made the decision in 35.85% of the interviewed households, the women made the decision in 9.43% of the households, and men and women made the decision jointly in 54.7% of the cases.

It was observed that 89.3% of the interviewed farmers were aware of the role of mulching crop residue in improving the quality of the soil. It was also observed that 35.2% and 89.9% of the household heads respectively got farmer-to-farmer and state extension on mulching.

The total crop residue production per household was 14.2 t/year, of which 76.1% was cereal residue and 23.9% was pulse residue. Considering only the cereal residue, 98.1% of the households used it for livestock feeding whereas 88.8% of the households used it for mulching. For pulse residue, 98.7% of the interviewed households were using it as feed and 71.8% of the interviewed households were using it as soil mulch. However, 3-4 % of the farmers reported crop residue sales and burning *in situ*. The biomass of cereal and pulse residue utilized as feed was 84.6% and 89.6%, respectively, and 15.4% and 10.4% as soil mulch respectively. The results of t-test presented in Table 7 show that the proportion of the pulse residue used as feed was significantly higher than the proportion of cereal residue used as feed ($P<0.01$). Contrary to that, the proportion of crop residue used for soil mulch was significantly higher in cereal residue compared to pulse residue ($P<0.01$).

Table 6. Socioeconomic and biophysical characters of the households.

Variables	Unit	Mean(s.d.)	%
Household characteristics			
Household head age	Years	45.1(13.3)	—
Household head sex (female)	%	—	14.5
Household head education	Years in school	4.84(3.55)	—
Size	Number	6.05(2.83)	—
Cultivated land			
Size	ha	3.68(2.47)	—
Slop			
Flat	%	—	52.2
Mild	%	—	40.3
Steep	%	—	7.55
Distance from the farmland	Hours on feet	0.93(0.76)	—
Livestock kept			
Small ruminants	Head/ha	2.31(3.78)	—
Large ruminants kept in the household	Head/ha	2.51(1.57)	—
Livestock kept in the household	TLU	2.09(1.31)	—
Crop residue stock from earlier harvests			
Cop residue biomass	t	14.2(13.2)	—
Pulse residue	t	10.8(10)	—
Cereal residue	t	3.40(5.97)	—
Decision making about crop residue			
Male	%	—	35.9
Female	%	—	9.43
Joint	%	—	54.7
Perception about mulching crop residue	%	—	89.3
Extension on mulching			
Farmer-to-farmer	%	—	24.5
State extension	%	—	54.7
Extension on livestock			
Farmer-to-farmer	%	—	35.2
State extension	%	—	89.9

TLU, tropical livestock units adopted from (Jahnke, 1982); s.d., standard deviation

Table 7: Utilization of cereal and pulse residue by the interviewed households

Utilization	Cereal	Pulse	P value
Livestock feed (%)	84.6(13.7)	89.6(15.1)	<0.001
Soil mulch (%)	15.4(13.7)	10.4(15.1)	<0.001

Percentage of the households used the crop residue as:

	Cereal	Pulse
Livestock feed	98.1	98.7
Soil mulch	88.8	71.8

Values between parentheses are noted for the standard deviation

Regression analysis

Household characters

Female headed households allocated significantly larger proportion of pulse residue as feed compared to the male headed households ($P<0.01$). The higher the literacy level of the household head, the larger the proportion of pulse and cereal residue used as soil mulch ($P<0.01$). The bigger the household size, the higher the proportion of pulse residue used as feed and the lesser proportion of pulse residue used as soil mulch ($P<0.01$). No significant effect of household size on the utilization of cereal residue was detected ($P>0.1$). It was observed that when the female joined in making the decision on crop residue utilization, more proportions of pulse residue were used as livestock feed and lesser proportions of pulse residue were used as soil mulch ($P<0.01$). However, the decision maker did not significantly affect the utilization of cereal residue ($P>0.1$).

Cultivated land

The households who cultivated steep and mild slope plots used higher proportion of both cereal and pulse residue as soil mulch compared to the households which cultivated flat plots. The distance between the cultivated land and the homestead decreased significantly the proportion of both cereal and pulse residue used as livestock feed and increased significantly the proportions used as soil mulch.

Extension and perception

Household heads who got farmer-to-farmer extension and state extension on mulching using crop residue allocated larger proportions of cereal and pulse residue for soil mulching ($P<0.01$). The extension services on livestock production increased the proportion of pulse residue used as livestock feed ($P<0.01$) and decreased the proportion of cereal residue used as livestock feed ($P<0.01$). The household heads who were aware of the importance of soil mulching used greater proportions of cereal and pulse residue as soil mulch.

Livestock kept by the household

The livestock herd size (TLU/ha) of the household did not decrease the proportions of crop residue used for mulching. As the number of small ruminants increased, the use of both cereal and pulse residue as feed significantly increased ($P<0.01$). Significant and positive correlation between the number of large ruminants and the use of cereal and pulse residue as feed was detected ($P<0.01$).

Crop residue stock from earlier harvests

The availability of crop residue stock from previous harvests within the household negatively affected ($P<0.01$) the proportion of cereal residue allocated as feed while it positively affected ($P<0.01$) the proportion of pulse residue allocated as feed.

Table 8. Multivariate Tobit estimation results on the crop residue uses as feed and soil mulch

	Cereal		Pulse	
	Mulch	Feed	Mulch	Feed
Explanatory variables	Estimate	Estimate	Estimate	Estimate
Household characters				
Age of the head (years)	0.07(0.07)	-0.04(0.07)	0.02(0.06)	0.02(0.08)
Sex of the head (female)	5.81(3.83)	-3.38(3.67)	-11.6(2.69)***	14.6(2.33)***
Education of the head (years)	0.62(0.26)**	-0.51(0.25)**	-0.27(0.17)	0.41(0.1)***
Size (persons)	0.43(0.42)	-0.18(0.42)	-1.51(0.52)***	1.12(0.44)***
Cultivated land				
Area (ha)	0.12(0.12)	—	0.19(0.16)	—
Slop				
Mild	1.51(0.87)*	—	1.98(1.17)*	—
Steep	1.62(0.89)*	—	2.17(1.19)*	—
Distance from the homestead (hours)	2.41(1.29)*	-2.5(1.26)**	2.171(1.44)*	-2.37(1.32)**
Extension and perception				
Farmer-to-farmer extension on soil mulch	3.87(0.7)***		5.46(0.89)***	
Farmer-to-farmer extension on livestock production	—	-0.140(0.35)	—	0.26(0.45)
Extension on mulching	5.68(0.71)***	—	7.85(0.92)***	—
Extension on livestock	—	-4.84(0.5)***	—	5.96(0.64)***
Perception about crop reside mulching	2.3(0.67)***	—	2.53(0.92)***	—
Decision maker on crop residue				
Female	3.64(4.78)	-4.13(4.52)	-18.8(3.87)***	17.6(3.25)***
Joint	1.36(4.52)	-1.71(4.31)	-13.5(3.6)***	13.5(3.02)***
Livestock kept by the household				
Livestock units density (TLU/ha)	0.00(0.43)	—	0.01(0.57)	—
Small ruminants (head/ha)	—	0.36(0.07)***	—	0.48(0.09)***
Large ruminants (head/ha)	—	0.78(0.29)***	—	0.99(0.39)**
Crop residue stock from earlier harvests (t)	0.01(0.01)	-0.02(0.000)***	-0.02(0.02)	0.02(0.000)**
Sigma	10.2(0.38)***	9.99(0.38)***	13.9(0.58)***	13.5(0.56)***

Value between parentheses is noted to the standard error of the estimate; ***, ** and *, significant at 0.01, 0.05 and 0.1 respectively; TLU, tropical livestock unit

Discussion

Descriptive analysis

There was high awareness among the farmers about the importance of mulching crop residue to improve the soil quality. However, the average proportion of crop residue allotted for soil mulching only met 50% of the recommendation for mulching. Farmers in the studied areas tried to maximize the utilization of crop residue by using as much of the proportion of pulse residue as they could for livestock feeding and to minimize the use of pulse residue as mulch. Introducing new feed resource like forages and grass, aiming to increase the biomass production of feed in the household, would allow the farmers to increase the use of crop residue as soil mulch.

According to FAO (2015) and Kearl (1982), one tropical livestock unit needs 239 g of CP and 28.7 MJ of ME and 7.5 kg of dry matter per day for maintenance purpose. Thus, the livestock kept in the households need an average of 20.9 t of dry matter, 666 kg of crude protein and 80033 MJ of metabolizable energy. In the current situation, the crop residue per household could provide 11.2 t of dry matter, 504 kg of crude protein and 75420 MJ of metabolizable energy. Therefore, the cereal and pulse residue could cover only 53.5%, 75.6% and 94.2% of the maintenance requirement of the household's livestock from dry matter, crude protein and metabolizable energy, respectively.

Although pulse residue has better feeding value compared to cereal residue, 10.4% of it is still lost as it was used as soil mulch. Calculation shows that using 100% of pulse residues as feed can provide the livestock with additional 1128 kg of pulse residue biomass, which can be converted into 282 kg of 4% fat cattle milk annually.

According to Thornton and Herrero (2015) and Rockström et al. (2009), 30% of crop residue production should be retained in the plot to reduce soil runoff by 80%. Compared to the previous recommendation, the proportion of straw left in the plot covers around 50% of the recommendation for soil mulch. However, to optimize the livestock productivity in the household and to enable more use of crop residue as mulch, introducing new feed resources at household level is required. Using pulse residue exclusively to feed the livestock could provide them with more nutrients and therefore increase their production level.

Regression analysis

Household characters

Female headed households allocated more proportion of pulse residue as feed compared to the male headed household ($P<0.01$). Meaning that when farmers notice the difference in livestock intake and preference between the cereal and pulse straw, they increase the use of pulse residue as feed. This signifies the importance of on-farm trials to demonstrate the difference in the nutritive value between cereal and pulse residue. Jaleta et al. (2013) stated that labor is important to increase the crop residue collection and transportation from the field to the homestead. The results of this study showed a positive effect of household size on the use of pulse residue as feed while it did not affect the use of cereal residue as feed. This implies that when active labor is available within the household, the household head prefers to use them to transport and store pulse residue rather than cereal residue. When women joined the decision making process on crop residue utilization, they used more proportion of pulse residue as livestock feed and less proportion of pulse residue as soil mulch. However, there was no significant effect of decision maker on the utilization of cereal residue. This means that the farmers who were in constant contact with the livestock could perceive more about the differences in palatability between cereal and pulse residue.

Cultivated land

The farmers who cultivated steep and mild slope plots used higher proportion of both cereal and pulse residue as mulch compared to the farmers that cultivated flat sloped plots. This result agrees with what Jaleta et al. (2013) reported. As the slope of the plot increased, the use of the residue for mulching increases. That means that farmers who cultivate sloppy plots are aware of the soil erosion more than the farmers who cultivated flat plots. The distance between the cultivated plots and the homestead is correlated positively with allocating more crop residue as mulch which agrees with the results of Jaleta et al. (2013). This result implies the importance of the need of labor for collecting and transporting the crop residue to the homestead to use it as livestock feed.

Extension and perception

The household heads who got farmer-to-farmer extension allocated higher proportion of cereal and pulse residue for mulching. The state extension service increased the utilization of the crop residue as mulch which agrees with Jaleta et al. (2015) and Jaleta et al. (2013). The result of the study also showed an important role of extension service on increasing the use of pulse residue as feed. However, the same extension negatively affects the utilization of cereal residue as feed. The overall results showed the significant role of the extension service in maximizing the utilization of crop residue through increasing the use of pulse residue as feed and the use of cereal residue mainly as soil mulch. Extension services on livestock and soil mulch, in addition to informal social networks, could effectively enhance of the utilization of crop residue.

Livestock kept by the household

When the number of the small ruminants in the household increases, the use of both cereal and pulse residue as feed increases. This demonstrates clear pressure the livestock has on cereal and pulse residue. Such result was obtained by Jaleta et al. (2013) on maize stover. The result shows the importance of the crop residue as a crucial feed resource in the mixed farming system of Ethiopia highlands.

Crop residue stock from earlier harvests

The stock of crop residue negatively affected the proportion of cereal residue allocated as feed while it positively affected the use of pulse residue as feed. This reflects the preference of the farmers towards using pulse residue as feed compared to cereal residue. Crop residues is the sole in-house feed resource for the livestock. When the production of crop residue increases, the household start to show clear preference towards using pulse residue (which has better feeding value compared to cereal residue) as feed over cereal residue. That means the increase in the biomass availability, by introducing new feed resource like grasses and introducing food-feed varieties which have high grain and crop residue yields, could increase the efficiency of crop residue utilization in the mixed farming system.

Conclusions

Crop residues are an important source of feed and soil mulch in the mixed cropping-livestock systems of Ethiopia highlands. Pulse residue has better nutritive value and palatability as livestock feed compared to cereal residue. Under limited resources in the households, better utilization of crop residue could be achieved by maximizing the use of pulse residue as feed and optimizing the use of cereal residue as soil mulch.

Institutional factors like extension services on mulching and livestock as well as access to information about the importance of crop residue mulching may lead to better utilization of crop residue. Providing extension and training services on the importance of the use of crop residue as mulch may help to improve the awareness among farmers and lead to enhance their use of crop residue as soil mulch. Better utilization could also be promoted by the extension service through bringing out the difference in nutritive value between the cereal and pulse residue.

On-farm trials could play an important role by showing the farmers the superiority of pulse residue over cereal residue as livestock feed. Policy interventions should encourage informal social networks that stimulate group discussion and better information flow to enhance better utilization of crop residue. Special attention of the livestock extension should be given to the sloppy areas to maximize the farmers' utilization of pulse residue as feed.

Increasing the feed availability in the household could by introducing new varieties of cereal and pulse crops with superior food-feed traits and alternative feed resources, such as grasses, at household level could decrease the pressure on the use of crop residue as feed. Generally, interventions introducing conservative agriculture should account for tradeoffs related to alternative and competing uses of crop residue. However, better utilization of crop residue could be achieved by using pulse residue exclusively for livestock feeding and cereal residue exclusively for soil mulching.

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PAPER 2
GENETIC VARIABILITY IN STRAW TRAITS AND FOOD-FEED RELATIONS FOR MULTI-DIMENSIONAL IMPROVEMENT IN CHICKPEA (*CICER ARIETINUM*)

Abstract

This study aimed to determine whether straw traits can be integrated into the multi-trait improvement of chickpea.

Twenty-four improved varieties and one local variety improved varieties released for high grain yield were replicated 4 times in a randomized complete block trial in two locations in Ethiopia. Straw from plots of the local variety was treated with 4% urea on dry matter basis and the change in the nutritive value due to this treatment was used as a baseline to qualify the enhancement of nutritive value as a result of varietal variation. All straw samples were evaluated for proximate analysis, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) using a combination conventional nutritional laboratory analyses and near infrared spectroscopy.

The Effect of the variety, location and variety-location interaction on grain yield, straw yield and straw nutritive value was significant. Urea treatment significantly ($P<0.001$) improved straw content of crude protein (CP), IVOMD and ME, by 49%, 4% and 4% respectively. The exploitable genotypic range was higher than the effect of urea by 13.11 units for CP, 42 units for IVOMD, 0.65 units for ME. The ADF correlated strongly with the other nutritive value parameter regardless of the location ($r> 0.65$). The IVOMD and ME of chickpea straw can be predicted by the chemical composition ($R^2= 0.9$ for IVOMD and 0.904 for ME). The correlation between grain yield and straw traits was weak in all locations ($r< 35$).

There is a possibility to improve grain yield and straw traits of chickpea simultaneously using appropriate breeding programs.

Keywords: chickpea straw, urea treatment, variety, food-feed

Introduction

Chickpea is one of the most important pulses in the world (Bampidisa and Christodoulou, 2011). It accounts for 12% of the world legume grain production. The grain of chickpea is an important source of protein, minerals and vitamins for humans (Bampidisa and Christodoulou, 2011). Growing chickpea improves the fertility of the soil by fixing atmospheric nitrogen, increases the intensity of land use and provides households with cash (Kassie et al., 2009). World production of chickpea grains was 14,239,000 t in 2014 (FAO, 2016).

In addition to grain, chickpea cultivation produces good quality straw compared to cereal straws. Chickpea straw contains on average 65 g/kg DM of crude protein (CP), 694 g/kg DM of neutral detergent fiber (NDF), 516 g/kg DM of acid detergent fiber (ADF), 111g/kg DM of acid detergent lignin (ADL) and 7.7 MJ/kg of metabolizable energy (ME) (Bampidisa and Christodoulou, 2011). Varietal selection to increase the nutritive value of chickpea straw holds promises.

Studies on chickpea have reported wide genetic variation in grain yield, number of secondary branches per plant, number of pods per plant, biomass yield (Malik et al., 2009), plant height (Aslamshad et al., 2009) which could lead to an exploitable genetic variation in straw quality and yield. Furthermore, studies have reported an existence of positive and significant correlation between grain yield and number of secondary branches per plant, plant height, number of pods per plant and biomass yield (Ali and Ahsan, 2012, Malik et al., 2009) which might reveal a positive correlation between grain yield and straw yield and quality. Kafilzadeh and Maleki (2012) reported wide genetic variation in grain yield and straw traits which presents potential for selecting chickpea varieties which combine superior grain and straw traits. Evaluation of the genotypic variation in straw yield and quality parameters helps identifying parental varieties with superior straw traits which could be used in evolving nutritionally superior cultivars (Sharma et al., 2010).

Urea treatment is one of the most effective treatments used to improve the nutritive value of crop residues. The ability of urea treatment to improve the nutritive value of a wide range of cereal straws by increasing crud protein, digestibility and energy has been reported (Van Soest, 2006). Ease of application and abundance of urea in local markets at a cheap price make urea treatment widely adopted in developing countries (Abdel Hameed et al., 2012; Aregawi et al., 2013). Therefore, urea treatment can be used as a baseline to ascertain whether genotypic variability in straw quality can be exploited to attain significant improvement.

When evaluating the feeding value of straw, the most critical parameter is IVOMD as this determines ME and is positively related to CP. The evaluation of IVOMD and ME of large number of straw samples both various *in vitro, in vivo* or *in sacco* methods tend to be both time consuming and expensive, therefore, prediction of IVOMD and ME of chickpea straw using chemical composition offers a convenient alternative. Determining the correlations among the nutritive value parameters could minimize the number of variables which present the nutritive value of chickpea straw. That will decrease the cost and the time spent in screening genotypes for straw quality and facilitate breeding new chickpea genotypes for superior straw quality.

Many studies reported that there is a possibility to exploit the genetic variation in grain yield and straw traits to improve straw traits and to breed varieties which combine superior food and feed traits. That studies included pearl millet (Bidinger et al., 2010, Blümmel et al., 2007), sorghum (Blümmel et al., 2010), and maize (Ertiro et al., 2013). Alemu et al (2016) reported on the genetic variation in straw traits and food-feed relations. However, the study did not study Kabuli and Desi genotypes separately.

No studies evaluated the varietal variation in food and feed traits of lentil and the correlations between grain yield and straw traits. Thus, the aim of this study was to determine whether straw traits can be integrated into the multi-trait improvement of lentil.

Materials and methods

Variety-dependent variation in straw and grain traits

Straw samples were collected from one trial of the National Program of chickpea Improvement in Ethiopia. The trial was carried out at Debre Zeit Agricultural Research Center in two experimental sites: Debre Zeit (8° 44’N; 38° 58′ E; elevation: 1900 m.a.s.l; average annual rainfall 867mm, minimum temperature 8°C, maximum temperature 28°C) and Chefe Donsa (8° 57'N; 39° 06′ E; elevation: 2450 m.a.s.l; average annual rainfall 843mm, minimum temperature 7 °C, maximum temperature 26 °C) during the main rainy season of the 2013 cropping year. The type of the experimental site soil was vertisols in both sites. Both experimental sites were planted with wheat during the previous cropping season.

Twenty-four improved varieties and one local variety (all of them Desi type) were included in the study (Table 9). The trials were replicated 4 times in the field with 4 rows per plot using randomized complete block design. The space between rows was 30 cm while the space between plants was 10 cm. The experimental plot size was 4 m×1.2 m. All plots were hand planted and did not receive fertilization or irrigation.

At the physiological maturity, above ground portions of all plants in each plot were harvested from two 2.4 m^2 areas laid over the two middle rows of each plot. The biomass from all samples were air-dried for two weeks to a constant moisture and then weighed. Grain yield from each plot was recorded after threshing. The difference between biomass yield and grain yield was recorded as straw yield. Sub-samples of representative straw were taken from each plot for feed nutritional analysis.

Urea treatment procedure

The straws of the local variety were bulked after sampling and 2 kg of it were used to test the effect of urea treatment. The straw was chopped to a theoretical cut length of 2 cm and divided into 10 replicates of 100 g weight each. Each replicate was divided into two parts, one of them was kept as control and the other was treated with urea according to Chenost and Kayouli (1997).

Briefly, the straw was treated with a 40 g/l urea solution in the ratio 40 ml of solution to 100 g straw to get final concentration of 4% urea/DM of straw. This mixture was placed in double-walled plastic bag and sealed. The bags were incubated under room temperature for 21 days. At the end of the experiment, bags were open and treated straws were dried by spreading them on the floor for three days. All replicates were ground in a laboratory mill to pass through a 1 mm mesh screen and stored for further analysis.

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, nitrogen content of the sample was determined by Kjeldahl method using Kjeldahl (protein/nitrogen) Model 1026 (Foss Technology Corp.) (AOAC, 2000), method 954.01). Crude protein was calculated by multiplying nitrogen content by 6.25. Neutral detergent fiber, ADF and ADL were determined as described by Van Soest and Robertson (1985). Neutral detergent fiber was not analyzed with a heat stable amylase and 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 (IVOMD) and ME were measured in rumen microbial inoculum using the *in vitro* gas production technique described by Menke & Steingass (1988).

Briefly, approximately 0.2 g of sample was weighed and placed in 100 ml graduated glass syringe. 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 fed on 15 kg of grass hay/head per day and 4 kg of wheat bran/head per day. Rumen fluid was pumped with a manually operated vacuum pump from the rumen into pre-warmed thermos flasks. The rumen fluid was mixed and filtered through four layers of cheesecloth and flushed with CO_2 and the bulked mixture was then mixed with the buffered mineral solution (1:2 v/v). The buffered rumen fluid (30 ml) was pipetted into each syringe and the syringes were immediately placed in a water bath and kept at 39 °C. Gas production was recorded after 24 hours of incubation and used to calculate IVOMD and ME according to Menke & Steingass (1988).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.

Calculations and statistical analysis

Yields of CP (kg/ha) and ME (thousands MJ/ha) were calculated using chemical analysis of the straw and the straw yield. The potential daily dry matter (DM) intake (DMI) of one head of sheep 30 kg live weight was calculated as follows: DMI (g/head per day) = 10×30×120/NDF (% DM), where 30 is the live weigh of sheep in kg, 120/NDF (% DM): potential daily DM intake (% live weight) according to Horrocks and Vallentine (1999). Crude protein and ME contents of straw were multiplied by DMI to get potential CP intake (CPI) and potential ME intake (MEI). Data of each experiment was subjected to analysis of variance according to the following model:

$Y_{ij} = M + G_i + B_j + E_{ij}$.

Where Y_{ij} is the response variable, M is the mean, G_i is the effect of variety i, B_j is the effect of the block j and E_{ij} is the random error. The data of the two sites were combined and analyzed according to the following model:

$Y_{ijk} = M + G_i + L_j + B_k(L_i) + GL_{ij} + E_{ijk}$

Where Y_{ij} is the response variable, M is the mean, G_i is the effect of variety i, L_j is the effect of the location j, B_k(Li) is the effect of the block k within location i, GL_{ij} is the interaction between the variety and the location and E_{ijk} is the random error.

Data of urea treatment experiment was analyzed using one-way analysis of variance to test the effect of urea treatment on the nutritive value of chickpea straw. In both trials, means were separated using the least significant difference method at a 0.05 level of probability.

Stepwise multiple regression analysis was used to identify the best model which describe the relation between IVOMD and ME and the chemical analysis of chickpea straw for each site.

Linear relationships among straw quality traits were investigated to minimize the number of the variables which express the nutritive value of chickpea straw. Likewise, linear relationships between grain and straw traits were calculated using Pearson's correlation. The strength of Pearson correlations was described according to the guide suggested by Evans

(1996). The correlation was considered very weak when r <0.19, weak when 0.2<r< 0.39, moderate when 0.4<r< 0.59, strong when 0.6 <r < 0.79 and very strong when 0.8<r< 1. The correlation analysis were identified for each site.

All statistical procedures were carried out using Statistical Analysis System software (SAS, 2012).

Results

Variation in yields

The effect of the variety, location and the interaction between the variety and the location on grain yield, straw yield of DM, straw yield of CP and the straw yield of ME was significant (P<0.001).

Chefe Donsa site

Table 9 presents means of grain yield, straw yield of DM, straw yield of CP and straw yield of ME in Chefe Donsa location. The grain yield ranged from 2.04 t/ha in the local variety to 4.92 t/ha in DZ2012CK0236. Nine cultivars yield significantly higher grains compared to the local variety.

Straw yield varied from the local variety with a yield of 3.85 t DM/ha to DZ2012CK0235 with a yield of 10.69 t DM/ha. Seven cultivars yielded significantly higher straw DM compared to the local varieties while 4 of them were among the high grain yielders.

The CP yield of straw ranged between 145 kg CP/ha in DZ2012CK0229 to 559 kg CP/ha in DZ2012CK0235. Two varieties yielded significantly higher CP compared to the local variety and none of them were among the high grain yielders.

The straw yield of ME varied from 62.3 thousands MJ ME/ha in the local variety to 81.3 thousands MJ ME/ha in DZ2012CK0235.

Five varieties yield higher ME of straw compared to the local varieties and 3 of them were among the high grain yielders.

Table 9. Means of yields of grain (t/ha), straw (t DM/ha), CP (kg CP/ha), and ME (1000 MJ/ha) of chickpea varieties grown in Chefe Donsa and Debre Zeit

	Chefe Donsa				Debre Zeit			
Variety	Grain	Straw	ME	CP	Grain	Straw	ME	CP
DZ2012CK0048	3.57*	6.98*	51.9	336	3.59*	3.22	22.7	279
DZ2012CK0227	3.1	5.01	37	234	3.75*	4.03*	29.6*	427*
DZ2012CK0228	3.84*	7.61*	56*	305	3.85*	3.79	27.2*	318
DZ2012CK0229	3.25	4.65	35.8	145	3.49*	3.45	24.2	289
DZ2012CK0230	2.57	7.83*	59*	414*	3.63*	3.17	22.5	286
DZ2012CK0231	2.66	6.29	45.7	351	3.98*	4.22*	28.8*	341*
DZ2012CK0232	3.05	6.95*	49.9	264	3.67*	3.83	28.0*	351*
DZ2012CK0233	3.05	6.52	47.5	304	3.37*	4.13*	29.3*	343*
DZ2012CK0234	2.37	4.42	31.9	173	3.21*	3.73	26.9	319
DZ2012CK0235	3.33	10.7*	81.3*	559*	3.07	3.87	28.6*	407*
DZ2012CK0236	4.92*	6.67	47.4	346	3.71*	3.10	20.4	221
DZ2012CK0237	4.21*	8*	56.7*	328	3.63*	3.59	26.0	280
DZ2012CK0238	3.88*	6.53	47.7	353	3.44*	3.36	24.2	306
DZ2012CK0239	4.57*	8.34*	61.6*	406	3.33*	3.20	23.8	305
DZ2012CK0240	3.48	5.33	40.2	256	3.25*	3.69	27.2*	351*
DZ2012CK0241	3.11	5.84	41.9	281	3.11	3.70	26.6	344*
DZ2012CK2011S10041	2.9	5.56	40.9	244	3.41*	3.26	23.3	267
DZ2012CK2011S150057	3.19	5.28	38.6	224	3.32*	3.35	23.1	266
DZ2012CK2011S160058	3	6.3	47.2	333	3.08	3.17	23.3	328
DZ2012CK2011S20042	3.72*	6.4	46.3	319	2.98	3.13	23.4	315
DZ2012CK2011S30043	3.64*	6.07	44.3	352	3.67*	3.55	25.0	277
DZ2012CK2011S50045	3.32	5.76	42	273	3.44*	3.37	23.7	310
Minjar	2.61	6.13	45.5	341	2.84	3.41	25.3	354*
Natoli	3.99*	6.76	48.5	358	3.96*	4.51*	32.0*	366*
Local	2.04	3.85	29.6	234	2.47	3.09	21.7	219
LSD (0.05)	1.5	3.1	23	176	0.684	0.913	6.69	111
SEM	0.511	1.08	8.11	61.9	0.24	0.32	2.35	39
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Means with * are higher than local variety; CP: crude protein, ME: metabolizable energy

Debre Zeit site

Means of grain yield, straw yield of DM, straw yield of CP and straw yield of ME in Debre Zeit location are presented in Table 10. Grain yield ranged from 2.47 t/ha in local variety to

3.98 t/ha in DZ2012CK0231. Nineteen cultivars ranging from 3.21 t/ha in DZ2012CK0234 to 3.98 t/ha in DZ2012CK0231 yielded higher grain than local variety.

Straw yield varied from 3.09 t DM/ha in local variety to 4.51 t DM/ ha in Natoli. From those high grain yielders varieties, 4 varieties ranging from 4.03 t DM/ha in DZ2012CK0227 to 4.51 t DM/ha yielded higher straw DM than local.

Crude protein yield of straw varied from 219 kg CP/ha in local variety to 427 kg CP/ha in DZ2012CK0227. Among the high grain yielders, six varieties ranging from 341 kg CP/ha in DZ2012CK0231 to 427 kg CP/ha in DZ2012CK0227 yielded higher CP of straw compared to local variety.

Straw yield of ME ranged from 20.4 thousand MJ/ha in DZ2012CK0236 to 32 thousand MJ/ha in Natoli. Within the high grain yielders, five varieties ranging from DZ2012CK0235 with a yield of 28.6 thousand MJ/ha to Natoli with value of 32 thousand MJ/ha, yielded higher ME of straw than local variety.

Among all varieties, four varieties combining superior yields of grain, straw DM, straw CP and straw ME yield, yielded higher grain and straw nutrients than local variety.

Variation in straw quality

The effect of the variety, location and the interaction between the variety and the location on the chemical composition, IVOMD and ME was significant (P<001).

Chefe Donsa site

Means of CP, cell wall constituents, IVOMD and ME of chickpea straw in Chefe Donsa are presented in Table 11.

The CP of straw ranged widely from 31.5 g/kg DM in DZ2012CK0229 to 62.3 g/kg DM in the local variety. The improved varieties did not have significantly higher CP compared to the local variety. Ten improved varieties had significantly less CP than that of the local variety while 2 of them were high grain yielders.

The NDF ranged between 644 g/kg DM in the local variety to 732 g/kg DM in Natoli. Nineteen varieties had higher NDF than that of the local variety whereas 9 of them were among the high grain yielders. The NDF (g/kg DM) of the high grain yielders ranged between DZ2012CK0048 (699) and Natoli (732).

Twenty varieties had higher ADF than that of the local variety while 9 of them were high grain yielders. The ADF of the high grain yielders varied from DZ2012CK2011S30043 with a value of 456 g/kg DM to DZ2012CK0237 with a value of 484 g/kg DM.

The ADL of the varieties ranged between the local variety (113 g/kg DM) to DZ2012CK0237 (130 g/kg DM). Eighteen varieties had higher ADL compared to the local variety, however, 9 of them were among the high grain yielders. The ADL of the high grain yielders ranged from DZ2012CK0238 (122 g/kg DM) to DZ2012CK0237 (130 g/kg DM).

The local variety had the highest IVOMD (526 g/kg DM) while DZ2012CK0237 had the lowest IVOMD (481 g/kg DM). Twenty varieties had less IVOMD compared to the local variety. Nine high grain yielders had less IVOMD compared to the local variety ranging between DZ2012CK0237 (481 g/kg DM) to DZ2012CK0048 (506 g/kg DM).

The ME of the varieties ranged from 7.7 MJ/kg DM in DZ2012CK0237 to 7.72 MJ/kg DM in the local variety. Nineteen varieties had higher ME compared to the local variety. Nine high grain yielders had less ME compared to the local variety ranging from DZ2012CK0237 (7.07 MJ g/kg DM) to DZ2012CK0048 (7.38 MJ/kg DM).

Debre Zeit site

Table 10 presents CP, cell wall constituents, IVOMD and ME of chickpea straw in Debre Zeit.

Crude protein in chickpea straw widely varied from 70.5 g/kg DM in local variety to 111 g/kg DM in DZ2012CK2011S16005. Five grain yielders hosted higher CP than local variety ranging from 91.9 g/kg DM in DZ2012CK2011S50045 to 106 g/kg DM in DZ2012CK0227.

Neutral detergent fiber (g/kg DM) and ADF (g/kg DM) ranged from (642 and 360) in DZ2012CK2011S16005 to (754 and 466) in DZ2012CK0236. Among the higher grain yielders, none of the varieties had less NDF or ADF than local verity. Acid detergent lignin of chickpea straw varied from 82.9 g/kg DM in DZ2012CK2011S16005 to 112 g/kg DM in DZ2012CK0236 considering all varieties while that ranged started by 83.5 g/kg DM in DZ2012CK0240 to DZ2012CK0236 considering high grain yielders only. Among high grain yielders, only three varieties hosted less ADL than that of local variety.

Chickpea straw IVOMD and ME had similar behavior. For all varieties in the trial, IVOMD (g/kg) and ME (MJ/kg) ranged from 484 and7.08 in Z2012CK0236 to 553 and 8.13 in DZ2012CK2011S16005. Chickpea straw IVOMD (g/kg) and ME (MJ/kg DM) of the high grain yielders ranging from 484 g and 7.08 in DZ2012CK0236 to 546 and 8.03 in DZ2012CK0239, was similar to that of local variety. Urea treatment significantly (P<0.001) improved straw content of CP by 49%, IVOMD by 4% ME by 4% (Table 12). Urea treatment decreased significantly NDF, ADF and ADL by 3%, 4% and 4% respectively. The exploitable genotypic range was higher than the effect of urea by 13.11 units for CP, 42 units for IVOMD, 0.65 units for ME.

Table 10 Effect of variety on the chemical composition, IVOMD and ME of chickpea straw grown in Chefe Donsa site.

Variety	CP	NDF	ADF	ADL	IVOMD	ME
DZ2012CK0048	48.7	699*	460*	123*	506†	7.38†
DZ2012CK0227	47†	692*	461*	124*	501†	7.37†
DZ2012CK0228	41.1†	713*	473*	122*	502†	7.35†
DZ2012CK0229	31.5†	697*	475	117	514	7.62
DZ2012CK0230	51.6	666	451	119	511	7.52
DZ2012CK0231	55.8	707*	473*	124*	496†	7.29†
DZ2012CK0232	37.2†	723*	489*	123*	492†	7.29†
DZ2012CK0233	44†	729*	478*	128*	496†	7.24†
DZ2012CK0234	38.5†	724*	484*	126*	493†	7.24†
DZ2012CK0235	50.4	660	439	116	513	7.58
DZ2012CK0236	51.9	718*	477*	125*	484†	7.1†
DZ2012CK0237	41.3†	729*	484*	130*	481†	7.07†
DZ2012CK0238	52.9	722*	462*	122*	496†	7.27†
DZ2012CK0239	48.2	706*	460	119	502†	7.36†
DZ2012CK0240	50.8	670	444	114	515	7.58
DZ2012CK0241	47†	709*	461	122*	489†	7.17†
DZ2012CK2011S10041	44.7†	703*	469*	124*	502†	7.38†
DZ2012CK2011S150057	41.6†	712*	473*	125*	498†	7.33†
DZ2012CK2011S160058	53.1	665	447	118	508†	7.5
DZ2012CK2011S20042	49.7	717*	478*	125*	492†	7.23†
DZ2012CK2011S30043	57.6	699*	456*	124*	498†	7.29†
DZ2012CK2011S50045	47.9	712*	465*	125*	496†	7.3†
Minjar	52.6	732	469*	124*	489†	7.17†
Natoli	57.3	686*	462*	122*	502†	7.39†
Local	62.3	644	429	113	526	7.72
LSD (0.05)	15	44	25	7	17	0.27
SEM	5.29	15.6	9.09	2.54	6.16	0.097
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*: > the local variety; †: <the local variety; CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM), ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM). IVOMD: *in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM)

Table 11. Effect of variety on the chemical composition, IVOMD and ME of chickpea straw grown in Debre Zeit site

Variety	CP	NDF	ADF	ADL	IVOMD	ME
DZ2012CK0048	86.8	677	401	89.5	522	7.63
DZ2012CK0227	106*	642	360†	86.5†	542	7.97
DZ2012CK0228	83.9	673	397	90.1	527	7.76
DZ2012CK0229	84.0	689	416	91.3	515	7.59
DZ2012CK0230	89.9	652	388	89.2	526	7.70
DZ2012CK0231	80.6	710	435	96.8	503	7.37
DZ2012CK0232	92.3*	652	385†	86.7	540	7.93
DZ2012CK0233	83.0	674	405	92.0	523	7.66
DZ2012CK0234	85.7	675	404	90.4	530	7.79
DZ2012CK0235	105*	667	375†	87.8	543	7.97
DZ2012CK0236	71.2	754	466	112	484	7.08
DZ2012CK0237	77.0	667	403	92.2	529	7.84
DZ2012CK0238	90.0	678	401	89.5	530	7.74
DZ2012CK0239	95.6*	651	371	83.9†	546	8.03
DZ2012CK0240	94.2*	649	368†	83.5†	545	7.98
DZ2012CK0241	91.5*	669	401	87.8	527	7.76
DZ2012CK2011S10041	81.4	686	414	95.0	524	7.71
DZ2012CK2011S150057	79.5	697	428	96.8	510	7.46
DZ2012CK2011S160058	111*	632†	360†	82.9†	553*	8.13*
DZ2012CK2011S20042	100*	634†	368†	83.5†	552*	8.13*
DZ2012CK2011S30043	78.0	712	422	101	514	7.55
DZ2012CK2011S50045	91.9*	667	397	92.1	520	7.60
Minjar	103*	644	371†	84.4†	545	7.99
Natoli	81.1	700	416	93.8	522	7.64
Local	70.5	699	438	98.5	515	7.59
LSD (0.05)	19.6	61.4	51.6	11.8	32.4	0.5
SEM	6.9	21.6	18.1	4.15	11.4	0.176
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*: > the local variety; †: <the local variety; CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM), ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM). IVOMD: *in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM)

Table 12. Effect of urea treatment on chemical composition and nutritive value of chickpea straw

Item	Control	Treatment	Δ	SEM	P value
CP	55.9	83.3	27.4	1.9	<0.001
NDF	714	696	-18	5.4	<0.001
ADF	461	444	-17	6.7	<0.001
ADL	114	110	-4	1.5	<0.001
IVOMD	498	518	20	5.66	<0.001
ME	7.33	7.63	0.3	0.11	<0.001

Δ: Change due to urea treatment; CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM), ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM). IVOMD: *in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM)

Relationships among nutritive value parameters

The stepwise regression analysis showed that IVOMD and ME of chickpea straw could be predicted from cell wall constituents (Table 13). In Chefe Donsa site, the ADF and ADL content of chickpea straw can be used to predict IVOMD (R^2= 0.843) while ME can be predicted using NDF and ADF (R^2= 0.864). In Debre Zeit site, IVOMD of chickpea straw can be predicted from ADF and ADL (R^2= 0.91) while ME can be predicted from NDF and ADF (R^2= 0.989). When the data of the two sites was combined and analyzed, IVOMD could be predicted using NDF and ADF (R^2= 0.91) while ME could be predicted using NDF, ADF and ADL (R^2= 0.91). The correlations among nutritive value parameters in chickpea straw proved significant (Table 14). It had been noticed that ADF correlated very strongly with other quality traits of chickpea straw (pooled r= 0.76 and 0.85 in Chefe Donsa and Debre Zeit site respectively).

Correlations between food and feed traits

Table 15 depicts the relation between grain yield and straw yield and nutritional quality traits.

Chefe Donsa site

The correlation between the grain yield and CP yield was insignificant (P>0.05). The grain yield correlated significantly but weakly with straw yields of DM and ME (r<0.4). The correlation between grain yield and CP and ADF of straw was insignificant. The grain yield correlated significantly but weakly to NDF, ADL, IVOMD and ME of straw (r< 0.4).

Debre Zeit site

Grain yield correlated weakly, positively and significantly with straw DM yield (r= 0.367; P= 0.002), CP yield (r= 0.298; P= 0.014) and ME yield (r= 0.362; P= 0.049). No relation was found between grain yield and nutritive value traits of straw (P>0.05 for CP, NDF, ADF, ADL, IVOMD and ME).

Table 13. Summary of stepwise regression analysis of the effect of chemical composition (g/kg DM) on IVOMD (g/kg) and ME (MJ/kg) of chickpea straw in tow locations

Location	Dependent variable	Step	Independent variables		Partial R^2	Model R^2	P value
			Entered	Removed			
Chefe Donsa	IVOMD	1	ADL		0.81	0.81	<0.001
		2	NDF		0.033	0.843	<0.001
	ME	1	ADL		0.82	0.82	<0.001
		2	NDF		0.044	0.864	<0.001
Debre Zeit	IVOMD	1	ADF		0.91	0.91	<0.001
		2	ADL		0.007	0.917	<0.001
	ME	1	ADF		0.886	0.886	<0.001
		2	NDF		0.011	0.898	0.005
		3	ADL		0.004	0.902	0.06
		4	ADL	ADL	0.004	0.898	0.07
Combined data	IVOMD	1	ADF		0.86	0.86	<0.001
		2	NDF		0.04	0.9	<0.001
	ME	1	ADF		0.823	0.823	<0.001
		2	NDF		0.077	0.9	<0.001
		3	ADL		0.004	0.904	<0.001

Chefe Donsa location:
IVOMD = 774 -0.15*NDF – 1.39*ADL; ME= 11.7 – 0.003*NDF – 0.02*ADL
Debre Zeit location:
IVOMD = 764 – 0.48*ADF – 0.49*ADL; ME = 12 -0.003*NDF – 0.006*ADF
Combined data:
IVOMD= 804 – 0.21*NDF -0.33*ADF; ME= 12.1 – 0.004*NDF – 0.003*ADF -0.003*ADL
CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM), ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM). IVOMD: *in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM)

Table 14 Pairwise correlations among nutritive value parameters of chickpea straw

Location		NDF	ADF	ADL	IVOMD	ME
	CP	-0.286	-0.649	-0.265	0.272	ns
	NDF		0.821	0.859	-0.867	-0.884
Chefe Donsa	ADF			0.789	-0.80	-0.748
	ADL				-0.899	-0.903
	IVOMD					0.984
	CP	-0.645	-0.866	-0.637	0.679	0.631
	NDF		0.841	0.779	-0.823	-0.834
Debre Zeit	ADF			0.843	-0.833	-0.812
	ADL				-0.819	-0.821
	IVOMD					0.99

CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM), ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM). IVOMD: *in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM); ns: not significant at 0.05 otherwise significant at 0.05

Table 15. Pearson's correlations between the grain yield and straw yield and quality traits in chickpea

	Location	
Straw Yields	Debre Zeit	Chefe Donsa
DM	0.367	0.317
CP	0.298	ns
ME	0.362	0.281
Straw quality		
CP	ns	ns
NDF	ns	0.276
ADF	ns	0.247
ADL	ns	ns
IVOMD	ns	-0.35
ME	ns	-0.333

CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM), ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM). IVOMD: *in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM); ns: not significant at 0.05 otherwise significant at 0.05

Discussion

The results of the current study showed that the varietal variation in grain yield and straw traits depended on the location. These results agree with Ertiro et al. (2013) who reported a significant genetic-location interaction. That means identifying the parental varieties which would be used later in improvement programs of chickpea should be based on the location.

Ertiro et al. (2013) reported a significant interaction between variety and location in maze. The varietal variation in straw traits found within the high grain yielding varieties present a high potential to select varieties with superior grain yield and straw traits. Such variation was reported in straw traits of pearl millet (Blümmel et al., 2010).

Urea treatment improved manly CP content of chickpea straw (by 49%) but the change in cell wall constituents, IVOMD and ME was marginal (<4%). Urea treatment could not break down lingo-cellulose and thus increase IVOMD and ME. (Van Soest, 2006) reported that the improvement in the nutritive value of crop residue by urea treatment is due to the increase in CP but not by breaking down lignocellulose bonds. The varietal range in CP and ME in Debre Zeit location (41 g/kg DM CP and 1.05 MJ/kg DM ME) was higher than that of Chefe Donsa (30.8 g/kg DM CP and 0.65 g/kg DM ME). This range is considerably higher than the increase caused by urea treatment. That means the varietal selection for straw quality traits can be an interesting option to improve the nutritive value of chickpea straw in the mixed farming systems.

In Debre Ziet, Natoli with the highest straw yield of DM and ME, out yielding the local variety by 1.42 t DM/ha and 10.3 thousand MJ ME/ha is recommended as a parental variety for any further efforts to improve the yield of straw from DM and ME. DZ2012CK0227 which is superior to local variety by 208 kg CP/ha is recommended for any improvement of straw yield of CP. In Chefe Donsa, DZ2012CK0235, out yielding the local variety by 6.85 t/h straw DM, 325 kg CP, and 51.7 thousands ME/ha is recommended for improving the overall yield of chickpea. Kearl (1982) reported that a sheep 30 kg live weight needs daily 750 g of DM, 59 g of CP and 4.95 MJ of ME for maintenance purpose. Accordingly, in Debre Zeit, DZ2012CK2011S16005, with the best straw in terms nutritive value parameters, covers 76%, 110% and 100% of maintenance requirement of a sheep 30 kg live weight from DM, CP and ME.

In Chefe Donsa, the local variety, having the best nutritive value, covers 74%, 54% and 87% of maintenance requirement of a sheep 30 kg live weight from DM, CP and ME. In Debre Ziet, DZ2012CK0227 respectively meeting 75 %, 100% and 91% of DM, CP and ME maintenance requirement of 30 kg live weight sheep and having high grain and straw yields can be nominated as a dual purpose variety. In Chefe Donsa, DZ2012CK0239 respectively meeting 68%, 49% and 75% of maintenance requirement of a sheep 30 kg live weight from DM, CP and ME can be nominated as a dual purpose variety.

Improving nutritive value of chickpea straw through varietal selection requires phenotyping large number of varieties for IVOMD and ME. The results of the stepwise regression analysis indicate that cell wall constituents of chickpea straw can be used accurately to predict IVOMD and ME. These prediction equations provide a convenient substitute to *in vitro*, *in vivo* or *in sacco* methods minimizing the cost and the time.

The current study shows that ADF of chickpea straw is correlated negatively and strongly to the other nutritive value parameters in both locations. Moreover, it can explain in average more than 70% of the variability in other quality parameters of chickpea straw. That means the lower the ADF, the higher the nutritive value of chickpea straw. Thus, ADF seems to be useful for ranking chickpea varieties for straw quality. Furthermore, chickpea breeders can use ADF as sole criteria to breed varieties with superior straw quality traits.

Grain yield is a major criteria targeted in chickpea improving program. Thus, it is imperative that efforts to increase the yield and nutritive value of chickpea straw do not depress grain yield. This study showed that the correlation between straw and grain yield was weak regardless of the location. This implies that varietal selection to improve the straw yield will not lead to a decrease in grain yield and vice versa.

Similarly, weak correlation between the grain yield and straw traits was reported for maize (Ertiro et al., 2013) and sorghum (Blümmel et al., 2010). Moreover, straw yield of DM cannot be predicted from grain yield and therefore straw yield of DM is required to be recorded alongside with grain yield when straw yield of DM is intended to be used as one of variety release criteria.

Correlations between CP, NDF, ADF, ADL and ME content of chickpea straw and grain yield were insignificant in Debre Zeit and weak in Chefe Donsa. That means no decline in grain yield is expected as a result of any increase in CP and ME content of chickpea straw nor a decrease in NDF, ADF or ADL. 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.

Furthermore, the recommended varieties as a parents for further improvement program of chickpea should be evaluated for other critical agronomy traits such as disease resistance and drought tolerance.

Conclusions

Wide varietal range was found in grain yield and straw yield and nutritive value. A selection of varieties superior in grain yield and straw traits in addition to the food-feed varieties of chickpea should be done on location basis.

The ADF of chickpea can be used as rank varieties for nutritive value. Weak correlations between grain yield and straw traits were found. Accordingly, improving straw traits of chickpea straw will not be associated with a decline in the grain yield.

The current study focused on early maturing varieties of Desi chickpea. Therefore, other studies have to address food-feed correlations in early and late maturing Kabuli genotypes in different locations. Currently, improvement programs of chickpea do not pay attention to straw traits, neither are straw traits considered in release criteria of new varieties.

Food-feed varieties of chickpea would not only contribute to soil health through providing additional biomass for soil mulching, but also address the increasing demand for food and feed, particularly in mixed crop-livestock farming systems. Therefore livestock nutritionists need to work with chickpea breeders to select varieties which have superior food and feed traits.

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PAPER 3

VARIATION IN THE STRAW TRAITS OF MORPHOLOGICAL FRACTIONS OF FABA BEAN (*VICIA FABA L.*) AND IMPLICATIONS FOR SELECTING FOR FOOD-FEED VARIETIES

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 from the local variety plots were combined and used to test the effect of 4% urea treatment on the nutritive value. 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. Urea treatment improved significantly CP, IVOMD and ME of faba bean straw by 53%, 6% and 8% respectively.

These findings indicate the possibility of selecting faba bean varieties which combine superior grain and straw traits. They also pinpoint the possibility of improving the nutritive value of faba bean straw by 4% urea treatment.

Keywords: faba bean straw, nutritive value, food-feed traits

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 smallholders (Ruiz, 1995). 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, about 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 DM 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.

Materials and methods

Plant material

Four improved varieties, namely Degaga, Mosisa, Shallo, Walki and one local variety were obtained from Sinana Agricultural Research Center, Oromia, Ethiopia (Table 16). 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 16. 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.

Table 16. 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

Urea treatment

The straws of the local variety were bulked after sampling and 2 kg of it was used to test the effect of urea treatment. The straw was chopped to a theoretical cut length of two cm and divided into ten replicates of 100 g weight each. Each replicate was divided into two parts, one of them was kept as control and the other was treated with urea according to Chenost and Kayouli (1997).

The straw was treated with a 40 g/L urea solution in the ratio 40 ml of solution to 100 g straw to reach a final concentration of 4% urea. This mixture was placed in a double-walled plastic bag and sealed. The bags were incubated at room temperature for 21 days. At the end of the treatment, the bags were open and dried by spreading them on the floor for three days. All replicates were ground in a laboratory mill to pass through a one mm mesh screen and stored for further analysis.

Straw quality analysis

Straw samples were ground to pass through a 1-mm sieve and analyzed for 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, CP were analyzed according to AOAC (2000). 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 hours 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.

Calculations and statistical analysis

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:

$$PUI = \frac{GY + 0.01 \times IVOMD \times SY}{GY + SY}$$

Where PUI: potential utility index (w/w), GY is grain yield (t/ha), IVOMD is expressed as % and SY is straw yield (t/ha).

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.

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):

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

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 isthe standard deviation.

Results

Grain yield, straw yield and potential utility index

Variety had a significant (P<0.001) effect on grain and straw yields (Table 17). 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 17. 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

Straw fractions

The effect of variety on proportion of straw fractions was significant (*P*<0.001; Table 18). Straw mainly consisted of stems and pods. The proportion of leaf to whole straw was less than 0.1. 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.

Straw quality

Table 18 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.

Effect of variety

Crude protein content of the local variety was not significantly different from improved varieties. Neutral detergent fiber ranged from 488 g/kg DM in Walki to 518 g/kg DM in Degaga. Acid detergent fiber ranged from 465 g/kg DM in Shallo to 473 g/kg DM in the local variety. Acid detergent lignin content of varieties ranged from 93.1 g/kg DM 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 DM in Shallo to 7.82 MJ/kg DM in Degaga. Metabolizable energy content of local variety was similar to that of Degaga but higher than that of other varieties.

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 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.

Leaf

Crude protein ranged from 120 g/kg DM in the local variety to 140 g/kg DM 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 DM in Walki to 388 g/kg DM 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 DM in Walki to 357 g/kg DM in local variety. All improve varieties had less ADF compared to the local variety. Acid detergent lignin content ranged from 68.1 g/kg DM in Walki to 79.2 g/kg DM 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 DM 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.

Pod

Crude protein content ranged from 76.3 g/kg DM in Walki to 89 g/kg DM in local variety. Crude protein content of local variety was higher than that of improved varieties. Neutral detergent fiber ranged from 417 g/kg DM in local variety to 444 g/kg DM in Degaga. Acid detergent fiber ranged from 370 g/kg DM in the local variety to 392 g/kg DM 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 DM in Shallo to 80.1 g/kg DM 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 DM in Degaga to 9.53 MJ/kg DM 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.

Stem

Crude protein and NDF were similar among varieties. Acid detergent fiber ranged from 671 g/kg DM in Mosisa to 693 g/kg DM 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 DM in Degaga, Mosisa and Shallo to 139 g/kg DM 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 DM in local variety to 5.88 MJ/kg DM 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.

Whole straw

Table 19 presents the effect of variety on the nutritive value of faba bean whole straw. Whole straw of all varieties had similar content of CP, NDF, ADF and ADL. *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 but lesser than Shallo. Metabolizable energy ranged from 6.31 g/kg DM in local variety to 6.69 MJ/kg DM 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. Urea treatment (Table 20) increased significantly CP of faba bean straw by 53%. Urea treatment decreased significantly NDF, ADF and ADL by 3%, 8% and 4% respectively. Urea treatment improved IVOMD and ME of faba bean straw by 6% and 8% respectively.

Table 18. Least square means of chemical composition and nutritive value of variety-botanical fraction interaction of faba bean straw

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

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

Table 19. 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
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

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); Means within a column with different superscripts differ (P< 0.05)

Table 20. Effect of urea treatment on chemical composition and nutritive value of faba bean straw

	Control	Treatment	Δ	SEM	P value
CP	53.7	82.2	28.5	1.5	<0.001
NDF	671	652	-19	3.21	<0.001
ADF	619	567	-52	4.23	<0.001
ADL	126	121	-5	1.21	<0.001
IVOMD	418	441	23	5.54	<0.001
ME (MJ/kg)	6.31	6.83	0.52	0.083	<0.001

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)

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 21 and 22 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) (figure 1). There was a weak association (r= 0.164, R^2 =0.027, P= 0.050) between grain yield and ME of the straw (figure 1). 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) (Figure 2).

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 23).

An examination of the eigenvectors showed that PC1 best explained the nutritive value of straw. Crude proteinand 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 contribute 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 (0.01)> the local variety (-0.71)> Shallo (-1.6)> Walki (-3.2) >Mosisa (-14.5).

Table 21. 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 (P)	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 22. 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(P)	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

Table 23. Principle component analysis of the chemical composition and nutritive value of the whole straw of faba bean

	PC1*	PC2
Eigenvalues	3.88	0.695
Variance (%)	77.8	139
Eigenvectors		
CP	0.445	0.123
NDF	-0.496	0.002
ADL	-0.481	0.326
ME	0.449	-0.427

* PC: principle component; 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)

Fig.1. Relationship between grain and straw traits

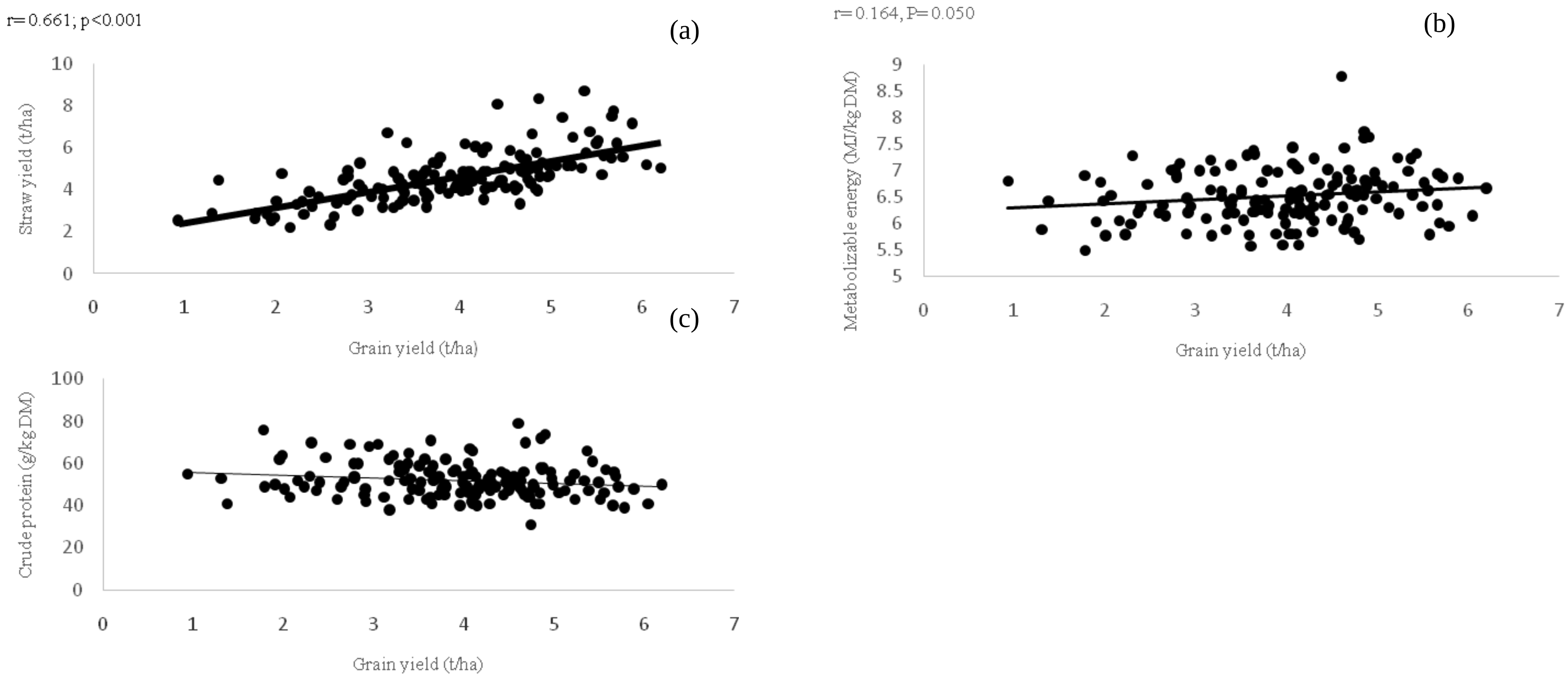
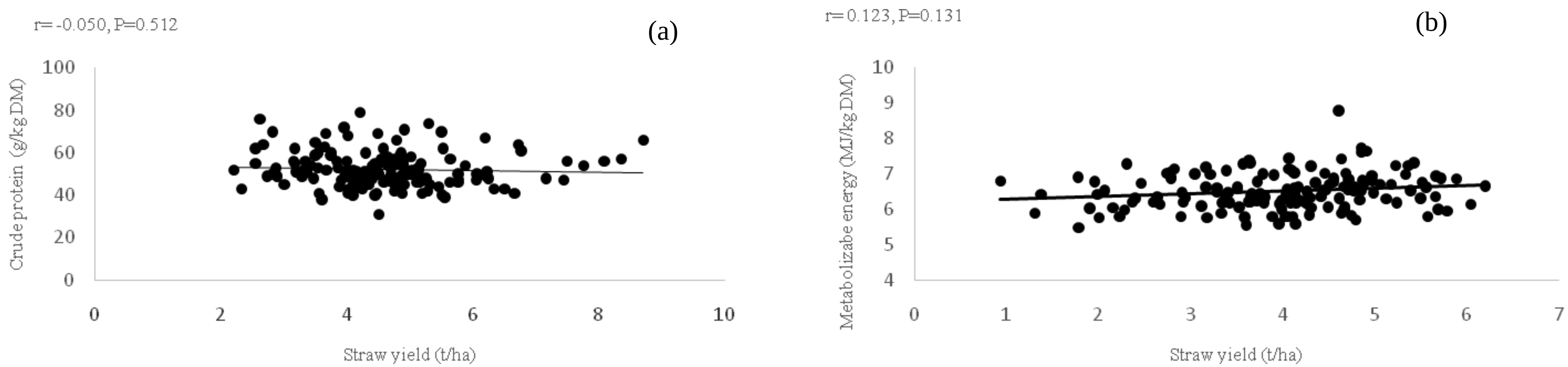


Fig.2. Correlation between straw yield and the crude protein and metabolizable content of straw



Discussion

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 (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.

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 & 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 (2008) on durum wheat which demonstrated that the straw of the local varieties contains a higher proportion of leaves than the improved varieties.

Straw quality

The effect of variety, botanical fractions and the interaction between the variety and the botanical fraction were highly significant. 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 (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.

The improvement in the nutritive value of faba bean straw by urea treatment was mainly by improving CP content by 53% whereas the effect of urea treatment on cell wall constituents, IVOMD and ME was small (<9%). These results agrees with Van Soest (2006) who reported that urea treatment improves the nutritive value of crop residue by increasing CP but not the digestibility.

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.

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 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.

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 Etrtiro 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.

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. Botanical structure of fab bean straw can be used reliably to express the nutritive value. The study also indicate to a possibility of improving the nutritive value of faba bean straw by 4% urea treatment. More genotypes of faba bean has to be evaluated for food and feed traits in different environments. Straw was evaluated for nutritive value using *in vitro* methods, however, that evaluation has to be confirmed *in vivo* studies.

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PAPER 4

INTEGRATING THE STRAW YIELD AND QUALITY INTO MULTI-DIMENSIONAL IMPROVEMENT OF LENTIL (*LENS CULINARIS*)

Abstract

Lentil straw is an important source of fodder for livestock in Africa, South Asia and the Middle East. However, improvement programs of lentil do not pay attention to straw traits, neither are straw traits considered in release criteria of new varieties. This study aimed to determine whether straw traits can be integrated into the multi-trait improvement of lentil.

Twenty-four varieties and one local variety were replicated 4 times in randomized complete block trial in Debre Zeit research center-Ethiopia in two experimental sites during the 2013-2014 cropping season. Combined straws from local variety plots in the trial were used to test the effect of 4% urea treatment across 21 days. All straw samples were analyzed for their proximate analysis, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) using a combination of conventional nutritional laboratory analyses and near infrared spectroscopy.

The effect of the variety, location and the interaction between the variety and location on grain yield, straw yield and the straw nutritive value was significant ($P<0.001$). Urea treatment significantly ($P<0.01$) improved lentil straw nutritive value, The average varietal range in crude protein (CP), IVOMD and ME for both locations were higher than the increase caused by urea treatment by 25.8 units, 53 units and 0.59 units respectively. The profile of the correlations among the nutritive value parameters of lentil straw was not consistent among locations. The predictability of IVOMD and ME of lentil by the chemical composition depended on the location. The relation between grain yield and straw traits was different across locations.

There is a possibility to improve grain yield and straw traits of lentil simultaneously using appropriate breeding programs.

Keywords: genetic variation, lentil, residue, grain

Introduction

Lentil straw is an important source of fodder for livestock in Africa, South Asia and the Middle East (Brennan et al., 2002). Lentil straw has been reported to have better degradation in the rumen as compared to cereal straws (López et al., 2005, Singh et al., 2011).

High acceptability and digestibility of lentil straw in the ration of livestock was reported by Abbeddou et al. (2011). Heuzé et al. (2015) reported that CP content of lentil straw ranged between 58 -111g/kg DM and metabolizable energy (ME) ranged between 6.7 and 8.3 MJ/kg DM. Heuzé et al. (2015) reported that the dry matter intake of sheep from lentil straw was 46.6 g/kg of metabolic weight. Although the better quality of lentil straw compared to cereal straw is documented, there is still need to improve its yield and nutritive value to allow for its use as a sole livestock feed. Several studies have reported on considerable variability in the leaf to stem ratio, plant height, the number of pods per plant and the number of branches per plant of lentil (Al-abdalla and al-nabelssi, 2014, Chakraborty and Haque, 2000, Tullu et al., 2001). This variation could result in a considerable exploitable genotypic variability in straw yield and quality. Genetic variability in the nutritive value of lentil straw has been reported (Erskine et al., 1990).

Evaluation of the genotypic variation in straw yield and quality parameters helps to identify parental genotypes with superior straw traits which could be used in developing nutritionally superior cultivars (Davila et al., 1998). Urea treatment is one of the effective treatments used to improve the nutritive value of crop residues. The ability of urea treatment to improve the nutritive value of a wide range of cereal straws by increasing crude protein, digestibility and energy has been reported (Van Soest, 2006). Ease of application and abundance of urea in local markets at a cheap price makes urea treatment more practical than other treatments (Abdel Hameed et al., 2012). Therefore, urea treatment can be used as a baseline to ascertain whether genotypic variability in straw quality can be exploited to attain significant improvement. When evaluating the feeding value of straw, the most critical parameter is IVOMD as this determines ME and is positively related to CP.

The evaluation of IVOMD and ME of a large number of straw samples using various *in vitro*, *in vivo* or *in sacco* methods tend to be time-consuming and expensive, therefore, prediction of IVOMD and ME of lentil straw using chemical composition offers a convenient alternative.

Determining the correlations among the nutritive value parameters could minimize the number of variables which present the nutritive value of lentil straw. That would decrease the cost and the time spent in screening genotypes for straw quality and facilitate breeding new lentil genotypes for superior straw quality.

Grain yield is a major criterion targeted in any lentil improving program. Thus, it is imperative that efforts to increase the yield and nutritive value of lentil straw do not depress grain yield. Accordingly, determining the relationship between straw and grain yield is essential.

Many studies reported that there is a possibility to exploit the genetic variation in grain yield and straw traits to improve straw traits and to breed varieties which combine superior food and feed traits. That studies included pearl millet (Bidinger et al., 2010, Blümmel et al., 2007), sorghum (Blümmel et al., 2010), and maize (Ertiro et al., 2013). Mersha et al. (2016) reported on food-feed relations in lentil. However, the study ignored the effect of location on food-feed correlation profile.

No/few studies evaluated the varietal variation in food and feed traits of lentil and the correlations between grain yield and straw traits. Thus, the aim of this study was to determine whether straw traits can be integrated into the multi-trait improvement of lentil.

Materials and methods

Genotype-dependent variation in straw and grain traits

Straw samples were collected from trials of the National Program of Lentil Improvement in Ethiopia. The trial was carried out at Debre Zeit Agricultural Research Center, Chefe Donsa experimental site (8° 57'N; 39° 06′ E; elevation: 2450 m.a.s.l; average annual rainfall 843 mm, minimum temperature 7 °C, maximum temperature 26 °C) and in Debre Zeit experimental site (8° 44'N; 38° 58′ E; elevation: 1900 m.a.s.l; average annual rainfall 867 mm, minimum temperature 8°C, maximum temperature 28°C) during the main rainy season of the 2013 cropping year. The soil of the experimental site was vertisols. The experimental site was planted with wheat during the previous cropping season.

Twenty-four late maturing varieties bred for early high grain yield and one local variety were included in the study (Table 24). The trial was replicated 4 times in the field with 4 rows per plot using randomized complete block design. The space between rows was 20 cm while the space between plants was 2 cm. The experimental plot size was 4 m×0.8 m. All plots were hand planted and did not receive fertilization or irrigation.

At the physiological maturity, above ground portions of all plants in each plot were harvested from two 1.6 m^2 areas laid over the two middle rows of each plot. The biomass from all samples was air-dried for two weeks to a constant moisture and then weighed. Grain yield from each plot was recorded after threshing. The difference between the biomass yield and the grain yield was recorded as straw yield. Sub-samples of representative straw were taken from each plot for feed nutritional analysis.

Urea treatment

The straws of the local variety were bulked after sampling and 2 kg of it was used to test the effect of urea treatment. The straw was chopped to a theoretical cut length of two cm and divided into ten replicates of 100 g weight each. Each replicate was divided into two parts, one of them was kept as control and the other was treated with urea according to Chenost and Kayouli (1997). The straw was treated with a 40 g/L urea solution in the ratio 40 ml of solution to 100 g straw to reach a final concentration of 4% urea. This mixture was placed in a double-walled plastic bag and sealed. The bags were incubated at room temperature for 21 days. At the end of the treatment, the bags were open and dried by spreading them on the floor for three days. All replicates were ground in a laboratory mill to pass through a one mm mesh screen and stored for further analysis.

Straw quality analysis

Straw samples were ground to pass through a 1-mm sieve and analyzed for 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, nitrogen content of the sample was determined by Kjeldahl method using Kjeldahl (protein/nitrogen) Model 1026 (Foss Technology Corp). The nitrogen content of the sample was determined by the Kjeldahl method using Kjeldahl (protein/nitrogen) Model 1026 (Foss Technology Corp.) (AOAC (2000), method 954.01). Crude protein was calculated by multiplying nitrogen content by 6.25. Neutral detergent fiber, ADF and ADL were determined as described by Van Soest and Robertson (1985). Neutral detergent fiber was not analyzed with a heat stable amylase and was expressed exclusive of residual ash. The acid detergent fiber was expressed exclusive of residual ash. Lignin was determined by solubilization of cellulose with a sulphuric acid. *In vitro* organic matter digestibility (IVOMD) and ME were measured in rumen microbial inoculum using the *in vitro* gas production technique described by Menke & Steingass (1988). Approximately, 0.2 g of sample was weighed and placed in 100 mL graduated glass syringe. 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 fed on 15 kg of grass hay/head per day and 4 kg of wheat bran/head per day. Rumen fluid was pumped with a manually operated vacuum pump from the rumen into pre-warmed thermos flasks. The rumen fluid was mixed and filtered through four layers of cheesecloth and flushed with CO_2 and the bulked mixture was then mixed with the buffered mineral solution (1:2 v/v). The buffered rumen fluid (30 mL) was pipetted into each syringe and the syringes were immediately placed in a water bath and kept at 39 °C. Gas production was recorded after 24 hours of incubation and used to calculate IVOMD and ME according to Menke and Steingass (1988).

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.

Calculations and statistical analysis

Yields of CP (kg/ha) and ME (thousands MJ/ha) were calculated using chemical analysis of the straw and the straw yield. The potential daily dry matter intake (DMI) of one head of sheep 30 kg live weight was calculated as follows: DMI (g/head per day) = 10×30×120/NDF (% DM), where 30 is the live weight of sheep in kg, 120/NDF (%DM): potential daily DM intake (% live weight) according to Horrocks and Vallentine (1999). Crude protein and ME contents of straw were multiplied by the dry matter intake to get potential CP intake and potential ME intake. Data of Chefe Donsa and Debre Zeit locations was separately subjected to analysis of variance according to the following model:

$Y_{ij} = M + G_i + B_j + E_{ij}$.

Where Y_{ij} is the response variable, M is the mean, G_i is the effect of lentil genotype $_i$, B_j is the effect of the block $_j$ and E_{ij} is the random error. Means of genotypes were compared to the mean of the local variety using least significant difference method.

The data of the two locations was combined and subjected to the analysis of variance according to the following model:

$Y_{ij} = M + G_i + L_j + B_k(L_i) + GL_{ij} + E_{ijk}$.

Where Y_{ij} is the response variable, M is the mean, G_i is the effect of lentil genotype $_i$, L_j is the effect of the location $_j$, $B_k(L_i)$ is the effect of the block k within k location i, GL_{ij} is the interaction between the variety and the location and E_{ijk} is the random error.

Data of urea treatment trial was analyzed using one-way analysis of variance to test the effect of urea treatment on the nutritive value of lentil straw.

Stepwise multiple regression analysis was used to identify the best model which describe the relation between IVOMD and ME and the chemical composition of lentil straw in each location.

Linear relationships among straw quality trait were investigated to reduce the number of the variables which express the nutritive value of lentil straw. Likewise, linear relationships between grain and straw traits were calculated using Pearson's correlation. The strength of Pearson correlations was described according to the guide suggested by Evans (1996). The correlation was considered very weak when $r < 0.19$, weak when $0.2 < r < 0.39$, moderate when $0.4 < r < 0.59$, strong when $0.6 < r < 0.79$ and very strong when $0.8 < r < 1$. Pearson’s correlation was determined for each location separately. All statistical procedures were carried out using Statistical Analysis System software (SAS, 2012).

Results

Variation in Yield

The analysis of variance of the combined data from all locations indicated to a significant effect of the variety ($P<0.001$), location ($P<0.001$) and the interaction between variety and location on grain yield, straw yield of DM, CP and ME.

Chefe Donsa

The results presented in Table 24 indicated to a significant varietal variation ($P<0.001$) in the yields of grain, straw, CP, and ME. Grain yield ranged from 1.91 t/ha in local variety to 3.74 t/ha in DZ-2012-LN-0039. Twelve varieties out of overall 25 yielded significantly higher grain compared to the local variety ranging from DZ-2012-LN-0195 with a yield of 2.91 t/hato DZ-2012-LN-0039 with a yield of 3.74 t/ha.

The straw yield of DM ranged between the local variety with a yield of 3.19 t DM/ha to DZ-2012-LN-0196 with a yield of 9.31 t DM/ha. Eighteen varieties had a higher straw yield of DM than the local variety and eight of them were among the high grain yielders. The straw yield of DM of the high grain yielders ranged from 5.99 t DM/ha in Derash to 8.96 t DM/ha in DZ-2012-LN-0195.

The straw yield of CP ranged from 137 kg CP/ha in DZ-2012-LN-0192 to 641 kg CP/ha in DZ-2012-LN-0200. Seventeen genotypes had a significantly higher yield of CP of straw compared to the local variety and eight of them were among the high grain yielding varieties. The straw yield of CP of the high grain yielding varieties ranged from DZ-2012-LN-0052 with a yield of 323 kg CP/ha to DZ-2012-LN-0191 with a yield of 538 kg CP/ha.

The straw yield of ME (thousand MJ ME/ha) varied from 25.4 in the local variety to 80.1 in DZ-2012-LN-0200. Eighteen genotypes had a significantly higher straw yield of ME compared to that of the local variety. Among the high grain yielders, eight genotypes yielded significantly higher ME (thousand MJ ME/ha) of straw than the local variety varying from 48.3 in Derash to 75.8 in DZ-2012-LN-0195.

Among all of the high grain yielder genotypes in the study, eight of them yielded high grain and straw yields of DM, CP and ME than that of the local variety.

Table 24. Genotypic variation in yields of grain (t/ha), straw DM (DM t/ha), straw CP (kg CP/ha), and straw ME (thousand MJ ME/ha) of lentil

	Chefe Donsa				Debre Zeit			
Variety	Grain	Straw	CP	ME	Grain	Straw	CP	ME
Derash	3.7*	5.99*	330*	48.3*	1.99*	4.88*	444	39.9*
DZ-2012-LN-0039	3.74*	4.38	182	35	1.27	3.73	400	31.2
DZ-2012-LN-0040	2.8	8.24*	518*	70.9*	0.460	3.50	443	29.2
DZ-2012-LN-0041	2.64	4.45	206	35.8	1.34	4.08	400	34.5
DZ-2012-LN-0042	3.01*	8.45*	514*	70.6*	0.15	2.67	320	22.7
DZ-2012-LN-0045	3.05*	4.66	242	38.5	0.764	2.57	283	21.3
DZ-2012-LN-0048	2.28	5.11*	311	43*	1.81*	4.44*	367	36.9*
DZ-2012-LN-0050	3.22*	4.8	229	39.1	1.06	2.9	290	23.3
DZ-2012-LN-0051	2.75	8.3*	473*	72.5*	1.21	4.21*	435	36.3*
DZ-2012-LN-0052	3*	6.9*	323*	58.3*	1.04	5.00*	613*	43.9*
DZ-2012-LN-0055	2.24	4.94*	246	40.8*	0.525	3.23	379	27.2
DZ-2012-LN-0056	3.71*	6.49*	355*	56.5*	1.28	5.39*	739*	47*
DZ-2012-LN-0057	3.55*	7.08*	411*	60.4*	1.28	4.55*	481*	38.8*
DZ-2012-LN-0190	2.2	7.39*	436*	63.5*	0.395	5.23*	690*	45.5*
DZ-2012-LN-0191	3.52*	7.31*	538*	63.2*	1.01	5.03*	626*	44.3
DZ-2012-LN-0192	2.15	3.37	137	26.7	0.827	3.13	340	25.7
DZ-2012-LN-0193	2.41	5.09*	371*	46*	1.11	3.99	417	34.8
DZ-2012-LN-0194	2.36	8.05*	566*	71.5*	0.387	3.15	426	27.2
DZ-2012-LN-0195	2.91*	8.96*	523*	75.8*	1.4*	3.39	350	28.7
DZ-2012-LN-0196	2.36	9.31*	555*	77*	1.43*	4.2*	422	34.9
DZ-2012-LN-0197	2.63	6.54*	524*	60*	0.393	3.98	501	34.4
DZ-2012-LN-0198	3.1*	7.31*	392*	62.1*	0.416	4.17*	548*	36.9*
DZ-2012-LN-0199	3.25*	4.46	169	35.3	0.937	3.44	390	27.9
DZ-2012-LN-0200	2.35	8.9*	641*	80.1*	0.195	3.14	457	26.4
Local variety	1.91	3.19	183	25.4	0.960	2.79	301	23.8
SEM	0.316	0.614	47.5	5.28	0.14	0.483	60.5	4.24
LSD (0.05)	0.897	1.75	135	15	0.426	1.37	172	12
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*:> the local variety at 0.05 level of significance. CP: crude protein; ME: metabolizable energy

Debre Zeit

The effect of the variety on grain yield, straw yield of DM, CP and ME was significant (Table 24). The grain yield ranged from 0.15 t/ha in DZ-2012-LN-0042 to 1.99 t/ha in Derash. Four varieties yielded significantly higher grain compared to the local variety.

The straw yield of DM (t DM/ha) varied from DZ-2012-LN-0045 (2.57) to DZ-2012-LN-0056 (5.39). Ten varieties yielded significantly higher DM of straw compared to the local variety. Three varieties had significantly higher grain and straw yield than that of the local variety ranging from 4.2 t DM/ha in DZ-2012-LN-0196 to 4.88 t DM/ha in Derash.

The CP yield of straw ranged from 238 kg CP/ha in DZ-2012-LN-0045 to 739 kg/ha in DZ-2012-LN-0056. Seven varieties had significantly more CP yield compared to the local variety, however, none of them were among the high grain yielders.

The straw yield of ME (thousands MJ ME/ha) ranged from DZ-2012-LN-0045 (27.2) to DZ-2012-LN-0056 (47). Tow high grain yielders had a significantly higher straw yield of ME than that of the local variety.

Variation in straw quality

Chefe Donsa

Table 25 presents the effect of genotype on the nutritive value of lentil straw. The straw content of CP ranged from 38 g/kg DM in DZ-2012-LN-0199 to 80 g/kg in DZ-2012-LN-0197. Eleven genotypes had higher CP than that of the local variety while two of them only were among the high grain yielders (DZ-2012-LN-0191 and DZ-2012-LN-0195).

The straw content of NDF varied from 438 g/kg DM in DZ-2012-LN-0200 to 550 g/kg DM in DZ-2012-LN-0199. Eighteen genotypes hosted lesser NDF than that of the local variety and seven of them were among the high grain yielders ranging from (DZ-2012-LN-0191) 455 g/kg DM to 489 g/kg DM (DZ-2012-LN-0052).

Acid detergent fiber ranged from 301 g/kg DM in DZ-2012-LN-0200 to 384 g/kg DM in DZ-2012-LN-0192. Nineteen genotypes had lesser ADF than that of the local variety while eight of them were among the high grain yielders ranging from DZ-2012-LN-0056 (317 g/kg DM) to DZ-2012-LN-0045 (356 g/kg DM).

The straw content of ADL varied from 66.2 g/kg DM in DZ-2012-LN-0197 to 95.9 g/kg DM in DZ-2012-LN-0192. Eighteen genotypes hosted less ADL than that of the local variety, furthermore, ten of them were among the highest grain yielding varieties. The high grain yielders ranged in ADL from 67.5 g/kg DM in DZ-2012-LN-0191 to 80.3 g/kg DM in Derash.

Straw IVOMD (g/kg) ranged from 532 in DZ-2012-LN-0192 to 614 in DZ-2012-LN-0197 while fifteen genotypes had better IVOMD than that of the local variety. Seven high grain yielding genotypes had significantly higher IVOMD than that of the local variety ranging from 567 g/kg in DZ-2012-LN-0042 to 585 g/kg in DZ-2012-LN-0056.

Varieties varied in ME (MJ/kg DM) from 7.91 in DZ-2012-LN-0199 to 9.17 in DZ-2012-LN-0197 while fifteen of them had better content than that of the local variety. Seven high yielding genotypes had significantly higher ME than that of the local variety ranging from 8.38 MJ/kg DM in DZ-2012-LN-0042 to 8.69 MJ/kg DM in DZ-2012-LN-0056.

Debre Zeit

Table 26 presents the effect of the variety on the nutritive value parameters of lentil straw in Debre Zeit location. The CP of lentil straw varied from DZ-2012-LN-0048 with a value of 82 g/kg DM to DZ-2012-LN-0200 with a value of 147 g/kg DM. The CP content of the high grain yielder did not significantly exceed that of the local variety. Only two of the high grain yielding varieties had significantly lesser CP compared to that of the local variety.

The NDF of lentil straw varied between 450 g/kg DM in DZ-2012-LN-0056 to 543 g/kg DM in DZ-2012-LN-0050. Sex varieties had significantly less NDF compared to the local variety. The high grain yielding varieties did not significantly differ from the local variety in NDF content.

The ADF of lentil straw ranged from DZ-2012-LN-0056 with a value of to 330 g/kg DM to DZ-2012-LN-0050 with a value of 402 g/kg DM. Only two varieties had significantly lesser ADF compared to the local variety. The ADF of the high grain yielding varieties did not significantly differ from the local variety.

The ADL (g/kg DM) of lentil straw ranged between DZ-2012-LN-0048 (84.5) to DZ-2012-LN-0200 (111). Four varieties had significantly higher ADL compared to the local variety. The high grain yielding varieties did not significantly differ from the local variety in ADF.

The IVOMD of lentil straw varied from DZ-2012-LN-0050 with a value of 550 g/kg to DZ-2012-LN-0198 with a value of 605 g/kg. Three varieties had significantly lesser IVOMD compared to that of the local variety. The IVOMD of the high grain yielding varieties were similar to the local variety except for Derash which had significantly smaller value.

The ME of lentil straw ranged from 8.06 MJ/kg DM in DZ-2012-LN-0050 to 8.84 MJ DM in DZ-2012-LN-0198. Four varieties had significantly smaller ME compared to the local variety and only one of them was a high grain yielding.

Table 25. Genotypic variation in chemical composition and nutritive value of lentil straw in Chefe Donsa location

Genotype	CP	NDF	ADF	ADL	IVOMD	ME
Derash	55	532	368	80.3†	544	8.06
DZ-2012-LN-0039	41	546	375	78.7†	536	7.96
DZ-2012-LN-0040	62.3*	491†	329†	77.9†	577*	8.58*
DZ-2012-LN-0041	45.9	514†	360†	82.2	540	8.01
DZ-2012-LN-0042	60.7*	486†	328†	77.8†	567*	8.38*
DZ-2012-LN-0045	51.9	532	356†	79.7†	557	8.24
DZ-2012-LN-0048	60.8*	479†	348†	75.6†	566*	8.42*
DZ-2012-LN-0050	48.3	538	367	78.6†	549	8.15
DZ-2012-LN-0051	57.1	494†	329†	74.6†	586*	8.74*
DZ-2012-LN-0052	46	489†	336†	74.5†	567*	8.47*
DZ-2012-LN-0055	49.4	507†	352†	77.5†	558	8.3
DZ-2012-LN-0056	53.9	481†	317†	69.1†	585*	8.69*
DZ-2012-LN-0057	58	479†	329†	69.3†	574*	8.53*
DZ-2012-LN-0190	58.9*	471†	320†	79.8†	580*	8.6*
DZ-2012-LN-0191	73.8*	455†	317†	67.5†	583*	8.65*
DZ-2012-LN-0192	40	548	384	95.9	532	7.92
DZ-2012-LN-0193	73.1*	454†	302†	72.4†	608*	9.05*
DZ-2012-LN-0194	70.6*	470†	314†	81.4	596*	8.89*
DZ-2012-LN-0195	58.5*	486†	323†	82.8	571*	8.46*
DZ-2012-LN-0196	59.9*	499†	341†	84.6	559	8.28
DZ-2012-LN-0197	80*	442†	301†	66.2†	614*	9.17*
DZ-2012-LN-0198	53.8	467†	327†	72.3†	572*	8.5*
DZ-2012-LN-0199	38	550	378	83.8	533	7.91
DZ-2012-LN-0200	72.3*	438†	301†	70.2†	606*	9.01*
Local variety	57.1	547	383	88.1	540	7.98
SEM	3.89	11.3	7.95	2.45	0.136	8.89
LSD (0.05)	11	32	22.6	6.95	25.3	0.387
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*:> the local variety at 0.05 level of significance; †:> the local variety at 0.05 level of significance; CP: crude protein (g/kg); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM); IVOMD: *In vitro* organic matter digestibility (g/kg DM); ME: Metabolizable energy (MJ/kg DM).

Urea treatment

Table 27 presents the effect of urea treatment on the nutritive value of lentil straw. Urea treatment increased significantly ($P<0.001$) CP, IVOMD and ME of lentil straw by 37%, 5% and 5% respectively compared to the control. The ADF was not significantly affected by urea treatment. Urea treatment decreased significantly ($P< 0.001$) NDF and ADL by 5%. The average varietal range in CP, IVOMD and ME for both locations was higher than the increase caused by urea treatment by 25.8 units, 53 units and 0.59 units respectively.

Relationships among straw quality traits

Table 28 presents the relationships among straw quality traits in lentil straw. In Chefe Donsa, ADF correlated very strongly to other quality traits (pooled r= 0.87). In Debre Ziet, the correlation between ADF and CP was insignificant while ADF correlated strongly to NDF, ADL, IVOMD and ME (pooled r= 0.77).

Stepwise regression analysis (Table 29) showed that in Chefe Donsa, ADF and ADL are useful to predict of IVOMD (R^2= 0.89) of lentil straw while ADF was useful in predicting ME (R^2= 0.88). In Debre Ziet, IVOMD and ME of lentil straw cannot be predicted using the chemical composition (R^2= 0.69 for IVOMD; R^2= 0.64 for ME).

Table 26. Genotypic variation in chemical composition and nutritive value of lentil straw in Debre Zeit location

Variety	CP	NDF	ADF	ADL	IVOMD	ME
Derash	91	512	385	87.2	556*	8.17*
DZ-2012-LN-0039	107	522	382	97.5	567	8.29
DZ-2012-LN-0040	126*	498	365	105*	576	8.35
DZ-2012-LN-0041	96	489	359	87.5	574	8.45
DZ-2012-LN-0042	122	512	356	92.7	593	8.56
DZ-2012-LN-0045	110	528	387	98.1	568	8.29
DZ-2012-LN-0048	82	495	370	84.5	559	8.31
DZ-2012-LN-0050	101	543	402	98.5	550*	8.06*
DZ-2012-LN-0051	103	469*	345	85.9	587	8.65
DZ-2012-LN-0052	122	490	358	95.0	600	8.80
DZ-2012-LN-0055	118	503	387	97.9	576	8.44
DZ-2012-LN-0056	138*	450*	330*	86.9	600	8.73
DZ-2012-LN-0057	105	460*	352	84.7	581	8.52
DZ-2012-LN-0190	131*	473*	361	98.5	596	8.69
DZ-2012-LN-0191	124*	462*	334*	84.9	604	8.82
DZ-2012-LN-0192	108	532	395	108*	559	8.20*
DZ-2012-LN-0193	104	483	353	92.2	592	8.74
DZ-2012-LN-0194	135*	476*	350	103	598	8.69
DZ-2012-LN-0195	104	481	348	92.5	580	8.46
DZ-2012-LN-0196	100	486	351	86.7	567	8.29
DZ-2012-LN-0197	125*	522	388	108*	589	8.61
DZ-2012-LN-0198	132*	484	368	94.8	605	8.84
DZ-2012-LN-0199	112	538	400	103	557*	8.09*
DZ-2012-LN-0200	147*	501	364	111*	585	8.42
Local variety	108	517	377	92.5	583	8.57
SEM	5.71	13.6	12.8	4.17	8.99	0.13
LSD (0.05)	16.2	38.7	36	11.8	25.5	0.37
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

*:> the local variety at 0.05 level of significance; CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg); IVOMD: *In vitro* organic matter digestibility (g/kg); ME: Metabolizable energy (MJ/kg DM).

Table 27. Effect of urea treatment on the nutritive value of lentil straw

Item	Control	Treatment	Δ	SEM	*P* value
CP	82.6	111	28.7	0.59	<0.001
NDF	532	467	-65	5.9	<0.001
ADF	380	365	-15	6.3	0.36
ADL	90.4	79.2	-4.2	2.6	<0.001
IVOMD	562	588	26	4.71	<0.001
ME	8.28	8.7	0.42	0.075	<0.001

Δ: Change due to urea treatment; CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM); IVOMD: *In vitro* organic matter digestibility (g/kg); ME: Metabolizable energy (MJ/kg DM).

Food-fodder relationship

Table 30 depicts the relationship between grain yield and straw traits. In Chefe Donsa, the correlation between grain yield and straw traits was weak (r<0.4). In Debre Zeit, the correlation between grain yield and straw yield of DM was positive and moderate. Grain yield correlated insignificantly to a straw yield of CP and ME. A strong and negative correlation was found between grain yield and CP and ADL of straw. A weak correlation was found between grain yield and NDF, ADL, IVOMD and ME of straw.

Table 28. Relationships among straw quality trait of lentil

Location		NDF	ADF	ADL	IVOMD	ME
Chefe Donsa	CP	-0.787	-0.799	-0.565	0.841	0.822
	NDF		0.946	0.756	-0.899	-0.89
	ADF			0.748	-0.948	-0.937
	ADL				-0.753	-0.748
	IVOMD					0.997
Debre Zeit	CP	Ns	ns	0.41	0.588	0.552
	NDF		0.916	0.669	-0.719	-0.776
	ADF			0.714	-0.775	-0.785
	ADL				-0.339	-0.442
	IVOMD					0.972

ns: P> 0.05; CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM); IVOMD: *In vitro* organic matter digestibility (g/kg); ME: Metabolizable energy (MJ/kg DM).

Table 29. Summary of stepwise regression analysis of the effect of chemical composition (g/kg DM) on IVOMD (g/kg) and ME (MJ/kg) of chickpea straw in tow locations

Location	Dependent variable	Step	Independent variables Entered	Removed	Partial R^2	Model R^2	P value
Chefe Donsa	IVOMD	1	ADF		0.89	0.89	<0.001
		2	ADL		0.01	0.9	<0.001
	ME	1	ADF		0.88	0.88	<0.001
Debre Zeit	IVOMD	1	ADF		0.6	0.6	<0.001
		2	ADL		0.09	0.69	<0.001
	ME	1	ADF		0.62	0.62	<0.001
		2	ADL		0.02	0.64	<0.001

IVOMD= 875 -0.82*ADF-0.39*ADL (Chefe Donsa); IVOMD= 794- 0.8*ADF -0.88*ADL (Debre Zeit); ME= 13.4-0.02*ADF *Chefe Donsa); ME= 11.6-0.01*ADF-0.01*ADL (Debre Zeit); CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg DM); IVOMD: *In vitro* organic matter digestibility (g/kg); ME: Metabolizable energy (MJ/kg DM).

Table 30. Correlation between grain yield and straw yield and straw quality traits

Straw traits	Chefe Donsa	Debre Zeit
Straw yield	0.39	0.432
CP yield	ns	ns
ME yield	0.378	ns
Quality		
CP	ns	-0.685
NDF	ns	ns
ADF	ns	ns
ADL	ns	-0.633
IVOMD	ns	-0.264
ME	ns	ns

CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg DM); ADL: acid detergent lignin (g/kg); IVOMD: *In vitro* organic matter digestibility (g/kg DM); ME: Metabolizable energy (MJ/kg DM).

Discussion

The effect of the variety on grain yield and straw yield and nutritive value depended on the location. These results are in agreement with Ertiro et al. (2013) in maize. That means identifying the parental varieties which would be used in improvement programs of chickpea should be based on the location.

The varietal variation in straw traits found within the high grain yielding varieties presents a high potential to select varieties with superior grain yield and straw traits. However, this selection has to be done based on the location. Such variation was reported in straw traits of pearl millet (Blümmel et al., 2010). Urea treatment improved mainly CP content of chickpea straw (by 35%) but the change in cell wall constituents, IVOMD and ME was marginal (5%). The reason could be that treatment could not break down lingo-cellulose and thus increase IVOMD and ME. Van Soest (2006) reported that the improvement in the nutritive value of crop residue by urea treatment is due to the increase in CP but not by breaking down lignocellulose bonds. The results of this study showed that the genotypic range in the nutritive value parameters was considerably higher than that improvement resulted from urea treatment. That implies that the varietal selection for straw quality traits can be an interesting option to improve the nutritive value of lentil straw in the mixed farming systems.

In Chefe Donsa, DZ-2012-LN-0195 significantly outyielded the local variety by 2 t/DM ha of grain, 5.77 t of straw DM/ha, 340 kg/CP ha of straw CP and 50 thousand MJ ME/ha of straw ME. Therefore, it is recommended as a parental genotype for any further efforts to improve the yield of straw from DM, CP and ME in Chefe Donsa. DZ-2012-LN-0197 which is superior to the local variety by 208 g/kg of CP and 1.19 MJ/kg DM of ME is recommended for any improvement of straw for nutritive value in Chefe Donsa. Kearl (1982) reported that daily requirements for a sheep of 30 kg live weight are 750 g DM, 59 g CP and 4.95 MJ ME for maintenance. The NDF can be used to predict the potential dry matter intake of sheep according to the following equation:

DMI (% of the live weight) = 120/NDF (%) (Horrocks and Vallentine, 1999).

Accordingly, DZ-2012-LN-0197 covers 110%, 111% and 151% of DM, CP and ME maintenance requirements respectively of a 30 kg sheep. Interestingly, DZ-2012-LN-

0191 has superior grain and straw traits. Furthermore, its straw meets 106%, 99% and 138% of DM, CP and ME maintenance requirement respectively of 30 kg live weight sheep. Thus, DZ-2012-LN-0191 is nominated as a dual purpose lentil cultivar in Chefe Donsa.

DZ-2012-LN-0056, out yielding the local variety by of 2.6 t straw DM/ha, 438 kg straw CP/ha and 23.2 thousand MJ ME/ha, could be recommended as a parental genotype to improve the straw yields of lentil in Debre Zeit. DZ-2012-LN-0200 had higher CP than the local variety by 38 g/kg DM. Moreover, it does not differ significantly from the local variety in terms of ME. Thus, it is recommended to improve the CP of lentil straw in Debre Zeit. There is no variety which combines high grain yield and superior straw yield and nutritive value in Debre Zeit. Improving the nutritive value of lentil straw through varietal selection requires phenotyping large number of genotypes for IVOMD and ME.

The results of the stepwise regression analysis indicate that the chemical composition of lentil straw can be used accurately to predict IVOMD and ME in Chefe Donsa but not in Debre Zeit. These prediction equations provide a convenient substitute to *in vitro*, *in vivo* or *in sacco* methods, thus minimizing the cost and time of undertaking IVOMD and ME evaluations. Such equations should be developed and used based on the location. Horrocks and Vallentine (1999) developed an equation to predict the dry matter digestibility of forages depending on ADF content.

The profile of the correlations of ADF and other nutritive value parameters in lentil straw was not stable across locations. The ADF of lentil straw is strongly and negatively correlated with other nutritive value parameters in Chefe Donsa. Moreover, it can explain more than 76% of the variability in other quality parameters of lentil straw. That means the lower the ADF, the higher the nutritive value of lentil straw. Thus, ADF can be recommended for the ranking lentil varieties for straw quality in Chefe Donsa. Furthermore, lentil breeders may use ADF as sole criteria to breed genotypes with superior straw quality traits in Chefe Donsa. However, ADF cannot be used to express the nutritive value of lentil straw in Debre Zeit as ADF does not correlate significantly to CP.

Grain yield is a major criterion targeted in lentil improvement programs. Thus, it is imperative that efforts to increase the yield and nutritive value of lentil straw do not depress grain yield. The correlation between the grain yield and the yield and nutritive value parameters of lentil straw depended on the location. This result agrees with (Ertiro et al., 2013) how reported that the correlations between food and feed traits in maize depend on the location. The correlation between straw and grain yield was weak in Chefe Donsa. This implies that varietal selection to improve the straw yield will not lead to a decrease in grain yield and vice versa. Moreover, the straw yield of DM cannot be predicted from grain yield and therefore the straw yield of DM needs to be recorded alongside grain yield.

Correlations between CP, NDF, ADF, ADL and ME content of lentil straw and grain yield were insignificant in Chefe Donsa. That means no decline in grain yield is expected as a result of any increase in CP and ME content of lentil straw nor a decrease in NDF, ADF or ADL. Similarly, no such correlation was reported by Blümmel et al. (2007) in pearl millet and Blümmel et al. (2010) in Sorghum. The correlation between the grain yield and CP of straw was strong and negative in Debre Zeit. That means the increase in grain yield will be associated with a decrease in CP in Debre Ziet. The performance of lentil genotypes in terms of food and feed traits, the correlation among nutritive value traits of straw and the food-feed relations was affected by environmental factors, therefore, further studies using a larger number of genotypes under different environments is recommended to validate this study further. Furthermore, the genotypes recommended in this study as parental genotypes for further improvement program of lentil need to be evaluated for other critical agronomy traits such as disease resistance and drought tolerance.

Conclusions

Currently, improvement programs of lentil do not pay attention to straw traits, neither are straw traits considered as a release criteria of new varieties.

The current study proves that there is a wide varietal variation in the yield and the nutritive value of lentil straw. The performance of lentil varieties in terms of straw traits depended on the environment.

Therefore, livestock nutritionists need to work closely with lentil breeders to select varieties which have superior food and feed traits. The interaction between the variety and the environment has to be considered in any effort aiming to improve food and feed traits of lentil.

The varietal variation in the nutritive value of lentil straw has to be confirmed by *in vivo* studies.

The study investigated food-feed relations in late maturing genotypes of lentil, therefore, other studies has to address that correlations in early maturing genotypes in different locations.

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PAPER 5

IMPROVING THE NUTRITIVE VALUE OF PULSE STRAWS USING DUNG AND WOOD ASH TREATMENT

Abstract

The study was conducted to evaluate the effect of cattle dung ash treatment (0, 100, 200 or 300 g dung ash/L) and wood ash treatment (0, 100, 150 or 200 g wood ash/L) on the nutritive value of chickpea, faba bean and lentil straw.

Mineral components of three replicates from each ash was determined by atomic absorption spectrophotometry. The pH of three replicate from each solution was determined by a portable pH-meter. All straw samples were evaluated for proximate analysis, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) using a combination of near infrared reflectance spectroscopy and conventional laboratory analyses. The effect of straw origin, the level of treatment and the straw origin-level of treatment interaction on the nutritive value of straw was analyzed for each treatment separately using general linear model procedure. One way analysis of variance was used to determine the effect of the ash source on minerals content. One way analysis of variance was used to test the effect of the concentration of ash on the pH of dung ash and wood ash solutions. Means were separated using least significant difference method at 0.05 level of significance.

The results of the study showed that the minerals content of ash was significantly affected by ash source. Dung ash had significantly higher content of ash, Fe, Mn, Na, Mg and P compared to wood ash. Wood ash had significantly higher content of Zn, Cu and Ca. The solutions containing ash had significantly higher pH compared to the plain water regardless of the source.

The pH of solutions containing dung ash was close to 10 while the pH of the solutions containing wood ash was close to 8.5. The effect of dung and wood ash treatment depended on the origin of straw. Dung ash treatment at level of 200g ash/L decreased significantly IVOMD of faba bean straw by 5% while it did not alter IVOMD of chickpea and lentil straw significantly. Soaking chickpea straw in plain water and in wood ash solutions decreased

IVOMD by 2%. Treating faba bean straw by wood ash decreased IVOMD by 2% at all levels. Treating lentil straw by a solution containing 200g wood ash/L decreased significantly IVOMD.

The study pinpoints that dung ash treatment at a level up to 300g ash/L and wood ash treatment at a level up to 200 g ash/L failed in improving the nutritive value of chickpea, faba bean and lentil straw. Therefore, further levels of ash applications could be considered for future areas of research.

Keywords: Alkaline treatment; cereal, pulse; straw; nutritive value

Introduction

Straws of cereal and pulse crops are important feeds for ruminants in the mixed crop-livestock systems in Asia and Africa (Abegaze et al., 2007). Although straw contains considerable quantities of cellulose and hemicellulose, the utilization of these components as an energy source by rumen microorganisms is limited by lignin-carbohydrates complexes (Graminha et al., 2008). Nevertheless, straw has high potential as livestock feed and any treatment which could improve its energy content by even 20% would be an important attainment (Chaudhry and Miller, 1996).

Although several alkaline treatments such as sodium hydroxide, calcium hydroxide and potassium hydroxide have been reported to improve nutritive value of straw, the practical use of these treatments is still restricted due to safety concerns, costs, environmental hazards and potential negative consequences on the health of the animals consuming the treated straw (Sarnklong et al., 2010).

Ashes, produced in considerable quantities by households in rural areas which use wood and dung cake as a domestic energy source (Ben Salem et al., 2005), can be cost-effective alternatives to traditional alkaline for straw treatment (Genin et al., 2007). Wood ash solution is alkaline (pH>10) and has been used to improve the nutritive value of wheat straw (Nolte et al., 1987), corn stover (Ramirez et al., 1992) and sorghum straw (Ramirez et al., 1991). Goat dung ash has improved the nutritive value of native Andean grass (Genin et al., 2002) and

Stipa tenacissima(Genin et al., 2007). Wood ash has alkaline properties because it contains considerable contents of minerals such as calcium, potassium and sodium (Tiisekwa et al., 1999). Alkaline solutions increase nutrients digestibility of low-qualityfibrous feeds through solubilization of silica and weakening lingo-cellulose bonds (Laswai et al., 2007). Treating straws and stover by wood ash solution decreased lignin, neutral (NDF) and acid (ADF) detergent fiber contents (Ramirez et al., 1992) but increased levels of ash (Nolte et al., 1987). Wood ash treatment of wheat straw (Nolte et al., 1987) and maize stover (Ramirez et al., 1992) improved *invivo digestibility* of DM, OM, NDF and ADF by goats. Goat consumed a bigger quantity of wood ash treated wheat straw compared to untreated wheat straw (Nolte et al., 1987). Genin et al. (2002) reported that the nutritive value of native Andean grass improved by dung ash and urea treatment. Treatment by 200 g/L solution of dung ash and 30 g/kg urea improved the nutritive value of Alfa (*Stipa tenacissima*) hay (Genin et al., 2007). Although wood ash treated straw contained high levels of ash, feeding for short time did not have negative consequences on the health of steers (Laswai et al., 2007).

This study aims to investigate the ability of cattle dung ash and wood ash treatments to improve the nutritive value of chickpea, faba bean and lentil straws.

Materials and methods

Straws and ash treatments

Straws of local varieties of faba bean (*Vicia faba*), chickpea (*Cicer arietinum*) and lentil (*Lens culinaris*) were collected from Sinana agricultural research center (7°N latitude and 40°E longitude; 2400 m.a.s.l) and Debre Zeit agricultural research center, experimental site (08053’N; 38049′ E; elevation: 2200 m.a.s.l) respectively. Each straw was pooled, hand mixed and chopped to a theoretical cut length of 2 cm before the treatment.

Eucalyptus (*Eucalyptus Spp*) wood was collected from one carpenter in Addis Ababa while cattle dung was collected from Legetafo village (20 km to the north-east of Addis Ababa, Ethiopia) where cattle were mainly fed on natural pasture and cereal crop residue.

Cattle dung and wood were burnt for 24 hours in vicinity. Ash of cattle dung was light gray to dark in color and had several impurities such as soil and small stones. Wood ash was darker in color and contained some contaminants including incompletely burnt pieces of wood, charcoal, stones and metal nails.

Solutions were prepared from dung ash as follow: 100 g dung ash/L, 200 g dung ash/L and 300 g dung ash/L, 100 g wood ash/L, 150 g wood ash/L and 200 g wood ash/L. This is because the solution containing 300 g wood ash/L was thick and not suitable for practical treatment of straw. Ash solution was prepared as per recommended by Ramirez et al. (1992). Three replicates 100 ml each from each solution were used to determine pH using a portable pH-meter.

Ten samples from each straw were treated by one of the following treatment: control (untreated), plain water (0 g ash/L), 100 g dung ash/L, 200 g dung ash/L, and 300 g dung ash/L, 100 g wood ash/L, 150 g wood ash/L and 200 g wood ash/L.

Six hundred mL of solution were used to treat 100 g of straw sample. The mixture of ash solution and straw was placed in plastic bags for 6 hours then squeezed by hand to remove as much solution as possible. Treated samples were further dried in ventilated oven at 40 °C for 48 hours. All samples were ground to pass 1 mm screen and kept for further feed nutritional analysis.

Feed nutritional analysis

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 the conventional analysis, ash and CP were analyzed according to AOAC (2000). Ash was determined by burning in a muffle furnace at 500˚C overnight (method 942.05). Nitrogen 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. The acid detergent fiber was expressed exclusive of residual ash. Lignin was determined by solubilization of cellulose with a sulphuric acid. *Invitro* 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 in 100 ml graduated glass syringe. Buffer mineral solution medium was prepared and placed in a water bath at 39 °C under constant flushing with CO2. Rumen fluid was collected after the morning feeding from three ruminally fistulated male cattle. Rumen fluid was pumped with a manually operated vacuum pump from the rumen into pre-warmed thermos flasks. The rumen fluids were mixed and filtered through four layers of cheesecloth and flushed with CO2 and the bulked mixture was then mixed with the buffered mineral solution (1:2 v/v). The buffered rumen fluid (30 ml) was pipetted into each syringe and the syringes were immediately placed in a water bath and kept at 39 °C. Gas production was recorded after 24 hours of incubation and used to calculate IVOMD and ME according toMenke and Steingass (1988) equations. A basal NIRS calibration was developed and validated using conventional laboratory analysis of 20% of the samples. The concentration of minerals in cattle dung and wood ash was determined by atomic absorption spectrophotometry. All chemical analyses were undertaken at the International Livestock Research Institute Animal Nutrition Laboratory in Addis Ababa, Ethiopia.

Data analysis

Data of dung ash treatment and wood ash treatment was separately analyzed. The effect of straw origin, level of treatment and straw origin-solution concentration interaction on chemical composition, IVOMD and ME of straw was analyzed using General Linear Model procedure (SAS, 2011). Differences among means of treatments within each straw were assessed using least significant difference test at 0.05 level of probability.

Results

Chemical composition and mineral content of ash were significantly ($P<0.001$) affected by ash origin (Table 31). Cattle dung ash had significantly higher content of DM, ash, Mn, Na, Mg and P while wood ash had a higher content of Fe, Zn, Cu and Ca. Generally, cattle dung ash solutions had pH close to 10 while wood ash solutions had values close to 8.5 (Table 32). Regardless of ash origin, solutions containing ash were not significantly different in pH value but they had significantly higher pH compared to that of plain water.

Table 31. Mineral composition of wood and dung ashes

	Ash source			
Item	Dung	Wood	SEM	P value
Ash (g/kg DM)	985[a]	433[b]	30.1	<0.001
Fe (g/kg DM)	23.4[a]	9.98[b]	1.683	<0.001
Zn (mg/kg DM)	112[b]	533[a]	14.2	<0.001
Cu (mg/kg DM)	24[b]	77.3[a]	4.38	<0.001
Mn (g/kg DM)	1.64[a]	1.11[b]	0.031	<0.001
Na (mg/kg DM)	157[a]	96.7[b]	13.2	<0.001
Ca (g/kg DM)	5.48[b]	15.3[a]	0.78	<0.001
Mg (g/kg DM)	6.47[a]	5.32[b]	0.135	<0.001
P (g/kg DM)	5[a]	2.17[b]	0.32	<0.001

Means within the same row with different letters are significantly different

Table 32. Means of pH of solutions prepared from dung and wood ashes

Item	Ash source	
Concentration	Dung	Wood
0 g ash/L	7.3[b]	7.3[b]
100 g ash/L	9.79[a]	8.48[a]
150 g ash/L	—	8.54[a]
200 g ash/L	10.24[a]	8.55[a]
300 g ash/L	10.27[a]	—
SEM	0.028	0.031
P value	<0.001	<0.001

Means within the same column with different superscripts are significantly different ($P < 0.05$)

Dung ash treatment

The origin of straw, level of treatment and origin of straw × level of treatment had a significant effect on the chemical composition and IVOMD of straw (Table 33). That means the effect of dung ash treatment depended on the origin of straw. Treating lentil straw by plain water and dung ash solutions did not alter the chemical composition and IVOMD of lentil straw. Soaking chickpea and faba bean straws in plain water did not alter the chemical composition and IVOMD. Dung ash solutions increased ash content in chickpea and faba bean straws at the same rate. Dung ash treatment at all levels increased chickpea straw content of CP at the same rate. The CP content of faba bean straw was not affected by dung ash treatment. Ash solutions caused a similar decrease in NDF of chickpea straw. The solutions containing 200 and 300 g dung ash/L caused a similar increase in the NDF of faba bean straw. Soaking faba bean straw in solutions containing 200 and 300 g dung ash/L reduced ADF in a similar rate whereas ADF of chickpea straw was not affected by dung ash treatment. Treating chickpea straw by dung ash solution resulted in a similar decrease in ADL for all levels of the treatment. Dung ash treatment at levels of 200 g and 300 g dung ash/L had a similar decreasing effect on ADL of faba bean straw. Dung ash treatment at levels of 200 and 300 g dung ash/L similarly decreased IVOMD of faba bean straw.

Table 33. Effect of dung ash treatment on chemical composition and nutritive value of chickpea, faba bean and lentil straw

Straw origin	Treatment level	Ash	CP	NDF	ADF	ADL	IVOMD
	Control	43^{b}	55.9^{b}	714^{a}	461	110^{a}	498
	0 (g/L)	44.6^{b}	55.9^{b}	714^{a}	461	106^{b}	498
Chickpea	100 (g/L)	48^{a}	58^{a}	714^{b}	463	105^{b}	491
	200 (g/L)	48.4^{a}	66.8^{a}	687^{b}	452	106^{b}	492
	300 (g/L)	47^{a}	66.6^{a}	692^{b}	451	107^{b}	496
	Control	79.1^{b}	53.7	671^{b}	619^{c}	126^{b}	418^{a}
	0 (g/L)	80^{b}	55.4	670^{b}	619^{c}	126^{b}	419^{a}
Faba bean	100 (g/L)	88.3^{a}	52.6	667^{b}	624^{c}	129^{b}	416^{a}
	200 (g/L)	88.1^{a}	53.3	687^{a}	644^{b}	135^{a}	403^{b}
	300 (g/L)	88.4^{a}	51.9	689^{a}	654^{a}	138^{a}	398^{b}
	Control	102	82.6	532	380	90	562
	0 (g/L)	101	85	520	386	90.5	553
	100 (g/L)	99.9	84.9	524	382	91.6	549
Lentil	200 (g/L)	101	84.6	525	383	91.8	551
	300 (g/L)	99.7	86.1	525	386	92.1	549
	Pooled SEM	1.45	2.9	5.23	5.79	1.63	4.98
Effects							
Straw origin		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment level		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Straw origin×treatment level		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Ash (g/kg DM); CP: crude protein (g/kg DM); NDF: neutral detergent fibers (g/kg DM); ADF: acid detergent fibers (g/kg DM); ADL: acid detergent lignin (g/kg DM); IVOMD:*in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM); means within a column in the same species with different superscripts are significantly different (P< 0.05)

Wood ash treatment

Wood ash treatment and straw origin-treatment interaction affected the chemical composition and IVOMD of straw except ADF (Table 34). Soaking faba bean straw in plain water did not change the chemical composition and IVOMD. Soaking chickpea straw in plain water decreased ADL and IVOMD. Treating lentil straw by plain water increased CP but did not change ash, cell wall constituents nor IVOMD. Treating chickpea straw by wood ash solution at a concentration of 200 g ash/L increased CP. Treating lentil straw by wood ash at concentrations of 100 g ash/L, 150 g ash/L and 200 g ash/L increased CP similarly. Wood ash treatment at a level of 200 g ash/L decreased significantly NDF of faba bean straw. The ADF of straw was not affected by wood ash treatment regardless of the origin. Wood ash treatment at all levels caused similar decrease in ADL of chickpea straw. Only the solution containing 300 g wood ash /L increased significantly ADL of faba bean straw. Wood ash solutions decreased IVOMD of chickpea and faba bean straw and the decreasing effect was similar for all treatment solutions. Only the level of 200 g ash/L of wood ash treatment caused a significant decrease in IVOMD of lentil straw.

Table 34. Effect of wood ash treatment on chemical composition and nutritive value of chickpea, faba bean and lentil straw

Straw origin	Treatment level	Ash	CP	NDF	ADF	ADL	IVOMD
	Control	43	46^{b}	714	461	114^{a}	498^{a}
	0 (g/L)	44.6	48.1^{ab}	714	463	110^{b}	491^{b}
Chickpea	100 (g/L)	44.9	48.4^{ab}	720	464	110^{b}	491^{b}
	150 (g/L)	47.9	47.9^{ab}	727	471	110^{b}	489^{b}
	200 (g/L)	47.6	50.8^{a}	713	459	109^{b}	491^{b}
	Control	79.1b	53.7	671^{a}	619	126^{b}	418^{a}
	0 (g/L)	80b	55.4	670^{a}	619	128^{ab}	419^{a}
Faba bean	100 (g/L)	80.1b	55.2	669^{a}	631	127^{ab}	410^{b}
	150 (g/L)	81b	52.9	667^{a}	632	129^{ab}	409^{b}
	200 (g/L)	83.6a	54.8	658^{b}	619	130^{a}	410^{b}
	Control	102	82.6^{b}	532	380	90	562^{a}
	0 (g/L)	101	85^{a}	533	386	90.5	553^{a}
Lentil	100 (g/L)	101	83.3^{a}	525	380	90.6	559^{a}
	150 (g/L)	106	83.1^{a}	523	378	89.8	558^{a}
	200 (g/L)	106	85.8^{a}	527	382	90.7	549^{b}
	Pooled SEM	3.3	2.8	4.48	5.31	1.47	4.49
Effects							
Straw origin		<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Treatment level		<0.001	<0.001	<0.001	0.3	<0.001	<0.001
Straw origin×treatment level		<0.001	<0.001	<0.001	0.45	<0.001	<0.001

Ash (g/kg DM); CP: crude protein (g/kg DM); NDF: neutral detergent fibers (g/kg DM); ADF: acid detergent fibers (g/kg DM); ADL: acid detergent lignin (g/kg DM); IVOMD:*in vitro* organic matter digestibility (g/kg); ME: metabolizable energy (MJ/kg DM); means within a column in the same species with different superscripts are significantly different (P< 0.05)

Discussion

Wood ash in our study had less Ca, P and Mg but higher Na compared to Acacia and Aleppo pine wood ashes reported by Ben Salem et al. (2005) and banana leaf ash reported by (Kanyinji et al., 2014). Wood ash used in the current study contained a less content of Ca, P, Mg, Fe, Zn, Cu but a higher content of Na compared to that reported by van Ryssen and Ndlovu (2004). This variation could be due to tree species, locations and seasons (Adebowale, 1985, Nolte et al., 1987). Cattle dung ash in our study had less content of Ca, P, Na and Mg compared to dromedary and goat dung ash reported by Genin et al. (2007). It has been already reported that the mineral content of ashes from dung is expected to have high variability due to many factors including diet composition, location, season and animal related factors (Genin et al., 2007).

Dung ash solution at a concentration of 300 g ash/L had less but almost equal pH to that of 300 g ash/L of dromedary and goat dung ash solutions reported by Genin et al. (2007). Wood ash solutions containing wood up to 300 g ash/L in our study had smaller pH value by almost two units compared to wood ash extract solution mentioned by Laswai et al. (2007). That could be due to the origin of the ash. The increase in the ash content of straw due to ash treatments was small (between 0 and 10%). That means chickpea, faba bean and lentil straw did not absorb dung and wood ash extracts. Contradictory results were observed by (Nolte et al., 1987) on wheat straw and (Ramirez et al., 1992) on corn stover where an increase in the ash content of the treated straw was reported.

Dung ash treatment increased CP of chickpea straw while wood ash treatment increased CP of chickpea and lentil straw. However, both of treatments tended to increase CP in other straws. That might indicate to the low solubility of the CP of these straws in weak alkaline solutions thus low availability to rumen microbes. Pulse straws seem to be a typical material for alkali treatment as they have a high content of hemicellulose which is known to be soluble in alkali solutions (Genin et al., 2007).

The current study showed that the change in the content of cell wall constituents caused by dung and wood ash treatment was very small (0-9%). That means dung and wood ash solutions did not break down lingo-cellulose bonds due to the low alkalinity. Dung and wood ash treatment slightly altered IVOMD of chickpea, faba bean and lentil straws (between 0 to 5%). On the contrary, dung and wood ash treatment has been reported to be an effective treatment to improve the digestibility of cereal crop residue and grasses (Nolte et al., 1987, Ramirez et al., 1991, Ramirez et al., 1992, Genin et al., 2002, Genin et al., 2007, Laswai et al., 2007). Dung and wood ash solution had weak alkalinity thus they increase the solubility of cell wall constituents (Nolte et al., 1987). Moreover, dung and wood ashes stimulate the growth of rumen microbes by supplying them with essential minerals (Hungate, 1966). Accordingly, dung and wood ash solution improves the digestibility of fibrous feeds. In the current study, pulse straws did not absorb dung and wood ash extracts. Therefore, dung and wood ash treatment could not increase the digestibility of cell wall constituents by increasing the growth of rumen microbes by supplying essential minerals.

Ghasemi et al. (2014) stated that the pH of a solution has to exceed 12 to be able to increase the digestibility of barley straw. The pH of dung and wood ash solutions in the current study was less than 10.5 which could not be sufficient to increase the solubility of fiber constituents in pulse straws and thus improving the digestibility. Increasing the concentration of ash in the treatment solutions was not correlated with any increase in the pH which means increasing the concentration of ashes will not increase the pH.

However, chemical composition of dung ash and wood ash and alkalinity properties of solutions prepared from dung and wood ash vary according to many factors including livestock and tree species in addition to environmental factors (van Ryssen and Ndlovu, 2004). Thus, the effect of treating pulse residue by dung and wood ash from different sources has to be studied. Increasing the alkalinity of ash solutions by adding alkalis (for example $Ca(OH)_2$) could lead to an improvement in the effectiveness of dung and wood ash treatment. Thus, the effect of different combinations of alkaline and ashes to improve the nutritive value of straws should be studied.

Conclusions

Treating pulse straws by a solution prepared from dung and wood ash at a concentration up to 300 g dung ash/L and 200 g wood ash/L failed to increase the nutritive value.

Improving the effectiveness of dung and wood ash in improving the nutritive value of pulse straws by combining other alkalis and increasing soaking duration should be studied. Studies reported that alkaline properties of dung and wood ash solutions vary according to many factors including animal species, tree species in addition to environmental factors. Thus, the effect of other sources and upper levels of dung and wood ashes in upgrading the nutritive value of pulse straws should be studied.

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