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In situ degradation of almond (*Prunus dulcis* L.) hulls, a potential feed material for ruminants

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Abstract: The nutritive values of almond hulls (AHs), alfalfa (ALF), and sugar beet pulp (SBP) were determined using the in situ nylon bag technique. The ruminal dry matter (DM) degradation kinetics of 4 varieties of AHs were compared with ALF and SBP. The almond varieties tested were Rabbi (RAB), Mamaii (MAM), Shahrud 15 (SH15), and Shokufe (SH). Samples were incubated in triplicate at 0, 4, 8, 12, 16, 24, 48, 72, and 96 h in 3 rumen-fistulated steers. The average total degradability fraction (TDF) of DM in AHs was 89.00%. Although the TDF of AHs (86.50%) was lower than that of SBP (98.00%), it was higher ($P < 0.05$) than that of ALF (67.00%). The soluble (a) fraction in AHs (55.00%) was higher than in both ALF (20.00%) and SBP (26.00%). This high (a) fraction of AHs was attributed to their relatively higher nonfibrous carbohydrate and lower neutral detergent fiber content than ALF and SBP. The degradation rate of ALF (0.14%) was significantly higher ($P < 0.05$) compared to the other samples, whereas that of SBP (0.05%) was not significantly different ($P > 0.05$) from those in AHs. The results showed that AHs are potential feed materials for ruminants.

Key words: Agricultural byproduct, almond hulls, almond varieties, in situ degradability

1. Introduction

With the dramatic rise in prices of corn, alfalfa, and other traditional feed ingredients, nutritionists are getting more creative and turning to nontraditional products (1). Agricultural residues are byproducts of cereals, sugarcane, oilseeds, oil plants, vegetables, and fruits obtained during harvesting and processing of a commodity from which human food is derived (2). These byproducts have been of interest to many researchers since the 1970s because of the desire to understand and reduce environmental waste in most countries (2,3). Using such byproducts for animal feed is a means of recycling something that otherwise, if accumulated, might cause environmental pollution (3). The almond hull is obtained by drying that portion of the almond fruit that surrounds the wooden shell and includes the exocarp and mesocarp of the fruit and can be utilized in different ways. The proportion of hull is 50.00% of the total weight of the almond (2,4). Almond and almond hull production has continuously increased over the past decades. In 2008, approximately 2,110,000 t of almonds were commercially produced in the world (5), resulting in the availability of equal tons of hulls (3). Almond hulls (AHs) were not considered as a valued feedstuff before 1948 and were used as a fuel material or were destroyed (6). The nutritional value of AHs has been determined in sheep (2,7,8), dairy cow (4), goat (9), horse (10), and pig (11), in which AHs were shown to have an energy value of 65.00% to 90.00% of barley and to be equivalent to early and mid-bloom alfalfa hay, and they were introduced as a safe and palatable feedstuff. In a study by Getachew et al. (12) about the relationships between chemical compositions of several ruminant feeds, nonfibrous carbohydrate (NFC) content of AHs (48.70%) was higher than that of alfalfa (ALF) (26.80%) and almost the same as that of sugar beet pulp (SBP) (43.80%). Crude protein (CP) contents of AHs and SBP were almost the same (8.00% and 9.00% for AHs and SBP, respectively), but were lower than that of ALF (26.00%), while neutral detergent fiber (NDF) contents of AHs, SBP, and ALF were also almost the same (33.60%, 31.80%, and 33.80% for AHs, SBP, and ALF, respectively).

The nutritive value of a ruminant feed is determined by the concentrations of its chemical components, as well as their digestibility. Determining the digestibility of feeds in live animals (in vivo) is laborious and expensive, requires large quantities of feed, and is time-consuming. The in situ nylon bag technique represents a less expensive and more

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rapid alternative. In addition, a number of authors have suggested that the degradation characteristics of feed in the rumen would provide valuable information about the nutritive value of the diet (13,14).

By keeping the above facts in view, and by considering the rise in price of alfalfa and other traditional feed ingredients and the similarity of AHs with traditional feedstuffs such as ALF and SBP in terms of chemical composition, rumen degradability of different varieties of AHs was compared with that of ALF and SBP by using the in situ nylon bag technique.

2. Materials and methods

2.1. Sampling sites and study areas

Samples were collected from 3 different regions in Iran. Varieties Rabbi (RAB) and Mamaii (MAM), Shahrud 15 (SH15), and Shokufe (SH) were respectively collected from Shahrekord (western part of Iran), Mashhad (eastern part of Iran), and Isfahan (central part of Iran). The ALF (full-bloom) and SBP were collected from a farm at the Animal Science Research Institute of Iran (ASRI). Three Taleshi steers at the ASRI farm with an average weight of 350 ± 50 (body weight [kg] ± standard error) were used in this study.

2.2. Chemical analysis

All samples were oven-dried, ground to pass through a 1-mm screen, and analyzed for the contents of dry matter (DM), ash, CP, ether extract (EE), acid detergent fiber (ADF), NDF, and acid detergent lignin (ADL) using standard methods. The chemical analyses were conducted in triplicate. The DM content and CP (total nitrogen × 6.25) were determined using methods 934.10 and 990.03 of the AOAC (15), respectively. Dry matter was determined by drying 10.00 g of fresh samples at 60 °C in a forced-air oven for 48 h. The NDF, ADF, and lignin were determined according to Van Soest et al. (16). Both ADF and NDF were expressed inclusive of residual ash. The crude oil (EE) content was measured using the Soxhlet method, with diethyl ether as the oil solvent. NFC was calculated according to the NRC (17) as follows:

NFC = 100 – (CP% + NDF% + EE% + ash%).

Total phenolic compounds and total tannins were measured by spectrophotometry as described by Makkar et al. (18) using the Folin–Ciocalteu method. Tannins were quantified as the difference between total phenolic compounds before and after tannin removal from the extract using polyvinylpyrrolidone.

2.3. Nondegraded dry matter loss (NDDML) from the nylon bag

Samples were placed in nylon bags and shaken for 1 h in a washing machine, followed by oven drying at 60 °C for 24 h, and then weighed. The difference between the weight of DM initially placed in the bag and the weight of residue DM after soaking in water was considered as the weight of NDDML.

2.4. In situ rumen degradability analysis

The dry matter degradability was determined according to the procedure described by Mehrez and Ørskov (19). Nylon bags (Ankom Technology, Macedon, NY, USA) of 160 × 85 mm in size with 40-µm pore size were used. Approximately 5.00 g of ground samples was passed through 1-mm screen, transferred to the bags, and incubated for 0, 4, 8, 12, 16, 24, 48, 72, and 96 h. The animals (3 Taleshi steers) were fed twice a day. Feed and water were offered ad libitum. The bags were removed after incubation and washed in cold running water until the water was clear and colorless. All the bags were further washed in a washing machine. Three additional empty bags (blanks) were also weighed to correct for microbial contamination after the bags had been held in the rumen. All washed bags were dried to a constant weight at 60 °C in a forced-air oven.

2.5. Calculation of degradation kinetics

Each incubation period was carried out in triplicate, and the nylon bag samples were randomly placed in the rumens of the steers. Dry matter disappearance at each time interval was calculated from the DM residues from each bag. The calculation of in situ degradability used the following equation:

$P = a + b\ (1 - e^{-ct})$, as described by Ørskov and McDonald (20), where:

P is the degradation of the incubated matter in time t, a is the immediately soluble fraction,

b is the insoluble but potentially degradable fraction, and c is the fractional degradation rate of b. The effective degradability of dry matter (EDDM) was also calculated following the equation of Ørskov and McDonald (20):

Effective degradability = $p = a + (b \times c) / (c + k)$,
where k = rate of passage (2% h^{-1}).

2.6. Statistical analysis

The statistical analysis of data was done by analysis of variance with the Statistical Analysis System software package (Release 9.1, SAS Institute Inc., Cary, NC, USA) (21) using the GLM procedure. The following model was used for the analysis of data:

Yijk = O + Ai + Rj + eijk,

where Yijk = dependent variable, O = overall mean, Ai = animal effect (i = 1, 2, or 3), Rj = effect of variety (j = 1, 2, 3, 4, 5, or 6), and eijk = the random residual error. The observed means of main effect factors were compared by Duncan's test. Statistical significance was considered to exist if $P < 0.05$.

3. Results

3.1. Nondegraded DM loss

The results of NDDML are shown in Table 1. Among the AHs, the greatest NDDML was related to SH (61.90%) and SH15 (57.16%), but RAB (55.00%) and MAM (55.26%) did not show significant differences. The least NDDML was related to ALF (21.20%) and SBP (31.65%); they were significantly ($P < 0.05$) lower than AHs (57.33%).

3.2. Dry matter digestibility at different rumen incubation times

Dry matter digestibility (%) of AHs, SBP, and ALF at different incubation times is shown in Table 2. There was no significant difference ($P > 0.05$) between RAB and MAM at any incubation time, except at 24 h. There was no significant difference ($P > 0.05$) between the SH15 and SH at 16 h or 48 h. However, there was a significant difference ($P < 0.05$) among AH varieties with ALF and SBP at 16 h and 48 h. The SBP was significantly higher ($P < 0.05$) than AHs and ALF at incubation times of 48 h, 72 h, and 96 h.

3.3. In situ DM degradability parameters

The results of comparing DM degradation (%) characteristics of AHs with those of ALF and SBP are shown in Table 3. The soluble (a) fraction of AHs (55.00%) was significantly higher ($P < 0.05$) than those of ALF (19.80%) and SBP (26.10%). The SH (60.00%) was also significantly higher ($P < 0.05$) than RAB (52.50%), MAM (52.00%), and SH15 (55.40%). The SBP (72.40%) and ALF (46.80%) had the highest ($P < 0.05$) potentially degradable (b) fraction in comparison with AHs for RAB (41.30%), MAM (41.80%), SH15 (31.00%), and SH (23.60%).

TDF was significantly higher ($P < 0.05$) in SBP (98.00%) than in ALF (67.00%) and AH varieties (82.00%, 94.00%, 86.00%, and 84.00%) for RAB, MAM, SH15, and SH, respectively.

The value of c, or the rate of degradability of fraction b, was significantly higher ($P < 0.05$) for ALF (0.14%). The AH (0.07) was not significantly different ($P > 0.05$) when compared with the SBP for RAB (0.80%), MAM (0.8%),

Table 1. Comparing nondegraded DM loss (%) of AH varieties with SBP and ALF.

%	RAB	MAM	SH15	SH	SBP	ALF
NDDML[1]	55.00^{b}	55.26^{b}	57.16^{ab}	61.90^{a}	31.65^{c}	21.20^{c}
SEM	3.21	3.30	4.02	5.37	2.75	1.95

NDDML[1]: nondegraded DM loss, RAB: Rabi; MAM: Mamaii; SH15: Shahrud 15; SH: Shokufe; SBP: sugar beet pulp; ALF: alfalfa; SEM: standard error of the mean. Values (a, b, c) with different letters are significantly different ($P < 0.05$).

Table 2. Comparing degradability (%) of AH varieties with SBP and ALF at different times of incubation.

Times	Varieties						
	RAB	MAM	SH15	SH	SBP	ALF	SEM
h_0	55.00^{c}	55.26^{c}	57.18^{b}	61.90^{a}	31.65^{d}	21.20^{e}	8.71
h_4	60.31^{b}	60.40^{b}	60.86^{b}	64.40^{a}	34.40^{d}	38.50^{c}	3.63
h_8	66.70^{a}	64.20^{a}	64.05^{a}	65.07^{a}	43.00^{c}	51.00^{b}	9.22
h_{12}	80.70^{a}	82.90^{a}	74.80^{b}	70.10^{c}	64.30^{d}	62.70^{d}	2.15
h_{16}	87.80^{a}	86.30^{a}	78.60^{b}	78.70^{b}	73.60^{c}	63.10^{d}	5.51
h_{24}	91.60^{a}	88.70^{b}	83.00^{c}	79.70^{d}	82.70^{c}	65.05^{e}	3.00
h_{48}	92.80^{a}	91.70^{a}	84.00^{b}	82.80^{b}	92.30^{a}	64.60^{c}	11.21
h_{72}	91.80^{b}	93.01^{b}	86.18^{c}	82.81^{d}	95.47^{a}	65.93^{e}	4.70
h_{96}	91.20^{b}	92.70^{b}	85.72^{c}	82.34^{d}	96.85^{a}	67.55^{e}	3.27

h_{0-96}: Rumen incubation time from 0 to 96 h, RAB: Rabbi; MAM: Mamaii; SH15: Shahrud 15; SH: Shokufe; SBP: sugar beet pulp; ALF: alfalfa; SEM: standard error of the mean.
Values ($^{a, b, c, d, e}$) with different letters within the same rows are significantly different ($P < 0.05$).

Table 3. Comparing ruminal DM degradation (%) characteristics of AHs with ALF and SBP.

Parameters	Varieties						
	RAB	MAM	SH15	SH	SBP	ALF	SEM
a	52.50[b]	52.00[b]	55.40[ab]	60.00[a]	26.10[c]	19.80[c]	1.32
b	41.30[b]	41.80[b]	31.00[c]	23.60[d]	72.40[a]	46.80	2.21
TDF	82.00[b]	94.00[b]	86.00[c]	84.00[d]	98.00[a]	67.00[e]	1.95
c	0.08[b]	0.08[b]	0.06[b]	0.06[b]	0.05[b]	0.14[a]	0.002
ED	84.40[a]	84.70[a]	79.00[b]	77.40[b]	77.20[b]	61.00[c]	1.98

a: soluble fraction (%); b: insoluble potentially digestible fraction (%); TDF: total potentially digestible fraction (%, a + b); c: rate of degradation (%/ h); ED: extent of ruminal DM (%); RAB: Rabbi; MAM: Mamaii; SH15: Shahrud 15; SH: Shahrud; SBP: sugar beet pulp; ALF: alfalfa; SEM: standard error of the mean. Values ([a, b, c, d, e]) with different letters within the same rows are significantly different ($P < 0.05$).

SH15 (0.60%), SH (0.60%), and SBP (0.50%) for the (c) fraction.

The effectively degraded DM (ED) determined at passage rates (k) of 0.02/h at k = 0.02/h was 0.61%, 0.77%, 0.84%, 0.85%, 0.79%, and 0.77% for ALF, SBP, RAB, MAM, SH15, and SH, respectively.

4. Discussion

The chemical composition and phenolic compounds in AHs are shown in Table 4. The means of CP, NDF, ADF, ASH, ADL, and EE in the varieties of AHs in the current study were 29.00, 300.00, 220.00, 89.00, 113.00, and 51.00 g/kg DM, respectively (1). However, the CP, NDF, ADF, EE, ash, and NFC contents for ALF were 263.00, 338.00, 286.00, 24.00, 108.00, and 268.00 g/kg, respectively, and 121.00, 429.00, 222.00, 19.00, 74.00, and 357.00 g/kg, respectively, for SBP (Table 5). Jafari et al. (1) also indicated that the NFC content of these 4 varieties were 600.00, 590.00, 500.00, and 580.00 g/kg for RAB, MAM, SH15, and SH, respectively. However, it was shown that variability among varieties of American AHs was high, similar to our results (4). It was reported that the CP of

Table 4. Chemical composition of 4 varieties of almond hulls (g/kg DM).

Parameters	Varieties				
	RAB	MAM	SH15	SH	SEM
DM	954.20[b]	947.50[b]	962.30[a]	928.30[c]	0.37
CP	32.70[a]	26.50[b]	32.00[a]	23.20[c]	0.14
NDF	280.50[c]	294.40[b]	320.64[a]	320.40[a]	0.63
ADF	188.30[c]	198.50[b]	251.20[a]	252.20[a]	0.22
Ash	81.20[c]	86.10[b]	128.30[a]	62.70[d]	0.14
ADL	92.40[d]	104.30[c]	143.10[a]	115.50[b]	0.18
EE	4.40[c]	4.40[c]	9.10[a]	8.40[b]	0.004
TP	35.70[a]	34.10[b]	32.00[c]	33.60[b]	0.03
TT	25.60[b]	23.20[c]	28.40[a]	26.60[b]	0.05
Ca	3.07[b]	3.70[b]	4.30[a]	3.80[b]	0.006
P	0.80[c]	0.80[c]	2.10[a]	0.90[b]	0.0014
NFC	60.11[a]	58.83[ab]	50.40[c]	58.22[b]	0.73

RAB: Rabbi; MAM: Mamaii; SH15: Shahrud 15; SH: Shokufe. DM: dry matter, CP: crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, ADL: acid detergent lignin, EE: ether extract, TP: total phenolic compound, TT: total tannin, Ca: calcium, P: phosphorous, NFC: nonfibrous carbohydrate, SEM: standard error of the mean. Values ([a, b, c, d]) with different letters within the same row are significantly different ($P < 0.05$).

Table 5. Chemical composition of ALF and SBP used in this study (g/kg DM).

Parameters	ALF	SBP
CP	263.00	121.00
NDF	338.00	429.00
ADF	286.00	222.00
EE	24.00	19.00
Ash	108.00	74.00
NFC	268.00	357.00

CP: Crude protein, NDF: neutral detergent fiber, ADF: acid detergent fiber, EE: ether extract, NFC: nonfibrous carbohydrate; ALF: alfalfa, SBP: sugar beet pulp.

Iranian AHs (2.00%–3.00%) was less than those of foreign counterparts (6.00%–9.00%).

The soluble fraction in AHs ranged from 55.00%–62.00%, and it seemed to be readily degradable by rumen bacteria. There are 2 reasons for this high soluble fraction in AHs rather than in ALF (20.00%) and SBP (26.00%): 1) having less NDF in AHs than in ALF and SBP; 2) NFC, which is the major factor in rumen degradability, is almost 3.50 times higher in AHs than in ALF. TDF reflects the proportion of DM that is degraded in the rumen, which is nutritionally important. The total degradability of AHs ranged from 82.00% to 94.00% and was lower than that of SBP (98.00%) and higher than that of ALF (67.00%) (Table 4). Alfalfa showed a lower soluble fraction and a higher slowly degradable fraction compared to AHs in an in situ ruminal dry matter degradability study comparing AHs (2 varieties of AHs; stone shell, paper shell, and a commercial mixture of AHs) with alfalfa hay; it was also concluded that higher soluble and lower slowly degradable fractions of almond hulls compared to alfalfa could be due to their low NDF and ADF contents as well as the high NFC contents in AHs compared with ALF (22). At different times of incubation at 4, 12, 24, 48, 72, and 96 h, the results of AHs (61.00%, 77.00%, 86.00%, 88.00%, 88.40%, and 87.90%) in the present study were higher than the results already reported (2). In situ degradability estimates are affected by factors such as feed particle size, bag surface area ratio, sample size, origin of feedstuff, bag material, pore size, test animal, washing procedure, and sampling schedule (23), The differences in our results and those of Yalchi and Kargar (22) could be due to the above-mentioned factors and variability of the AHs. It was shown that ED was negatively related to NDF and ADF concentrations (24). Therefore, the higher mean of ED in AHs (81.00%) than in ALF (61.00%) and SBP (77.00%) is due to a lower NDF and ADF in AHs as found in this study.

In conclusion, based on in situ measurements, the AHs showed greater DM disappearance than ALF and even a greater soluble fraction than SBP, in which the higher NFC and lower NDF content of almond hulls are subjected to a higher soluble fraction. The results indicate that almond hulls are an agricultural byproduct that can be utilized as feed material for ruminants.

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