WFL Publisher
Science and Technology

Meri-Rastilantie 3 B, FI-00980
Helsinki, Finland
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Journal of Food, Agriculture & Environment Vol.8 (2): 781-784. 2010

www.world-food.net

Chemical composition and *in situ* ruminal degradability of dry matter and neutral detergent fiber from almond hulls

Taher Yalchi [1]* and Shahryar Kargar [2]

*[1] Moghan Junior College of Agriculture, University of Mohaghegh Ardabili, Ardabil, Iran. [2] Department of Animal Sciences, Isfahan University of Technology, Isfahan 84156 - 83111, Iran. *e-mail: taheryalchi@uma.ac.ir, taheryalchi@yahoo.com*

Received 30 January 2010, accepted 8 April 2010.

Abstract

A study was conducted to determine chemical composition and *in situ* ruminal degradability of almond hulls in comparison with alfalfa hay (AF). Almond hulls represented two varieties for which the common names are stone shell (SS) and paper shell (PS) and a commercial mixture (CM). The crude protein (CP) of AF was higher ($P<0.05$) than any of the almond hulls. For almond hulls CP was lowest ($P<0.05$) for PS at 21.8 g kg^{-1} dry matter (DM). PS was lowest and highest ($P<0.05$) in neutral detergent fiber (NDF) and non-fibrous carbohydrates (NFC) (347.0 and 544.6 g kg^{-1} DM, respectively). These contents were in contrast to AF, which was highest and lowest ($P<0.05$) in NDF and NFC (585.9 and 144.6 g kg^{-1} DM, respectively). The rapidly degradable DM fraction was highest ($P<0.05$) for PS, but this value was lowest ($P<0.05$) for AF. PS had a lower ($P<0.05$) slowly degradable DM fraction compared with the CM, SS and AF, but this value was highest ($P<0.05$) for AF. There was no difference ($P>0.05$) in the slowly degradable NDF fraction among AF, CM and PS but it was greatest ($P<0.05$) for SS. Almond hulls have high potential degradability of DM and degradability index value of DM compared to AF. SS and PS had a higher effective degradability (ED) of DM compared with AF. AF and SS had a higher ED of NDF compared with AF and PS. Results showed that almond hulls as a horticultural by-product have a medium nutritive value and can be used as a feedstuff for ruminants.

Key words: Almond hull, by-product, chemical composition, *in situ* degradability.

Introduction

Almond, scientifically known as *Prunus dulcis*, belongs to the Rosaceae family and is also related to stone fruits such as peaches, plums and cherries [15]. Almond, with or without the brown skin, is consumed as the whole nut or used in various confectioneries and chocolates; its discarded components are used as livestock feed [29]. Agricultural and horticultural by-products are residues obtained after processing of fruits, vegetables and crops. They may include pulps, pomaces and hulls. Using such by-products for animal feeding is a means of recycling materials that otherwise, if accumulated, might cause environmental pollution [14].

Almond hull is the by-product obtained by drying that portion of the almond fruit that surrounds the hard shell. The proportion of the hull, shell and nut is 50% hull, 25% shell and 25% nut on an air-dry basis [1, 7]. Production of almonds and the by-product hull has been increasing rapidly in recent years. Approximately 2,112,815 and 110,000 metric tons of almonds with shell were produced commercially in the world and Iran, respectively, in 2008 [8], resulting in availability of equal tons of hulls [7]. Unlike many other by-products (pulps and pomaces) almond hulls are dried in the harvesting process. Low moisture content makes this by-product attractive for livestock feed by reducing transportation costs and allowing for long-term storage [24]. The world-wide use of by-product feedstuffs is common practice, yet few published reports document the amounts of plant by-product feedstuffs generated [12].

Various workers have examined the chemical composition of almond hulls and reported that hulls as a feedstuff contained 2.1 to 8% CP [7, 9], 1.69 to 2.9% ether extract (EE) [10, 24], 5.03 to 12% ash [4, 19], 13.7 to 29.9% acid detergent fiber (ADF) [19, 24], 28 to 38.49% neutral detergent fiber (NDF) [10, 24], 48.7 to 57.8% non-fibrous carbohydrate (NFC) [24] and 4.1 to 14.9% acid detergent lignin (ADL) [17, 19]. Shultz *et al.* [27] reported that apparent 24-hour rumen digestion of DM from almond hulls by *in sacco* method was 56%. Also they found that this by-product is an intermediate energy source.

A number of authors suggested that degradation characteristics of feeds in the rumen will provide a useful basis for the evaluation of their nutritive value [22, 26]. The NDF degradability of roughages is an essential parameter in predicting their energetic value. The cell wall components in these feedstuffs are the main nutritive constituents and the extent of rumen degradation is the main factor that influences their energetic value [17]. Moreover, NDF degradability has been used in models to estimate the physical fill of fibrous feeds in the rumen [16, 28] and, therefore, the intake capacity of ruminants. Due to many confounding factors, it is likely that digestibility of forage fiber measured *in vitro* or *in situ* is a better indicator of the potential of forages to enhance dry matter (DM) intake than NDF digestibility measured *in vivo* [31].

There is little information available on the ruminal degradability of DM and NDF of almond hulls produced in Iran. The present study was, therefore, carried out to determine the chemical composition and degradability of almond hulls. Because alfalfa hay is one of the main feed used in the feeding of ruminants in Iran, its nutritive value was compared with almond hulls.

Materials and Methods

This experiment was conducted using almond hulls from the north-western part of Iran. Almond hulls were obtained from several almond gardens. Samples represented the two important almond varieties in production, whose common names are stone shell (SS), paper shell (PS) and a commercial mixture (CM). Broken branches, leaves, dust and other residual was separated from hulls and then hulls were chopped about 2 cm. AF in full bloom was cut and sun-cured then chopped (about 2 cm) and stored on concrete in an enclosed building. DM was determined from fresh samples in oven at 105ºC for 24 h or until constant weight [3]. The residual samples were oven-dried at 55ºC for 48 h. Samples of 200 g of each oven-dried feed were ground in a Wiley mill (1 mm screen) and used for subsequent chemical analysis. CP, EE, ash, ADF and ADL contents of samples were determined by standard methods [3]. NDF was analyzed according to Van Soest *et al.* [30]. NFC, cellulose and hemicellulose were calculated as follows [17]:

NFC = 100 - (CP % + NDF % + EE % + ash %)

Cellulose = (ADF % - ADL %)

Hemicellulose = (NDF % - ADF %)

The nylon bag method [11]was used to determine the rate of degradability of DM and NDF from the feeds when suspended in the rumens of four rumen-fistulated Balochi wether sheep of approximately 50±3 kg live weight. The animals were fed 1.3 kg day^{-1} of a ration consisting of AF, wheat straw, barley and wheat bran with a ratio of forage to concentrate of 60:40 (DM basis), which was calculated to provide maintenance. This ration in form of total mixed ration (TMR) was offered to sheep in two equal feedings at 08:00 and 18:00 h. The polyester bag size for determination of DM degradability was 12 cm ×19 cm, with a pore size of 50 µm. All the samples of feeds were dried and milled through a 4.0-mm sieve. Then, 5 g of each sample was put in the nylon bag and incubated in the rumen for 2, 4, 8, 12, 24, 48, 72 or 96 h. All bags were inserted at the same time, just before the morning feeding (08:00 h). In each sheep, one bag was used for each time interval. After withdrawing the bags from the rumen, they were washed in a washing machine for 1 h using cold water, and then kept in a freezer. When all the bags had been taken from the rumen, they were dried for 2 days at 55°C. The value of degradability at time 0 was obtained by washing three bags in a washing machine for 1 h using cold water. For each bag, the residue was analyzed for DM. For determination of NDF degradability the incubation times and work method were obtained in a similar manner as described above. However, the bag size was 3 cm×6 cm with a pore size of 46 µm and weight of sample was 0.5 g. For each bag, the residue was analyzed for NDF. Disappearance of DM and NDF at each incubation time was calculated from the proportion remaining after incubation in the rumen.

Degradation of DM and NDF was calculated using the equation of Ørskov and McDonald [21]:

$$P = a+b(1- e^{-ct})$$

where P is the disappearance rate at time t, a the rapidly degradable DM or NDF fraction, b the slowly degradable DM or NDF fraction in the rumen, c the rate constant of degradation of b and t is the time of incubation.

Effective degradability of DM (EDDM) and NDF (EDNDF) was calculated using the equation of Ørskov and McDonald [21]:

$$\text{EDDM or EDNDF} = a+ [b\times c/(c+k)]$$

where k is the fractional outflow rate from the rumen (per hour) and a, b and c are as described above. The k values used to calculate EDDM and EDNDF were 0.02, 0.04 and 0.06 h^{-1}, which is a normal range of rates observed in ruminants fed forages [21]. The index value (IV) was calculated from following equation [23]:

$$IV = a + 0.4b + 200c$$

This index was calculated for DM degradability (IVDM) and NDF degradability (IVNDF).

Data from chemical analysis and degradability tests were subjected to analysis of variance as a completely randomized design with four replicates using a general linear model procedure and treatment means were compared by the Duncan test. All statistical analysis was performed using the SAS [25] procedure.

Results

Chemical composition: The chemical compositions of AF and almond hulls are shown in Table 1. The CP content of AF was greater (P<0.05) than all of almond hulls. For almond hulls, CP was least (P<0.05) for PS at 21.8 g kg^{-1} DM. AF had a greater (P<0.05) ash compared with any of almond hulls, but this content was least (P<0.05) for PS at 53.2 g kg^{-1} DM. The EE content was greatest and least for PS and SS at 33.5 and 16.3 g kg^{-1} DM, and the difference for PS compared with SS and AF was significant (P<0.05). PS was least and greatest (P<0.05) in NDF and NFC (347.0 and 544.6 g kg^{-1} DM, respectively) but these contents were in contrast to AF, which was greatest and lowest (P<0.05) in NDF and NFC (585.9 and 144.6 g kg^{-1} DM, respectively). The ADL content was greatest (P<0.05) for CM at 117.8 g kg^{-1} DM, but this content was similar (no significant differences) for the other feeds, among which AF had the lowest content. The ADF, cellulose and hemicellulose showed similar differences among the almond hulls and AF. These chemical compositions were greatest (P<0.05) for AF (Table 1) but ADF and hemicellulose were lowest for PS.

DM degradation: The rapidly degradable DM fraction (*a*DM) (Table 2) was greatest (P<0.05) for PS at 450.4 g kg^{-1} DM, but this value was least (P<0.05) for AF at 144.1 g kg^{-1} DM. PS had a lower (P<0.05) slowly degradable DM fraction (*b*DM) at 323.6 g kg^{-1} DM

Table 1. Mean chemical composition of alfalfa hay and almond hulls (g kg^{-1} DM).

Variables	AF	CM	SS	PS	S.E.M. [1]
DM [2]	906.4 a	893.6 b	901.4 ab	902.5 ab	3.34
CP	150.0 a	28.6 b	27.2 b	21.8 c	1.70
Ash	102.8 a	64.7 c	76.6 b	53.2 d	1.44
EE	18.8 bc	26.2 ab	16.3 c	33.5 a	2.60
NDF	585.9 a	360.5 b	362.3 b	347.0 c	4.32
ADF	367.4 a	242.8 b	240.2 b	237.9 b	7.59
ADL	98.9 b	117.8 a	111.7 ab	105.8 ab	5.21
Cellulose	268.5 a	125.0 b	128.5 b	132.1 b	5.94
Hemicellulose	218.5 a	122.1 b	117.7 b	109.1 b	8.99
NFC	144.6 c	520.0 b	517.7 b	544.6 a	6.07

[1] Standard error of means. [2] (g kg^{-1} as fed). Mean in the same row with different letters differ (P<0.05).

Table 2. *In situ* DM degradation variables and effective degradability of alfalfa hay and almond hulls.

	AF	CM	SS	PS	S.E.M. [1]
Variables					
a (g kg^{-1})	144.1 c	421.4 ab	416.3 b	450.4 a	9.29
b (g kg^{-1})	528.1 a	350.2 c	388.3 b	323.6 d	8.28
c (h^{-1})	0.063 ab	0.052 b	0.067 a	0.063 ab	0.004
PDDM (g kg^{-1})	672.1 c	771.6 b	804.6 a	774.0 b	5.52
IVDM	48.18 c	66.45 b	70.55 a	70.54 a	0.45
Effective degradability (g kg^{-1})					
EDDM2	546.0 d	684.0 c	718.3 a	704.0 b	3.77
EDDM4	468.7 c	641.7 b	665.8 a	665.0 a	4.58
EDDM6	416.7 c	620.3 b	631.3 ab	642.5 a	6.48

[1] Standard error of means. Mean in the same row with different letters differ (P<0.05).

compared with the CM, PS and AF, and greatest (P<0.05) for AF at 528.1 g kg^{-1} DM versus *a* value. The degradation rate of DM (*c*DM) was greatest (P<0.05) for SS at 0.067 h^{-1}, but similar for AF, CM and PS, however CM had the lowest value. The potential degradability (PD) of DM (*a+b*) was greatest and least (P<0.05) for SS and AF at 804.6 and 672.1 g kg^{-1} DM, respectively. The IVDM was greatest for SS and PS at 70.55 and 70.54, but this index was least (P<0.05) for AF at 48.18. The EDDM calculated at 0.04 (EDDM4) and 0.06 (EDDM6) h^{-1} outflow rates showed similar differences among the almond hulls and AF. The EDDM of AF was lowest (P<0.05) at the three out flow rates. The EDDM calculated at 0.02 h^{-1} (EDDM2) was greatest (P<0.05) for SS at 718.3 g kg^{-1} DM. SS and PS had a greater EDDM compared with CM.

NDF degradation: Table 3 shows that the rapidly degradable NDF fraction (*a*NDF) of AF and almond hulls was negative amounts and this value for AF and SS was greatest and least (-21.7 and -102.4 g kg^{-1} DM, respectively). There was no difference (P>0.05) between the slowly degradable NDF fraction (*b*NDF) for AF, CM and PS (576.9, 586.8 and 571.2 g kg^{-1} DM, respectively) and it was greatest (P<0.05) for SS (659.3 g kg^{-1} DM). There was no difference (P>0.05) between the degradation rate of NDF (*c*NDF) and PD of NDF (PDNDF) of AF and almond hulls, however, SS had a greater amount for these variables. The IVNDF was greatest (P<0.05) for AF at 30.27 and lowest for PS at 26.55, but there was no difference (P>0.05) between the IVNDF for almond hulls. The EDNDF calculated at 0.02 (EDNDF2) and 0.04 (EDNDF4) h^{-1} out flow rates showed similar differences among all treatments. AF and SS had a higher EDNDF compared with CM and PS. The EDNDF calculated at 0.06 (EDNDF6) was greatest (P<0.05) for AF at 238.0 g kg^{-1} DM.

Table 3. *In situ* NDF degradation variables and effective degradability of alfalfa hay and almond hulls.

	AF	CM	SS	PS	S.E.M. [1]
Variables					
a (g kg^{-1})	-21.7 a	-36.2 a	-102.4 b	-54.2 a	12.59
b (g kg^{-1})	576.9 b	586.8 b	659.3 a	571.2 b	16.02
c (h^{-1})	0.047	0.040	0.054	0.046	0.004
PDNDF (g kg^{-1})	555.3	550.6	556.9	517.0	17.11
IVNDF	30.27 a	27.80 b	26.98 b	26.55 b	0.52
Effective degradability (g kg^{-1})					
EDNDF2	384.7 a	354.7 b	381.5 a	337.5 b	5.54
EDNDF4	294.0 a	257.0 b	282.3 a	246.5 b	5.35
EDNDF6	238.0 a	199.3 c	218.8 b	191.5 c	5.27

[1] standard error of means. Mean in the same row with different letters differ (P<0.05).

Discussion

Chemical composition: The chemical composition of forage affects degradability of nutrients. The CP of almond hulls evaluated in this study (21.8 -28.6 g kg^{-1} DM) was lower than in some previous reports [4, 5, 9, 10, 17], but was consistent with Fadel [7]. Differences among studies may be related to species or genetic variation. The CP content of almond hulls usually varies in the range of 48.7 [24] and 80.0 [10] g kg^{-1} DM. However, the AF used in this experiment, was cut in full bloom, and had medium quality; its CP content was almost 5 times more than CP content of almond hulls. CP requirements for sheep, goats and dairy cows were estimated to be 94-150, 75-160 and 120-190 g kg^{-1} of dietary DM [6, 17], respectively. The CP concentration of the almond hulls used in this experiment would be inadequate for the requirements of maintenance and production of these ruminants. Thus, it is recommended that treating almond hulls with urea as a cheap source of nitrogen would reduce the need to provide supplementary ruminal CP for these classes of livestock. However, the almond hulls used in this experiment varied significantly in ash and EE contents, even though these results were similar to previous observations [4, 5, 10, 17, 24]. Cell wall carbohydrates (NDF, ADF and cellulose) and ADL of almond hulls as determined in the current study, were similar to previous reports [1, 4, 5, 17, 24]. In the present experiment, the NFC of almond hulls ranged from 517.7 to 544.6 g kg^{-1}, confirming findings of some researchers [5, 10]. There were main differences between almond hulls and AF for cell wall content (except ADL) and NFC content. The cell wall content of almond hulls was lower than that of AF but the NFC was higher than in AF. The NFC content of almond hulls was almost 3.5 times more than AF's. This result showed that almond hull as a by-product feed is a non-forage fiber source and similar to beet pulp, citrus pulp and cottonseed [31].

DM degradation: *In situ* coefficients were used to develop a system to predict feed nutritive value and voluntary intake [22]. Almond hulls were high in *a*DM compared with AF, which can increase voluntary DM intake. High *a*DM of almond hulls versus AF could be due to their low NDF and ADF contents as well as the high NFC content, as shown in Table 1. Also PS was low in NDF and high in NFC compared to SS, so PS had a high *a*DM. The *b*DM, determined in the current study for AF, was similar to previous observations [18]. Concordant with Nocek and Khon [18], AF had a *b*DM of about 547 g kg^{-1}, but this contrasts to Hackmann *et al.* [13] who reported only about 407 g kg^{-1}. The *b*DM of AF was greater than almond hulls, which could be due to high NDF and low NFC content of this feed compared with almond hulls. Also these variables for SS were greater than for CM and PS, because SS had a high NDF and low NFC content in comparison to CM and PS. The PD of almond hulls, especially SS, was greater than AF, which could be due to high *a*DM of almond hulls. EDDM of almond hulls was greater than AF, which was related to NDF, ADF and NFC contents. Yan and Agnew [32] showed that EDDM was negatively related to NDF and ADF concentrations.

NDF degradation: The *a*NDF for AF (-21.7 g kg^{-1} DM), determined in the current study, was dissimilar to Nocek and Khon [18] who reported no measurable *a*NDF. The *b*NDF and PDNDF for AF determined in the current study were similar to previous observation for AF [13]. Concordant with Hackman [13], AF had *b*NDF and PDNDF fractions of about 537 and 537 g kg^{-1} DM, respectively, but this contrasts to Nocek and Khon [18] who reported only about 489 and 489 g kg^{-1} DM. The IVNDF was greatest for AF but this contrasts to IVDM. Comparing EDNDF among almond hulls, it seems that SS with high NDF had a high EDNDF.

Many experiments have shown that non-forage fiber sources, such as almond hulls, have a positive effect on fiber digestion as fiber concentration in the ration is increased using these fiber sources [31]. The NDF digestibility is a function of the potentially digestible fraction and its rate of digestion and rate of passage. Digestibility of NDF measured *in vivo* is confounded by different retention times in the rumen, which can be affected by differences in DM intake [20]. In addition, exposure to acidic conditions in the small intestine and fermentation in the large intestine *in vivo* might reduce differences observed for fermentation by rumen microorganisms *in situ*. For this reason, NDF digestibility determined *in situ* is an important measure of forage quality and should be distinguished from NDF digestibility *in vivo* [31].

Conclusions

In this study, almond hulls had low CP and medium amounts of cell wall but had high NFC. This by-product is a non-forage fiber source similar to beet pulp. Almond hulls were high in *a*DM, which can increase voluntary intake; they also had high PDDM and IVDM compared with AF. It could be an excellent energy source for ruminants; however, the high lignin content limits its value as a feed source for ruminants.

Acknowledgements

The authors acknowledged Prof. Ahmad Afzalzadeh, University of Tehran for his invaluable guidance and suggestions.

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