INFLUENCE OF VARIETAL SELECTION AND TREATMENTS ON NUTRITIVE VALUE OF SOME PULSE RESIDUE

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By

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DEDICATION

I dedicate this dissertation to my wife, family, friends, supervisors and my country Syria and to every Syrian person who still clean in that difficult situation. I dedicate my work to everybody supported me by good willing or by praying especially my teachers in the elementary school who taught me how to be faithful to my goals. More appreciations are to the people who tackled me during my study (Especially in Syria) as they taught me that as bigger the goal I have, as bigger the sacrifice it deserves.

STATEMENT OF THE AUTHOR

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BIOGRAPHICAL SKETCH

The author was born in Syria, *Hama* district, *Taybet El-Imam* town in 1983 from his Saber Alkhtib and his mother Fatimah Alkhtib. He attended his primary school in *Mohammad Jeran* school and his secondary school at *Salah Eldin* school from 1988 – 2000 G.C. He joined Aleppo University, faculty of agriculture in 2000 and graduated with Bsc in animal production (ruminants' production) in 2005 G.C. Soon after his graduation, he was employed at general commission of scientific agricultural research, *Gedrin* station for *Awassi* sheep research. He got MSc in animal nutrition from Aleppo University, faculty of agriculture in 2008. He worked intensively on crop residue and agro-industrial by-products and animal nutrition technologies during his career in Syria for almost 7 years. The author is married with no children yet.

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ABBREVIATIONS

ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
Ca	Calcium
CP	Crude Protein
CPI	Crude Protein Intake
CR	Crop Residue
Cu	Cupper
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 Spectroscopy
OLS	Ordinary Least Squares
OM	Organic Matter
P	Phosphorus
SAS	Statistical Analysis System
SD	Standard Deviation
TLU	Tropical Livestock Unit
Zn	Zinc

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Influence of varietal selection and treatments on nutritive value of some legume residue

ABSTRACT

Crop residue (CR) is a multi-purpose resource in the mixed crop-livestock systems of Ethiopian highlands. They serve mainly as livestock feed and inputs for soil and water conservation. They are generated predominantly from cereals and pulses. However, in view of the allocation of CR, soil conservation and livestock are two competing enterprises. Identifying determinants of the intensity of use of cereal and pulse residue may help in designing strategies for more efficient CR utilization. Data on CR 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 a multivariate Tobit model. Results of the study showed that farmers prefer using CR from pulses over CR from cereals for livestock feeding purposes. The proportion of CR from pulses that was used as feed was positively affected by education level of the farmer, livestock extension service, number of small ruminants and CR 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 CR 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 CR generated in the preceding season. In view that pulse CR have better nutritive value compared to cereal CR, better utilization of CR 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 an 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 CR in the household. Increasing the biomass of CR will

help optimizing the utilization of this resource for both livestock feeding and soil mulching. According to the previous results, improving the yield and the nutritive value of chickpea, faba bean and lentil can improve the utilization of CR and enhance livestock productivity in the farming unit. Varietal selection based on straw traits requires sufficient genotypic variation in straw parameters. Furthermore, the expected improvement in the nutritive value of CR during multi-trait improvement has to be considerable compared to that could be achieved by practical treatments. Thus, urea treatment, widely used to improve the nutritive value of CR and ash treatment, a practical and cost-effective treatment to improve CR quality, were used as a baseline to evaluate the variation in straw quality. Besides, integrating straw quality into improvement programs of pulses requires a reliable method to phenotype straw samples for nutritive quality traits. Final evaluation of superior straws should be done *in situ* trial; such trials need an evaluation of IVOMD and ME before commencement. Thus, predicting IVOMD and ME using chemical analysis facilitates conducting such trials. An evaluation of the relationship between straw and grain traits is important to explore the existence of any tradeoff between grain yield and straw traits. Accordingly, to determine the existence of varietal variation in straw quality, twenty three cultivars, one local variety and one improved and released variety of lentil released for high grain yield were replicated four times in a randomized complete block trial. Fourteen cultivars, one local variety and two improved and released varieties of chickpea released for high grain yield were replicated four times in a randomized complete block trial. Both trails were carried out in Ethiopia, Debre Ziet Agricultural Research Centre. Five varieties of faba bean, four improved and released variety and one local variety, were investigated for varietal variation in straw yield, grain yield and nutritive value of straw morphological fractions. Samples of the whole faba bean biomass were collected and separated into grain and straw. The straw was further divided into leaves, stems and pods. Straw from plots of the local varieties of the trials was used to determine the effect of 4% urea treatment, the effect of dung ash treatment (control, 0g ash/L, 100 g ash/L, 200 g ash/L 300 g ash/L) and wood ash treatment (control, 0 g ash/L, 150 g ash/L, 200 g ash/L) on the nutritional value. All straw samples were evaluated for proximate analysis, *in vitro* organic matter digestibility (IVOMD) and metabolizable energy (ME) using Near Infra-red Spectroscopy. Varietal variation ($P<0.001$) in grain yield and straw yield and nutritive value was found in chickpea and lentil. Significant varietal variations ($P<0.001$) were detected in dry matter (DM), ash, IVOMD, ME and potential ME intake (MEI) but not in

CP, neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL), potential DM intake (DMI) and potential CP intake (CPI) of whole faba bean straw. Urea treatment significantly (P<0.001) improved CP, ME, IVOMD, DMI, CPI and MEI of chickpea straw, faba bean and lentil straw. Least significant difference (LSD) among chickpea genotypes was higher than the increase resulted from urea treatment for IVOMD, ME, DMI, and MEI (1.15, 1.17, 1.45 and 1.24 folds respectively). The increase in CP and CPI in chickpea straw due to urea treatment was higher than the corresponding genotypic LSD (1.53 times and 1.66 time respectively). The increase caused by urea treatment of faba bean straw was higher than corresponding genotypic LSD (66.2 times for CP, 12.5 times for IVOMD, 2.1 times for ME, 5.5 times for CPI and 1.4 times for MEI). Genotypic LSD of DMI of faba bean straw was 1.3 times higher than that resulted from urea treatment. Urea treatment significantly (P<0.001) improved CP, ME, IVOMD, DMI, CPI and MEI of lentil straw. In lentil, the increment in CP and CPI of straw resulted from urea treatment was 2.61 times and 0.47 times higher than the corresponding genotypic based LSD respectively while that increment in IVOMD, ME, DMI was 1.1 times, 2.5 times and 0.92 times higher than the corresponding genotypic LSD. Dung and wood ash treatment failed to improve the nutritive value of faba bean, chickpea and lentil straws. Leaves of faba bean straw showed the highest IVOMD and content of CP, while pods were highest in ME. Varietal variations in straw quality traits within fractions were significant (P<0.001). Canonical correlation analysis showed significant correlations between the nutritive value of the whole faba bean straw and the nutritive value and proportions of its botanical fractions. (P<0.001). Furthermore, canonical correlation between nutritive value of whole faba bean straw and relative proportion of fractions was significant and moderate (P<0.001). Therefore, botanical structure can be used as reliable method for screening faba bean genotypes for straw quality. The results of the current study showed that ADF, correlating very strongly (r>0.8) to other nutritional quality parameters in chickpea, faba bean and lentil straws, can present solely straw nutritive value. Straw yield of chickpea correlated weakly with grain yield (r=0.367, P= 0.002) while no relation between grain yield and straw quality traits was found (CP: r=0.087, P=0.526; IVOMD: r=,-0.49 P= 696; ME: r=-0.049, P= 0.668). Grain and straw yields were positively, strongly and significantly (P<0.001) correlated in faba bean. Grain yield of faba bean weakly correlate to CP (r= 0.162, P= 0.42), IVOMD (r= 0.027, P= 0.741) and ME content of straw (r=0.164, P= 0.05). In lentil, straw yield correlated weakly with grain yield (r=0.39, P<0.001) while no relation between grain yield and straw quality traits was found (CP: r=-0.23, P= 0.06; IVOMD: r= -0.104, P= 0.397; ME: r= -0.11, P= 0.37). Accordingly, straw yield and quality traits can be integrated into multi-trait improvement programs of chickpea, faba bean and lentil without compromising grain yield leading to varieties with superior grain and straw traits. These varieties are expected to have a multi-dimensional benefit in the farm including securing more food for humans and feed for livestock and contributing positively to soil conservation.

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., 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 (CR) have shown that leaving 30% of the residue on crop farm plots reduces soil erosion by up to 80% (Rockström et al., 2009, Thornton and Herrero, 2015). In mixed crop-livestock farming systems, the use of CR 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 CR to the total dry mater intake of the livestock in Ethiopia ranges from 10% to 70% (Alemayehu, 2003, Zinash et al., 2001). The CR 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 CR from pulses have better nutritive value compared to CR 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 CR could be achieved by maximizing the use of pulse CR for livestock feeding and optimizing the use of cereal CR for both mulching and livestock feeding. Studies on the utilization of CR are limited and have mainly focused on maize residue (Jaleta et al., 2015, Jaleta et al., 2013). Thus, identifying the determinants of CR utilization of CR considering the difference in nutritional value between cereal and pulse and pulse straws will be the first step to direct the possible interventions by livestock which can lead to improve the utilization of CR in the mixed farming system. Moreover, improving the nutritive value of pulse straws will improve livestock productivity and will might increase the use of cereal straws for soil mulching. In

Ethiopia, chickpea (*Cicer arietinum*), faba bean (*Vicia faba)* and lentil (*Lens culinaris*) are grown over an area of 877000 ha and yields 1100000 tonnes annually (CSA, 2014) and their grains are a primary source of protein and cash income for the farmers (Mulualem et al., 2012). Growing chickpea, faba bean and lentil will accompanied by large amounts of straw which are superior to cereal straws in terms of nutritive value (López et al., 2005). Chickpea straw contains in average 65 g/kg of crude protein (CP), 694g/kg of neutral detergent fiber (NDF), 516g/kg of acid detergent fiber (ADF), 111g/kg of acid detergent lignin (ADL), and 7.7 MJ/kg of metabolizable energy (ME) (Bampidisa and Christodoulou, 2011). It has been already reported that the chickpea straw has moderate nutritive value as ruminant feedstuff (Aghajanzadeh-Golshani et al., 2012, Maheri-Sis et al., 2011). The nutritive value of faba bean straw is relatively high, containing an average 7.4 g/kg crude protein (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 -111g/kg DM and metabolizable energy (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/kg of metabolic weight. Therefore, chickpea, faba bean and lentil are not only an important source of food for households, they are 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. Extensive studies on urea treatment have been carried out to upgrade the nutritive value of cereal straws, however, studies on improvement of the nutritive value of legume straws are limited. There are several constraints that limit the adoption of urea treatment by farmers in developing countries. These include availability and cost of urea, availability of water, constraints of crop residue storage, lack of skills and knowledge associated with its use, availability of labour and potential of toxicity (Chenost and Kayouli, 1997, Fall, 1988). Furthermore, the utilization of the incremented CP due to urea treatment is reported to be low (<30% of the fixed CP by the crop residue due to urea treatment) (Ribeiro, 1994). An increase by 1.55 times in grain yield was reported in chickpea as a result of 100kg/ha of urea fertilization (Namvar and Sharifi, 2011). Applying nitrogen fertilization in rate of 30 kg/ha (68.2 kg of urea/ha) increased grain yield of faba bean by 135% in average (Aguilera-Diaz and Recalde-Manrique, 1995). A recent study has reported that application of 50 kg/ha of urea fertilization increased grain yield of lentil by 40% and straw yield by 60% (Tena et al., 2016). Another study showed that urea fertilization increased the biomass production and CP content of rice straw (Cui et al., 2016). Thus, finding feasible alternative to urea treatment to improve nutritive value of chickpea straw will not only improve its nutritive value, but it will also contribute increasing grain yield indirectly through providing more nitrogen fertilization to the farm. 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). In contrary to that, Genin et al. (2007) reported low effectiveness of dung ash treatment in improving roughages. Varietal selection to increase the nutritive value of chickpea straw holds promises. Studies on chickpea have reported wide genetic variation for 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 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 indicate to 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 could promise selecting chickpea varieties which combine superior grain and straw traits. Studies on the varietal variation of faba bean have mainly focused on agronomic traits (Alghamdi, 2009, Keneni et al., 2005, Mulualem et al., 2012, Ricciardi et al., 2001). These studies reveal a high genetic variation in plant height, the number of pods per plant, seeds per pod and branches per plant, and the duration of vegetation and maturity which may lead to an exploitable variation in straw yields and quality. Gebremeskel et al. (2011) revealed that location and variety have an effect on the cell wall components and the digestibility of faba bean straw. Several studies have reported on considerable variability in leaf to stem ratio, plant height, number of pods per plant and number of branches per plant of lentil (Al-abdalla and al-nabelssi, 2014, Chakraborty and Haque, 2000). 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). Inadequate fertilization is one of the most important constraints of crop production in general (Tena et al., 2016). Exploiting the genetic variation in the nutritive value of lentil straw would divert the use of urea for straw treatment to fertilization. Integrating straw quality traits into multidimensional improvement programs of any crop requires wide genotype-dependent variability in the nutritive value of residue, possibility of manipulating residue traits and grain yield independently and a reliable method for phenotyping large numbers of residue samples for nutritive value (Sharma et al., 2010)

1.1. Research gap

Crop residue from pulses and cereals is an important resource for livestock and soil conservation in mixed farming system of Ethiopia. However, analyzing the factors optimizing its utilization were not studied. Urea, dung ash and wood ash treatments as a methods to improve the nutritional value of CR was intensively researched, however, their effect on pulse crop residue were not studied. Genetic variation and possibility of integrating straw traits into multi-dimensional improvement of crops was studied in many crops. but not in chickpea, faba bean and lentil.

1.2. Research Questions and Objectives

The research questions addressed in this study were:

1) What are the factors feecting the utilization of cereal and pulse residues in the mixed farming system of Ethiopia (specifically improvement of pulse residue yield and quality)?
2) Dose urea treatment improve the nutritional value of chickpea, faba bean and lentil straws?
3) Can dung and wood ash treatments increase the nutritive value of chickpea, faba bean and lentil straws?
4) Is there any possibility to exploit the varietal variation in straw traits for parallel improvement of the both grain and straw of chickpea, faba bean and lentil?

1.3. General objective

The general objective of this study is to test possibility of integrating straw traits into multi-dimensional improvement of chickpea, faba bean and lentil.

1.4. Specific objectives

The specific objectives of this dissertation were:

1) To analyze the improving the overall utilization of CR mainly through improving pulse residue biomass and quality in the mixed farming system of Ethiopia.
2) To determine the possibility of increasing the nutritive value of chickpea, faba bean and lentil straw using urea, dung ash and wood ash treatments.
3) To analyze the possibility of introducing straw traits into multi-trait improvement of chickpea, faba bean and lentil.

2. LITERATURE REVIEW

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 CR 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 CR. Very few studies analyzed the factors affecting the utilization of CR 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 was 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 CR 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 for feed and energy, which may facilitate stover use as soil mulch (Jaleta et al., 2015). Livestock herd affected positively the use of maize stover for feeding and decreased the use 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 CR (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 between6.2-7.2 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 male 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 effectvesness of these tannins are not studied yet. The nutritive value of faba bean straw is relatively high, containing an 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 metabolizable energy (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 $g/kg^{0.75}$.

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

Although CR 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, CR 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 CR 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 substrate and urea treatment process. 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 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).

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

Integrating the nutritive value of CR 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 CR 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 CR 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 there pricing of the stover is strongly correlated with the favourable fodder quality traits (Rama Devi et al., 2000). Inclusion of straw quality in multi-dimensional crop improvement requires wide genotypic variation in CR traits, reliable method for phenotyping huge number of straw samples for quality traits in short time and sufficient description of the relation between grain yield and

CR traits (Sharma et al., 2010). Table 1 present results of studies on the genetic variation in the grain and CR traits in several crops. Beyond of variation in fodder quality, variety of CR 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 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 CR is the potential intake of DM, CP and ME. Conventional lab analysis and *in situ* trials to evaluate CP, ME and DMI of CR are costly, time consuming and do not cope with phenotyping large number of CR samples. Near infrared spectroscopy (NIRS) 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, Botanical structure based ranking of CR quality offers a reliable option. Studies shows existence of botanical–based variation in CR 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. Varietal variation in the dry matter intake of the CR was observed. Intake of 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). According to these studies, there is high possibility to integrate CR traits into multi-dimensional improvement of crops.

Table 1. Genetic variation in grain and CR 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
		CR 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
		CR yield (t/ha)	2.8-5.5	
		CP (g/kg DM)	4.3-8.6	
		IVOMD	40.7-46.1	256
		Digestible CR yield (t/ha)	40.7-46.1	
(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
		CR 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
		CR 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. 2years
		In sacco DM digestibility for 24h	32.1-37.5	
		Gain yield (t/ha)	1.01-1.91	
		CR yield (t/ha)	2.33-5.03	

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

Table 2. Relationship between grain and CR 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.

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3. MATERIALS AND METHODS

3.1. Data collection

3.1.1 Survey data

The survey was carried out in cereal-pulse-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).

Table 3. General information about the studied areas

District	Village	N of households interviewed	Altitude (m.a.s.l)	Average Temp. (°C) Min	Max	Precipitation (mm)	Agro-ecology
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

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. Farmers within each PA were selected using a proportionate to size sampling method. The total number of the farmers participated in the study was 160 farmers. Data was collected using a structured questionnaire. The data collected included household characteristics, resource ownership by households and CR production and utilization. Cop residue production (t/household) was estimated from the grain production of each crop using conversion factors (Table 4).

Table 4. Multipliers used for estimation of CR 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)

3.1.2. Experiment 1: Varietal variation in feed and food traits in chickpea

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, Akaki experimental site (08^{0}53'N; 38^{0}49′ E; elevation: 2200 m.a.s.l; average annual rainfall 1025 mm) during the main rainy season of the 2013 cropping year. The type of the experimental site soil was vertisols. The experimental site was planted with wheat during the previous cropping season. Fourteen *Desi* cultivars, one local variety and two released varieties for high grain yield (*Minjar* and *Natoli*) were included in the study (Table 9). The trial was replicated 4 times in the field with 8 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 8 m×2.4 m. All plots were hand planted and did not receive fertilization or irrigation. At physiological maturity, above ground portions of all plants in each plot were harvested from two 9.6 m^2 areas laid over the four 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.

3.1.3. Experiment 2: Varietal variation in feed and food traits in faba bean

Four improved varieties, namely Degaga, Mosisa, Shallo, and Walki and one local variety were obtained from Sinana Agricultural Research Center, Oromia, Ethiopia. The germplasm of the improved varieties was obtained from the International Center for Agricultural Research in the Dry Areas (ICARDA). Germplasm was initially tested by the Ethiopian Institute of Agricultural Research for adaptability to the local environment and crossbred with local varieties. The selected varieties in this study are among those released based on their high yield potential. The 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 studied varieties are presented in Table 1. The experimental plots were planted by hand and received optimal crop management as per the recommended practices for faba bean. The plots were manually seeded at rate of 200 kg/ha. Chemical fertilization was applied with 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 experiment 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. The 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.

3.1.4. Experiment 3: Varietal variation in feed and food traits in lentil

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 Dona experimental site (08° 57' N, 39° 6' E, elevation: 2450 m.a.s.l, average annual rainfall 876 mm) 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 tree cultivars bred for early maturity and high grain yield, one local variety and one released variety for high grain yield (namely *Derash*) were included in the study (Table 11). The trial was replicated 4 times in the field with eight 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 8 m×1.6 m. All plots were hand planted and did not receive fertilization or irrigation. At physiological maturity, above ground portions of all plants in each plot were harvested from two 6.4 m^2 areas laid over the four 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 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.

3.1.5. Ash and urea treatments

Straw of local variety in the study was bulked after sampling and 3 kg of each were used to test the effect of ash and urea treatment. Each bulked straw was randomly divided into 10 sub-bulks and each sub-bulk was divided into 9 replicates 100 g each. The replicates was assigned randomly to one of the following groups: control (no treatment), plain water, dung ash treatment (100 g ash/L), dung ash treatment (200 g ash/L), dung ash treatment (300 g ash/L), wood ash treatment (100 g ash/L), wood ash treatment (150 g ash/L), wood ash treatment (200 g ash/L) and urea treatment. Eucalyptus wood was collected from one carpenter in Addis Ababa while cattle dung were collected from Lagatafo village (20 km to the east of Addis Ababa, Ethiopia). Cattle dung and wood were burnt for a 24 hours a vicinity in the International Livestock Research Institute (ILRI). Dung ash was light grey to dark in color and could have several impurities such as soil while wood ash was darker in color and more homogenous. Dung and wood ash treatment followed the procedure proposed by Nolte et al. (1987). Briefly, ash was soaked in water for 48 h then filtered through a double layer cotton cloth to get a clear solution. Four solutions were prepared from dung ash as follow: 0 g ash/L, 100 g ash/L, 200 g ash/L and 300 g ash/L. The concentrations used for wood ash treatment were 0 g ash/L, 100 g ash/L, 150 g ash/L and 200 g ash/L. This is because the solution of 300 g wood ash/L was so thick and cannot be used practically for CR treatment. To treat the straw with ash solution, straw replicate was mixed with 100 mL of solution and filled in plastic bag for 6 h and after then hand-squeezed to remove as much solution as possible. Treated samples were dried in ventilated oven (40 °C) for 48 h. Urea treatment in our study followed guides of Chenost and Kayouli (1997). Briefly, straw was treated with a 40 g/L urea solution in rate of 40 mL of solution to 100 g 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 treatment, bags were open and dried by spreading them on the floor for three days. Straws of all replicates were ground in a laboratory mill to pass through a one mm mesh screen and stored for further analysis.

3.2. Straw quality analysis

Straw samples were analyzed for dry matter (DM), 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 Spectroscopy (NIRS; Instrument FOSS 5000 Forage Analyzer with WINSI II software package). For the conventional analysis, DM, ash, CP were analyzed according to AOAC (2000) (method 934.01). Ash was determined according to method 942.05. Nitrogen content of the sample was determined by Kjeldahl method using Kjeldahl (protein/nitrogen) Model 1026 (Foss Technology Corp.) (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). Heat stable amylase was not to analyze NDF and NDF 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 & Steingass (1988). Gas production was recorded after 24 hours of incubation and used to calculate IVOMD and ME according to Menke & Steingass (1988) equations. All chemical analyses were undertaken at the International Livestock Research Institute, Animal Nutrition Laboratory in Addis Ababa, Ethiopia.

3.3. Calculations and statistical analysis

3.3.1. Survey data

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 CR utilization. The implication is that our latent dependent variable (y^*), which denotes interest in a specific CR, is not observed until the interest in the CR utilization exceeds some known constant threshold (L); i.e., we observe y^* only when $y^* > L$. Using ordinary least squares (OLS) 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:

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

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 CR are 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]:

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

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:

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

Since the four types of allocation of the CR 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:

$$\boldsymbol{L} = \int_{-\infty}^{-\boldsymbol{X}_1\beta_1} \ldots \int_{-\infty}^{-\boldsymbol{X}_m\beta_m} f(\xi_1, \ldots., \xi_4) d\xi_1 \ldots d\xi_m. \tag{4}$$

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:

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

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 $\boldsymbol{L'L} = \boldsymbol{\Sigma}$ and $\boldsymbol{e}$ is a vector of independent standard normal random draws, then:

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

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

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

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

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 CR	
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, ton/household

3.3.2. Varietal variation in feed and food traits and effect of ash and urea treatments

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)* $= 1000 \times 30 \times 120/NDF$ *(% 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). Chenost and Kayouli (1997) reported that only some of 30% of the fixed CP in straw treated with urea could be utilized by the rumen microorganisms. That is because some of the fixed CP due to urea treatment is linked irreversibly to cell walls (Ribeiro, 1994) and some of the fixed CP is rapidly degraded and not utilized by rumen bacteria (Sarwar et al., 2004, Yang et al., 2010). Accordingly, CP and CPI of urea treated straw were corrected and the corrected values were used further in discussing the results. Daily requirements of one sheep 30 kg live weight for maintenance –adopted from Kearl (1982)– jointly with DMI, CPI and MEI were used to evaluate the straw. Data of experiment 1 and 3 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, G_i is the effect of genotype i, B_j is the effect of the block j and E_{ij} is the random error. For experiment 2, a general linear model was used to test the effect of variety on grain yield, straw yield and the proportion of botanical fractions of the straw. For straw quality, two different models were applied. To compare straw quality traits, the first model included the effect of variety, straw fraction (pods, leaves and stems), and the variety-fraction interaction. The second model analyzed the effect of variety on the nutritive value of the whole straw. One way analysis of variance was used to analyze the effect of urea treatment on chemical composition and nutritive value of individual straws. Other one way analysis of variance was used to analyze the effect of straw origin on the change in chemical composition and nutritive value of straw due to urea treatment. Effect of concentration of ash on the pH of treatment solution was analyzed using one way analysis of variance. Effect of ash origin on mineral composition of ash was analyzed using one way analysis of variance. For both dung and wood ash trials, the effect of ash solution concentration, origin of straw and the interaction between ash solution concentration and straw origin was analyzed. Analyses of variance in the current study were done using GLM procedure of SAS 9.3. Least significant difference at 0.05 level of probability was the mean separation method. Canonical correlation is a multivariate analysis used to assess the correlation between two sets of variables at the same time. The canonical correlation analysis was conducted to explain the relationship between (a) the quality traits (DMI, CPI, and MEI) of the whole straw of faba bean) and each faba bean straw fraction and (b) the correlation between the quality traits of the whole faba bean straw and the relative proportion of the three straw fractions. Estimating IVOMD and ME content of straw is required for any further *in situ* evaluation of nutritive value of chickpea straw. Gas production method to measure IVOMD and ME is time consuming and costly. Predicting IVOMD and ME of chickpea straw using the chemical analysis offers feasible alternative to *in vitro* estimation of ME and OM digestibility using gas production technique. Stepwise multiple regression analysis was used to identify the best model which describe the relation between IVOMD and ME and chemical analysis of chickpea straw. Linear relationships between grain and straw traits were calculated using Pearson's correlation. Pearson’s correlation was calculated between CP and IVOMD of untreated straws and their corresponding values in urea treated straws for each crop separately. 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 $0.8 < r < 1$. All statistical procedures were carried out using Statistical Analysis System software (SAS, 2012).

4. RESULTS AND DISCUSSION

4.1. Determinants of farmers' utilization of cereal and pulse residue in the highlands of Ethiopia

4.1.1. Descriptive analysis

Summary of the descriptive statistics of the variables used in the regression model is presented in Table 6. Results 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. 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 CR 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 CR 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 CR 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 CR 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 5 show that the proportion of the pulse residue used as feed was significantly higher than the proportion of cereal residue used as feed ($P<0.01$).

Table 6. Descriptive statistics of variables used in the empirical analysis

Variables	Unit	Statistic	
		Mean(s.d.)	%
Household characteristics			
Household head age	Years	45.1(13.3)	—
Household head sex (male)	%	—	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	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	Tropical livestock units	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 CR			
Male	%	—	35.9
Female	%	—	9.43
Joint	%	—	54.7
Perception about mulching CR	%	—	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.

Contrary to that, the proportion of CR used for soil mulch was significantly higher in cereal residue compared to pulse residue (P<0.01). There was high awareness among the farmers about the importance of mulching CR to improve the soil quality. However, the average proportion of CR allotted for soil mulching only met 50% of the recommendation for mulching. Farmers in the studied areas tried to maximize the utilization of CR 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 CR 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 DM per day for maintenance propose.

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

Utilization	Cereal	Pulse	SL
Livestock feed (%)	84.6(13.7)	89.6(15.1)	***
Soil mulch (%)	15.4(13.7)	10.4(15.1)	***

Percentage of the households used CR as:

	Cereal	Pulse
Livestock feed	98.1	98.7
Soil mulch	88.8	71.8

Values between parentheses are noted for the standard deviation.

Thus, the livestock kept in the households need an average of 20.9 ton of dry matter, 667 kg of crude protein and 80033 MJ of ME. In the current situation, the CR per household could provide 11.2 ton of DM, 504 kg of CP and 75420 MJ of ME. Therefore, cereal and pulse residue could cover only 53.5%, 75.6% and 94.2% of the maintenance requirement of the household's livestock from DM, CP and ME, 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 residue 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 CR 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 CR 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.

4.4.2. Regression analysis

Effect of socioeconomic and biophysical factors on cereal and pulse residue utilization is presented in Table 8.

4.4.2.1 Household characters

Female headed households allocated significantly larger proportion of pulse residue as feed compared to the male headed households ($P<0.01$). It was observed that when the female joined in making the decision on CR 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. 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. 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 CR collection and transportation from the field to the homestead. The result of our study shows that 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 ($P<0.01$) while no significant effect of household size on the utilization of cereal residue was detected. 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.

4.4.2.2. 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. That means farmers who cultivate sloppy plots are aware of 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 CR as mulch which agrees with the results of Jaleta et al. (2013). This result implies the importance of the need for labor for collecting and transporting the CR to the homestead to use it as livestock feed.

4.4.2.3. Extension and perception

Household heads who got farmer-to-farmer extension and state extension on mulching using CR 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 ($P<0.01$) which is in line with Jaleta et al. (2015) and Jaleta et al. (2013). Household heads who were aware of the importance of soil mulching used greater proportions of cereal and pulse residue as soil mulch. Moreover, the higher the literacy level of the household head, the larger the proportion of pulse and cereal residue used as soil mulch ($P<0.01$). That showed the significant role of the extension service in addition to informal social networks in maximizing the utilization of CR through increasing the use of pulse residue as feed and the use of cereal residue mainly as soil mulch.

4.4.2.4. Livestock kept by the household

Livestock herd size (TLU/ha) of the household did not decrease the proportions of CR 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 ($P<0.01$). 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 CR as a crucial feed resource in the mixed farming system of Ethiopia highlands.

4.4.2.5. Crop residue stock from earlier harvests.

The stock of CR 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 residue is major in-house feed resource for the livestock. When the production of CR 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 CR yields, could increase the efficiency of CR utilization in the mixed farming system.

Table 8. Multivariate Tobit estimation results on the CR 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				
Flat				
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		-0.14(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 CR				
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(0.00)**
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; CR: crop residue.

4.2. Varietal variation in straw and grain traits in chickpea, faba bean and lentil

4.2.1. Straw quality

4.2.1.1. Chickpea

Effect of genotype on chemical composition ad nutritive value of chickpea straw proved significant (P<0.001) (Table 9). Significant (P<0.001) genotypic variation in DM of chickpea straw was found however the range was not important. Ash content of chickpea straw ranged from 29.8 g/kg in DZ2012CK0236 to 62.3 g/kg in DZ2012CK0230 for all trail genotypes and for high grain yielders as well. Only two genotypes hosted higher ash content compared to local variety. Crude protein in chickpea straw varied widely from 70.5 g/kg in local variety to 111 g/kg in DZ2012CK2011S16005. Five grain yielders hosted higher CP than local variety ranging from 91.9 g/kg in DZ2012CK2011S50045 to 106 g/kg in DZ2012CK0227. Neutral detergent fiber (g/kg) and ADF (g/kg) ranged from (642 and 360) in DZ2012CK2011S16005 to (754 and 466) in DZ2012CK0236 with both high grain yielders and all genotypes. Among the higher grain yielders, none of the genotypes had lesser NDF or ADF than local verity. Acid detergent lignin of chickpea straw varied from 82.9 g/kg in DZ2012CK2011S16005 to 112 g/kg in DZ2012CK0236 considering all genotypes while that ranged started by 83.5 g/kg in DZ2012CK0240 to DZ2012CK0236 considering high grain yielders only. Among high grain yielders, only three genotypes hosted lesser ADL than local variety. Chickpea straw IVOMD and ME had the same behavior. For all genotypes 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) of the high grain yielders ranging from 484 g and 7.08 in DZ2012CK0236 to 546 and 8.03 in DZ2012CK0239, was not higher than that of local variety. Potential dry matter intake of chickpea straw ranged from 478 g DM/ head per day in DZ2012CK0236 to 574 g DM/ head per day in DZ2012CK2011S16005. Within high grain yielders only, DMI varied from DZ2012CK0236 (478g DM/head per day) to DZ2012CK0227 (562 g DM/head per day). None of the high grain yielders had better DMI than that of local variety. Potential intake from CP ranged from 34 g CP/head per day in DZ2012CK0236 to 64.4 g

CP/head per day in DZ2012CK2011S16005. Only four high grain yielders hosted better CPI than that of local variety. Grain yielders CPI ranged from DZ2012CK0236 to 59.6 g CP/head per day in DZ2012CK0227. Potential intake of DM of all genotypes ranged from DZ2012CK0236 with value of 3.83 MJ ME/head per day to DZ2012CK2011S16005 with value of 4.69 MJ/head per day. Among grain yielders, only DZ2012CK0227 with MEI of 4.48 MJ/head per day was better local variety. Grain yielders ranged in MEI from DZ2012CK0236 (3.83 MJ/head per day) to DZ2012CK0227 (4.48 MJ/head per day). Urea treatment improve the nutritive value of chickpea by decreasing significantly ($P<0.001$) fiber constituents and increasing significantly DMI, CP, CPI, IVOMD, ME and MEI. Least significant difference among genotypes for IVOMD, DMI, ME and MEI was considerably higher than the corresponding improvement due to urea treatment but not for CP and CPI which was lesser. When the improvement in CP and CPI due urea treatment were corrected, they became much lesser than the corresponding LSD among genotypes. Ash treatment failed improving the nutritive value of chickpea straw (section 4.5.2). Accordingly, when the improvement in the nutritive value of chickpea straw due to urea treatment and ash treatment were considered as a baseline, genotypic variation in straw quality trait can be considered high as LSD among genotypes has higher values than the corresponding improvements due to urea treatment.

Our findings show that yet grain yield was similar in all improved genotypes their straw varied widely in nutritive value. Such genetic variations was proved in many crops (Table 1). When DMI, CPI and MEI were compared to the nutrients requirement of dry sheep 30 kg live weight, the best straw in terms of DMI meets 110% of the requirement, the best straw in CPI meets 73% of the requirement and the best straw in MEI meet 95%of the requirement.

Table 9. Effect of genotype on the chemical composition and nutritive value of chickpea straw

Genotype	DM	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
Cultivars											
DZ2012CK0048	925	49.8	86.8	677	401	89.5	522	7.63	532	46.2	4.06
DZ2012CK0227	924	49.6	106*	642	360*	86.5*	542	7.97	562	59.6*	4.48*
DZ2012CK0228	926	52.7	83.9	673	397	90.1	527	7.76	536	44.9	4.16
DZ2012CK0229	924	46.1	84.0	689	416	91.3	515	7.59	523	43.9	3.97
DZ2012CK0230	922	62.3*	89.9	652	388	89.2	526	7.70	553	49.6	4.26
DZ2012CK0231	928	47.3	80.6	710	435	96.8	503	7.37	508	41.3	3.76*
DZ2012CK0232	923	53.8	92.3*	652	385*	86.7	540	7.93	555	51.9*	4.41
DZ2012CK0233	923	49.2	83.0	674	405	92.0	523	7.66	536	44.5	4.12*
DZ2012CK0234	926	42.6	85.7	675	404	90.4	530	7.79	537	46.8	4.20
DZ2012CK0235	926	43.4	105*	667	375*	87.8	543	7.97	540	56.9*	4.30
DZ2012CK0236	931	29.8	71.2	754	466	112	484	7.08	478	34.0	3.38
DZ2012CK0237	927	45.0	77.0	667	403	92.2	529	7.84	541	41.8	4.24
DZ2012CK0238	925	51.1	90.0	678	401	89.5	530	7.74	533	48.1	4.14
DZ2012CK0239	928	54.4	95.6*	651	371	83.9*	546	8.03	555	53.7*	4.47
DZ2012CK0240	923	46.5	94.2*	649	368*	83.5*	545	7.98	555	52.4*	4.43
DZ2012CK0241	924	52.6	91.5*	669	401	87.8	527	7.76	543	50.6	4.25
DZ2012CK2011S10041	927	39.7	81.4	686	414	95.0	524	7.71	524	42.6	4.04
DZ2012CK2011S15005	923	50.9	79.5	697	428	96.8	510	7.46	517	41.2	3.87
DZ2012CK2011S16005	923	55.4*	111*	632*	360*	82.9*	553*	8.13*	574*	64.4*	4.69
DZ2012CK2011S20042	922	54.8	100*	634*	368*	83.5*	552*	8.13*	569*	57.0*	4.63
DZ2012CK2011S30043	932	34.8	78.0	712	422	101	514	7.55	505	39.4	3.81
DZ2012CK2011S50045	924	56.8*	91.9*	667	397	92.1	520	7.60	540	49.7	4.10
Varieties											
Local variety	927	43.8	70.5	699	438	98.5	515	7.59	515	36.4	3.91
Minjar	926	55.1*	103*	644	371*	84.4*	545	7.99	560	57.8*	4.48
Natoli	927	37.5	81.1	700	416	93.8	522	7.64	514	41.8	3.93*
LSD (0.05)	5.09	15.2	19.6	61.4	51.6	11.8	32.4	0.5	50.5	14.5	0.656
SEM	1.79	5.34	6.9	21.6	18.1	4.15	11.4	0.176	17.8	5.13	0.23

Means with * higher than local variety except fiber constituents which are lesser; DM: dry matter (g/kg as fed); 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; ME: metabolizable energy (MJ/kg DM); DMI, CPI and MEI are denoted to potential intake of DM (g/head per day), CP (g/head per day) and ME (MJ/head per day) of straw respectively by 30 kg live weight sheep; $P<0.001$ for all traits..

4.2.1.2. Faba bean

No significant differences were detected among the varieties in CP, NDF, ADF, ADL, DMI and CPI of the whole straw whereas varietal variation was detected for DM, OM, ash, IVOMD, ME and MEI (Table 10). The genotypic range in DM was very small (2 g/kg). Ash content of faba bean straw ranged between 79.1 g/kg DM in local variety and 70.5 g/kg DM in *Shallo*. The genotypic range in ash was 8.6 g/kg DM. none of improved varieties high higher ash content compared to local variety, however, improved varieties were not similar. *In vitro* OM digestibility of faba bean straw ranged between 437 g/kg in *Shallo* to 404 g/kg in *Degaga*. The genotypic range in IVOMD was 33 g/kg. Only *Shallo* had higher IVOMD than local variety, however, the improved varieties had different values. Metaboilizable energy of faba bean straw ranged between 6.69 MJ/kg DM in *Shallo* to 6.31 MJ/kg DM in local variety. Potential ME intake (MJ ME/head per day) varied from *Degaga* (3.35) to *Walki* (3.69). The genotypic range in ME and MEI was 0.38 MJ/kg DM. and 0.34 MJ/head per day respectively. All of the improved varieties except *Degaga* had higher ME and MEI compared to local varieties but they were similar to each other. Urea treatment significantly ($P<0.001$) improved CP, ME, IVOMD, DMI, CPI and MEI of faba bean straw (section 4.5.1). The increase caused by urea treatment of faba bean straw was higher than corresponding genotypic LSD (66.2 times for CP, 12.5 times for IVOMD, 2.1 times for ME, 5.5 times for CPI and 1.4 times for MEI). Genotypic LSD of DMI of faba bean straw was 1.3 times than that due to urea treatment. Least significant difference in CPI and CPI were 24% and 56% of corrected corresponding improvement due to urea treatment. Our findings show that yet grain yield was similar in all improved varieties their straw varied in nutritive value. Such result was found in chickpea and lentil (section 4.2.1.1 and 4.2.1.2 respectively) and in other cereal crops (Table 1). According to the same calculations in section 4.2.1.1, the best straw in terms of DMI meets 73% of maintenance requirement of a sheep 30 kg live weight, the best genotype in terms of CPI meets 49% the requirement and the best straw in terms of MEI meets 75% of the requirement.

Table. 10. Effect of the variety on chemical composition and nutritive value of faba bean whole straw

	Variety						
	Local	*Degaga*	*Mosisa*	*Shallo*	*Walki*	SEM	SL
DM	901^{ab}	902^{a}	901^{bc}	901^{bc}	900^{c}	0.316	***
Ash	79.1^{a}	76.3^{a}	75.3^{ab}	70.5^{b}	76.5^{a}	1.43	***
CP	53.7	52.7	52.2	50.5	51.3	1.54	ns
NDF	671	679	665	671	661	7.43	ns
ADF	619	617	602	599	599	7.46	ns
ADL	126	126	123	122	123	1.68	ns
IVOMD	418^{bc}	404^{c}	429^{ab}	437^{a}	417^{bc}	6.6	***
ME	6.31^{b}	6.33^{b}	6.61^{a}	6.69^{a}	6.65^{a}	0.09	***
DMI	538	531	543	538	550	6.94	ns
CPI	29.1	28	28.5	27.5	28.7	1.22	ns
MEI	3.41^{b}	3.35^{b}	3.6^{ab}	3.61^{ab}	3.69^{a}	0.096	***

Designation of abbreviations are reported in Table 9.

4.2.1.2. Lentil

Table 11 present the effect of genotype on the nutritive value of lentil straw. Genotype affected significantly (*P*<0.001) nutritive value parameters of lentil straw. The genotypic rang of DM was very small (3 g/kg) thus it was ignored. Ash content of straw ranged from 88.8 g/kg in DZ-2012-LN-0193 to 107 g/kg in DZ-2012-LN-0056. Among high grain yielders, only 2 genotypes hosed higher ash than local variety. Straw content of CP ranged from 38 g/kg in DZ-2012-LN-0199 to 80 g/kg in DZ-2012-LN-0197. Five genotypes had higher CP than that of local variety while one of them was among the high grain yielders (DZ-2012-LN-0191). Straw content of NDF varied from 438 g/kg in DZ-2012-LN-0200 to 550 g/kg in DZ-2012-LN-0199. Eighteen genotypes hosed lesser NDF than local variety and seven of them were high grain yielders ranging in from 455 g/kg (DZ-2012-LN-0191) to 489 g/kg (DZ-2012-LN-0052). Acid detergent fiber range from 301 g/kg in DZ-2012-LN-0200 to 384 g/kg in DZ-2012-LN-0192. 19 genotypes had lesser ADF than that of local variety while 8 of them were high grain yielders ranging from DZ-2012-LN-0056 (317 g/kg) to DZ-2012-LN-0045 (356 g/kg). Straw content of ADL varied from 66.2 g/kg in DZ-2012-LN-0197 to 95.9 g/kg in DZ-2012-LN-0192. Eighteen genotypes hosted lesser ADL than that of local variety, furthermore, ten of them were among the highest grain yielding genotypes. High grain yielders ranged in ADL from 67.5 g/kg in DZ-2012-LN-0191 to 80.3 g/kg in *Derash*. Straw IVOMD (g/kg) ranged from 532 in DZ-2012-LN-0192 to 614 in DZ-2012-LN-0197 and fifteen genotypes hosted higher IVOMD than local variety. High grain yielding genotypes had IVOMD ranging from 567 g/kg in DZ-2012-LN-0042 to 585 g/kg in DZ-2012-LN-0056. Genotypes varied in ME (MJ/kg) from 7.91 in DZ-2012-LN-0199 to 9.17 in DZ-2012-LN-0197 while 15 of them had better content than that of local variety. High yielding genotypes ranged in ME from 8.38 MJ/kg in DZ-2012-LN-0042 to 8.69 MJ/kg in DZ-2012-LN-0056. Genotypes ranged in DMI (g/head per day) from 655 in DZ-2012-LN-0199 to 823 in DZ-2012-LN-0200 but 17 of them had better value than that of local variety. The high grain yielding genotypes in the study ranged in DMI from DZ-2012-LN-0052 with 737 g DM/head per day to DZ-2012-LN-0191 with 793 g DM/head per day. Genotypes varied in CPI (g CP/head per day) from 24.8 in DZ-2012-LN-0199 to 65.4 in DZ-2012-LN-0197, however, only five genotypes including one high grain yielders had better value than that of local variety. The genotypes included in the study varied in MEI (MJ ME/head per day) from 5.18 in DZ-2012-LN-0199 to 7.49 DZ-2012-LN-0197 but 16 of them hosted better value than that of local variety. The high grain yielders ranged in MEI (MJ ME/head per day) from 6.21 in DZ-2012-LN-0042 to 6.86 in DZ-2012-LN-0191. Urea treatment increased the nutritive value of lentil straw (section 4.5.1) while no improvement was found due to ash treatments (4.5.2). Least significant difference among genotypes was lesser than the improvement due to urea treatment in CP and CPI but they were relatively close to each other in IVOMD, ME, DMI and MEI. When CP and CPI improvement by urea treatment are corrected (as described in section 4.2.1.1.), they become closer to the corresponding genotypic LSD. Accordingly, when the improvement in the nutritive value of lentil straw due to urea treatment was used as a baseline, genotypic variation in straw quality trait can be considered high as LSD among genotypes is close to the improvement by urea treatment. . Similar to the results in chickpea and faba bean and in other crops presented in Table 1, wide variation in nutritive value of lentil straw was found even among the high grain yielders. The best straw in terms of DMI meets 110% of the requirement, the best genotype in terms of CPI meets 111% the requirement and the best straw in terms of MEI meets 151% of the requirement (calculations done as described in section 4.2.1.1).

Table 11. Genotype-dependent variation in chemical composition and nutritive value of lentil straw

Genotype	DM	Ash	CP	NDF	ADF	ADL	ME	IVOMD	DMI	CPI	MEI
Cultivars											
DZ-2012-LN-0039	908	101	41	546	375	78.7*	7.96	536	660	27.1	5.26
DZ-2012-LN-0040	906	98.6	62.3	491*	329*	77.9*	8.58*	577*	734*	45.7	6.29*
DZ-2012-LN-0041	907	100	45.9	514*	360*	82.2	8.01	540	700	32.1	5.61
DZ-2012-LN-0042	906	100	60.7	486*	328*	77.8*	8.38*	567*	741*	45	6.21*
DZ-2012-LN-0045	907	95.7	51.9	532	356*	79.7*	8.24	557	677	35.2	5.58
DZ-2012-LN-0048	906	97.3	60.8	479*	348*	75.6*	8.42*	566*	753*	45.8	6.34*
DZ-2012-LN-0050	907	100	48.3	538	367	78.6*	8.15	549	670	32.5	5.47
DZ-2012-LN-0051	906	106	57.1	494*	329*	74.6*	8.74*	586*	730*	41.7	6.38*
DZ-2012-LN-0052	906	100	46	489*	336*	74.5*	8.47*	567*	737*	33.9	6.24*
DZ-2012-LN-0055	906	98.8	49.4	507*	352*	77.5*	8.3	558	711*	35.2	5.9
DZ-2012-LN-0056	906	107*	53.9	481*	317*	69.1*	8.69*	585*	748*	40.4	6.50*
DZ-2012-LN-0057	906	96.8	58	479*	329*	69.3*	8.53*	574*	751*	43.5	6.41*
DZ-2012-LN-0190	906	103	58.9	471*	320*	79.8*	8.6*	580*	764*	45	6.58*
DZ-2012-LN-0191	906	103	73.8*	455*	317*	67.5*	8.65*	583*	793*	58.6*	6.86*
DZ-2012-LN-0192	907	92.1	40	548	384	95.9	7.92	532	658	26.3	5.22
DZ-2012-LN-0193	906	88.8	73.1*	454*	302*	72.4*	9.05*	608*	797*	58.6*	7.23*
DZ-2012-LN-0194	906	92.7	70.6*	470*	314*	81.4	8.89*	596*	766*	54.1*	6.81*
DZ-2012-LN-0195	906	103	58.5	486*	323*	82.8	8.46*	571*	741*	43.4	6.27*
DZ-2012-LN-0196	906	106	59.9	499*	341*	84.6	8.28	559	721*	43.1	5.97*
DZ-2012-LN-0197	905	100	80*	442*	301*	66.2*	9.17*	614*	816*	65.4*	7.49*
DZ-2012-LN-0198	906	107*	53.8	467*	327*	72.3*	8.5*	572*	771*	41.5	6.55*
DZ-2012-LN-0199	907	98.2	38	550	378	83.8	7.91	533	655	24.8	5.18
DZ-2012-LN-0200	905	103	72.3*	438*	301*	70.2*	9.01*	606*	823*	59.9*	7.43*
Varieties											
Derash	907	95.9	55.0	532	368	80.3*	8.06	544	678	37.7	5.47
Local	907	102	57.1	547	383	88.1	7.98	540	659	37.8	5.27
SEM	0.279	1.80	3.89	11.3	7.95	2.45	8.89	0.136	16.9	3.67	0.231
LSD (0.05)	1	5	11.0	32	22.6	6.95	0.387	25.3	48	10.4	0.656

Designation of abbreviations are reported in Table 9.

4.2.3. Pairwise correlations among nutritional quality parameters

Tables 12, 13 and 14 present pairwise correlations among nutritional quality parameters of chickpea, faba bean and lentil straws. Ash content of chickpea straw correlated weakly with CP content. The correlation between ash and ADF, ADL, IVOMD and CPI was moderate in chickpea straw. Ash correlated strongly and positively with DMI and MEI in chickpea straw. Neutral detergent fiber correlated strongly and negatively with CP, and CPI and very strongly with other nutritive value parameters in chickpea straw. In chickpea straw, ADF correlated moderately with ash, strongly with ADL and CPI and very strongly with other nutritive value parameters. Chickpea straw ADL related moderately to ash, strongly to NDF and ADF, and very strongly to other nutritive value parameters. Pairwise Pearson correlations among nutritive value parameters in faba bean straw were significant for all pairs (P<0001). In faba bean straw, ash strongly correlated to NDF, DMI and CPI while it correlated moderately to other nutritive value parameters. Crude protein of faba bean straw correlated strongly to ADF, ADL, IVOMD, ME, DMI and MEI. The correlation between CP and NDF and CPI in faba bean straw was very strong. In faba bean straw, NDF correlated very strongly to ADF, ADL, IVOMD, ME, DMI, CPI and MEI. Acid detergent fiber correlated very strongly to ADL, IVOMD, ME, DMI, CPI and MEI. The correlation between IVOMD and ME, DMI, CPI and MEI was very strong in faba bean straw. Metabolizable energy related strongly to CPI and very strongly to DMI and MEI in faba bean straw. The relationship between DMI and both CPI and MEI was very strong in faba bean straw. Potential crude protein intake correlated very strongly to MEI in faba bean straw. No relation between ash and other nutritive value parameters of lentil straw were found. in lentil straw. Lentil straw CP correlated moderately with ADL, very strongly with IVOMD, ME CPI and MEI and strongly with other nutritive value parameters. In lentil straw, NDF correlated strongly with ADL, IVOMD, ME and CPI. The correlation between NDF and ADF, DMI and MEI was very strong in lentil straw. Acid detergent lignin correlated strongly to IVOMD, ME, DMI, CPI and MEI in lentil straw. The relationship between IVOMD and CPI was in lentil straw strong but that relation with ME and MEI was very strong. The association between ME and MEI was very strong in lentil straw. In lentil straw, ME related very strongly to MEI. In lentil straw, the correlation between DMI and CPI was strong while the correlation between DMI and MEI was very strong. The relationship between CPI and MEI was very strong in lentil straw. Studying the pairwise correlations among nutritional quality parameters of straw is crucial as it can lead to decrease the number of the parameters which can be used to represent straw quality and thereafter assimilate it into multi-trait improvement of crops. Acid detergent fiber had a very strong correlation with all nutritive value parameters in the three crops. Generally, negative and very strong correlation between ADF of straws and overall nutritive value was found. The pooled correlation between ADF and other nutritive value parameters was very strong in in all straws (chickpea: pooled r= 0.85, pooled R^2=0.72; Faba bean pooled r= 0.91, pooled R^2= 0.92; Lentil: pooled r= 0.89, pooled R^2= 0.8). Accordingly, the variability in ADF of chickpea, faba bean and lentil straws can in average explain 72%, 82% and 80% of the variability in other nutritive value parameters respectively. Thus, ADF can present solely the nutritive value of chickpea straw, faba bean and lentil straw. As ADF of the straw increase, the nutritive value decrease. The relationship among nutritional quality parameters of chickpea, faba bean and lentil straws could be affected by the environmental factors. Thus, such correlations should be confirmed by deeper multi-environmental studies.

Table 12 . Pairwise correlations among nutritional quality parameters of chickpea straw

	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
Ash	—	0.39	-0.755	-0.533	-0.495	0.466	0.471	0.74	0.459	0.634
CP	—	—	-0.645	-0.866	-0.637	0.679	0.631	0.681	0.99	0.699
NDF	—	—	—	0.841	0.779	-0.823	-0.834	0.997	-0.721	-0.953
ADF	—	—	—	—	0.843	-0.833	-0.812	-0.864	-0.9	-0.884
ADL	—	—	—	—	—	-0.819	-0.821	-0.796	-0.68	-0.842
IVOMD	—	—	—	—	—	—	0.99	0.843	0.74	0.953
ME	—	—	—	—	—	—	—	0.894	0.7	0.96
DMI	—	—	—	—	—	—	—	—	0.756	0.965
CPI	—	—	—	—	—	—	—	—	—	0.772

P <0.001 for all correlation pairs; Designation of abbreviations is presented in Table 9.

Table 13 . Pairwise correlations among nutritional quality parameters of faba bean straw

	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
Ash	—	0.591	-0.677	-0.534	-0.467	0.363	0.415	0.678	0.65	0.573
CP	—	—	-0.812	-0.784	-0.789	0.673	0.645	0.778	0.964	0.731
NDF	—	—	—	0.95	0.927	-0.805	-0.852	-0.983	-0.915	-0.952
ADF	—	—	—	—	0.976	-0.829	-0.934	-0.93	-0.876	-0.965
ADL	—	—	—	—	—	-0.871	-0.911	-0.906	-0.872	-0.941
TIVOMD	—	—	—	—	—	—	0.861	0.784	0.748	0.849
ME	—	—	—	—	—	—	—	0.829	0.741	0.944
DMI	—	—	—	—	—	—	—	—	0.911	0.963
CPI	—	—	—	—	—	—	—	—	—	0.863

P <0.001 for all correlation pairs; Designation of abbreviations is defined in Table 9.

Table 14. Pairwise correlations among nutritional quality parameters of lentil straw

	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
Ash	—	-0.04	-0.223	-0.193	-0.302	0.074	0.058	0.199	0.000	0.134
CP	—	—	-0.787	-0.799	-0.565	0.841	0.822	0.798	0.984	0.832
NDF	—	—	—	0.946	0.756	-0.899	-0.89	-0.995	-0.868	-0.975
ADF	—	—	—	—	0.748	-0.948	-0.937	-0.936	-0.857	-0.956
ADL	—	—	—	—	—	-0.753	-0.748	-0.755	-0.636	-0.769
IVOMD	—	—	—	—	—	—	0.997	0.9	0.887	0.962
ME	—	—	—	—	—	—	—	0.892	0.871	0.958
DMI	—	—	—	—	—	—	—	—	0.884	0.983
CPI	—	—	—	—	—	—	—	—	—	0.907

P <0.001 for all correlation pairs except that contains ash. Designation of abbreviations is defined in Table 9.

4.2.2. Predicting IVOMD and ME of chickpea, faba bean and lentil straw using chemical composition

The promising genotypes for straw quality and the nominated food-feed genotypes of chickpea, faba bean and lentil should be evaluated for straw quality using *in situ* trials. Data on IVOMD and ME of tested straw is crucial in conducting such trials. Estimating IVOMD and ME content of the straws using gas production method cannot be employed in this process as it is costly and time consuming. Other available option is to predict IVOMD and ME content of straws using chemical composition. Stepwise regression analysis showed that IVOMD and ME of chickpea straw can be predicted from ash, NDF and ADL with satisfactory precision (R^2: IVOMD: =0.789, ME:= 0.804) (Table 15). *In vitro* OM digestibility of faba bean straw can be predicted using ADL content with R^2 of 0.76 whereas ME of faba bean straw can be predicted using ADF with R^2 of 0.872 (Table 16). Stepwise regression analysis presented in Table 16 shows that IVOMD and ME of lentil straw can be predicted simply using ADF (R^2: IVOMD = 0.9, ME= 0.8). The relation between the IVOMD and ME and chemical composition in the straws of chickpea, faba bean and lentil may be affected by environmental factors. Therefore, such prediction equations should investigated in multi-environmental studies.

Table 15. Stepwise regression analysis of the effect of chemical composition on IVOMD and ME of chickpea straw

Dependent variable	Model		Model statistics				Change statistics	
			Coefficient	SE	SL	R^2	R^2	SL of F change
IVOMD	1	Constant	730	1.91	***	0.694	0.694	***
		ADF	-4.8	4	***			
	2	Constant	825	31.6	***	0.745	0.051	**
		ADF	-2.8	0.7	***			
		NDF	-2.66	7.4	***			
	3	Constant	948	52.7	***	0.774	0.029	***
		ADF	-2.25	0.67	***			
		NDF	-4.47	0.95	***			
		Ash	-5.13	1.81	**			
	4	Constant	945	50.2	***	0.798	0.024	**
		ADF	-1.2	0.75	ns			
		NDF	-3.87	0.93	***			
		Ash	-4.73	1.74	***			
		ADL	-7.96	2.96	***			
	5	Constant	975	47.1	***	0.789	0.008	ns
		NDF	-4.66	0.8	***			
		Ash	-5.28	1.72	***			
		ADL	-1.04	2.56	***			
ME	1	Constant	13.19	0.484	***	0.695	0.695	***
		NDF	-0.008	0.001	***			
	2	Constant	12.9	0.429	***	0.77	0.075	***
		NDF	-0.005	0.001	***			
		ADL	-0.018	0.004	***			
	3	Constant	14.8	0.698	***	0.804	0.034	***
		NDF	-0.008	0.001	***			
		ADL	-0.015	0.004	***			
		Ash	-0.008	0.003	***			

Designation of abbreviations is presented in Table 9; ***: P<0.001; SE: standard error.

Table 16. Stepwise regression analysis of the effect of chemical composition (g/kg DM) on IVOMD (g/kg) and ME (MJ/kg) of faba bean straw

Dependent variable		Model	Model statistics				Change statistics	
			Coefficient	SE	SL	R^2	R^2	SL of F change
IVOMD	1	Constant	857	20.2	***	0.76	0.76	***
	1	ADL	-3.51	0.16	***			
		Constant	829	22.9	***	0.77	0.01	**
	2	ADF	-5.29	0.734	***			
	2	ADL	0.407	0.165	***			
ME	1	Constant	13.6	0.223	***	0.872	0.872	***
	1	ADF	-0.012	0.00	***			
	2	Constant	15.6	0.449	***	0.891	0.02	***
	2	ADF	-0.014	0.001	***			
	2	CP	-0.014	0.003	***			
	3	Constant	15	0.512	***	0.896	0.005	***
	3	ADF	-0.016	0.001	***			
	3	CP	-0.011	0.003	***			
	3	NDF	0.003	0.001	***			

Designation of abbreviations is presented in Table 9; ***: P<0.001; SE: standard error.

Table 17. Stepwise regression analysis of the effect of chemical composition, IVOMD and ME of lentil straw

Dependent variable	Model		Model statistics				Change statistics	
			Coefficient	SE	SL	R^2	R^2	SL of F change
IVOMD	1	Constant	871	11.9	***	0.9	0.9	***
		ADF	-0.9	0.04	***			
	2	Constant	783	23.8	***	0.92	0.02	***
		ADF	-0.7	0.05	***			
		CP	0.5	0.12	***			
	3	Constant	783	23	***	0.921	0.001	***
		ADF	-0.6	0.06	***			
		CP	0.5	0.12	***			
		ADL	-0.4	0.17	***			
	4	Constant	860	0.34	***	0.922	0.001	***
		ADF	-0.7	0.06				
		CP	0.42	0.12	***			
		ADL	-0.53	0.17	***			
		Ash	-0.51	0.18	***			
ME	1	Constant	13	0.2	***	0.8	0.8	***
		ADF	-0.14	0.001	***			
	2	Constant	14.2	0.39	***	0.82	0.02	***
		ADF	-0.014	0.001	***			
		Ash	-0.01	0.003	***			
	3	Constant	14.5	0.39	***	0.83	0.01	***
		ADF	-0.012	0.001	***			
		Ash	-0.012	0.003	***			
		ADL	-0.009	0.003	***			
	4	Constant	13.4	0.6	***	0.831	0.001	***
		ADF	-0.01	0.001	***			
		Ash	-0.01	0.003	***			
		ADL	-0.009	0.003	***			
		CP	0.005	0.002	***			

Designation of abbreviations is presented in Table 9; ***: $P<0.001$; SE: standard error.

4.2.3. Predicting the nutritive value of faba bean straw using botanical structure

The results of the study showed that the effect of variety on the relative proportion of straw fractions was significant (P<0.001; Table 23). Faba bean straw mainly consisted of stems followed by pods. The proportion of leaf to the whole straw was less than 0.1. The proportion of leaf of *Mosisa*, *Walki*, and *Shallow* were not significantly different form each other. *Degaga* and local variety were not significantly different from each other in terms of leaf proportion. *Mosisa*, *Walki*, and *Shallow* had significantly higher leaf proportion compared to *Degaga* and local variety. The proportion of stem in local variety and *Degaga* were not significantly different from each other. The proportion of stem of *Mosisa*, *Walki*, and *Shallow* were not significantly different form each other. *Mosisa*, *Walki*, and *Shallow* had significantly lesser stem proportion compared to *Degaga* and local variety. Varieties can be ordered for their proportion of pod starting with the variety with the highest proportion as follow: *Walki*, *Shallo*, *Degaga*, *Mosisa* and local variety. However, *Walki* and *Shallo* were no significantly different from each other in pod proportion. *Degaga* and *Mosisa* and *Shallo* were not different from each other in pod proportion. Regarding pod proportion, *Degaga*, *Mosisa* and local variety were not significantly different form each other. The range between the highest and the lowest proportions of the varieties was 0.053 units in leaves, 0.084 units in stems and 0.057 units in pods.

4.2.3.1. Effect of botanical fraction of straw on nutritive value

Table 18 shows that the effect of variety, botanical fraction and the variety-fraction interaction on the chemical composition, IVOMD and ME of the straw samples was significant (P<0.001). That means the effect of the variety on the chemical composition and nutritive value depended on the botanical fraction of the straw. The leaf had the highest contents of ash, CP and IVOMD while pod had the highest value of ME. The stem contained the highest content of fiber constituents while it hosted the lowest value of CP, IVOMD and ME. Leaf had significantly better DMI, CPI and MEI compared to pod and stem while stem had the lowest values.

4.2.3.2. Leaf

Dry matter content of leaf ranged from 891 g/kg in *Walki* to 893 g/kg in local variety, *Degaga* and *Mosisa*. Dry matter content of local variety was similar to that of *Degaga* and *Mosisa* but lesser than that of *Shallo* and *Walki*. Ash content of leaf of ranged from 136 g/kg in local variety to 169 g/kg in Walki. Leaf of local variety had significantly lesser ash content compared to the improved varieties which were different from each other. Varieties content of CP of leaf ranged from 120 g/kg in local variety to 140 g/kg in *Mosisa*. Leaf of local variety had higher CP content compared to *Mosisa* and *Walki* but similar to *Degaga* and *Shallo*. Leaf content of NDF ranged from 294 g/kg in *Walki* to 388 g/kg in local variety. NDF of local variety was similar to that of *Degaga* and *Shallo* but higher than that of other improved varieties. Leaf content of ADF ranged from 266 g/kg in *Walki* to 357 g/kg in local variety. All improve varieties had lesser ADF compared to local variety. Acid detergent lignin content of leaf ranged from 68.1 g/kg in *Walki* to 79.2 g/kg in local variety. *Degaga* was similar to local variety in ADL while other improved varieties were lesser. *In vitro* organic matter digestibility of leaf ranged from 601 g/kg in *Degaga* to 694 g/kg in *Walki*. While ME ranged from 8.63 MJ/kg in local variety to 9.06 MJ/kg in *Walki*. Leaf of local variety had similar values of IVOMD and ME compared to *Degaga* but lesser than that of *Mosisa*, *Shallo* and *Walki*. In leaf, DMI ranged from 933 g DM/head per day in local variety to 1238 g DM/head per day in *Walki*. All improved varieties leaves were better in DMI than local variety except *Degaga* which was similar. Leaf CPI (g CP/head per day) varied from local variety (112) to *Walki* (168). The improved varieties had better CPI of leaf compared to local variety. Potential ME intake of leaf (MJ ME/head per day) ranged from local variety (8.06) to *Walki* (11.3). All improved varieties leaves were better in DMI than local variety except *Degaga* which was similar. Leaf of the improved varieties varied in chemical composition and nutritive value.

4.2.3.2. Pod

Pod content of DM ranged from 889 g/kg in local variety, *Mosisa*, *Shallo* and *Walki* to 891 g/kg in *Degaga*. Pod of *Degaga* had lesser DM than that of local variety which was similar to other improved varieties. Ash content of pod ranged from 115 g/kg in *Degaga*, *Mosisa* and *Shallo* to 120 g/kg in local variety. Ash content of local variety pod was equal to that of *Walki* but higher than that of *Degaga*, *Mosisa* and *Shallo*. Crude protein content of pod ranged from 76.3 g/kg in *Walki* to 89 g/kg in local variety. Crude protein content of local variety pod was higher than that of improved varieties which were similar. Pod content of NDF ranged from 417 g/kg in local variety to 444 g/kg in *Degaga*. Acid detergent fiber of pod ranged from 370 g/kg in local variety to 392 g/kg in *Mosisa*. Pod of local variety had lesser NDF and ADF contents compared to *Degaga*, *Mosisa* and *Walki* but similar contents compared to Shallo. Pod content of ADL ranged from 74.7 g/kg in *Shallo* to 80.1 g/kg in *Degaga*. Pod of local variety had the same ADL content compared *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 local variety. Pod content of ME ranged from 9.1 MJ/kg in *Degaga* to 9.53 MJ/kg in *Shallo*. *In vitro* organic matter digestibility and ME of pod of local variety were higher than these of Degaga and *Walki* but similar to that of *Mosisa* and *Shallo*. Pod DMI varied from 818 g DM/head per day (Mosisa) to 866 g DM/head per day (local variety and Degaga). None of the improved varieties had better DMI than that of local variety. Potential CP intake of pod (g CP/head per day) varied from 56.9 in *Degaga* to 77.3 in local variety. Local variety had better CPI than that of all improved varieties. The improved varieties varied for all nutritive value parameters of pod except ash and CPI. Pod MEI (MJ ME/head per day) ranged from 7.45 in *Degaga* to 8.15 in local variety. The improved varieties were not superior to local variety in CPI. The improved varieties varied in all nutritive value parameters except ash, CP and CPI.

4.2.3.3. Stem

All varieties were similar in CP, NDF, DMI, CPI and MEI of stem. Stem content of DM of varieties ranged from 904 g/kg in *Shallo* and *Walki* to 905 g/kg in local variety, *Mosisa* and *Degaga*. Local variety had similar DM content compared to the improved varieties. Stem content of ash ranged from of 58.7 g/kg in *Shallo* to 65 g/kg in local variety. Stem content of ash in local variety was higher than that of *Shallo* but similar to that of *Degaga*, *Mosisa* and *Walki*. Stem of all varieties had similar CP and NDF content. Stem content of ADF ranged from 671 g/kg in

Mosisa to 693 g/kg in local variety. Local variety content of ADF as high as that of *Degaga* and *Walki* but bigger than that of *Mosisa* and *Shallo*. Stem content of ADL ranged from 136 g/kg in *Degaga*, *Mosisa* and Shallo to 139 g/kg in local variety. Stem of local variety and *Walki* had similar ADL content while stem of local variety had higher ADL content than that of *Degaga*, *Mosisa* and *Shallo*. *In vitro* organic matter digestibility of stem ranged from 387 g/kg in *Walki* to 410 g/kg in *Shallo*. *In vitro* organic matter digestibility of local variety stem was higher than that of *Shallo* but similar to that of other improved varieties. Metabolizable energy of stem ranged from 5.57 MJ/kg in local variety to 5.88 MJ/kg in *Shallo*. Metabolizable energy content of local variety stem was similar to that of *Degaga* but lesser than that of other improved varieties. Stem of the improved varieties varied in ash, IVOMD and ME but not in ash, ADF and ADL.

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

Straw fraction		DM	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
Leaf		892^{b}	155^{a}	130^{a}	338^{c}	303^{c}	73.1^{c}	653^{a}	8.85^{b}	1181^{a}	140^{a}	9.6^{a}
Pod		890^{c}	116^{b}	80.4^{b}	432^{b}	383^{b}	77.8^{b}	558^{b}	9.35^{a}	840^{b}	67.8^{b}	7.87^{b}
Stem		904^{a}	62.8^{c}	39.1^{c}	734^{a}	680^{a}	137^{a}	398^{c}	5.76^{c}	491^{c}	19.3^{c}	2.83^{c}
SEM		0.122	0.718	0.887	2.61	2.36	0.524	2.94	0.029	6.14	1.3	0.07
Fraction-variety interaction												
Fraction	Variety											
Leaf	Local	893^{a}	136^{d}	120^{b}	388^{a}	357^{a}	79.2^{a}	610^{c}	8.63^{c}	933^{c}	112^{e}	8.06^{c}
Leaf	Degaga	893^{a}	143^{c}	126^{b}	375^{a}	332^{b}	77.1^{abc}	601^{c}	8.65^{c}	967^{c}	121^{d}	8.39^{c}
Leaf	Mosisa	893^{a}	166^{a}	140^{a}	321^{b}	282^{c}	73.4^{d}	683^{ab}	8.9^{b}	1130^{b}	159^{b}	10.07^{b}
Leaf	Shallo	892^{b}	156^{b}	126^{b}	321^{b}	284^{c}	68.6^{e}	672^{b}	8.96^{ab}	1139^{b}	144^{c}	10.2^{b}
Leaf	Walki	891^{b}	169^{a}	135^{a}	294^{c}	266^{d}	68.1^{e}	694^{a}	9.06^{ab}	1238^{a}	168^{a}	11.3^{a}
Pod	Local	889^{b}	120^{a}	89^{a}	417^{c}	370$_{b}$	75.6^{bcd}	581^{b}	9.41^{ab}	866^{a}	77.3^{a}	8.15^{a}
Pod	Degaga	891^{a}	115^{b}	81.1^{b}	444^{a}	388^{a}	80.1^{a}	527^{c}	9.10^{c}	866^{a}	56.9^{b}	7.45^{b}
Pod	Mosisa	889^{b}	115^{b}	77.7^{b}	442^{a}	392^{a}	78.5^{ab}	563^{ab}	9.39^{ab}	818^{b}	63.8^{b}	7.69^{b}
Pod	Shallo	889^{b}	115^{b}	78^{b}	420^{bc}	372^{b}	74.7^{cd}	567^{ab}	9.53^{a}	861^{a}	67.7^{b}	8.22^{a}
Pod	Walki	889^{b}	118^{ab}	76.3^{b}	435^{bc}	391^{a}	79.9^{a}	550^{b}	9.33^{b}	838^{b}	64.4^{b}	7.85^{ab}
Stem	Local	905^{ab}	65.9^{a}	39.4	738	693^{a}	139^{a}	391^{b}	5.57^{c}	488	19.3	2.72
Stem	Degaga	905^{a}	65.2^{a}	41.3	737	680^{ab}	136^{b}	397^{ab}	5.69^{bc}	489	20.3	2.79
Stem	Mosisa	905^{ab}	62.4^{ab}	49.7	724	671^{b}	136^{b}	404^{ab}	5.83^{ab}	498	20	2.91
Stem	Shallo	904^{ab}	58.7^{b}	37.8	737	677^{b}	136^{b}	410^{a}	5.88^{a}	489	18.6	2.88
Stem	Walki	904^{b}	61.6^{ab}	37.0	736	680^{ab}	137^{ab}	387^{b}	5.82^{ab}	490	18.1	2.85
Pooled SEM		0.310	1.61	1.98	5.83	5.32	1.17	6.61	0.648	13.9	2.9	0.16
SL of the effects												
Variety		***	***	***	***	***	***	***	***	***	***	***
Fraction		***	***	***	***	***	***	***	***	***	***	***
Variety×Fraction		***	***	***	***	***	***	***	***	***	***	***

Designation of abbreviations is presented in Table 9.

Canonical correlation between DMI, CPI and MEI (potential intake of nutrients) of whole straw and their corresponding value in leaf was very strong (Table 19). The potential intake of nutrients of whole straw correlated very strongly with the potential intake of pod. Potential intake of whole straw strongly correlated with potential intake of nutrients of stem. The signs of the coefficients shows that DMI, CPI and MEI of whole straw correlated positively with DMI, CPI and MEI of leaf, pod and stem. That mean potential intake of nutrients of whole straw can be predicted by the potential intake of nutrients of straw fractions. Potential intake of nutrients of the whole straw correlated strongly with the proportion of leaf, pod and stem (Table 20). Stem had negative coefficients while leaf and pod had positive coefficients. That mean as the proportion of stem increase the potential intake of nutrients of whole straw decrease. Moreover, when the proportion of leaf and pod increase, the potential intake of nutrients of whole straw increase. Coefficient of stem has the highest magnitude compared to the coefficients of leaf and pod. That mean variation in stem proportion is the main reason of the variability in the potential nutrients intake of whole straw.

Table 19. Canonical correlations between potential intake of nutrients whole straw with the potential intake of nutrients of leaf, pod and stem

	Leaf	Stem	Pod
	Can1	Can1	Can1
r	0.96***	0.71***	0.98***
R^2	0.92	0.5	0.97
Pillai's Trace test	***	***	***
Coefficients			
DMI	0.95	0.29	0.743
CPI	0.87	0.07	0.943
MEI	0.94	0.41	0.70

DMI, CPI and MEI are denoted to potential intake of DM, CP and ME of straw by 30 kg live weight sheep; only first canonical results are shown as Pillai's Trace test proved significant; Can: Canonical; ***: P< 0.001.

Table 20. Canonical correlations analysis: correlations between the nutritive value of the whole straw and the relative proportion of the three straw fractions

	Potential intake
	Can1
r	0.48***
R^2	0.23
Pillai's Trace test	***
Coefficients	
Leaf	0.264
Stem	-0.417
Pod	0.318

Only first canonical results are shown as Pillai's Trace test proved significant; Can: Canonical; ***: P< 0.001.

4.3. Yields

4.3.1. Chickpea

The results of the study indicated significant (*P*<0.001) genotypic variations in yields of grain, DM of straw, CP of straw and ME of straw (Table 21) which comport with the results of studies on other crops (Table 1). 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 did. 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 genotypes, four genotypes ranging from 4.03 t DM/ha in DZ2012CK0227 to 4.51 t DM/ha yielded higher straw DM than that of local variety. 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 genotypes 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, seven genotypes ranging from DZ2012CK0240 with yield of 27.2 thousand MJ/ha to DZ2012CK0227 with value of 32 thousand MJ/ha, yielded higher ME of straw compared to local variety. Among all genotypes, four genotypes combining superior yields of grain, straw DM, straw CP and straw ME, yielded higher grain and straw nutrients than local variety, therefore, they can be recommended for any multi-trait improvement efforts of chickpea. Considering ADF as a proxy of the nutritive value, DZ2012CK0227 and DZ2012CK0240 had superior grain and straw traits and are recommended as dual purpose cultivars. Interestingly, DZ2012CK0227, nominated as a dual purpose cultivar, meets 75 %, 100% and 91% of DM, CP and ME maintenance requirement of 30 kg live weight sheep. The current study succeeded identifying germplasm with superior straw traits. Furthermore, tow genotypes combined superior food and fodder traits.

Table 21. Effect of genotype on chickpea yields of grain, straw, CP, and ME

Genotype	Grain	Straw	ME	CP
Cultivars				
DZ2012CK0048	3.59*	3.22	22.7	279
DZ2012CK0227	3.75*	4.03*	29.6*	427*
DZ2012CK0228	3.85*	3.79	27.2*	318
DZ2012CK0229	3.49*	3.45	24.2	289
DZ2012CK0230	3.63*	3.17	22.5	286
DZ2012CK0231	3.98*	4.22*	28.8*	341*
DZ2012CK0232	3.67*	3.83	28.0*	351*
DZ2012CK0233	3.37*	4.13*	29.3*	343*
DZ2012CK0234	3.21*	3.73	26.9	319
DZ2012CK0235	3.07	3.87	28.6*	407*
DZ2012CK0236	3.71*	3.10	20.4	221
DZ2012CK0237	3.63*	3.59	26.0	280
DZ2012CK0238	3.44*	3.36	24.2	306
DZ2012CK0239	3.33*	3.20	23.8	305
DZ2012CK0240	3.25*	3.69	27.2*	351*
DZ2012CK0241	3.11	3.70	26.6	344*
DZ2012CK2011S10041	3.41*	3.26	23.3	267
DZ2012CK2011S15005	3.32*	3.35	23.1	266
DZ2012CK2011S16005	3.08	3.17	23.3	328
DZ2012CK2011S20042	2.98	3.13	23.4	315
DZ2012CK2011S30043	3.67*	3.55	25.0	277
DZ2012CK2011S50045	3.44*	3.37	23.7	310
Varieties				
Local	2.47	3.09	21.7	219
Minjar	2.84	3.41	25.3	354*
Natoli	3.96*	4.51*	32.0*	366*
LSD (0.05)	0.684	0.913	6.69	111
SEM	0.24	0.32	2.35	39

Grain yield: t/ha; straw yield of DM: t/ha; CP yield of straw: kg/ha; ME yield of straw: 1000 MJ/ha; CP: crude protein; ME: metabolizable energy; Means in column with same letter are not significantly different at P= 0.05; SEM: standard error mean; LSD: least significant difference; SL: significant level; P<0.001 for all traits.

4.3.2. Faba bean

Variety had a significant (*P*<0.001) effect on the grain and straw yields (Table 22). Grain yield ranged from 2.89 t/ha in local variety to 4.38 t/ha in *Mosisa*. The genotypic range in grain yield was 1.49 t/ha. Local variety showed significantly lower grain yields than the improved varieties (*P*<0.001). No significant difference in grain yield was found among the improved varieties. Straw yield of DM ranged from 4.31 t/ha in *Degaga* to 5.68 t/ha in

Mosisa. The genotypic range in straw yield of DM was 2.03 t/ha. Straw yield of DM of improved varieties was significantly higher than the straw yield of local variety ranging from *Mosisa (*5.68 t DM/ha) to *Degaga* (4.31). Crude protein yield of straw ranged from 194 kg/ha in local variety to 300 kg/ha in *Mosisa*. The genotypic range of CP yield of straw was 106 kg/ha. Only *Mosisa* (300 kg CP/ha) and *Shallo* (250 kg CP/ha) had significantly higher yield of CP of straw than that of local variety. Metaboilizable energy yield of straw ranged from 23 thousand MJ/ha in local variety to 37.5 thousands MJ/ha in *Mosisa*. Genotypic range in ME yield was 14.5 thousand MJ/ha. All improved varieties had higher ME yield of straw (thousand MJ ME/ha) than that of local variety ranging from *Mosisa* (37.7) to *Degaga* (27.1). Our results show that although all improved varieties had similar grain yield, they varied in straw yields of DM, CP and ME. Similar results were found in many other crops presented in Table 1. *Mosisa* consistently had high grain yields of grain and straw and it can be recommended as high biomass yielder for food and feed. *Walki* with high IVOMD, ME and MEI meets 73%, 86% and 75% of maintenance needs of sheep 30 kg live weight. Additionally, it has higher straw yield of DM and ME than local variety. Therefore, *Walki* is recommended as dual-purpose faba bean variety.

Table 22. Effect of variety on yields and proportion of botanical fractions in faba bean

Item	*Mosisa*	*Walki*	*Degaga*	*Shallo*	Local	SEM
Grain yield	4.38^{a}	4.21^{a}	4.2^{a}	4.06^{a}	2.89^{b}	0.170
Straw yield	5.68^{a}	4.42^{c}	4.31^{c}	4.98^{b}	3.65^{d}	0.181
CP yield	300^{a}	226^{bc}	226^{bc}	250^{b}	194^{c}	12.1
ME yield	37.5^{a}	29.4^{c}	27.1^{c}	33.3^{b}	23^{d}	1.26
Straw fractions (w/w)						
Leaf	0.093^{a}	0.076^{a}	0.048^{b}	0.095^{a}	0.042^{b}	0.007
Stem	0.687^{b}	0.68^{b}	0.733^{a}	0.702^{b}	0.764^{a}	0.012
Pod	0.224^{bc}	0.258^{a}	0.226^{bc}	0.245^{ab}	0.201^{c}	0.011

Designation of abbreviations is presented in Table 22.

4.3.3. Lentil

The results presented in Table 23 indicated significant (P<0.001) genotypic variations in the yields of grain, straw, CP of straw, and ME of straw. Grain yield ranged from 1.91 t/ha in local variety to 3.74 t/ha in DZ-2012-LN-0039. Twelve genotypes out of overall 25 yielded significantly higher grain compared to local variety ranging from DZ-2012-LN-0195 with yield of 2.91 t/ha to DZ-2012-LN-0039 with yield of 3.74 t/ha. Straw yield of DM ranged between local variety with yield of 3.19 t DM/ha to DZ-2012-LN-0196 with yield of 9.31 t DM/ha. Eighteen (18) genotypes had higher straw yield of DM than local variety and 8 of them were among the high grain yielders ranging from 5.99 t DM/ha in *Derash* to 8.96 t DM/ha in DZ-2012-LN-0195. 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. Eight high grain yielders genotypes yielded significantly higher straw CP than local variety ranging from DZ-2012-LN-0052 with yield of 323 kg CP/ha to DZ-2012-LN-0191 with yield of 538 kg CP/ha. Straw yield of ME (thousand MJ ME/ha) varied from 25.4 in local variety to 80.1 in DZ-2012-LN-0200. Among the higher grain yielders, 8 genotypes yield significantly higher ME (thousand MJ ME/ha) of straw than 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, 8 of them yielded high grain and straw yields of DM, CP and ME than that of the local variety. The results of this study show that the high grain yielders (genotypes which had higher grain yield than local variety) varied widely in straw yields of DM, CP and ME. Interestingly, many genotypes, like DZ-2012-LN-0191, combine superior biomass yield of for human consumption and straw for livestock feeding. Generally, DZ-2012-LN-0191, a high grain yielding cultivar, had superior straw in terms of yield and quality and it is therefore recommended as a promising dual-purpose lentil cultivar. Interestingly, DZ-2012-LN-0191, nominated as a dual purpose cultivar, meets the 106%, 99% and 138% of nutritional needs of 30 kg live weight sheep from DM, CP and ME respectively.

Table 23. Effect of genotype on lentil yields of grain, straw DM, straw CP, and straw ME

Genotype	Grain	Straw	CP	ME
Cultivars				
DZ-2012-LN-0039	3.74*	4.38	182	35.0
DZ-2012-LN-0040	2.80	8.24*	518*	70.9*
DZ-2012-LN-0041	2.64	4.45	206	35.8
DZ-2012-LN-0042	3.01*	8.45*	514*	70.6*
DZ-2012-LN-0045	3.05*	4.66	242	38.5
DZ-2012-LN-0048	2.28	5.11*	311*	43.0*
DZ-2012-LN-0050	3.22*	4.80	229	39.1
DZ-2012-LN-0051	2.75	8.30*	473*	72.5*
DZ-2012-LN-0052	3.00*	6.90*	323*	58.3*
DZ-2012-LN-0055	2.24	4.94*	246	40.8*
DZ-2012-LN-0056	3.71*	6.49*	355*	56.5*
DZ-2012-LN-0057	3.55*	7.08*	411*	60.4*
DZ-2012-LN-0190	2.20	7.39*	436*	63.5*
DZ-2012-LN-0191	3.52*	7.31*	538*	63.2*
DZ-2012-LN-0192	2.15	3.37	137	26.7
DZ-2012-LN-0193	2.41	5.09*	371*	46.0*
DZ-2012-LN-0194	2.36	8.05*	566*	71.5*
DZ-2012-LN-0195	2.91*	8.96*	523*	75.8*
DZ-2012-LN-0196	2.36	9.31*	555*	77.0*
DZ-2012-LN-0197	2.63	6.54*	524*	60.0*
DZ-2012-LN-0198	3.10*	7.31*	392*	62.1*
DZ-2012-LN-0199	3.25*	4.46	169	35.3
DZ-2012-LN-0200	2.35	8.90*	641*	80.1*
Varieties				
Derash	3.70*	5.99*	330*	48.3*
Local	1.91	3.19	183	25.4
SEM	0.316	0.614	47.5	5.28
LSD (0.05)	0.897	1.75	135	15

Designation of abbreviations is presented in Table 22.

4.4. Correlations between food and feed traits

Table 24 depicts the relation between grain yields and straw yield and nutritional quality traits in chickpea, faba bean and lentil. Grain yield correlated weakly, positively and significantly with straw DM yield (*r*= 0.367), CP yield (*r*= 0.298) and ME yield (*r*= 0.362) of chickpea. No relation was found between grain yield and nutritive value traits of straw of chickpea (CP: *r*= 0.078; NDF: *r*= -0.138; ADF: *r*= 0.096; ADL: *r*= -0.128; IVOMD: *r*= -0.49; ME: *r*= -0.053).

Linear correlation between grain and straw yield and ME yield of straw was positive, strong and significant in faba bean (*r* =0.661 for grain yield; r= 0.652 for ME yield). Grain yield correlated positively and moderately to CP yield of faba bean straw (r= 0.49). That means the increase in grain yield will be associated with an increase in DM yield of straw, CP yield of straw and ME yield of straw in faba bean. The correlation between grain yield and CP yield of faba bean straw was weak, negative and significant (*r* = -0.162). The correlation between grain yield and CP of faba bean straw was weak, positive and significant (r= 0,162). No relation was found between grain yield and NDF, ADF, ADL, IVOMD and ME of straw in faba bean.

The association between grain and straw yields of lentil was weak, positive and significant (*r*= 0.39). Grain yield and CP yield were of lentil insignificantly related (*r*= 0.197) with each other while grain and ME yields tended to be positively and weakly associated (*r*= 0.378). The relationship between grain yield and the straw content of CP, NDF, ADF, ADL, IVOMD and ME in lentil was insignificant (CP: *r*= -0.23, NDF: *r*= -0.04; ADF: *r*= -0.03; ADL: *r*= -0.11; IVOMD: *r*= -0.104; ME: *r*= -0.11). The overall results indicate that improvement of grain yield was not accompanied with a decrease in straw yields and quality traits in chickpea, faba bean and lentil. Increasing CR biomass of crops is important as it will improve the utilization of CR in the farm. Our results are in line with studies presented in Table 2. Selection for CR biomass necessitates recording CR yield. Moreover, estimating CR production will facilitate calculating feed budget in national level. Both of them needs a simple and reliable way for estimating CR yield. The results of the current study showed that the variation in grain yield accounts for 13%, 44% and 15% of the variation in straw yield of DM in chickpea, faba bean and lentil. That means grain yield cannot be used alone as predictor of straw yield of DM in chickpea, faba bean and lentil. Therefore, straw yield should be recorded alongside with grain yield if straw yield is aimed to be used as criteria in releasing new varieties of chickpea, faba bean and lentil.

Table 24. Correlation between grain yield and straw yield and straw quality traits

	Chickpea	Faba bean	Lentil
Straw Yields			
DM	0.367***	0.661***	0.39***
CP	0.298*	0.49***	0.197ns
ME	0.362*	0.652***	0.378***
Straw quality			
CP	0.078ns	0.162*	-0.23ns
NDF	-0.138ns	0.022ns	-0.04ns
ADF	0.096ns	-0.08ns	-0.03ns
ADL	-0.128ns	-0.051ns	-0.11ns
IVOMD	-0.049ns	0.027ns	-0.104ns
ME	-0.053ns	0.164ns	-0.11ns

DM: dry matter; CP: crude protein; NDF: neutral detergent fiber; ADF: acid detergent fiber; ADL: acid detergent lignin, IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy; *, **, **: significant at 0.05, 0.01 and 0.001 level of probability respectively; ns: P> 0.05.

4.5. Effect of urea and ash treatments on chemical composition and nutritive value of chickpea, faba bean and lentil straws

4.5.1. Urea treatment

Urea treatment resulted in a considerable improvement of nutritive value of chickpea faba bean and lentil straw by increasing CP, IVOMD, ME, DMI, CPI and MEI and decreasing fiber constituents (Table 25, 26, 27). Similar results were summarized by Van Soest (2006). Table 29 presents the change in chemical composition and nutritive value of chickpea, faba bean and lentil due to urea treatment. Straw origin affected significantly ($P<0.001$) the change in all nutritive value parameters except ash, CP, IVOMD and ME which were similar across all straws. However, the increase in CP, IVOMD and ME content due to urea treatment was not significantly affected by straw origin. The decrease in fiber constituents among straw origins was significantly different ($P<0.001$). Decrease in NDF in lentil was significantly higher than in chickpea and lentil compared to faba bean straw, however the decrease in NDF due urea treatment in chickpea was not different from that in faba bean. Decrease in ADF in faba bean straw was higher significantly compared to that of chickpea and lentil which were not significantly different from each other. Decrease in ADL in faba bean straw was significantly higher than the decrease in lentil which was higher than the decrease in chickpea. The increase in DMI due to urea treatment in chickpea and faba bean straws were not significantly different from each other while it was lower than the increase in lentil straw. Lentil straw hosed the best improvement in CPI followed by chickpea and faba bean straw. The best increase in MEI due to urea treatment was found in chickpea followed by lentil and faba bean.

Table 25. Effect of urea treatment on chemical composition and nutritive value of chickpea straw

Item	Control	Treatment	Δ	SEM	SL
DM	906	913	7.4	0.39	***
Ash	43	56.3	13.3	1.5	***
CP	46	73.4	27.4	1.9	***
NDF	702	684	-18	5.4	***
ADF	480	463	-16.7	6.7	***
ADL	110	106	-4.33	1.5	***
IVOMD	517	535	20	5.66	***
ME	7.6	7.9	0.3	0.11	***
DMI	511	531	20.3	5.7	***
CPI	19.5	38.7	19.2	1.4	***
MEI	3.49	3.81	0.317	0.088	***

Δ: Change due to urea treatment; DM: dry matter (g/kg as fed); CP: crude protein (g/kg DM); NDF: neutral detergent fiber (g/kg DM); ADF: acid detergent fiber (g/kg); ADL: acid detergent lignin (g/kg DM), IVOMD: *in vitro* organic matter digestibility; ME: metabolizable energy (MJ/kg DM); DMI: Potential DM intake; CPI: Potential CP intake; MEI: Potential MEI intake; ***: Means within the same raw are significantly different ($P<0.001$).

Table 26. Effect of urea treatment on chemical composition and nutritive value of faba bean straw

	Control	Treatment	Δ	SEM	SL
DM (g/kg)	901	903	2	0.417	***
Ash	97.1	112	14.9	1.163	***
CP	53.7	82.2	28.5	1.5	***
NDF	671	652	-19	3.21	***
ADF	619	567	-52	4.23	***
ADL	126	101	-25	1.21	***
IVOMD	418	441	23	5.54	***
ME (MJ/kg)	6.31	6.83	0.52	0.083	***
DMI	538	553	15.1	2.37	***
CPI	29.1	47.6	18.5	0.851	***
MEI	3.41	3.79	0.384	0.048	***

Designation of abbreviations is presented in Table 26.

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

Item	Control	Treatment	Δ	SEM	SL
DM	907	907	-0.003	0.16	ns
Ash	102	119	17.2	2.2	***
CP	57.1	85.8	28.7	0.59	***
NDF	547	482	-65	5.9	***
ADF	383	368	-15	6.3	ns
ADL	88.2	77	-11.2	2.6	***
IVOMD	540	566	26	4.71	***
ME	7.98	8.42	0.44	0.075	***
DMI	659	721	62	5.7	***
CPI	37.8	60.1	22.3	0.63	***
MEI	5.27	5.96	0.69	0.071	***

Designation of abbreviations is presented in Table 26.

Table 28. Effect of straw origin on change in chemical composition and nutritive value of chickpea, faba bean and lentil straw due to urea treatment

Item	Chickpea	Faba Bean	Lentil	SEM	SL
DM	7.4[a]	2.34[b]	-0.003[c]	0.516	***
Ash	13.3	14.9	17.2	1.85	ns
CP	27.4	28.5	28.7	1.82	ns
NDF	-18[b]	-19.4[b]	-65[a]	6.83	***
ADF	-16.7[b]	-52.5[a]	-15[b]	7.19	***
ADL	-4.33[c]	-24.3[a]	-11.2[b]	2.36	***
IVOMD	20	22.5	26	6.10	ns
ME	0.3	0.521	0.44	0.11	ns
DMI	20.3[b]	14.3[b]	62[a]	6.54	***
CPI	19.2[b]	15.6[c]	22.3[a]	1.22	***
MEI	0.956[a]	0.364[c]	0.687[b]	0.066	***

Designation of abbreviations is presented in Table 26.

Fertilizing chickpea at rate of 100 kg urea/ha increased grain yield by 55% (Namvar and Sharifi, 2011). Applying nitrogen fertilization in 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). A recent study has reported that application of urea fertilization at 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 3.95 t/ha in chickpea, 4.6 t/ha in faba bean and 3.62 t/ha in lentil. Thus treating straw yield of chickpea, faba bean and lentil harvested from one ha needs 158 kg, 184 kg and 144.8 kg of urea fertilizer respectively. If these quantities of urea are used by farmers for fertilization purpose, it will increase considerably grain and straw yields of crops. So, when production of grain, DM of straw, CP of straw and ME of straw in addition to the nutritive value of the straw is considered, using urea to fertilize the land may be more beneficial than using it to treat pulse straws.

4.5.2. Ash treatments

Chemical composition and mineral content of ash were significantly affected by ash origin (Table 29). Dung ash had significantly higher content of DM, ash, Mn, Na, Mg and P compared while wood ash had higher content of Fe, Zn, Cu and Ca. Wood ash in our study had lesser Ca, P and Mg while it has higher Na compared to Acacia and Aleppo wood ashes reported by Ben Salem et al. (2005). These variation could be due to genetic and environmental factors among tree species. Dung ash in our study had lesser content of Ca, P, Na and Mg compared to dromedary and goat dung ash reported by Genin et al. (2007). Ashes from dung and wood are expected to have high variability due to many factors including diet composition, location, season, wood source and animal related factors (Genin et al., 2007). Ash solutions from dung ash and wood ash had higher pH value compared to plain water (Table 30). Dung ash solutions at concentrations of 150 g ash/L and 200 g ash/L were not significantly deferent from each other for pH value, although, they had significantly higher pH value compared to 100 g ash/L. Wood ash solutions at concentrations of 100 g ash/L, 200 g ash/L and 300 g ash/L were not significantly different from each other. Dung ash solution at concentration of 300 g/L had lesser but almost equal pH to that of 300 g ash/L of dromedary and goat dung ash solutions. Wood ash solution in our study had lesser pH value compared to ash extract solution reported by Laswai et al. (2007). Alkalinity of dung and wood ash solutions of the current study were within the range reported by Nolte et al. (1987). The solutions prepared from wood ash had pH values near to 9 while pH of solutions prepared from dung ash were near to 10. However, alkalinity of solutions regardless of the source is expected to be sufficient to affect the digestibility of roughages (Genin et al., 2007).

Table 29. Minerals content of dung and wood ash

	Ash source			
Item (unit)	Dung	Wood	SEM	SL
DM (g/kg)	993	936	0.95	***
Ash (g/kg DM)	985	433	30.1	***
Fe (g/kg DM)	23.4	9.98	1.683	***
Zn (mg/kg DM)	112	533	14.2	***
Cu (mg/kg DM)	24	77.3	4.38	***
Mn (g/kg DM)	1.644	1.114	0.031	***
Na (mg/kg DM)	157	96.7	13.2	***
Ca (g/kg DM)	5.48	15.3	0.78	***
Mg (g/kg DM)	6.47	5.32	0.135	***
P (g/kg DM)	5	2.17	0.32	***

***: Means within row are significantly different (P<0.001).

Table 30. Effect of ash origin on pH of ash solutions

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

Means with different letters in a column are significantly different (P < 0.05); ***: P< 0.001.

Table 31 and 32 shows the effect of dung ash and wood ash treatment on the nutritive value of chickpea, faba bean and lentil straw. There was a significant effect of treatment level, straw orign and the treatment level-straw origin interaction on the nutritive value of srtraw for both dung ash and wood ash treatments. That means the effect of level of treatment depend on the origin of the straw.

5.4.2.1. Chickpea straw

Dung ash treatment did not significantly affect DM, CP, ADF, IVOMD and MEI of chickpea straw but no other parameters. Generally soaking in plain water did not affect chemical composition and nutritive value of chickpea straw. Treatment of straw by dung ash increased ash content and all levels had similar increase rate. Soaking straw in a solution of 300 g dung ash/L did not alter NDF while treatment by 100 g dung ash/L and 200 g dung ash/L caused similar decrease. Only dung ash treatment at level of 100 g ash/L decreased ADL of straw while other levels of treatment failed causing any significant change. All solutions of dung ash failed changing ME of straw except the solution containing 300 g dung ash/L which caused a significant decrease. Potential DM intake of chickpea straw was increased by treatment by 100 g dung ash /L and 200 g dung ash /L equally but not by other levels of treatment. Treatment of straw at levels of 100 g dung ash/L, 200 g dung ash/L and 300 g dung ash /L caused similar increase in CPI. Wood ash treatment did not affect DM, NDF and ADF of straw. Wood ash treatment at levels of 0 g ash/L and 100 g ash/L did not affect straw content of ash while levels of 150 g ash/L and 200 g ash/L similarly increased straw content of ash. Wood ash treatment of straw did not affect ADL except the level of 200 g ash/L which caused a significant decline. Wood ash treatment at level of 150 g ash/L decreased IVOMD of straw while other level showed insignificant effect. Soaking in plain water had no effect on ME while other level of wood ash treatment caused similar decrease. Treatment of straw by wood ash at level of 200 g ash/L decreased DMI while other levels had no significant effect. Treatment of straw by 100 g wood ash/ L and 150 g wood ash/L decreased MEI while other the change caused by other levels was insignificant.

4.5.2.2. Faba bean

Dung ash treated straw had higher DM compared to the untreated straw, however, all level of treatment were similar. Dung ash treatment of straw caused significant increase in ash content regardless of the level, however the increase caused by treatment was the same in all levels. Treatment of straw at levels of 200 g dung ash /L and 300 g dung ash /L had similar decreasing effect on NDF, ADF and ADL but other levels had insignificant effect. Dung ash treatment of straw at levels of 200 g ash/L and 300 g ash/L similarly decreased IVOMD but the alteration caused by other levels was insignificant. Treatment of straw by 100 g dung ash/L caused a decline in ME of straw but no other levels. Dung ash treatment of at 300 g ash /L decreased DMI while other levels had insignificant effect. Treatment of straw by 100g dung ash/L did not affect MEI while other levels had similar declining effect. No significant effect of soaking with plain water on DM was found while the wood ash treatment at other levels caused a significant increase. Soaking with plain water and wood ash treatment at level of 200 g ash/L increased straw content of ash while other levels did not cause any significant change. Wood ash treatment did not have any significant effect on CP of straw. Soaking with plain water and solution containing 200 g wood ash/L caused a significant decline in NDF of straw while the change caused by other levels of treatment was insignificant. Wood ash treatment did not significantly affect ADF of straw. Wood ash treatment at level of 150 g ash/L caused a significant decrease in ADL while the changes caused by other level of treatment were insignificant. Treatment of straw by a solution containing 200 g wood ash/L did not cause any significant change in IVOMD while other levels of treatment caused similar decrease. Soaking straw with plain water increased significantly ME while wood ash treatment at level of 100 g ash/L and 150 g ash/L caused a significant decline. Treatment of straw by 200 g wood ash/L did not cause any significant change in ME of straw. Straw treatment with wood ash solution did not come with any significant effect on DMI nor on CPI. Wood ash treatment at levels of 100 g ash/L and 150 g ash/L decreased significantly MEI of straw while soaking with plain water have insignificant effect.

4.5.2.3. Lentil

Dung ash treatment did not significantly affect DM, ash, NDF, ADF, ADL, IVOMD, ME, DMI and MEI of lentil straw. Treatment at level of 300 g dung ash /L increased CP and CPI of straw while other levels did not have any significant effect. Wood ash treatment did not significantly affect DM and ash content of lentil straw. Soaking straw is plain water and a solution containing 100 g wood ash /L increased CP while other levels of treatment failed to cause any significant change. Treatment with 200 g wood ash /L did not affect NDF while other levels similarly caused significant decline. Wood ash treatment of lentil straw did not significantly affect ADF and ADL. Soaking straw in plain water decreased significantly IVOMD and ME while other levels of wood ash treatment had insignificant effect. Potential dry matter intake of lentil straw was not significantly affected by wood ash treatment. Treating lentil straw by wood ash at level of 100 g ash/L increased significantly CPI while other levels of treatment had insignificant effect. Treatment at level of 200 g wood ash /L decreased MEI straw while the change caused by other levels of treatment was insignificant. Straws of chickpea, faba bean and lentil seem to be typical material for alkali treatment as they have high content of hemicellulose which is known to be soluble in alkali solutions (Genin et al., 2007). Yet, dung ash and wood ash solutions failed in decreasing NDF content and increasing IVOMD of chickpea, faba bean and lentil straws. Similar results was reported by Genin et al. (2007) and Nolte et al. (1987).

Table 31. Effect of dung ash treatment on chemical composition and nutritive value of pulse straws

Straw origin	Treatment level	DM	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
	Control	906	43^{b}	46	702^{a}	480	110^{a}	517	7.6^{a}	511^{b}	19.5^{b}	3.49
	0 (g/L)	907	44.6^{b}	48.1	702^{a}	482	106^{ab}	510	7.4^{ab}	511^{b}	20.4^{b}	3.52
Chickpea	100 (g/L)	907	48^{a}	56.9	675^{b}	471	105^{b}	511	7.41^{ab}	532^{a}	25.1^{a}	3.54
	200 (g/L)	907	48.4^{a}	56.7	680^{b}	470	106^{ab}	515	7.51^{ab}	527^{a}	24.8^{a}	3.56
	300 (g/L)	908	47^{a}	54.3	688^{ab}	485	107^{ab}	507	7.37^{b}	521^{ab}	23.4^{a}	3.45
	Control	901^{b}	79.1^{b}	53.7	671^{b}	619^{b}	126^{b}	418^{a}	6.31^{a}	537^{ab}	28.8	3.39^{a}
	0 (g/L)	904^{a}	85.2^{a}	55.4	670b	619b	12b	410^{ab}	6.1b^{c}	538^{ab}	28	3.4^{b}
Faba bean	100 (g/L)	904^{a}	88.3^{a}	52.6	667^{b}	624^{b}	129^{b}	416^{a}	6.22^{ab}	540^{a}	28.3	3.36^{a}
	200 (g/L)	903^{a}	88.1^{a}	53.3	687^{a}	644^{a}	135^{a}	403^{b}	6.02^{bc}	524^{bc}	27.9	3.16^{b}
	300 (g/L)	904^{a}	88.4^{a}	51.9	689^{a}	654^{a}	138^{a}	398^{b}	5.93^{c}	523^{c}	27.1	3.1^{b}
	Control	907	102	57.1^{b}	547	383	88.2	540	7.98	659	37.8^{b}	5.27
	0 (g/L)	907	101	59.5^{ab}	535	389	88.7	527	7.82	656	27.7^{b}	5.24
	100 (g/L)	907	99.9	59.4^{ab}	539	385	89.8	527	7.74	668	39.9^{ab}	5.18
Lentil	200 (g/L)	907	101	59.1^{ab}	540	386	90	529	7.79	668	39.7^{ab}	5.22
	300 (g/L)	907	99.7	60.6^{a}	540	389	90.3	527	7.76	668	40.7^{a}	5.20
	Pooled SEM	0.479	1.45	1.21	5.23	5.79	1.63	4.98	0.08	5.1	0.922	0.079
SL of the effects												
Straw origin		***	***	***	***	***	***	***	***	***	***	***
Treatment level		***	***	***	***	***	***	***	***	***	***	***
Straw orign×treatment level		***	***	***	***	***	***	***	***	***	***	***

DM: dry matter (g/kg as fed); 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); Means with different letters in a column within one straw are significantly different ($P < 0.05$); ***: $P< 0.001$; O×C: origin – level of treatment interaction.

Table 32. Effect of wood ash treatment on chemical composition and nutritive value of pulse straws

Straw origin	Treatment level	DM	Ash	CP	NDF	ADF	ADL	IVOMD	ME	DMI	CPI	MEI
	Control	906	43^{b}	46^{b}	702	480	110^{a}	517^{a}	7.6^{a}	511^{ab}	19.5^{b}	3.49^{a}
	0 (g/L)	907	44.6^{b}	48.1^{ab}	702	482	106^{ab}	510a^{b}	7.4a	511ab	20.4^{ab}	3.52a
Chickpea	100 (g/L)	906	44.9^{b}	48.4^{ab}	708	483	106^{ab}	508^{ab}	7.33^{b}	507^{ab}	20.3^{ab}	3.34^{b}
	150 (g/L)	906	47.9^{a}	47.9^{ab}	715	490	106^{ab}	504^{b}	7.22^{b}	502^{b}	20^{ab}	3.26^{b}
	200 (g/L)	905	47.6^{a}	50.8^{a}	701	478	105^{b}	510^{ab}	7.32^{b}	512^{a}	21.6^{a}	3.37^{ab}
	Control	901^{b}	79.1^{c}	53.7	671^{a}	619	126^{b}	418^{a}	6.31^{b}	537	28.8	3.39^{a}
	0 (g/L)	901b	85.2^{a}	55.4	670^{c}	619	128^{ab}	410^{b}	6.53^{a}	549	30.4	3.4^{a}
Faba bean	100 (g/L)	903^{a}	80.1^{bc}	55.2	669^{ab}	631	129^{ab}	409^{b}	6.05^{d}	539	29.7	3.26^{b}
	150 (g/L)	903^{a}	81^{bc}	52.9	667^{ac}	632	130^{a}	410^{b}	6.1^{cd}	541	28.5	3.3^{b}
	200 (g/L)	903^{a}	83.6^{ab}	54.8	658^{bc}	619	127^{ab}	419^{a}	6.25^{bc}	548	30	3.43^{a}
	Control	907	102	57.1^{b}	547^{a}	383	88.2	540^{a}	7.98^{a}	659	37.8^{b}	5.27^{a}
	0 (g/L)	907	101	59.5a	540^{b}	389	88.7	527^{b}	7.82^{b}	656	37.7^{b}	5.24^{a}
Lentil	100 (g/L)	907	101	60.3^{a}	538^{b}	383	88.8	531^{a}	7.82^{a}	670	40.5^{a}	5.25^{a}
	150 (g/L)	907	106	57.8^{b}	542^{b}	381	88	537^{a}	7.91^{a}	665	38.6^{b}	5.27^{a}
	200 (g/L)	907	106	57.6^{b}	548^{a}	385	88.9	536^{a}	7.84^{a}	657	38^{b}	5.16^{b}
	Pooled SEM	0.324	1.63	0.899	4.48	5.31	1.47	4.49	0.072	4.23	0.685	0.069
SL of the effects												
Straw origin		***	***	***	***	***	***	***	***	***	***	***
Treatment level		***	***	***	***	***	***	***	***	***	***	***
Straw orign×treatment level		***	***	***	***	***	***	***	***	***	***	***

Designation of abbreviation is presented in Table 33.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusions

Crop residue is 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 (Keftasa, 1988). Under limited resources in the households, better utilization of CR 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 CR mulching may lead to better utilization of CR. Providing extension and training services on the importance of the use of CR as mulch may help to improve the awareness among farmers and lead to enhance their use of CR 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 CR. 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 CR as feed. Generally, interventions introducing conservative agriculture should account for tradeoffs related to alternative and competing uses of CR. However, better utilization of CR could be achieved by using pulse residue exclusively for livestock feeding and cereal residue exclusively for soil mulching. The preliminary result in this thesis encouraged us to investigate the possibility of integrating straw traits in improvement programs of chickpea, faba bean and lentil to produce superior food-feed varieties. Currently, improvement programs of chickpea, faba bean and lentil do not pay attention to straw traits, neither are straw traits considered in release criteria of new varieties. The current study proves that straw traits can be integrated to multi-dimensional improvement programs of chickpea, faba bean and lentil. Therefore, livestock nutritionists need to work with crop breeders to select varieties which have superior food and feed traits.

Food-feed varieties of chickpea, faba bean and lentil 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. Ash treatment was ineffective in improving the nutritive value of chickpea, faba bran and lentil straw therefore it is better to be utilized in other ways. On contrary, urea treatment improved the nutritive value of chickpea, faba bean and lentil straws. However, using urea to fertilize the land seems to come with more advantage to the farm rather than using it for straw treatment.

5.2 Recommendations

The current study highlights the following recommendations for future research on integration of straw traits into multi-traits improvement efforts of chickpea, faba bean and lentil.

- Genetic variability of grain and straw traits and food feed relations in chickpea, faba bean and lentil should be studied using larger number of genotypes in multi-environmental trials to test genetic-environment interaction effect on grain and straw traits.
- More studies should be done on chickpea and lentil to find out a reliable method of screening large number of straw samples for feeding value. Botanical structure prove to be effective in predicting the nutritive value of faba bean straw. Thus, it should be investigated in chickpea and lentil as well.
- Dry matter intake of straw is important determent of the nutritive value. More studies on predicting DMI of chickpea, faba bean and lentil straws using simple, cheap and fast method should be carried out.
- Promising genotypes for straw traits should be further tested in *in situ* studies.
- Comparing the profitability of using urea for fertilization vs. straw treatment on farming unit level should be deeply explored.
- Effect of genotype on the efficiency of urea treatment to improve the nutritive value of chickpea, faba bean and lentil straws should be studied.

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7. APPENDICES

7.1. List of Publications

The following papers were prepared from the dissertation research:

7.2. List of Appendix Tables

Table 1. Summary of GLM results of the effect of genotype on grain and straw traits in chickpea

Item	df	MS	F value	Pr>F	SL
Grain yield (t/ha)	16	12.6	29.2	<0.001	***
Straw yield of DM (t/ha)	16	10.8	30	<0.001	***
Straw yield of CP (kg/ha)	16	73916	22.6	<0.001	***
Straw yield of ME (1000 MJ/ha)	16	515	42.3	<0.001	***
DM (g/kg as fed)	16	130	21.8	<0.001	***
Ash (g/kg DM)	16	63	53.3	<0.001	***
CP (g/kg DM)	16	390	25.2	<0.001	***
NDF (g/kg DM)	16	743	39.7	<0.001	***
ADF (g/kg DM)	16	934	65	<0.001	***
ADL (g/kg DM)	16	58.5	77.3	<0.001	***
IVOMD (g/kg)	16	395	28.3	<0.001	***
ME (MJ/kg DM)	16	0.09	29.2	<0.001	***
DMI (g/head per day)	16	414	30.6	<0.001	***
CPI (g/head per day)	16	133	28.7	<0.001	***
MEI (MJ/head per day)	16	0.093	35.8	<0.001	***

Table 2. Summary of GLM results of the effect of fraction variety and F*V on nutritive value of faba bean straw

Item	df			MS			F value			P value	
	F	V	F*V	F	V	F*V	F	V	F*V	F	V
DM (g/kg as fed)	2	4	8	9394	27.3	6.38	4206	12.2	2.86	<0.001	<0
Ash (g/kg DM)	2	4	8	308047	1417	2319	3979	18.3	30	<0.001	<0
CP (g/kg DM)	2	4	8	298957	342	1202	2535	2.9	10.2	<0.001	<0
NDF (g/kg DM)	2	4	8	6295198	16313	17334	6160	15.9	16.9	<0.001	<0
ADF (g/kg DM)	2	4	8	5819592	15301	15929	6939	18.3	19	<0.001	<0
ADL (g/kg DM)	2	4	8	187297	352	308	4553	8.5	7.5	<0.001	<0
IVOMD (g/kg)	2	4	8	2433627	28374	20206	1876	21.8	15.5	<0.001	<0
ME (MJ/kg DM)	2	4	8	564.6	1.5	0.3	4481	12.2	2.75	<0.001	<0
DMI (g/head per day)	2	4	8	12954351	162298	164027	2369	29.6	30	<0.001	<0
CPI (g/head per day)	2	4	8	548534	3740	6758	2315	15.7	28.5	<0.001	<0
MEI (MJ/head per day)	2	4	8	1828	21.2	16.9	2485	28.8	23	<0.001	<0

Table 2. Summary of GLM results of the effect of genotype on grain and straw traits in faba bean

Item	df	MS	F value	Pr>F	SL
Grain yield (t/ha)	4	10.9	12.4	<0.001	***
Straw yield of DM (t/ha)	4	17.6	18	<0.001	***
Proportion of leaf	4	155	10.83	<0.001	***
Proportion of stem	4	456	10.5	<0.001	***
Proportion of pod	4	141	3.87	<0.001	***
Straw yield of CP (kg/ha)	4	46428	10.59	<0.001	***
Straw yield of ME (1000 MJ/ha)	4	935	19.7	<0.001	***
DM (g/kg as fed)	4	12.5	4.18	<0.001	***
Ash (g/kg DM)	4	297	4.81	<0.001	***
CP (g/kg DM)	4	46.6	0.62	0.65	ns
NDF (g/kg DM)	4	1463	0.84	0.48	ns
ADF (g/kg DM)	4	2891	1.73	0.15	ns
ADL (g/kg DM)	4	118	1.4	0.24	ns
IVOMD (g/kg)	4	4668	3.58	<0.001	***
ME (MJ/kg DM)	4	1.1	4.47	<0.001	***
DMI (g/head per day)	4	1467	1.02	0.4	ns
CPI (g/head per day)	4	12	0.27	0.9	ns
MEI (MJ/head per day)	4	0.63	2.27	<0.001	***

Table 3. Summary of GLM results of the effect of genotype on grain and straw traits in lentil

Item	df	MS	F value	Pr>F	SL
Grain yield (t/ha)	24	58.7	9.6	<0.001	***
Straw yield of DM (t/ha)		0.895	2.99	<0.001	***
Straw yield of CP (kg/ha)		66522	9.82	<0.001	***
Straw yield of ME (1000 MJ/ha)		837	10	<0.001	***
DM (g/kg as fed)		1.5	6.5	<0.001	***
Ash (g/kg DM)		62.6	6.48	<0.001	***
CP (g/kg DM)		362	7.99	<0.001	***
NDF (g/kg DM)		3553	9.35	<0.001	***
ADF (g/kg DM)		2062	10.89	<0.001	***
ADL (g/kg DM)		140	7.08	<0.001	***
IVOMD (g/kg)		1688	7.11	<0.001	***
ME (MJ/kg DM)		0.4	7.21	<0.001	***
DMI (g/head per day)		7657	8.95	<0.001	***
CPI (g/head per day)		345	8.56	<0.001	***
MEI (MJ/head per day)		1.4	8.78	<0.001	***

Table 3. Summary of GLM results of the effect of urea treatment nutritive value of chickpea straw

Item	df	MS	F value	Pr>F	SL
DM (g/kg as fed)	1	277	182	<0.001	***
Ash (g/kg DM)	1	7785	326	<0.001	***
CP (g/kg DM)	1	15096	430	<0.001	***
NDF (g/kg DM)	1	15127	52	<0.001	***
ADF (g/kg DM)	1	12434	27.8	<0.001	***
ADL (g/kg DM)	1	940	40.8	<0.001	***
IVOMD (g/kg)	1	9250	28.9	<0.001	***
ME (MJ/kg DM)	1	3.53	26.4	<0.001	***
DMI (g/head per day)	1	18511	56.3	<0.001	***
CPI (g/head per day)	1	7384	395	<0.001	***
MEI (MJ/head per day)	1	4.56	59.2	<0.001	***

Table 4. Summary of GLM results of the effect of urea treatment nutritive value of lentil straw

Item	df	MS	F value	Pr>F	SL
DM (g/kg as fed)	1	13.7	51.7	<0.001	***
Ash (g/kg DM)	1	513	10.2	<0.001	***
CP (g/kg DM)	1	1982	566	<0.001	***
NDF (g/kg DM)	1	7605	21.6	<0.001	***
ADF (g/kg DM)	1	432	1.1	0.36	ns
ADL (g/kg DM)	1	214	3.21	<0.001	***
IVOMD (g/kg)	1	1003	4.52	<0.001	***
ME (MJ/kg DM)	1	0.32	5.65	<0.001	***
DMI (g/head per day)	1	7009	21.4	<0.001	***
CPI (g/head per day)	1	1056	267	<0.001	***
MEI (MJ/head per day)	1	0.814	19.2	<0.001	***

Table 5. Summary of GLM results of the effect of urea treatment nutritive value of faba bean straw

Item	df	MS	F value	Pr>F	SL
DM (g/kg as fed)	1	27.5	15.8	<0.001	***
Ash (g/kg DM)	1	1106	81.8	<0.001	***
CP (g/kg DM)	1	4073	180	<0.001	***
NDF (g/kg DM)	1	1877	18.2	<0.001	***
ADF (g/kg DM)	1	13799	77.3	<0.001	***
ADL (g/kg DM)	1	2955	203	<0.001	***
IVOMD (g/kg)	1	2539	8.3	<0.001	***
ME (MJ/kg DM)	1	1.36	19.7	<0.001	***
DMI (g/head per day)	1	1021	18.2	<0.001	***
CPI (g/head per day)	1	1220	169	<0.001	***
MEI (MJ/head per day)	1	0.66	28.73	<0.001	***

Table 6. Summary of GLM results of the minerals content of dung and wood ash

item	df	MS	F value	Pr>f	SL
DM (g/kg)	1	47.5	1750	<0.001	***
Ash (g/kg DM)	1	4575	167	<0.001	***
Fe (mg/kg DM)	1	271662961	32	<0.001	***
Zn (mg/kg DM)	1	265911	437	<0.001	***
Cu (mg/kg DM)	1	4266	74.1	<0.001	***
Mn (mg/kg DM)	1	421450	139	<0.001	***
Na (mg/kg DM)	1	5597	10.6	<0.001	***
Ca (g/kg DM)	1	146	79.5	<0.001	***
Mg (g/kg DM)	1	2	36	<0.001	***
P (g/kg DM)	1	12	37.2	<0.001	***

Table 7. Effect of ash concentration on pH of ash solution

	df	MS	F value	Pr>f	SL
Dung ash solution	3	0.08	34.4	<0.001	***
Wood ash solution	3	0.05	25.6	<0.001	***

Table 8. Summary of GLM results of the effect of dung ash treatment nutritive value of chickpea, lentil and faba bean straw

	Straw origin					Solution concentration				
Item	df	MS	F value	Pr>F	SL	df	MS	F value	Pr>F	SL
DM (g/kg as fed)	2	88.5	38.64	<0.001	***	4	11.7	5.14	<0.001	***
Ash (g/kg DM)	2	15683	743.4	<0.001	***	4	226.5	10.7	<0.001	***
CP (g/kg DM)	2	20358	1379	<0.001	***	4	42.3	2.8	<0.001	***
NDF (g/kg DM)	2	43237	157	<0.001	***	4	669	2.44	<0.001	***
ADF (g/kg DM)	2	187886	560	<0.001	***	4	1189	3.55	<0.001	***
ADL (g/kg DM)	2	15497	585	<0.001	***	4	82	3.1	<0.001	***
IVOMD (g/kg)	2	5854	23.6	<0.001	***	4	1326	5.35	<0.001	***
ME (MJ/kg DM)	2	3.28	51.9	<0.001	***	4	0.42	6.64	<0.001	***
DMI (g/head per day)	2	39608	152	<0.001	***	4	634	2.44	<0.001	***
CPI (g/head per day)	2	5618	661	<0.001	***	4	21.3	2.51	<0.001	***
MEI (MJ/head per day)	2	5.99	96.8	<0.001	***	4	0.138	1.97	<0.001	***

Table 9. Summary of GLM results of the effect of wood ash treatment nutritive value of chickpea, lentil and faba bean straw

	Straw origin					Solution concentration				
Item	df	MS	F value	Pr>F	SL	df	MS	F value	Pr>F	SL
DM (g/kg as fed)	2	177	169	<0.001	***	4	7.15	6.81	<0.001	***
Ash (g/kg DM)	2	10285	386	<0.001	***	4	153	5.76	<0.001	***
CP (g/kg DM)	2	12010	1487	<0.001	***	4	26	1.53	<0.001	***
NDF (g/kg DM)	2	166082	826	<0.001	***	4	155	0.77	<0.001	***
ADF (g/kg DM)	2	482669	1714	<0.001	***	4	237	0.84	<0.001	***
ADL (g/kg DM)	2	22661	1042	<0.001	***	4	14	0.66	<0.001	***
IVOMD (g/kg)	2	30833	152	<0.001	***	4	423	2.1	<0.001	***
ME (MJ/kg DM)	2	11.2	214	<0.001	***	4	0.255	4.88	<0.001	***
DMI (g/head per day)	2	132629	740	<0.001	***	4	109	0.61	<0.001	***
CPI (g/head per day)	2	3935	839	<0.001	***	4	11.26	2.4	<0.001	***
MEI (MJ/head per day)	2	20	421	<0.001	***	4	0.08	1.8	<0.001	***

7.3. 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