Trop Anim Health Prod (2015) 47:1581–1590
DOI 10.1007/s11250-015-0901-9

REGULAR ARTICLES

Effects of different forms of white lupin (*Lupinus albus*) grain supplementation on feed intake, digestibility, growth performance and carcass characteristics of Washera sheep fed Rhodes grass (*Chloris gayana*) hay-based diets

Gebru Tefera[1] · **Firew Tegegne**[2,3] · **Yeshambel Mekuriaw**[2] · **Solomon Melaku**[4] · **Atsushi Tsunekawa**[3]

Received: 27 March 2015 / Accepted: 31 July 2015 / Published online: 7 August 2015

Abstract Protein is the major limiting nutrient in feeding ruminants especially in dryland areas. Thus, looking for locally available protein sources such as white lupin (*Lupinus albus*) grain is commendable. The objective of this experiment was to determine effects of supplementation of different forms of white lupin grain (WLG) on feed and nutrient intake, digestibility, growth and carcass characteristics. Twenty-five yearling male Washera sheep with initial body weight (BW) of 16.26±1.41 kg (mean±SD) were used. Animals were blocked into five based on their initial BW and were randomly assigned to one of the following five dietary treatments: Rhodes grass (*Chloris gayana*) hay (RGH) alone (T_1) or supplemented with 300 g (on dry matter (DM) basis) raw WLG (T_2) or raw soaked and dehulled WLG (T_3) or roasted WLG (T_4) or raw soaked WLG (T_5). Supplementation with WLG significantly improved total DM and nutrient intake ($P<0.001$), nutrient digestibility ($P<0.01$), and average daily gain (ADG) and feed conversion efficiency (FCE) ($P<0.001$). Carcass quality parameters were significantly ($P<0.001$) higher for supplemented sheep. However, the difference in carcass quality parameters among supplemented groups was not significant ($P>0.05$). It is concluded that roasting white lupin grain can lead to a better feed and nutrient intake and consequently better carcass quality. White lupin grain can be recommended not only for maintenance but also for optimum performance of ruminants.

Keywords Carcass characteristics · Digestibility · Dryland · Growth · Rhodes grass · White lupin · Washera sheep

Introduction

Ethiopia is endowed with a large number of ruminant population standing the first in Africa. Sheep production in Ethiopia has great potential in contributing to food security of smallholder farmers (Legesse 2008). The country has, however, benefited very little from this sub-sector owing to a multitude of problems, mainly attributable to feed in quantity and quality particularly during the dry periods. The consequent poor growth performance of ruminants hinders the country in penetrating to regional and international markets.

To meet the demand for food of the ever-growing human population in Ethiopia, natural grazing lands are alarmingly converted into cropping land (FAO 2011). Consequently, crop residues are becoming the vital source of feeds especially in crop-livestock mixed farming systems (Tolera 2007; Bogale et al. 2008; Tegegne and Assefa 2010). However, crop residues are poor in protein, which is the major limiting nutrient especially in the dryland areas of the tropics and sub-tropics. Therefore, looking for home-grown protein sources such as white lupin grain (WLG) is one possible option.

White lupin (*Lupinus albus* L.) is available in many parts of the world where it is used as a feed source (Watkins and Mirosh 1987; Brenes et al. 1993). White

---

✉ Firew Tegegne
firewtegegne@alrc.tottori-u.ac.jp

[1] Koga irrigation and watershed management project, Bahir Dar, Ethiopia

[2] Department of Animal Production and Technology, Bahir Dar University, P.O. Box 79, Bahir Dar, Ethiopia

[3] Arid Land Research Center, Tottori University, 1390 Hamasaka, Tottori 680-0001, Japan

[4] Haramaya University, School of Animal and Range Sciences, P.O.Box 138, Dire Dawa, Ethiopia

lupin is also produced by smallholder subsistent farmers mainly in the two regional states of Ethiopia; Amhara and Benishangulgumuz (Yeheyis et al. 2010). Until recently, it was highly neglected and considered as poor man's food in Ethiopia, mainly used as live fence or sown on fallow land. *L. albus* is a valuable multipurpose plant contributing for improving soil fertility, food for humans and animal feed. Consequently, farmers have shown increasing interest in cultivating white lupin (Yeheyis et al. 2010). Unfortunately, because of the presence of high alkaloid content (16,752 mg/kg DM) (Yeheyis et al. 2012a), raw WLG is bitter, unpalatable and often toxic for humans and livestock. The presence of toxic and bitter alkaloids and glycosides in *L. albus* was previously reported (Watkins and Mirosh 1987; Brenes et al. 1993). According to Muzquiz et al. (2012), it has been possible to genetically eliminate the alkaloids in different *Lupinus* spp. In addition to genetic selection, there are some physical and chemical methods for eliminating these anti-nutritional factors. However, because of lack of access for chemicals and unaffordable cost, when available, traditional methods of processing such as roasting, soaking and dehulling are being exercised by smallholder farmers in Ethiopia. These practices are scientifically supported since most alkaloids of lupin are water-soluble and can be decreased to 0.04 % by soaking in running water (Pisarikova et al. 2008; Yeheyis et al. 2011). For WLG meant for human consumption, roasting, soaking and dehulling are practiced by smallholder farmers in Ethiopia.

The crude protein content of local WLG (Yeheyis et al. 2011) and cultivars elsewhere (Sujak et al. 2006; Bähr et al. 2014) is higher than most of the improved forage legumes promoted in Ethiopia (Melaku et al. 2004), indicating that it can be utilized as potential protein supplement. However, there is scanty information in Ethiopia on its supplement potential for ruminants. This experiment was, therefore, conducted to determine effects of supplementation of different forms of WLG on feed and nutrient intake, digestibility, growth performance and carcass characteristics.

Material and methods

Study site

The experiment was conducted at Wetet Abay town, northwest Ethiopia, located at 37° 8.97′ E longitude and 11° 24.62′ N latitude. The town has an altitude of 1950 m.a.s.l and about 1500 mm rainfall per annum. The mean minimum and maximum temperature of the area are 12 and 31 °C, respectively (WARDO 2009).

Feed preparation

Rhodes grass was harvested at late maturity stage, seed were separated manually and biomass was stored under shade. The hay was chopped to the size of about 3–5 cm—to minimize selectivity and increase intake. The hay was offered ad libitum at 30 % in excess of daily consumption determined based on the previous 5 days average intake.

Raw white lupin grain (WLG) was purchased from local markets and roasted using a clay plate until a black spot was seen at the centre of the grain. While roasting, grains were mixed thoroughly to minimize the difference in degree of roasting. After roasting, grains were air-cooled on a polyethylene plastic sheet. Soaking of roasted WLG was done by keeping it in sacks in running water (river) for 4 days as usually practiced by the farmers. Dehulling was performed manually. Both soaked and dehulled forms of the WLG were air-dried on a polyethylene plastic sheet. After preparation, the different forms of WLG were stored in a cool dry shed until used.

Experimental animals and their management

Twenty-five intact male yearling Washera sheep with initial body weights of 16.26±1.41 kg (mean±SD) were purchased from local markets in the area where white lupin is grown. The age of the sheep were determined by dentition and verbal report from owners. The experimental animals were quarantined for 2 weeks when they were treated against internal and external parasites using albendazole (300 mg/head) and diazinon (60 %), respectively. The sheep were also vaccinated against common sheep diseases in the area based on the recommendation of a veterinarian. The experimental animals were housed in a ventilated shed with individual pens equipped with watering and feeding troughs.

Experimental design and treatments

At the end of the quarantine period, the sheep were weighed and blocked into five blocks of five animals per block based on their initial body weight. The five treatment diets were randomly assigned to each animal in a block. The feeding trial lasted for 90 days. The treatment diets were Rhodes grass (*Chloris gayana*) hay (RGH) offered ad libitum (T_1), RGH + 300 g raw white lupin grain (WLG) (T_2), RGH+300 g raw soaked dehulled WLG (T_3), RGH+300 g roasted WLG (T_4), and RGH+300 g raw soaked WLG (T_5). Supplemented sheep were offered the supplement in two equal portions at 1000 and 1600 hours in a separate feeding trough.

Common salt (NaCl) and water were available all the time. The amounts of feed offered and refused were recorded daily for each animal. Substitution rate was calculated using the following formula:

$$\text{Sub. rate} = \frac{\text{Basal diet DM intake of control - Basal diet DM intake of supplement group}}{\text{Supplement DM intake}}$$

Digestibility and feeding trials

Digestibility trial was conducted before the feeding trial. Experimental animals were acclimatizing to the dietary treatments for 15 days. Then, they were fitted with faecal collection bags for 3 days followed by 7 days of faeces collection. Total faeces voided over 24 h was weighed daily for each sheep, and after thoroughly mixing, 20 % representative samples were taken and kept frozen at −10 °C. Finally, samples were pooled for each animal, thoroughly mixed, 20 % of the composite samples taken and dried at 60 °C in a forced draft oven to a constant weight. The dried faecal samples were ground to pass through a 1-mm sieve and kept in airtight containers. The digestibility of the supplements was determined by difference. The apparent digestibility coefficient of dry matter (DM), organic matter (OM), crude protein (CP), neutral detergent fibre (NDF) and acid detergent fibre (ADF) were determined using the following formula:

$$\text{Apparent D coefficient} = \frac{\text{Nutrient intake - Nutrient excreted in faeces}}{\text{Nutrient intake}}$$

After the completion of digestibility trial, the experimental animals were weighed and re-blocked and then offered experimental diets and allowed to acclimatize for additional 15 days before the commencement of the feeding trial that lasted 90 days.

Body weight change and feed conversion efficiency

The initial and final body weights (BW) were obtained by weighing sheep on two consecutive days before feeding and watering using a spring balance with sensitivity of 100 g. Experimental sheep were subsequently weighed at 10-day intervals during the feeding trial. Feed conversion efficiency was calculated as average daily gain (ADG) divided by feed intake.

Carcass characteristics

At the end of the feeding trial, all experimental sheep used in the study from each feeding treatment were fasted overnight, weighed and slaughtered to assess the effect of treatments on carcass characteristics following the slaughtering procedures developed by Clotter (1985) for small ruminants in developing countries. The empty BW was calculated as slaughter live weight less alimentary tract contents. The hot carcass weight (HCW) was estimated after removing the weight of the head, thoracic, abdominal and pelvic contents as well as legs below the hock and knee joints. Dressing percentage (DP) was computed as proportions of HCW to slaughter weight and empty BW. The cross-section of the rib-eye muscle area (REMA) was traced on transparency paper between the 11th and 12th of the left half side of the carcass. The REMA was taken as the mean of the two sides of the ribs. The offal was categorized into edible and inedible components. Offal components are categorized into edible and inedible based on testing, tradition, culture and taboos of the people in different parts of the country. Total edible offal component (TEOC) was taken as the sum of the empty gut, blood, liver, kidney, heart, tongue, kidney fat, abdominal fat, reticulo-rumen, omasum, abomasum, small and large intestines (SLI), testicles and tail whereas total inedible offal component (TIOC) was computed as the sum of the spleen, skin and feet, penis, lung, trachea and oesophagus (LTO), gut content, and head.

Chemical analysis

Feed samples were dried in an oven at 60 °C for 72 h and ground to pass a 1-mm sieve screen and kept in airtight plastic bags pending analysis. Dry matter (DM), organic matter (OM) and nitrogen (N) were determined according to the procedure of AOAC (1990). The CP content was calculated as N*6.25. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analyzed according to the procedure of Van Soest and Robertson (1985).

Statistical analysis

The data obtained on feed and nutrient intake, digestibility, body weight change and carcass characteristics were subjected to analysis of variance (ANOVA) using the general linear model of SAS (2000). Differences between treatment means were separated using Duncan's multiple range tests when P values of the means were significant ($P<0.05$). The model to be used for the analysis of data were

$$Y_{ij} = \mu + t_i + b_j +_{eij}$$

where:

Y_{ij} Response variable
μ Overall mean
t_i ith treatment effects
b_j jth block effects
e_{ij} Random error

Results

Chemical composition of experimental feeds

The chemical composition of feed items constituting treatment diets is presented in Table 1. Though hay was made from mature Rhodes grass, its CP content was moderately high. As expected, the CP content of WLG was high. Soaking (T_5) resulted in 13 % increase in CP content; soaking and dehulling combined (T_3) improved by 51%, while roasting (T_4) resulted in decline of CP by 6 %.

Feed and nutrient intake

Feed and nutrient intakes are presented in Table 2. Though supplementation level was set at 300 g DM/day/sheep, WLG refusals on average were 167, 141, 108, 148 g for T_2, T_3, T_4, and T_5, respectively. A highly significant ($P<0.001$) difference was recorded in WLG DM intake within the supplemented groups with the highest consumption recorded in sheep assigned for T_4. Rams receiving WLG supplementation had significantly ($P<0.05$) lower DM intake of RGH. Supplementation of different forms of WLG resulted in significantly higher ($P<0.001$) total DM, OM and CP intake. Among supplemented groups, the highest CP intake was recorded for T_3 and the lowest for T_2.

Table 2 Daily feed and nutrient intake of Washera sheep fed on Rhodes grass hay supplemented with different forms of white lupin grains

Variables	Treatments					SEM	SL
	T_1	T_2	T_3	T_4	T_5		
RGH DMI (g/day)	414^a	366^b	356^b	364^b	361^b	12.9	*
WLG DMI (g/day)	–	133^c	159^b	192^a	152^b	4.84	***
Total DMI (g/day)	414^c	500^b	515^{ab}	557^a	514^{ab}	15.68	***
DMI (%BW)	2^b	3^{ab}	3^{ab}	3^{ab}	3^{ab}	0.094	*
OM intake (g/day)	338^c	410^b	424^b	466^a	422^b	13.49	***
CPI intake (g/day)	41^d	88^c	128^a	104^b	103^b	2.75	***
NDF intake (g/day)	326	324	311	347	340	11.31	ns
ADF intake (g/day)	246^{ab}	252^a	223^b	266^a	254^a	8.48	*
ADL intake (g/day)	56^{ab}	57^{ab}	52^b	61^a	57^{ab}	1.87	*
Substitution rate	–	0.11	0.12	0.10	0.11	0.03	ns

Means with different superscripts (a, b, c, d) in a row differ significantly

SEM standard error of mean, *ns* not significant, *SL* significance level, *DMI* dry matter intake, *OM* organic matter, *CP* crude protein, *NDF* neutral detergent fibre, *ADF* acid detergent fibre, *ADL* acid detergent lignin, *RGH* Rhodes grass hay, *WLG* white lupin grain, T_1 RGH offered alone, T_2 RGH+300 g raw WLG, T_3 RGH+300 g raw soaked, dehulled WLG, T_4 RGH+300 g roasted WLG, T_5 RGH+300 g raw soaked WLG

*$P<0.05$; ***$P<0.001$

Feed and nutrient digestibility

The DM, OM, CP, NDF and ADF digestibility coefficients of treatment diets are given in Table 3. Significantly higher digestibility of DM ($P<0.05$), OM ($P<0.01$) and CP ($P<0.001$) were observed in supplemented compared to the non-supplemented groups. The digestibility coefficients of different forms of white lupin grain are given in Table 4. There were no significant differences ($P>0.05$) among the treatments.

Table 1 Chemical composition of experimental feeds (g/kg DM)

Feed items					
Composition	White lupin grain forms				
	RGH	Raw	Raw, soaked and dehulled	Roasted	Raw soaked
DM	912	926	931	941	925
OM	826	888	898	906	886
CP	81	385	583	362	436
NDF	813	282	148	314	350
ADF	604	257	87	252	268
ADL	129	72	35	75	64

ADF acid detergent fibre, *ADL* acid detergent lignin, *CP* crude protein, *DM* dry matter, *OM* organic matter, *RGH* Rhodes grass hay

Table 3 Apparent digestibility coefficients of nutrients in Washera sheep fed on Rhodes grass hay supplemented with different forms of white lupin grains

Variables	Treatments					SEM	SL
	T_1	T_2	T_3	T_4	T_5		
DM	0.58^{b}	0.71^{a}	0.77^{a}	0.74^{a}	0.71^{a}	0.03	*
OM	0.59^{b}	0.74^{a}	0.79^{a}	0.76^{a}	0.74^{a}	0.03	**
CP	0.60^{b}	0.85^{a}	0.89^{a}	0.84^{a}	0.86^{a}	0.02	***
NDF	0.58	0.67	0.74	0.70	0.68	0.04	ns
ADF	0.61	0.70	0.73	0.73	0.69	0.03	ns

Means within a row not bearing a common superscript (a, b) are significantly different

ADF acid detergent fibre, *CP* crude protein, *DM* dry matter, *OM* organic matter, *NDF* neutral detergent fibre, *ns* not significant ($P>0.05$), *SEM* standard error of mean, *SL* significance level, T_1 (control) hay alone, T_2 hay+raw lupin grain, T_3 hay+raw soaked, dehulled lupin grain, T_4 hay+roasted lupin grain, T_5 hay+raw soaked lupin grain

*$P<0.05$; **$P<0.01$; ***$P<0.001$

Body weight change and feed conversion efficiency

Results of body weight (BW) change and feed conversion efficiency (FCE) are given in Table 5. Supplementation with WLG resulted in significantly higher ($P<0.001$) final BW, average daily gain (ADG) and FCE. Among the supplemented groups, sheep on T_4 had significantly higher ($P<0.001$) ADG and final BW than on T_2.

Carcass characteristics

Supplementation with WLG significantly ($P<0.001$) improved mean values of slaughter weight (SW), empty BW (EBW), hot carcass weight (HCW), dressing percentage (DP) expressed as SW (DPSW) and rib-eye muscle area (REMA) (Table 6). However, the difference among supplemented groups (T_2–T_5) was not significant ($P>0.05$), except for SW that T_4 was significantly ($P<0.001$) higher than T_2.

Table 5 Body weight change and feed conversion efficiency of Washera sheep fed on Rhodes grass hay supplemented with different forms of white lupin grains

Variables	Treatments					SEM	SL
	T_1	T_2	T_3	T_4	T_5		
IBW (kg)	16.4^{a}	16.1^{a}	16.2^{a}	16.3^{a}	16.2^{a}	0.09	ns
FBW (kg)	14.4^{c}	17.6^{b}	18.2^{ab}	18.6^{a}	18^{ab}	0.2	***
ADG (g)	-22^{c}	16.4^{b}	21.8^{ab}	25.3^{a}	19.6^{ab}	2.4	***
FCE	0.053^{a}	0.032^{b}	0.042^{b}	0.045^{b}	0.037^{b}	0.005	***

Means with different superscripts (a, b, c) in a row are significantly different

SEM standard error of mean, *ns* not significant ($P>0.05$), *IBW* initial body weight, *FBW* final body weight, *ADG* average daily gain, *FCE* feed conversion efficiency, *SL* significance level, T_1 (control) hay alone, T_2 hay+raw lupin grain, T_3 hay+raw soaked dehulled lupin grain, T_4 hay+roasted lupin grain, T_5 hay+raw soaked lupin grain

***$P<0.001$

Edible offal components

Supplementation with WLG significantly ($P<0.001$) affected most of the edible offals (Table 7). Similarly, supplementation significantly ($P<0.001$) increased the amount of abdominal and kidney fat.

Inedible offal components

Total inedible offal component (TIOC) and each inedible offal component were significantly ($P<0.01$) affected, except the spleen and penis, by supplementation with WLG (Table 8). All inedible offal components were not different ($P>0.05$) among supplemented groups.

Discussion

Chemical composition of experimental feeds

Though hay was made from mature Rhodes grass, its CP content (81 g/kg DM) was relatively higher than most

Table 4 Digestibility of different forms of white lupin grain (WLG) used to supplement Washera sheep fed on Rhodes grass hay

Variables	WLG forms				SEM	SL
	Raw	Raw soaked, dehulled	Roasted	Raw soaked		
DM	73.1	77.6	74.0	71.2	3.84	ns
OM	74.6	79.1	76.2	73.1	3.54	ns
CP	85.0	89.7	84.1	86.4	3.55	ns
NDF	67.8	74.1	70.5	67.2	4.81	ns
ADF	70.5	73.2	73.6	67.6	3.52	ns

WLG white lupin grain, *ADF* acid detergent fibre, *CP* crude protein, *DM* dry matter, *OM* organic matter, *NDF* neutral detergent fibre, *ns* not significant, *SEM* standard error of mean, *SL* significance level

Table 6 Effect of different forms of WGL supplementation on carcass parameters of Washera sheep fed on Rhodes grass hay

Carcass parameters	Treatments					SEM	SL
	T_1	T_2	T_3	T_4	T_5		
SW (kg)	14.4^{c}	17.6^{b}	18.2^{ab}	18.6^{a}	18.00^{ab}	0.21	***
EBW (kg)	10.70^{b}	15.48^{a}	15.59^{a}	16.00^{a}	15.59^{a}	0.32	***
HCW (kg)	4.1^{b}	6.0^{a}	5.9^{a}	6.2^{a}	6.0^{a}	0.14	***
DPSW (%)	28.5^{b}	34.2^{a}	32.8^{a}	33.3^{a}	33.5^{a}	0.006	***
DPEBW (%)	38.1	38.7	38.3	38.7	38.7	0.00004	ns
REMA (cm^2)	4.06^{b}	5.94^{a}	5.94^{a}	6.0^{a}	6.22^{a}	0.14	***

Means with different superscripts (a, b, c) in a row are significantly different

***$P<0.001$

SEM standard error of mean, *ns* not significant, *SL* significance level, *SW* slaughter weight, *EBW* empty body weight, *HCW* hot carcass weight, *REMA* rib-eye muscle area, *DPEBW* dressing percentage as base of empty body weight, *DPSW* dressing percentage as base of slaughter weight, T_1 RGH offered alone, T_2 RGH+300 g raw white lupin grain (WLG), T_3 RGH+300 g raw soaked, dehulled WLG, T_4 RGH+300 g roasted WLG, T_5 RGH+300 g raw soaked WLG

tropical feeds commonly available during the dry season (Bediye and Sileshi 1989; Bediye et al. 2007; Tolera 2007; Tegegne and Assefa 2010). The CP content of RGH was sufficient for maintenance of body weight and to maximize digestibility of DM and NDF of straw-based diets (Van Soest 1994; McDonald et al. 2002).

Table 7 Effect of different forms of white lupin grain supplementation on edible offal of Washera sheep fed on Rhodes grass hay

Edible offal	Treatments					SEM	SL
	T_1	T_2	T_3	T_4	T_5		
Empty gut (g)	1088^{b}	1389^{a}	1422^{a}	1434^{a}	1398^{a}	38.10	***
Blood (g)	574^{b}	854^{a}	855^{a}	882^{a}	860^{a}	23.96	***
Liver (g)	180^{b}	354^{a}	356^{a}	367^{a}	358^{a}	10.76	***
Kidney (g)	45^{b}	71^{a}	71^{a}	79^{a}	75^{a}	4.98	**
Heart (g)	60^{b}	74^{a}	74^{a}	76^{a}	75^{a}	4.31	ns
Tongue (g)	73	77	71	74	72	2	ns
Kidney fat (g)	19^{b}	71^{a}	71^{a}	71^{a}	71^{a}	1.85	***
Abdominal fat (g)	39^{b}	99^{a}	99^{a}	102^{a}	100^{a}	2.01	***
Reticulo-rumen (g)	407	427	428	441	430	11.00	ns
Omas-abomasum (g)	173	177	177	183	178	4.10	ns
SLI (g)	513^{b}	641^{a}	642^{a}	662^{a}	645^{a}	7.74	***
Testicle (g)	119^{b}	160^{a}	164^{a}	165^{a}	161^{a}	2.82	***
Tail (g)	180^{b}	534^{a}	531^{a}	551^{a}	537^{a}	7.37	***
TEOC (g)	3474^{b}	4933^{a}	4965^{a}	5079^{a}	4965^{a}	79.22	***

Means with different superscripts (a, b) in a row are significantly different

SEM standard error of mean, *ns* not significant, *SL* significance level, *SLI* small and large intestines, *TEOC* total edible offal component, *LTO* lung trachea and oesophagus, T_1 RGH offered alone, T_2=RGH+300 g raw white lupin grain (WLG), T_3=RGH+300 g raw soaked, dehulled WLG, T_4=RGH+300 g roasted WLG, T_5=RGH+300 g raw soaked WLG

**$P<0.01$; ***$P<0.001$

The CP content of the different forms of WLG (362–583 g/kg DM) was also comparable or higher than CP in oilseed cakes (*noug*, sunflower, cotton, linseed, rapeseed, sesame and groundnut) which are used as protein supplements in Ethiopia (Bediye and Sileshi 1989; Bediye et al. 2007). This is very important in situations where the major limiting factor for animal production is deficiency of N in basal feeds such as cereal; crop residues are important feed resources in Ethiopia (Tolera 2007; Tegegne and Assefa 2010). The difference in CP content between raw (385 g/kg DM) and roasted (362 g/kg DM) WLG (Table 1) could not be explained as roasting had no effect on the same component (Yeheyis et al. 2011). The improvement in CP content in soaked and dehulled WLG (Table 1) was in line with the finding of the latter authors.

Table 8 Effect of different forms of white lupin grain supplementation on inedible offal of Washera sheep fed on Rhodes grass hay

Variables	Treatments					SEM	SL
	T_1	T_2	T_3	T_4	T_5		
Spleen (g)	34	36	36	37	36	1.13	ns
Skin and feet (g)	1472^{b}	1887^{a}	1890^{a}	1949^{a}	1921^{a}	26	***
Penis (g)	34	35	35	37	36	0.85	ns
LTO (g)	228^{b}	302^{a}	303^{a}	312^{a}	304^{a}	3.74	***
Gut content (g)	3770^{b}	3988^{a}	3991^{a}	4119^{a}	4015^{a}	50.54	**
Head (g)	785^{b}	854^{a}	850^{a}	882^{a}	860^{a}	10.83	**
TIOC (g)	6324^{b}	7104^{a}	7106^{a}	7337^{a}	7173^{a}	86.55	***

Means with different superscripts (a, b) in a row are significantly different

SEM standard error of mean, ns=not significant, *SL* significance level, *LTO* lung trachea and oesophagus, *TIOC* total inedible offal components, T_1 RGH offered alone, T_2 RGH+300 g raw white lupin grain (WLG), T_3 RGH+300 g raw soaked, dehulled WLG, T_4 RGH+300 g roasted WLG, T_5 RGH+300 g raw soaked WLG

**$P<0.01$; ***$P<0.001$

Feed and nutrient intake

Rhodes grass hay DM intake of control group in the current study (414 g/day) was relatively higher than the value (360 g/day) reported for Adilo male yearling sheep fed ad libitum RGH (Gebregiorgis et al. 2012). Differences could be attributed to variations in chemical composition of experimental feedstuffs, season of the studies and sheep breed used, though they are indigenous to Ethiopia (Bishaw and Melaku 2008; Mekuriaw et al. 2012). The higher intake of RGH DM by sheep on the control treatment as compared to the supplemented group might be due to the higher consumption of the basal diet to fulfil the nutrient requirement. The low RGH DM intake in the supplemented sheep might be due to the substitution effect though it was not significant ($P>0.05$) (Table 2).

The dry matter intake (DMI) (%BW) was comparable to results obtained by supplementing Washera sheep with 290 g/day blue sweet lupin (Yeheyis et al. 2012b). The significantly high ($P<0.05$) feed and nutrient intake recorded (Table 2) can be attributed to roasting, soaking and dehulling (Smith and Warren 1986). Yeheyis et al. (2011) reported that roasted WLG had lower alkaloid content (1.07 %) than the raw form (1.43 %). Thus, the higher WLG DM intake recorded in T_4 than in other supplemented treatments could be attributed to the roasting process, which is more efficient in alkaloid reduction than the other processing techniques used (*Ibid*). However, comparatively lower WLG DM intake (133–192 g/day) was recorded in this experiment (Table 2) than the value reported (270 g/day) for sweet blue lupin (*Lupinus angustifolius* L.—imported) using the same sheep breed (Yeheyis et al. 2012b). This could be more explained by the palatability problem related to the alkaloid content of WLG. Local white lupin grown in northwest Ethiopia has relatively high alkaloid content (16,752 mg/kg DM) as compared to sweet white lupin (178 mg/kg DM) (Yeheyis et al. 2012a). Thus, whether the traditional treatment methods (roasting, soaking and dehulling), which were believed to reduce alkaloid content (Yeheyis et al. 2011), were enough to reduce the anti-nutritional factor to a level that may not negatively affect WLG intake is open to question.

From CP intake data (Table 2), one can see that its concentration in the supplemented groups ranged from 16 to 24 % of the total DM intake which is above the 7–8 % required to satisfy the maintenance requirement of ruminant animals for efficient utilization of feeds at the level of the rumen (Van Soest 1994; McDonald et al. 2002; Norton 2003). Therefore, the improvement in intake of most of the nutrients in the supplemented groups can be warranted by the relatively higher intake of CP. Yu et al. (2002) reported that dry roasting of lupin grain may increase bypass crude protein without having a greater impact on the rumen-degradable characteristics of starch-free organic matter. A previous study showed that roasting could increase protection of lupin oil from ruminal hydrogenation (Robinson and McNiven 1993).

Based on the DM requirement of sheep for maintenance (2–2.5 % BW) and growth (4–4.5 % BW) (ARC 1980; NRC 1985), all supplemented groups consumed more than maintenance requirements while DM intake of all the treatment diets failed to meet growth requirements for DM.

Raw lupin protein is highly degradable in the rumen (Freer and Dove 1984) which may result in poor animal performance (Guillaume et al. 1987). Silano et al. (1981) reported that moderate heat treatment not only enhances palatability and acceptance but also reduces ruminal degradation of protein supplement, and it improves nitrogen retention and supply of amino acids for intestinal absorption. Thus, roasting, in addition to increasing DM and nutrient intake, may improve the value of the protein supplement (Silano et al. 1981).

Feed and nutrient digestibility

The relatively low DM and OM digestibility coefficient of Rhodes grass hay used in this study (0.58 and 0.59, respectively) could be attributed to harvesting of the grass after seed setting. Denekew (2004) reported that OM digestibility declined from 0.72 to 0.49 when harvesting grass for hay making was delayed from early leaf to maturity stage.

The possible explanation for the lower CP apparent digestibility of Rhodes grass hay might be due to lower CP (81 g/kg DM) and higher NDF (813 g/kg DM) contents that negatively affect microbial growth and fermentation in the rumen (McDonald et al. 2002). Comparable to the present study, different research results conducted in Ethiopia, supplementation increased digestibility of DM, OM and CP (Abate and Melaku 2008; Tekletsadik 2008).

Body weight change

Though CP content of Rhodes grass hay should have fulfilled the minimum requirement (Van Soest 1994; McDonald et al. 2002), sheep on the control diet lost 22 g/day. This was comparable with the finding recorded when Arado sheep were fed with teff (*Eragrostis tef*) straw as basal diet in Tigray, Ethiopia (Gereslassie and Melaku 2009). This low performance could not be fully explained by the DMI (414.6 g DM/day) (Table 2) which in principle could suffice the minimum maintenance requirement (2–2.5 % BW) (ARC 1980; NRC 1985). The higher NDF (813 g/kg DM) and ADL (129 g/kg DM) contents of matured Rhodes grass hay might have limited the use and availability CP. Moreover, sheep in the control treatment had low apparent nutrient digestibility (Table 3).

Supplements result in improved animal performance in several ways, such as by providing essential nutrients for rumen microorganisms, enhancing the microorganism activities in the rumen and providing nutrients for the sheep (Van Soest 1994). The ADG observed in this study was lower than the findings of Hailu et al. (2011), Simachew (2009) and Yeheyis et al. (2012b) who reported 25.0–34.0, 38.9–55.6 and 73.7–91.3 g/day, respectively, for the same sheep breed (Washera) implying that the experimental sheep in this study performed below their potential. This could be attributed to limited feed intake (Table 2), which is much less than the requirement for growth (4–4.5 % BW) (NRC 1985; McDonald et al. 2002), that was probably caused by alkaloids. High alkaloid levels in the diet of experimental animal have been known to depress feed intake and growth (Carr and Pearson 1976). Given that ADG had strong and positive correlation with CP intake (0.92) (Table 9), the low growth performance of sheep on T_2 was expected. However, this did not seem to apply for T_3 in which sheep had the maximum CPI (Table 2).

According to Kung et al. (1991), heat treatment decreases rumen degradability of lupin protein and thereby increases the supply of dietary protein to the lower gut, improving body weight gain, feed efficiency and nitrogen retention in lambs. The highly significant effect ($P<0.001$) of supplementing with roasted WLG on ADG (Table 5), without affecting digestibility coefficients, and FCE ($P>0.05$) is in agreement with the latter authors. The effect of roasting in reducing the alkaloid content and consequently on growth performance (Rahma and Rao 1984) could not be conclusive as alkaloid's negative effect on DMI could not be ruled out.

Carcass characteristics

Dressing percentage (DP) is one of the important carcass parameters (Massae and Mtenga 1992) which could also be influenced by nutrition. Better quality feeds could increase growth and in turn increase DP (Díaz et al. 2002). Positive effect of WLG supplementation had been observed on carcass characteristics (Table 3). Comparable to the present study, Mulu (2005) reported DP ranging from 27.3 to 38.4 expressed as percent SW when Wogera sheep were supplemented with brewery dried grain. Higher DP values for yearling Arsi-Bale, Horro, and Tigray highland sheep were reported (Feyera and Animut 2011; Gebretsadik and Kebede 2011) which could be attributed to breed difference. However, higher DP for yearling Washera sheep (breed used in the present study) supplemented with graded levels of concentrate mix (42.4 to 46.8 and 49.8 to 54.2 on slaughter BW and EBW basis, respectively) (Hailu et al. 2011). In addition, Simachew (2009) reported DP of 30–40 and 46–52 % on slaughter BW and EBW basis, respectively, for Washera sheep weighing 17.3–23.0 kg at slaughter (SW) (fed grass hay basal diet supplemented with 300 g *noug* seed meal, maize bran and their mixture). The differences within the same breed could possibly be associated with the relatively higher SWs, slaughtering conditions and type and quality of feeds used in the latter experiments.

The mean EBW of Washera sheep in the present study (Table 3) was within a range of 9.6–17.1 kg which was reported for Hararghe highland sheep fed urea-treated maize Stover and concentrate mix (Yeheyis et al. 2012a, b), but lower than 19.9–23.3 kg who reported for Tigray highland sheep fed iso-nitrogenous oil seed cakes in cactus (*Opuntia ficus-indica*)–*tef* straw (*E. tef*)-based feeding (Degu et al. 2009).

The highest ($P<0.001$) REMA observed in supplemented sheep than in the non-supplemented sheep (Table 3) might be due to the efficient utilization of feeds offered for growth of

Table 9 Correlation between nutrient intake, apparent nutrient digestibility, ADG and carcass parameters of Washera sheep fed on grass hay supplemented with different forms of white lupin grain

PARAMETERS	DMI	OMI	CPI	DMD	OMD	CPD	HCW	EBW	DP/EBW	REMA	TEO	TNEO	ADG
DMI	1												
OMI	0.99***	1											
CPI	0.85	0..82	1										
DMD	0..88*	0..85	0.96**	1									
OMD	0.90*	0.88*	0.96**	0.99**	1								
CPD	0.85	0.82	0.95**	0.97**	0.97**	1							
HCW	0.94*	0.92*	0.92**	0.94*	0.93**	0.95*	1						
EBW	0.94*	0.92*	0.89*	0.95*	0.96**	0.96**	0.99***	1					
DP/EBW	0.71	0.70	0.40	0.52	0.55	0.59	0.77	0.75	1				
REMA	0.95*	0.93*	0.88*	0.93*	0.95*	0.94*	0.99***	0.99***	0.77	1			
TEO	0.94*	0.92*	0.89*	0.95*	0.96**	0.96**	0.99***	0.99***	0.77	0.99***	1		
TNEO	0.98*	0.96**	0.86	0.91*	0.92**	0.91*	0.98**	0.98**	0.79	0.99**	0.98**	1	
ADG	0.96**	0.94**	0.92*	0.95**	0.97**	0.95**	0.99***	0.99***	0.79	0.99***	0.98**	0.98**	1

ADG average daily gain, *CPD* crude protein digestibility, *CPI* crude protein intake, *DMD* dry matter digestibility, *DMI* dry matter intake, *DP/EBW* dressing percentage on empty body weight base, *EBW* empty body weight, *HCW* hot carcass weight, *OMI* organic matter intake, *OMD* organic matter digestibility, *REYA* rib-eye area, *TEOC* total non-edible offal components

*$P<0.05$; **$P<0.01$; ***$P<0.001$

useful muscle component in the former group. A comparable result to the present study in REMA (3.1–6.9 cm^2) was reported for Arsi-Bale sheep (Tafa et al. 2010). However, REMA from the current study is lower than the values reported for different Ethiopian sheep breeds (Feyera and Animut 2011; Hagos and Melaku 2009).

Supplementation increased the amount of visceral and kidney fat, heart, head, LTO and SLI which agreed with previous reports (Hailu et al. 2011; Simachew 2009), except that the latter authors reported higher TIOC in supplemented sheep. Contrary to the current finding, TIOC in Afar rams decreased as supplementation level increased and might depend on slaughtering conditions (Hagos and Melaku 2009).

Conclusion

Among the three processing methods used, roasting could be recommended for ruminant producer smallholder farmers who are threatened by the dwindling access to expensive concentrate. The relevance of dehulling, which is a labour-intensive and time-consuming task, can be questioned. And yet, the improvement in CP content due to dehulling cannot be ignored. Supplementation of Washera sheep with different forms of white lupin grain improved feed and nutrient intake, digestibility, growth and carcass quality parameters. In a country where livestock lose weight during the long dry seasons, white lupin grain can be recommended not only for maintenance, which can be seen as a strategy in dryland areas, but also for optimum performance of ruminants. In terms of CP content, however, high performance could be expected from white lupin grain supplementation. Thus, since this kind of study on local white lupin grain is the first of its kind in Ethiopia, there has to be further investigations on the processing methods as well as animal evaluation.

Acknowledgments The first author would like to acknowledge Koga irrigation project for granting the research budget and Haramaya University for availing laboratory facilities.

Conflict of interest The authors declare that they have no competing interests.

References

Abate, D. and Melaku, S., 2008. Effects of supplementing urea treated barley straw with vetch (*Vicia dasycarpa*, l.) or alfalfa (*Medicago sativa* 'Hunter river') hay on feed intake, digestibility and growth of Arsi Bale Sheep. Tropical Animal Production and Health, 41, 579–586.

AOAC (Association of Official Analytical Chemists), 1990. Official methods of chemical analysis. 15th edition, (Association of Official Analytical Chemists, Arlington).

ARC (Agricultural Research Council), 1980. The nutrient requirements of ruminant livestock. Technical review Agricultural Research Council working party, (published on behalf of the ARC by the Commonwealth Agricultural Bureau, UK).

Bähr, M., Fechner, A., Hasenkopf, K., Mittermaier, S. and Jahreis, G., 2014. Chemical composition of dehulled seeds of selected lupin cultivars in comparison to pea and soya bean. LWT-Food Science and Technology, 59, 587–590.

Bediye, S. and Sileshi, Z., 1989. The composition of Ethiopian feeds. Research Report No. 6. Addis Ababa: Institute of Agricultural Research, Addis Ababa.

Bediye, S., Sileshi, Z. and Dereje, F., 2007. Chemical composition and nutritive values of Ethiopian feeds, Research Report 73, Ethiopian Institute of Agricultural Research, Addis Ababa.

Bishaw, F. and Melaku, S., 2008. Effects of supplementation of Farta sheep fed hay with sole or mixtures of noug seed meal and wheat bran on feed intake, digestibility and body weight change. Tropical Animal Health and Production, 40, 597–606.

Bogale, S., Melaku, S. and Yami, A., 2008. Potential use of crop residues as livestock feed resources under smallholder farmers' conditions in Bale highlands of Ethiopia. Tropical and Subtropical Agro-ecosystems, 8, 107–114.

Brenes, A., Marquardt, R.R., Guenter, W. and Rotter, B.A., 1993. Effect of enzyme supplementation on the nutritional value of raw, autoclaved, and dehulled lupins (*Lupinus albus*) in chicken diets. Poultry Science, 72, 2281–2293.

Carr, J.R. and Pearson, G., 1976. Nutritive values of lucerne leaf-protein concentrate and lupin-seed meal as protein supplements to barely diets for growing pigs. Nutrition Abstracts and Review, 46, 751.

Clotter, J.A., 1985. Manual for the slaughter of small ruminants in developing countries, FAO animal production and health paper 49, Rome.

Degu, A., Melaku, S. and Berhane, G., 2009. Supplementation of isonitrogenous oil seed cakes in cactus (*Opuntia ficus-indica*)-tef straw (*Eragrostis tef*) based feeding of Tigray Highland sheep. Animal Feed Science and Technology, 148, 214–226.

Denekew, Y. 2004. Assessment of botanical composition and stage of harvesting of selected natural pasture for optimum utilization as hay at Andassa Livestock Research Center, North Western Ethiopia, (unpublished MSc Thesis, Alemaya University).

Díaz, M.T., Velasco, S., Caneque, V., Lauzurica, S., de Huidobro, F . R., Perez, C., Gonzáleza, J. and Manzanaresa C., 2002. Use of concentrate or pasture for fattening lambs and its effect on carcass and meat quality. Small Ruminant Research, 43, 257–268.

Food and Agricultural Organization of the United Nations. Ethiopia Country Programming Framework 2012–2015. 2011. http://coin.fao.org/coin-static/cms/media/17/13770110474620/fao_country_programming_framework_-_cpf.pdf. Accessed 24 March 2015.

Feyera, T. and Animut, G., 2011. Effect of supplementing wheat bran, *Acacia albida* leaf meal and their mixture on feed intake and carcass characteristics of Horro sheep fed vetch (*Lathyrus sativus*) haulm basal diet. Pakistan Journal of Nutrition 10, 1013–1021.

Freer, M. and Dove, H., 1984. Rumen degradation of protein from sunflower meal, rapeseed meal, and lupin seed meal placed in nylon bags. Animal Feed Science and Technology, 11, 87–101.

Gebregiorgis, F., Negesse, T. and Nurfeta, A., 2012. Feed intake and utilization in sheep fed graded levels of dried moringa (*Moringa stenopetala*) leaf as a supplement to Rhodes grass hay. Tropical Animal Health and Production, 43, 511–517.

Gereslassie, Z. and Melaku, S., 2009. Supplementation of sesame seed (*Sesame indicum*) cake, wheat bran and their mixtures on feed intake, digestibility, live weight changes and carcass characteristics of Arado sheep fed a basal diet of teff straw. East African Journal of Science, 3, 37–42.

Gebretsadik, G. and Kebede, K., 2011. Feed utilization, digestibility and carcass parameters of Tigray highland sheep fed urea treated wheat straw supplemented with mixtures of wheat bran and noug seed cake, in Southern Tigray, Ethiopia. Livestock Research for Rural Development, 23 (9).

Guillaume, B., Otterby, D.E., Linn, J.G. and Stern, M.D., 1987. Comparison of sweet white lupin seeds with soybean mea1 as a protein supplement for lactating dairy cows. Journal of Dairy Science, 70, 2339–2348.

Hagos, T. and Melaku, S., 2009. Feed intake, digestibility, body weight and carcass parameters of Afar rams fed tef (*Eragrostis tef*) straw supplemented with graded levels of concentrate mix. Tropical Animal Health and Production, 41, 599–606.

Hailu, A., Melaku, S., Tamir, B. and Tassew, A., 2011. Body weight and carcass characteristics of Washera sheep fed urea treated rice straw supplemented with graded levels of concentrate mix. Livestock Research for Rural Development, 23 (8).

Kung, L., Maciorowski, K., Powell, K.M., Weidner, S. and Eley, C.L. 1991. Lupin as a protein supplement for growing lambs. Journal of Animal Science, 69, 3398–3405.

Legesse, G., 2008. Productive and economic performance of small ruminant production in production system of the Highlands of Ethiopia, (unpublished PhD Thesis, University of Hohenheim).

Massae, E. E. and Mtenga, L. A., 1992. Effects of plane of nutrition on growth performance and carcass composition on lambs in Tanzania. In: B. Rey, S. H. B. Lebbie, L. Reynolds (eds), Small ruminant research and development in Africa, Nairobi, 1990, 401–415.

McDonald, P., Greenhalgh, J.F.D., Edwards, R.A. and Morgan, C.A., 2002. Animal nutrition. 6th edition, (Pearson Prentice Hall, UK).

Mekuriaw, Y., Urge, M. and Animut, G., 2012. Intake, digestibility, live weight changes and rumen parameters of Washera sheep fed mixtures of lowland bamboo (*Oxytenanthera abyssinica*) leaves and natural pasture grass hay at different ratios. Pakistan Journal of Nutrition, 11, 322–331.

Melaku, S., Peters, K. J. and Tegegne, A., 2004. Effect of supplementation with foliages of selected multipurpose trees, their mixtures or wheat bran on feed intake, plasma enzyme activities, live weight and scrotal circumference gain in Menz sheep. Livestock Production Science, 89, 253–264.

Mulu, M., 2005. Effect of feeding different levels of breweries' dried grain on live weight and carcass characteristics of Wogera sheep fed on hay basal diet, (unpublished MSc Thesis, Haramaya University).

Muzquiz, M., Varela, A., Burbano, C., Cuadrado, C. Guillamo'n, E., and Pedrosa, M.M., 2012. Bioactive compounds in legumes: pronutritive and antinutritive actions. Implications for nutrition and health. Phytochemistry Review, 11, 227–244.

Norton, B.W. The nutritive value of tree legumes. 2003. http://www.fao.org/ag/AGP/AGPC/doc/Publicat/Gutt-shel/x5556e0j.htm.

NRC (National Research Council), 1985. Nutrient Requirements of Sheep. 6th edition, (National Academy Press, Washington DC).

Pisarikova, B. Zraly, Z., Bunka, F. and Trckova, M., 2008. Nutritional value of white lupine cultivar Butan in diets for fattening pigs. Veterinary Medicine, 53 (3), 124–134.

Rahma, E.H. and Rao, M.S.N., 1984. Effect of dibittering treatment on the composition and protein components of Lupin seed (*Lupins termis*) flour. Journal of Agriculture and Food Chemistry, 32, 1026–1043.

Robinson, P.H. and McNiven, M.A., 1993. Nutritive-value of raw and roasted sweet white lupins (*Lupinus albus*) for lactating dairy-cows. Animal Feed Science and Technology, 43, 275–290.

SAS (Statistical Analysis System), 2000. SAS/STAT Guide to personal computers, Version 9.0., Statistical Analysis System Institute Inc., USA.

Silano, V., Bansul, H.C. and Bozzin, A., 1981. Improvement of nutritional quality of food crops, (FAO Production, Rome).

Simachew, G., 2009. Effects of supplementation with maize bran, noug seed meal and their mixtures on feed utilization and carcass characteristics of Washera sheep fed hay, (unpublished MSc thesis, Haramaya University).

Smith, G. H. and Warren, B., 1986. Supplementation to improve the production of yearling steers grazing poor quality forage. 1. The effects of forage type and a cottonseed meal supplement. Australian Journal of Experimental Agriculture, 26, 7–12.

Sujak, A., Kotlarz, A. and Strobel, W., 2006. Compositional and nutritional evaluation of several lupin seeds. Food Chemistry, 98, 711–719.

Tafa. A., Melaku, S. and Peters, K.J., 2010. Supplementation with linseed (*Linum usitatissimum*) cake and/or wheat bran on feed utilization and carcass characteristics of Arsi-Bale sheep. Tropical Animal Health and Production, 42, 677–685.

Tegegne, F. and Assefa, G. Feed resources assessment in Amhara Regional State. Ethiopia Sanitary and Phytosanitary Standards and Livestock and Meat Marketing Program (SPS-LMM) Texas A&M University System. 2010. http://borlaug.tamu.edu/files/2012/03/Feed-Resource-Assessment-in-Amhara-National-Regional-State.pdf . Accessed 24 Dec 2014.

Tekletsadik, E., 2008. The effects of supplementation with barley bran, linseed meal and their mixtures on the performance of Arsi-Bale sheep fed a basal diet of faba bean haulms, (unpublished MSc Thesis, Haramaya University).

Tolera, A. Feed resources for producing export quality meat and livestock in Ethiopia, examples from selected Woredas in Oromia and SNNP regional states. Ethiopia Sanitary and Phytosanitary Standards and Livestock and meat Marketing Program (SPS-LMM) Texas A&M University System. 2007. http://borlaug.tamu.edu/files/2012/03/Feed-Resources-for-Producing-Export-Quality-Meat-and-Livestock-in-Ethiopia-examples-from-selected-Woredas-in-Oromia-and-SNNP-Regional-States.pdf. Accessed 24 Dec 2014.

Van Soest, P.J., 1994. Nutritional ecology of the ruminants. 2nd edition, (Cornell University Press, New York).

Van Soest, P.J.; Robertson, J.B., 1985. Analysis of forage and fibrous foods: A laboratory manual for animal science, (Cornell University Press, New York).

Watkins, B. A. and Mirosh, L.W., 1987. White lupins as a protein source for layers. Poultry Science, 66, 1798–1806.

WARDO (Mecha *Woreda* Agricultural and Rural Development Office), 2009. Mecha *Woreda* Agricultural and Rural Development Office annual report.

Yeheyis, L. Kijora, C., Van Santen, E., Wink, M. Jürgen Danier and Peters K. J., 2012a. Crude protein, amino acid and alkaloid contents of annual sweet lupin (*Lupinus* spp. L.) Forages and seeds grown in Ethiopia, Experimental Agriculture, 48, 414–427.

Yeheyis, L. Kijora, C. and Tegegne, F., 2012b. Sweet blue lupin (*Lupinus angustifolius* L.) seed as a substitute for concentrate mix supplement in the diets of yearling Washera rams fed on natural pasture hay as basal diet in Ethiopia. Tropical Animal Health and Production, 44, 1255–1261.

Yeheyis, L., Kijora, C., Melaku, S., Girma, A. and Peters, K.J., 2010. White lupin (*Lupinus albus* L.), the neglected multipurpose crop: Its production and utilization in the mixed crop-livestock farming system of Ethiopia, Livestock Research for Rural Development, 22 (74).

Yeheyis, L., Kijora, C., Wink, M. and Peters, K.J., 2011. Effect of a traditional processing method on chemical composition of local white lupin (*Lupinus albus* L.) seed in north-western Ethiopia, Zeitschrift für Naturforschung, 6, 403–408.

Yu, P., Leury, B.J. and Egan, A.R., 2002. Ruminal behavior of protein and starch free organic matter of *Lupinus albus* and *Vicia faba* in dairy cows. Asian-Australasian Journal of Animal Science, 15, 974–981.