Integrating the straw yield and quality into multi-dimensional improvement of lentil (*Lens culinaris*)

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## ABSTRACT

**Background:**

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

**Results:**

Wide genotypic variation (*P*<0.001) was found in grain yield, straw yield and straw nutritive value. Urea treatment significantly (*P*<0.01) improved lentil straw nutritive value, although, the genotypic range in CP, IVOMD, ME, DMI, CPI and MEI was higher by 13.3 units, 56 units, 0.82 units, 106 units, 18.3 units and 1.62 units respectively. Acid detergent fiber correlated very strongly with other nutritive value parameters of lentil straw (pooled *r*= 0.87) and therefore it can be used for screening lentil varieties for fodder quality. Furthermore, IVOMD and ME of lentil can be accurately predicted using ADF ($R^2$= 0.9 for IVOMD and 0.8

for ME). Straw yield correlated weakly with grain yield (*r*=0.39, *P*<0.001) while no relation between grain yield and straw nutritive value was found (*P*> 0.05).

**Conclusion:**

There is possibility to improve grain yield and straw traits of lentil simultaneously.

Keywords: genetic variation, lentil, residue, grain

## INTRODUCTION

Lentil straw is an important source of fodder for livestock in Africa, South Asia and the Middle East [1]. Lentil straw has been reported to have better degradation in the rumen as compared to cereal straws[2, 3]. High acceptability and digestibility of lentil straw in the ration of livestock was reported by Abbeddou, Rihawi, Hess, Iniguez, Mayer and Kreuzer [4]. Heuzé, Tran, Sauvant, Bastianelli and Lebas [5] 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, Tran, Sauvant, Bastianelli and Lebas [5] reported that the dry matter intake of sheep from lentil straw was 46.6 g/kg of metabolic weight. Although better quality of lentil straw compared to cereal straw is documented, there is still need to improve its yield and nutritive value to allow for its use as a sole livestock feed. Several studies have reported on considerable variability in leaf to stem ratio, plant height, number of pods per plant and number of branches per plant of lentil [6-8]. 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 [9]. Evaluation of the genotypic variation in straw yield and quality parameters helps to identify parental genotypes with superior straw traits which could be used in developing nutritionally superior cultivars [10]. Urea treatment is one of the effective treatments used to improve the nutritive value of crop residues. The ability of urea treatment to improve the nutritive value of a wide range of cereal straws by increasing crude protein, digestibility and energy has been reported [11]. Ease of application and abundance of urea in local markets at cheap price makes urea treatment more practical than other treatments[12]. Therefore, urea treatment can be used as a baseline to ascertain whether genotypic variability in straw quality can be exploited to attain significant improvement. When evaluating the feeding value of straw, the most critical parameter is IVOMD as this determines ME and is positively related to CP. The evaluation of IVOMD and ME of large number of straw samples using various *in vitro*, *in vivo* or *in sacco* methods tend to be time consuming and expensive, therefore, prediction of IVOMD and ME of lentil straw using chemical composition offers a convenient alternative. Determining the correlations among the nutritive value parameters could minimize the number of variables which present the nutritive value of lentil straw. That would decrease the cost and the time spent in screening genotypes for straw quality and facilitate breeding new lentil genotypes for superior straw quality. Grain yield is a major criteria targeted in lentil improving program. Thus, it is imperative that efforts to increase the yield and nutritive value of lentil straw do not depress grain yield. Accordingly, determining the relationship between straw and grain yield is essential. This overall aim of this study was to determine whether straw traits can be integrated into multi-trait improvement of lentil.

## MATERIAL AND METHODS

Genotype-dependent variation in straw and grain traits

Straw samples were collected from trials of the National Program of Lentil Improvement in Ethiopia. The trial was carried out at Debre Zeit Agricultural Research Center, Chefe Dona experimental site (8° 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 three 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 1). The trial was replicated 4 times in the field with 4 rows per plot using randomized complete block design. The space between rows was 20 cm while the space between plants was 2 cm. The experimental plot size was 4 m×0.8 m. All plots were hand planted and did not receive fertilization or irrigation. At physiological maturity, above ground portions of all plants in each plot were harvested from two 1.6 $m^2$ areas laid over the two middle rows of each plot. The biomass from all samples 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.

Urea treatment

The straws of the local variety were bulked after sampling and three kg of it was used to test the effect of urea treatment. The straw was chopped to a theoretical cut length of two cm and divided into ten replicates of 0.3 kg weight each. Each replicate was divided into two parts, one of them was kept as control and the other was treated with urea according to Chenost and Kayouli [13]. The straw was treated with a 40 g $L^{-1}$ urea solution in the ratio 40 ml of solution to 100 g straw to reach final concentration of 4% urea. 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, the bags were open and dried by spreading them on the floor for three days. All replicates were ground in a laboratory mill to pass through a one mm mesh screen and stored for further analysis.

Straw quality analysis

Dray matter, ash and CP were analyzed according to AOAC [14]. Dry matter was determined by oven drying at 105 ˚C overnight (method 934.01). Ash was determined by burning all organic matter of the sample using muffle furnace at 500 ˚C overnight (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 [15]. Neutral detergent fiber was not analyzed with a heat stable amylase and was expressed exclusive of residual ash. Acid detergent fiber was expressed exclusive of residual ash. Lignin was determined by solubilization of cellulose with sulphuric acid. *In vitro* organic matter digestibility (IVOMD) and ME were measured in rumen microbial inoculum using the *in vitro* gas production technique described by Menke & Steingass [16]. Briefly, approximately 0.2 g of sample was weighed and placed in 100 mL graduated glass syringe. Buffer mineral solution medium was prepared and placed in a water bath at 39 °C under constant flushing with $CO_2$. Rumen fluid was collected after morning feeding from three ruminally fistulated male cattle fed on 15 kg of grass hay/head per day and 4 kg of wheat bran/head per day. Rumen fluid was pumped with a manually operated vacuum pump from the rumen into pre-warmed thermos flasks. The rumen fluid was mixed and filtered through four layers of cheesecloth and flushed with $CO_2$ and the bulked mixture was then mixed with the buffered mineral solution (1:2 v/v). The buffered rumen fluid (30 mL) was pipetted into each syringe and the syringes were immediately placed in a water bath and kept at 39 °C. Gas production was recorded after 24 hours of incubation and used to calculate IVOMD and ME according to Menke & Steingass [16]. All chemical analyses were undertaken at the International Livestock Research Institute (ILRI) Animal Nutrition Laboratory in Addis Ababa, Ethiopia.

Calculations and statistical analysis

Yields of CP (kg $ha^{-1}$) and ME (thousands MJ $ha^{-1}$) were calculated using chemical analysis of the straw and the straw yield. The potential daily dry matter intake (DMI) of one head of sheep 30 kg live weight was calculated as follows: DMI (g per head per day) = 1000×30×120/NDF (% DM), where 30 is the live weigh of sheep in kg, 120/NDF (%DM): potential daily DM intake (% live weight) according to Horrocks and Vallentine [17]. Crude protein and ME contents of straw were multiplied by DMI to get potential CP intake (CPI) and potential ME intake (MEI). Data of the genotypic variation in gain yield and straw traits 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 lentil genotype $_i$, $B_j$ is the effect of the block $_j$ and $E_{ij}$ is the random error. Means of genotypes were compared to the mean of the local variety using least significant difference method. Data of urea treatment trial was analyzed using one-way analysis of variance to test the effect of urea treatment on the nutritive value of lentil straw. In both trials, means were separated using least significant difference method at 0.05 level of probability. Stepwise multiple regression analysis was used to identify the best model which describe the relation between IVOMD and ME and chemical analysis of lentil straw. Linear relationships among straw quality trait was investigated to reduce the number of the variables which express the nutritive value of lentil straw. Likewise, linear relationships between grain and straw traits were calculated using Pearson's correlation. The strength of Pearson correlations was described according to the guide suggested by Evans [18]. 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 [19].

## RESULTS

Variation in Yield

The results presented in Table 1 indicated significant genotypic variations (*P*<0.001) in the yields of grain, straw, CP, and ME. Grain yield ranged from 1.91 t/ha in local variety to 3.74 t ha$^{-1}$ in DZ-2012-LN-0039. Twelve genotypes out of overall 25 yielded significantly higher grain compared to the local variety ranging from DZ-2012-LN-0195 with yield of 2.91 t ha$^{-1}$to DZ-2012-LN-0039 with yield of 3.74 t ha$^{-1}$. Straw yield of DM ranged between the local variety with yield of 3.19 t DM ha$^{-1}$ to DZ-2012-LN-0196 with yield of 9.31 t DM ha$^{-1}$. Eighteen genotypes had higher straw yield of DM than the local variety and eight of them were among the high grain yielders ranging from 5.99 t DM ha$^{-1}$ in Derash to 8.96 t DM ha$^{-1}$ in DZ-2012-LN-0195. Straw yield of CP ranged from 137 kg CP ha$^{-1}$ in DZ-2012-LN-0192 to 641 kg CP ha$^{-1}$ in DZ-2012-LN-0200. Seventeen genotypes had significantly higher yield of CP of straw compared to the local variety and eight of them were among the high grain yielding genotypes ranging from DZ-2012-LN-0052 with yield of 323 kg CP ha$^{-1}$ to DZ-2012-LN-0191 with yield of 538 kg CP ha$^{-1}$. Straw yield of ME (thousand MJ ME ha$^{-1}$) varied from 25.4 in the local variety to 80.1 in DZ-2012-LN-0200. Eighteen genotypes had significantly higher straw yield of ME compared to that of the local variety. Among the high grain yielders, eight genotypes yielded significantly higher ME (thousand MJ ME ha$^{-1}$) of straw than the local variety varying from 48.3 in Derash to 75.8 in DZ-2012-LN-0195. Among all of the high grain yielder genotypes in the study, eight of them yielded high grain and straw yields of DM, CP and ME than that of the local variety.

## Variation in straw quality

Table 2 presents the effect of genotype on the nutritive value of lentil straw. Genotype affected significantly ($P$<0.001) chemical composition and nutritive value of lentil straw. The genotypic rang of DM was very small (3 g kg$^{-1}$) thus it was not reported. Ash content of straw ranged from 88.8 g kg$^{-1}$ in DZ-2012-LN-0193 to 107 g/kg in DZ-2012-LN-0056. Among the high grain yielders, only two genotypes hosed higher ash than that of the local variety. Straw content of CP ranged from 38 g kg$^{-1}$ in DZ-2012-LN-0199 to 80 g kg$^{-1}$ in DZ-2012-LN-0197. Eleven genotypes had higher CP than that of the local variety while two of them only was among the high grain yielders (DZ-2012-LN-0191 and DZ-2012-LN-0195). Straw content of NDF varied from 438 g/kg in DZ-2012-LN-0200 to 550 g kg$^{-1}$ in DZ-2012-LN-0199. Eighteen genotypes hosed lesser NDF than that of the local variety and seven of them were among the high grain yielders ranging from (DZ-2012-LN-0191) 455 g kg$^{-1}$ to 489 g kg$^{-1}$ (DZ-2012-LN-0052). Acid detergent fiber ranged from 301 g kg$^{-1}$ in DZ-2012-LN-0200 to 384 g kg$^{-1}$ in DZ-2012-LN-0192. Nineteen genotypes had lesser ADF than that of the local variety while eight of them were among the high grain yielders ranging from DZ-2012-LN-0056 (317 g kg$^{-1}$) to DZ-2012-LN-0045 (356 g kg$^{-1}$). Straw content of ADL varied from 66.2 g kg$^{-1}$ in DZ-2012-LN-0197 to 95.9 g kg$^{-1}$ in DZ-2012-LN-0192. Eighteen genotypes hosted lesser ADL than that of the local variety, furthermore, ten of them were among the highest grain yielding genotypes. The high grain yielders ranged in ADL from 67.5 g kg$^{-1}$ in DZ-2012-LN-0191 to 80.3 g kg$^{-1}$ in Derash. Straw IVOMD (g kg$^{-1}$) ranged from 532 in DZ-2012-LN-0192 to 614 in DZ-2012-LN-0197 while fifteen genotypes had better IVOMD than that of the local variety. Seven high grain yielding genotypes had significantly higher IVOMD than that of the local variety ranging from 567 g kg$^{-1}$ in DZ-2012-LN-0042 to 585 g kg$^{-1}$ in DZ-2012-LN-0056. Genotypes varied in ME (MJ kg$^{-1}$) from 7.91 in DZ-2012-LN-0199 to 9.17 in DZ-2012-LN-0197 while fifteen of them had better content than that of the local variety. Seven high yielding genotypes had significantly higher ME than that of the local variety ranging from 8.38 MJ/kg in DZ-2012-LN-0042 to 8.69 MJ/kg in DZ-2012-LN-0056. Genotypes ranged in DMI (g per head per day) from 655 in DZ-2012-LN-0199 to 823 in DZ-2012-LN-0200 but only seventeen of them had better value than that of the local variety. Seven high yielding genotypes had significantly higher DMI than that of the local variety ranging from DZ-2012-LN-0052 with 737 g DM per head per day to DZ-2012-LN-0191 with 793 g DM/head per day. Genotypes varied in CPI (g CP per head per day) from 24.8 in DZ-2012-LN-0199 to 65.4 in DZ-2012-LN-0197, however, only five of them including one high grain yielder had better value than that of the local variety. The genotypes included in the study varied in MEI (MJ ME per head per day) from 5.18 in DZ-2012-LN-0199 to 7.49 DZ-2012-LN-0197 whereas only sixteen of them had better value than that of the local variety. Seven high yielding genotypes had significantly higher MEI (MJ ME per head per day) than that of the local variety ranging from 6.21 in DZ-2012-LN-0042 to 6.86 in DZ-2012-LN-0191. Table 3 shows that urea treatment increased significantly ($P$<0.001) the nutritive value of lentil straw by improving CP, IVOMD, ME, DMI, CPI and MEI and decreasing NDF and ADL. However, the genotypic range in CP, IVOMD, ME, DMI, CPI and MEI was higher by 13.3 units, 56 units, 0.82 units, 106 units, 18.3 units and 1.62 units respectively.

Relationships among straw quality traits

Table 4 presents the relationships among straw quality traits in lentil straw. No relation between ash and other nutritive value parameters was found. CP and ADL were moderately correlated ($r$= -0.565) while other pairs of correlations were strongly and very strongly correlated. Generally, ADF correlated very strongly to other quality traits except ash (pooled $r$= 0.87, pooled $R^2$= 0.76). Stepwise regression analysis (Table 5) showed that ADF is useful to predict of IVOMD ($R^2$= 0.9) and ME ($R^2$= 0.8) of lentil straw.

### Relationship between grain yield and straw traits

Table 6 depicts the relationship between grain yield and straw traits. The association between grain and straw yields was weak, positive and significant (*r*= 0.39, *P*<0.001). Grain yield and CP yield were insignificantly related (*r*= 0.197, *P*= 0.107) with each other while grain and ME yields tended to be positively and weakly associated (*r*= 0.378, *P*= 0.002). The relationship between grain yield and the straw content of CP, NDF, ADF, ADL, IVOMD, ME, DMI, CPI and MEI was insignificant (CP: *r*= -0.23, *P*= 0.06, NDF: *r*= -0.04, *P*= 0.76, ADF: *r*= -0.03, *P*= 0.79, ADL: *r*= -0.11, *P*= 0.36, IVOMD: *r*= -0.104, *P*= 0.397, ME: *r*= -0.11, *P*= 0.37; DMI: *r*= -0.069, *P*= 0.556; CPI: *r*= -0.118, *P*= 0.313; MEI: *r*= -0.078, *P*= 0.507).

## DISCUSSION

Wide genetic variation was found for straw traits even within the high grain yielding genotypes. The results of this study showed that the genotypic range in the nutritive value parameters was considerably higher than that improvement resulted from urea treatment. That implies that varietal selection for straw quality traits can meaningfully improve the nutritive value of lentil straw. DZ-2012-LN-0195 significantly out yielded the local variety by 2 t DM $ha^{-1}$ of grain, 5.77 t of straw DM $ha^{-1}$, 340 kg CP $ha^{-1}$ of straw CP and 50 thousand MJ ME $ha^{-1}$ of straw ME. Therefore, it is recommended as a parental genotype for any further efforts to improve the yield of straw from DM, CP and ME. DZ-2012-LN-0197 which is superior to the local variety by 208 g $kg^{-1}$ of CP and 1.19 MJ $kg^{-1}$ of ME is recommended for any improvement of straw content for nutritive value. Kearl [20] reported that daily requirements for a sheep of 30 kg live weight are 750 g DM, 59 g CP and 4.95 MJ ME for maintenance. Accordingly, DZ-2012-LN-0197 covers 110%, 111% and 151% of DM, CP and ME maintenance requirements respectively of a 30 kg sheep. Interestingly, DZ-2012-LN-0191 has superior grain and straw traits. Furthermore, its straw meets 106%, 99% and 138% of DM, CP and ME maintenance requirement respectively of 30 kg live weight sheep. Thus, DZ-2012-LN-0191 is nominated as a dual purpose lentil cultivar. Improving nutritive value of lentil straw through varietal selection requires phenotyping large number of genotypes for IVOMD and ME. The results of the stepwise regression analysis indicates that ADF of lentil straw alone can be used accurately to predict IVOMD and ME. These prediction equations provide a convenient substitute to *in vitro*, *in vivo* or *in sacco* methods, thus minimizing the cost and time of undertaking IVOMD and ME evaluations. The current study shows that ADF of lentil straw is strongly and negatively correlated to other nutritive value parameters. Moreover, it can explain more than 76% of the variability in other quality parameters of lentil straw. That means the lower the ADF, the higher the nutritive value of lentil straw. Thus, ADF can be recommended for the ranking lentil varieties for straw quality. Furthermore, lentil breeders may use ADF as sole criteria to breed genotypes with superior straw quality traits. Grain yield is a major criteria targeted in lentil improvement programs. Thus, it is imperative that efforts to increase the yield and nutritive value of lentil straw do not depress grain yield. This study showed that the correlation between straw and grain yield was weak. This implies that varietal selection to improve the straw yield will not lead to a decrease in grain yield and vice versa. Moreover, straw yield of DM cannot be predicted from grain yield and therefore straw yield of DM needs to be recorded alongside grain yield. Correlations between CP, NDF, ADF, ADL and ME content of lentil straw and grain yield were insignificant. That means no decline in grain yield is expected as a result of any increase in CP and ME content of lentil straw nor a decrease in NDF, ADF or ADL. Similarly, no such correlation was reported by Ertiro, Twumasi-Afriyie, Blümmel, Friesen, Negera, Worku, Abakemal and Kitenge [21] in maize, Blümmel, Bidinger and Hash [22] in pearl millet and Blümmel, Vishala, Ravi, Prasad, Reddy and Seetharama [23] in Sorghum. The performance of lentil genotypes in terms of food and feed traits, the correlation among nutritive value traits of straw and the food-feed relations could be affected by environmental factors, therefore, further studies using larger number of genotypes under different environments is recommended to validate this study further. Furthermore, the genotypes recommended in this study as parental genotypes for further improvement program of lentil need to be evaluated for other critical agronomy traits such as disease resistance and drought tolerance.

## CONCLUSIONS

Currently, improvement programs of lentil do not pay attention to straw traits, neither are straw traits considered in release criteria of new varieties. Food-feed varieties of 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. Therefore, livestock nutritionists need to work with lentil breeders to select varieties which have superior food and feed traits.

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## REFERENCES

1. Brennan J, Aw-Hassan A, Quade K and Nordblom T, Impact of Ashutosh and Shiv, 2011. Research on Australian Agriculture, in *Economic Research Report*, Ed (2002).

2. López S, Davies D, Giráldez F, Dhanoa M, Dijkstra J and Frane J, Assessment of nutritive value of cereal and legume straws based on chemical composition and *in vitro* digestibility. *J. Sci. Food Agric.* **85**:1550-1557 (2005).

3. Singh S, Kushwaha B, Nag S, Mishra A, Bhattacharya S, Gupta P and Singh A, *In vitro* methane emission from Indian dry roughages in relation to chemical composition. *Current Science* **101**:57-65 (2011).

4. Abbeddou S, Rihawi S, Hess H, Iniguez L, Mayer A and Kreuzer M, Nutritional composition of lentil straw, vetch hay, olive leaves, and saltbush leaves and their digestibility as measured in fat-tailed sheep. *Small Rumin. Res.* **96**: 126-135 (2011).

5. Heuzé V, Tran G, Sauvant D, Bastianelli D and Lebas F, *Lentil (Lens culinaris)*. http://feedipedia.org/node/284 2016].

6. Al-abdalla N and al-nabelssi A, Phenotypic adaptability and stability of macrosperma lentil landraces in dara'a govrenorate, syria. *Agric. For.* **60**:169-179 (2014).

7. Chakraborty M and Haque M, Genetic variability and component analysis in lentil (*Lens culinaris* Medik). *J. Res. Birsa Agric. Univ.* **12**:199-204 (2000).

8. Tullu A, Kusmenoglu I, K.E.McPhee K and Muehlbauer F, Characterization of core collection of lentil germplasm for phenology, morphology, seed and straw yields. *Genet. Resour. Crop Evol.* **48**:143-152 (2001).

9. Erskine W, Rihawi S and Capper E, Variation in lentil straw quality. *Anim. Feed Sci. Technol.* **28**:61-69 (1990).

10. Davila J, Sanchez dela Hoz M, Loarce Y and Ferrer E, DNA and coefficients of percentage to determine genetic relationships in barley. *Genome* **41**: 477-486 (1998).

11. Van Soest J, Rice straw, the role of silica and treatments to improve quality. *Anim. Feed Sci. Technol.* **130** 137-171 (2006).

12. Abdel Hameed A, Salih M and EL Seed F, Effect of urea treatment on the chemical composition and rumen degradability of groundnut hull. *Pak. J. Nutr.* **11** 1146-1151 (2012).

13. Chenost M and Kayouli C, *Roughage Utilization in Warm Climates.* Food and Agriculture Organization of the United Nations, Rome (1997).

14. AOAC, *Official Methods of Analysis*. AOAC International, Gaithersburg (2000).

15. Van Soest P and Robertson J, *Analysis of Forage and Fibrous Foods, a laboratory manual for Animal Science*. Cornell University, New York (1985).

16. Menke K and Steingass H, Estimation of the energy feed value obtained from chemical analysis and *in vitro* gas production using rumen fluid. *Anim. Res. Dev.* **28**:7–55 (1988).

17. Horrocks R and Vallentine J, *Harvested Forages*. Academic Press, London (1999).

18. Evans J, *Straightforward statistics for the behavioral sciences*. Pacific Grove : Brooks/Cole Publishing Company, California, USA (1996).

19. SAS, *SAS/STAT 12.1 User's Guide* SAS Inc., Cary, NC, USA (2012).

20. Kearl L, *Nutrient requirements of ruminants in developing countries*. International Feedstuffs Institute, Utah State University, Utah, USA (1982).

21. Ertiro T, Twumasi-Afriyie S, Blümmel M, Friesen D, Negera D, Worku M, Abakemal M and Kitenge K, Genetic variability of maize stover quality and the potential for genetic improvement of fodder value. *Field Crop Res.* **153**:79-85 (2013).

22. Blümmel M, Bidinger F and Hash T, Management and cultivar effects on ruminant nutritional quality of pearl millet (*Pennisetum glaucum (L.) R. Br.*) stover: II. Effects of cultivar choice on stover quality and productivity. *Field Crop Res.* **21**:129-138 (2007).

23. Blümmel M, Vishala A, Ravi D, Prasad K, Reddy C and Seetharama N, Multi-environmental investigations of food-feed trait relationships in kharif and rabi sorghum ( *Sorghum bicolor (L) Moench*) over several years of cultivars testing in India. *Anim. Nutr*.*Feed Technol.* **10**:11-21 (2010).

**Table 1.** Genotypic variation in yields of grain (t ha$^{-1}$), straw DM (DM t ha$^{-1}$), straw CP (kg CP ha$^{-1}$), and straw ME (thousand MJ ME ha$^{-1}$) of lentil

| Genotype | Grain | Straw | CP | ME |
|---|---|---|---|---|
| Cultivars | | | | |
| DZ-2012-LN-0039 | 3.74* | 4.38 | 182 | 35 |
| DZ-2012-LN-0040 | 2.8 | 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* |
| DZ-2012-LN-0050 | 3.22* | 4.8 | 229 | 39.1 |
| DZ-2012-LN-0051 | 2.75 | 8.3* | 473* | 72.5* |
| DZ-2012-LN-0052 | 3* | 6.9* | 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 | 2.2 | 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* |
| 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* |
| DZ-2012-LN-0197 | 2.63 | 6.54* | 524* | 60* |
| DZ-2012-LN-0198 | 3.1* | 7.31* | 392* | 62.1* |
| DZ-2012-LN-0199 | 3.25* | 4.46 | 169 | 35.3 |
| DZ-2012-LN-0200 | 2.35 | 8.9* | 641* | 80.1* |
| Varieties | | | | |
| Improved variety-Derash | 3.7* | 5.99* | 330* | 48.3* |
| Local variety | 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 |

DM: dry matter; CP: crude protein; ME: metabolizable energy; *: means have higher values compared to that of the local variety. $P < 0.001$ for all traits.

**Table 2.** Genotypic 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 | 6.5* |
| 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 | | | | | | | | | | | |
| Improved variety-Derash | 907 | 95.9 | 55 | 532 | 368 | 80.3* | 8.06 | 544 | 678 | 37.7 | 5.47 |
| Local variety | 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 | 32 | 22.6 | 6.95 | 0.387 | 25.3 | 48 | 10.4 | 0.656 |

*: means have higher values than that of the local variety except fiber constituents which have lesser values. DM: dry matter (g kg$^{-1}$ as fed); ash (g kg$^{-1}$); CP: crude protein (g kg$^{-1}$); NDF: neutral detergent fiber (g kg$^{-1}$); ADF: acid detergent fiber (g kg$^{-1}$); ADL: acid detergent lignin (g kg$^{-1}$); IVOMD: *In vitro* organic matter digestibility (g kg$^{-1}$); ME: Metabolizable energy (MJ kg$^{-1}$); DMI: Potential daily DM intake by 30kg live weigh sheep (g DM per head per day); CPI: Potential daily CP intake by 30kg live weigh sheep (g CP per kg head per day); MEI: Potential daily metabolizable energy intake by 30kg live weigh sheep (MJ ME per head per day). $P$<0.001 for all traits.

**Table 3**. Effect of urea treatment on the nutritive value of lentil straw

| Item | Control | Treatment | Δ | SEM | *P* value |
|---|---|---|---|---|---|
| DM | 907 | 907 | -0.003 | 0.16 | 0.43 |
| Ash | 102 | 119 | 17.2 | 2.2 | <0.001 |
| CP | 57.1 | 85.8 | 28.7 | 0.59 | <0.001 |
| NDF | 547 | 482 | -65 | 5.9 | <0.001 |
| ADF | 383 | 368 | -15 | 6.3 | 0.36 |
| ADL | 88.2 | 77 | -11.2 | 2.6 | 0.034 |
| IVOMD | 540 | 566 | 26 | 4.71 | 0.009 |
| ME | 7.98 | 8.42 | 0.44 | 0.075 | 0.003 |
| DMI | 659 | 721 | 62 | 5.7 | <0.001 |
| CPI | 37.8 | 60.1 | 22.3 | 0.63 | <0.001 |
| MEI | 5.27 | 5.96 | 0.69 | 0.071 | <0.001 |

Δ: Change due to urea treatment; designation of abbreviations are presented in Table 2.

**Table 4.** Relationships among straw quality trait of lentil

| | 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 | | -0.868 | -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 include ash which were insignificant; designation of abbreviations are presented in Table 1.

**Table 5.** Stepwise regression analysis of the effect of chemical composition, IVOMD and ME of lentil straw

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

Designation of abbreviations are presented in Table 1.

**Table 6.** Correlation between grain yield and straw yield and straw quality traits

| | Grain yield | |
|---|---|---|
| Straw traits | *r* | *P* value |
| Straw yield | 0.39 | <0.001 |
| CP yield | 0.197 | 0.107 |
| ME yield | 0.378 | 0.002 |
| | | |
| Quality | | |
| Ash | 0.06 | 0.64 |
| CP | -0.23 | 0.06 |
| NDF | -0.04 | 0.76 |
| ADF | -0.03 | 0.79 |
| ADL | -0.11 | 0.36 |
| IVOMD | -0.104 | 0.397 |
| ME | -0.11 | 0.37 |
| DMI | -0.069 | 0.556 |
| CPI | -0.118 | 0.313 |
| MEI | -0.078 | 0.507 |

Designation of abbreviations is presented in Table 1.