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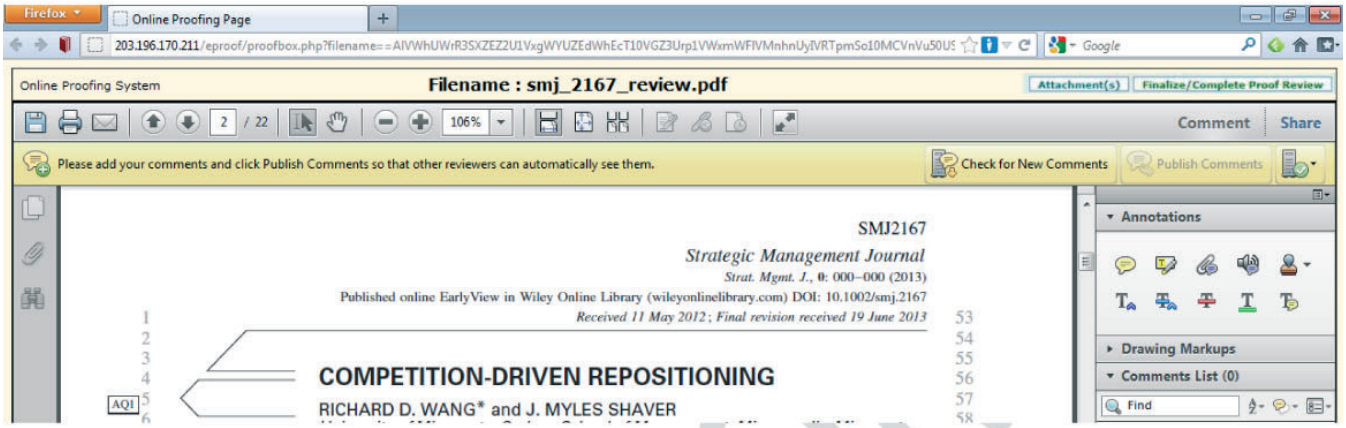

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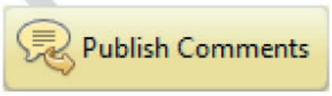

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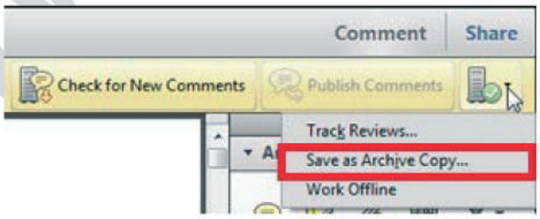

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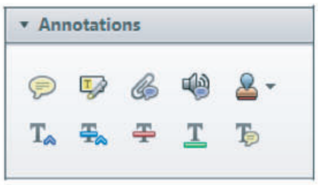

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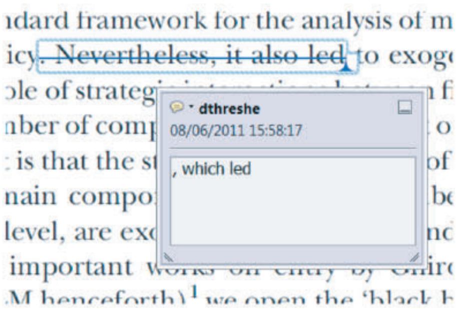

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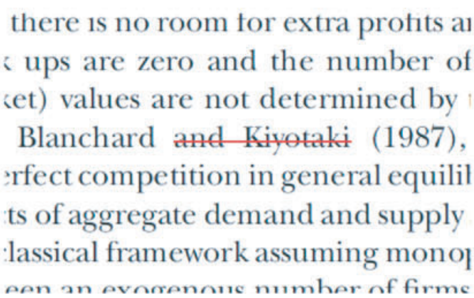

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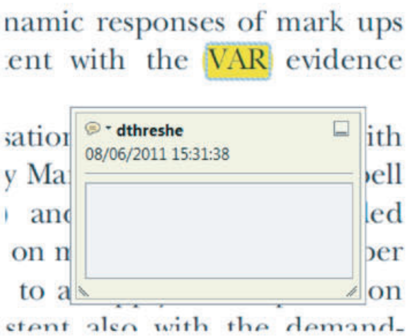

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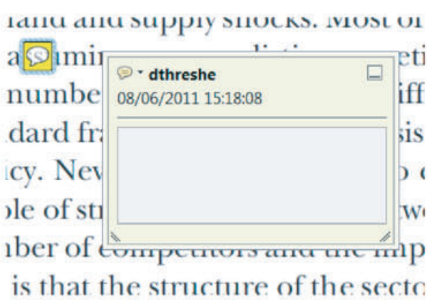

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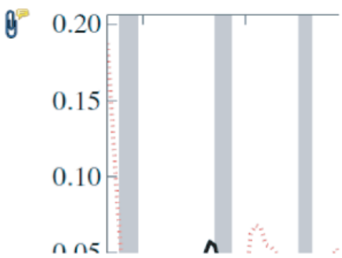

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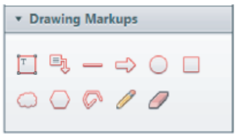

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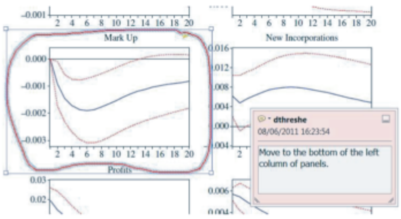

Research Article

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Integrating 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 programmes 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 nutritive value of straw. Urea treatment significantly ($P < 0.01$) improved the nutritive value of straw; however, the genotypic range was comparatively higher by 13.3 units, 56 units, 0.82 units, 106 units, 18.3 units and 1.62 units in crude protein, *in vitro* organic matter digestibility, metabolisable energy, potential dry matter intake, potential crude protein intake and potential metabolisable energy intake respectively. Acid detergent fibre correlated very strongly (pooled $r = 0.87$) with other nutritive value parameters of straw, therefore, it can be used to screen lentil varieties for fodder quality. Furthermore, acid detergent fibre can accurately predict *in vitro* organic matter digestibility ($R^2 = 0.9$) and metabolisable energy ($R^2 = 0.8$). Straw yield weakly correlated ($r = 0.39$, $P < 0.001$) with grain yield while no relation ($P > 0.05$) was found between grain yield the possibility to simultaneously improve grain yield and nutritive traits of lentil straw.

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 *et al.*[4] Heuzéet *al.*[5] reported that crude protein (CP) content of lentil straw ranged between 58 and 111 g kg^{-1} DM and metabolisable energy (ME) ranged between 6.7 and 8.3 MJ kg^{-1} DM. Heuzé *et al.*[5] reported that the dry matter intake of sheep from lentil straw was 46.6 g kg^{-1} of metabolic weight. Although the nutritive quality of lentil straw is documented to be better than that of cereal straws there is 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 considerable exploitable genotypic variability in straw yield and quality. Genetic variability in the nutritive value of lentil straw has been reported.[9] Evaluation of genotypic variation in straw yield and quality parameters may identify parental genotypes with superior straw traits which could be used by crop breeders to breed for 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 CP, digestibility and energy has been reported.[11] Ease of application and abundance of urea in local markets at a 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 *in vitro* organic matter digestibility (IVOMD) as this determines ME and is positively related to CP. However, the evaluation of IVOMD and ME on large numbers of straw samples tends 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 minimise the number of variables which present the nutritive value of lentil straw. That would decrease the cost and time spent in screening genotypes for straw quality and facilitate breeding of new lentil genotypes for superior straw quality. Grain yield is a major criterion targeted in lentil improving programme and it is imperative

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that efforts to increase yield and nutritive value of lentil straw do not depress grain yield. Accordingly, determining the relationship between straw and grain yield is essential. The 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 experimental site has vertisols type of soils. 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 four times in the field with four rows per plot using randomised 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 fertilisation 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 was air-dried for 2 weeks to 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 nutritional analysis.

Urea treatment

The straws of the local variety were bulked after sampling and 3 kg of it was used to test the effect of urea treatment. The straw was chopped to a theoretical cut length of 2 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 40 g L^{-1} urea solution in the ratio of 40 mL solution to 100 g straw to reach a final concentration of 4% urea. This mixture was placed in double-walled plastic bag and sealed. The bags were incubated at room temperature for 21 days. At the end of the treatment, the bags were opened and dried by spreading them on the floor for 3 days. All replicates were ground using a laboratory mill to pass through a 1 mm mesh screen and stored for further analysis.

Straw quality analysis

Dry matter, ash and CP were analysed according to AOAC methods.[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 the Kjeldahl method using Kjeldahl (protein/nitrogen) Model 1026 (Foss Technology Corp., ~~XXXXX, XXXXX~~) (method 954.01). Crude protein was calculated by multiplying nitrogen content by 6.25. Neutral detergent fibre, acid detergent fibre (ADF) and acid detergent lignin (ADL) were determined as described by Van Soest and Robertson.[15] Neutral detergent fibre was not analysed with a heat stable amylase and was expressed exclusive of residual ash. Acid detergent fibre was expressed exclusive of residual ash. Lignin was determined by solubilisation of cellulose with sulphuric acid. IVOMD and ME were measured in rumen microbial inoculum using the *in vitro* gas production technique described by Menke and Steingass.[16] Briefly, approximately 0.2 g of sample was weighed and placed in a 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 h of incubation and used to calculate IVOMD and ME according to Menke and Steingass.[16] All chemical analyses were undertaken

Table 1. Genotypic variation in yields of grain (t ha^{-1}), straw DM (t DM ha^{-1}), straw CP (kg CP ha^{-1}), and straw ME (1000 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, metabolisable energy.
*, values with an asterisk are higher compared to that of the local variety.
$P < 0.001$ for all traits.

AQ2

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 straw yield. 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/neutral detergent fibre (NDF) (% DM), where 30 is the live weight of sheep in kg, 120/NDF (% DM): potential daily DM intake (% live weight) according to Horrocks and Vallentine.[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 grain 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, M is ~~XXXXX~~, 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 analysed 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 were investigated to reduce the number of the variables which express the nutritive value of lentil straw. Likewise, linear relationships between grain and straw traits were calculated using Pearson's correlation. The strength of Pearson correlations was described according to the guide suggested by Evans.[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

Table 1 shows significant ($P < 0.001$) genotypic variations in yields of grain, straw, CP, and ME. Grain yield ranged from 1.91 t ha^{-1} in local variety to 3.74 t ha^{-1} in DZ-2012-LN-0039. Twelve genotypes of the 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 DM straw yield 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 a yield of 323 kg CP ha^{-1} to DZ-2012-LN-0191 with a yield of 538 kg CP ha^{-1}. The 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 the high grain yielder genotypes in the study, eight of them yielded grain yield and straw yields of DM, CP and ME higher compared to the local variety.

Variation in straw quality

Table 2 shows the effect of genotype on nutritive value of lentil straw. Genotype significantly ($P < 0.001$) affected chemical composition and nutritive value of lentil straw. The genotypic range 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^{-1} in DZ-2012-LN-0056. Among the high grain yielders, only two genotypes hosted 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). Neutral detergent fibre varied from 438 g kg^{-1} in DZ-2012-LN-0200 to 550 g kg^{-1} in DZ-2012-LN-0199. Eighteen genotypes hosted lesser NDF than that of the local variety and seven of them were among the high grain yielders ranging from (DZ-2012-LN-0191) 455 g kg^{-1} to 489 g kg^{-1} (DZ-2012-LN-0052). Acid detergent fibre 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 ADL less 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 15 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 15 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^{-1} in DZ-2012-LN-0042 to 8.69 MJ kg^{-1} 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 17 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 per 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 CPI than the local variety. 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 16 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 significantly ($P < 0.001$) increased the nutritive value of lentil straw by improving CP,

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

*, values with an asterisk are higher compared to that of the local variety except for fibre 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 fibre (g kg^{-1}); ADF, acid detergent fibre (g kg^{-1}); ADL, acid detergent lignin (g kg^{-1}); IVOMD, *in vitro* organic matter digestibility (g kg^{-1}); ME, metabolisable energy (MJ kg^{-1}); DMI, potential daily DM intake by 30 kg live weight sheep (g DM per head per day); CPI, potential daily CP intake by 30 kg live weight sheep (g CP per kg head per day); MEI, potential daily metabolisable energy intake by 30 kg live weight sheep (MJ ME per head per day).
$P < 0.001$ for all traits.

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 for ash (pooled $r = 0.87$, pooled $R^2 = 0.76$). Stepwise regression analysis (Table 5, Fig. 1) 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 shows 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 ($r = 0.197$, $P = 0.107$) while grain and ME yields tended to be positively and weakly associated ($r = 0.378$, $P = 0.002$). The relationship between grain yield and straw content of CP, NDF, ADF, ADL, IVOMD, ME, DMI, CPI and MEI was insignificant

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 is the change due to urea treatment.
Abbreviations are as given in the footnotes to Tables 1 and 2.

Table 4. Relationships among straw quality traits of lentil

Item	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 those that include ash, which were insignificant.
Abbreviations are as given in the footnotes to Tables 1 and 2.

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	−0.014	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			

Abbreviations are as given in the footnotes to Tables 1 and 2.

(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 improvement as a result of 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 outyielded 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 can be recommended as a parental genotype for further efforts to improve straw yield of 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

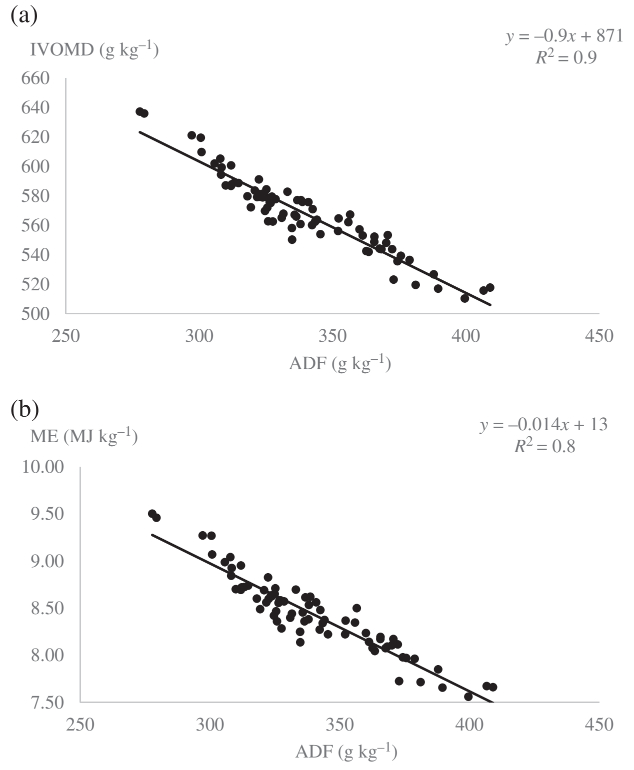

Figure 1. The relationship between ADF and IVOMD and ME of lentil straw.

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

	Grain yield	
Straw trait	*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

Abbreviations are as given in the footnotes to Tables 1 and 2.

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. 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 can be recommended as a dual purpose lentil cultivar. Improving the nutritive value of lentil straw through varietal selection requires phenotyping a large number of genotypes for IVOMD and ME. Results of the stepwise regression analysis indicate that ADF of lentil straw alone can be accurately used to predict IVOMD and ME. The prediction equations provide a convenient substitute to *in vitro*, *in vivo* or *in sacco* methods, thus minimising the cost and time of undertaking IVOMD and ME evaluations. The current study shows that ADF of lentil straw is strongly and negatively correlated with 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 the sole criterion to breed genotypes with superior straw quality traits. Grain yield is a major criterion targeted in lentil improvement programs. Thus, it is imperative that efforts to increase the yield and nutritive value of lentil straw do not depress grain yield. 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 *et al.*[21] in maize, Blümmel *et al.*[22] in pearl millet and Blümmel *et al.*[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 programme of lentil need to be evaluated for other critical agronomy traits such as disease resistance and drought tolerance.

CONCLUSIONS

Currently, improvement programmes 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 address the increasing demand for food and feed, particularly in mixed crop–livestock farming systems, but also contribute to soil health through providing additional biomass for soil mulching. Therefore, livestock nutritionists need to work with lentil breeders to select varieties which have superior food and feed traits.

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