

## Effects of ground almond hulls on alfalfa silage quality

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**ABSTRACT.** The efficient utilisation of agricultural by-products has lately gained importance in sustainable animal feeding practices. This study sought to improve the quality of alfalfa silage and the value of almond hulls by incorporating them to alfalfa herbage, which has poor ensiling characteristics without additives. Ground almond hulls from three cultivars (Nonpareil, Ferragnes, and Texas) were added to chopped alfalfa (2–3 cm pieces) at a rate of 100 g/kg and allowed to ferment in polyethylene bags to produce silage. The results showed an increase in dry matter content in the treatment groups, a pH reduction, no detectable growth of enterobacteria, and a partial improvement in fermentation parameters. The use of almond hulls, a cost-effective and natural by-product, in alfalfa silage positively affects silage quality and increases its added value.

### Introduction

The use of food waste, which is produced in large quantities, in sectors such as animal feed and human food increases its economic value. Almond hulls are a good example of such by-products. Approximately 50% of the entire almond fruit consists of the outer hull, 25% of the inner shell, and the remaining 25% is the kernel. These proportions indicate that roughly twice as much outer hull is obtained compared to the primary product, the kernel. Although various approaches have been developed to evaluate the potential of hulls, they are predominantly used as feed for dairy cows, especially in California (Swanson et al., 2020). Considering that California accounts for approximately 80% of global almond production (Almond Board of California, 2023), assessing hull utilisation in this region is highly relevant. Nonetheless, despite the recent significant increase in almond production, demand for hulls as animal feed is expected to decline (Meadows, 2023). The reduction in dairy cattle numbers in California, attributed to urbanisation and environ-

mental regulations (MacDonald et al., 2020), has reduced the profitability of almond hulls as cattle feed (Meadows, 2023). As a result, interest is growing in alternative uses for hulls beyond production regions, and converting them into higher value-added products. Transportation expenses are a major factor limiting hull export from their production area (Duncan et al., 2024). Drying and grinding almond hulls to approximately 3 mm pieces is expected to reduce transport costs by about 70%, while also improving storage, packaging, application efficiency, and expanding potential uses. Moreover, studies indicate that grinding increases digestibility and feed aggregation (Duncan et al., 2024). Almond hulls are rich in structural carbohydrates (haemicellulose, cellulose, and lignin), as well as non-structural carbohydrates (glucose, fructose, and sucrose), but have low protein content (Offeman et al., 2014; Holtman et al., 2015; Sırakaya, 2023). Properly dried hulls can be preserved for extended periods (Jafari et al., 2011); however, poor storage conditions may lead to mould growth due to moisture absorption, and environmental exposure (e.g., precipitation) may

leach sugars (Asmus, 2015). Using almond hulls as a silage supplement may serve as an alternative strategy to mitigate these storage and quality issues. Alfalfa is a nutrient-rich feed ingredient valued for its high protein content. Although it is commonly used as hay, certain climatic conditions or leaf loss after baling may make it more suitable for ensiling. However, the limited content of fermentable carbohydrates (Chen et al., 2021) and elevated buffering capacity (Undersander et al., 2011) of alfalfa decrease silage quality. These limitations may be overcome by using commercial inoculants or additives rich in soluble carbohydrates to improve the ensiling process.

Given the high costs associated with silage additives almond hulls represent a promising natural and cost-effective alternative for improving alfalfa silage quality, as well as reducing feed expenses. Based on this premise, the present study aimed to determine the effects of different types of almond hulls on alfalfa silage quality.

## Material and methods

### Silage preparation

Alfalfa was harvested at the early flowering stage from the Yeşilova region (38°24'12"N, 33°49'35"E, Aksaray, Turkey). After wilting for 24 h, alfalfa was manually chopped into 2–3 cm pieces using plant shears. Almond hulls (AH) were collected from an orchard in the Develi region of Kayseri, Turkey (38°22'13"N, 35°26'44"E) for use as supplements. Three almond cultivars, Nonpareil (Npr), Ferragnes (Frg), and Texas (Tex) were shade-dried and ground using an IKA MF.10 laboratory mill (Staufen, Germany) to pass through a 3 mm sieve. The experiment included 4 treatment groups with 5 replicates each: control (pure alfalfa), and 3 treatments combining alfalfa with 10% of each almond hull variety. Mixtures of 900 g alfalfa and 100 g almond hulls were vacuum-sealed (Caso VC 11, Caso Design, Arnsberg, Germany) in 30 × 35 cm polyethylene bags (Caso Professional Vacuum Rolls, Caso Design, Arnsberg, Germany), and fermented under ambient conditions (25 ± 2 °C) for 90 days. After fermentation, silages were analysed for fermentation parameters, then dried at 50 ± 1 °C, ground to 1 mm pieces, and stored for chemical analysis.

### Chemical analyses and digestibility values

Dry matter (DM) content was determined by oven-drying at 50 ± 1 °C until constant weight. The dried samples were then ground in an IKA

MF.10 laboratory mill (Staufen, Germany) and passed through a 1 mm sieve for chemical analyses. The following parameters were determined: crude protein (CP), ether extract (EE), crude ash (CA), crude fibre (CF), acid detergent fibre (ADF), neutral detergent fibre (NDF), acid detergent insoluble protein (ADICP), neutral detergent insoluble protein (NDICP), lignin, starch, fructose, glucose, sucrose, maltose, calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), sulphur (S), zinc (Zn), sodium (Na), manganese (Mn), iron (Fe), and copper (Cu).

CP was determined using the DUMAS method (AOAC International, 2006) with a VELP NDA 701 analyser (Usmate Velate, Italy). Crude fat content was determined by petroleum ether extraction in an ANKOM XT15 system (Macedon, NY, USA) following AOCS (2004) guidelines. CA content was measured by combustion at 550 °C in a CARBOLITE ELF 11/6 muffle furnace (Sheffield, UK) according to AOAC International (2005). Fiber fractions (CF, ADF, NDF) were analysed using an ANKOM2000 fibre analyser (Macedon, NY, USA) following AOAC International (1997; 2022) methods. ADICP and NDICP, CP were determined by performing CP analysis on the residues from ADF and NDF analyses. Starch content was measured using a polarimetric method (ISO 10520, 1997). Soluble sugars (glucose, fructose, maltose, sucrose) were analysed using high-performance liquid chromatography (Agilent 1260, Santa Clara, CA, USA). For mineral analysis, 0.5 g samples were digested with 10 ml of HNO<sub>3</sub> and 2 ml of HCl in a SPEEDWAVE microwave system (Jena, Germany) at 200 °C (1600 W) for 15 min. After cooling and filtration through 0.2 µm syringe filters, mineral concentrations were determined by ICP-MS (AGILENT 7500, Santa Clara, CA, USA) (AOAC International, 2009).

The digestibility and energy parameters were calculated based on the chemical analysis data using established equations from Nutrient Requirements of Dairy Cattle (NRC, 2001). The evaluated parameters include non-fibre carbohydrates (NFC), digestible dry matter (DDM), dry matter intake relative to body weight (DMI<sub>BW</sub>%), total digestible nutrients (TDN<sub>IX</sub>), and net energy for lactation (NEL).

### Fermentation profiles

Upon opening the silage bags, 20 g of each sample was mixed with 80 ml of distilled water (20% w/v). The mixture was filtered through filter paper, and the pH of the filtrate was measured using a pH meter. For organic acids and NH<sub>3</sub>-N analysis, 40 g of silage was homogenised with 360 ml of distilled water and filtered through a Whatman

No. 1 filter paper.  $\text{NH}_3\text{-N}$  content was determined by collecting 100 ml of filtrate and analysing using the Kjeldahl method in a Gerhardt VAP 20 distillation apparatus (Königswinter, Germany), as described by Canpolat (2019). Selected filtrates were stored at  $-20^\circ\text{C}$  for further organic acid analyses. Lactic acid concentration was measured spectrophotometrically (Canpolat, 2019), while acetic, propionic, and butyric acids were quantified using gas chromatography (GC 2010, Shimadzu Corporation, Kyoto, Japan).

### Microbiological analysis

After opening the silage samples, 10 g of each sample was mixed with 90 ml of peptone water to prepare  $10^{-1}$  dilutions. Serial dilutions were then prepared to  $10^{-5}$ , and microbial counts were determined using the spread plate technique. Yeasts and mould, enterobacteria, clostridia, and lactic acid bacteria (LAB) were enumerated. Culture conditions were as follows: yeasts and moulds at  $25 \pm 1^\circ\text{C}$  for 5 days, enterobacteria at  $37 \pm 1^\circ\text{C}$  for 24 h, clostridia at  $35 \pm 2^\circ\text{C}$  for 48 h, and LAB at  $37 \pm 1^\circ\text{C}$  for 72 h. Colony-forming units (CFU) were counted after incubation and presented on a logarithmic scale. The media used were: Potato Dextrose Agar (Merck, Darmstadt, Germany) for yeasts and moulds, Violet Red Bile Agar with Glucose (Condalab, Madrid, Spain) for enterobacteria, Reinforced Clostridial Agar (Condalab) for clostridia, and MRS Agar (Merck) for LAB.

### Statistical analysis

Statistical analysis was conducted using Mini-tab 16.1 software applying a completely randomised one-way analysis of variance (ANOVA). Results are presented as mean plus standard deviation (mean  $\pm$  SD). Differences between groups were assessed using Tukey's test with  $P < 0.05$  considered statistically significant.

## Results and discussion

Table 1 presents the nutritional composition of fresh almond hulls and alfalfa, while Table 2 lists the proportional distribution of almond fruit components (outer hull, inner shell, and kernel) for both fresh and dry matter. The proportions of these components differed depending on the variety. On a fresh basis, outer hull content in Npr, Frg, and Tex varieties was 77.94%, 56.53%, and 71.66%, respectively. These differences were largely associated with hull thickness. The thinner hulls of Frg almonds allow faster drying on the

branch, reducing the proportional yield of the fruit. Accordingly, Npr and Tex fruits contained a higher percentage of hulls. The Almond Board of California reports that the outer hull accounts for approximately 49% of the fruit. A review study provided a hull range of 35–62%, depending on the variety (Prgomet et al., 2017). Discrepancies in the values obtained are likely due to differences in moisture content and a lack of standardised reporting in prior studies. Nevertheless, current and previous research has indicated that hulls constitute at least 50% of the total fruit weight. Given these findings, almond growers can be considered producers of both nut and fodder crops.

Table 3 summarises the fermentation parameters of silage prepared by combining almond hulls with alfalfa. The pH data showed that the addition of almond hulls increased the acidity of alfalfa silage. The pH of the control silage (Alf) was 5.88 compared to 5.08, 5.09, and 5.36 for NprAH + Alf, FrgAH + Alf, and TexAH + Alf silages, respectively ( $P < 0.05$ ). The inclusion of almond hulls lowered the pH and had a positive effect on silage quality. In a similar study, almond hull addition at different rates reduced the pH of alfalfa silage, with the lowest pH (4.49) recorded at 6% inclusion level (Aydın et al., 2023). Although the current results are consistent, the average pH with 10% AH addition was 5.18 – a difference likely caused by the variations in AH composition and alfalfa nutrient content. Additionally, AH inclusion significantly reduced  $\text{NH}_3\text{-N}$  content ( $P < 0.05$ ), indicating suppressed proteolysis and improved silage quality. Similar findings were reported by Aydın et al. (2023), who observed a decline in  $\text{NH}_3\text{-N}$  content following almond hull supplementation. The analysis of lactic, acetic, propionic, and butyric acid concentrations showed that AH addition reduced lactic acid levels, with the lowest value observed in the TexAH + Alf group. Acetic acid concentrations showed variable trends in individual treatment groups, while propionic acid increased significantly in AH-supplemented silages ( $P < 0.05$ ). In contrast, butyric acid levels remained stable with no significant differences observed. The lactic acid/acetic acid ratio of 2.5–3.0 is considered indicative of good fermentation quality (Kung et al., 2018). In this study, this ratio was within the acceptable range for the Alf, NprAH + Alf, and FrgAH + Alf groups; however, in the TexAH + Alf group, the ratio shifted toward higher acetic acid percentage. These findings partially contrast with Aydın et al. (2023),

**Table 1.** Chemical and nutritional composition of fresh almond hulls and alfalfa, dry matter (DM)%

	Alf	Npr AH	Frg AH	Tex AH
DM	26.00 ± 0.65	40.63 ± 0.67	73.81 ± 0.71	53.63 ± 1.51
Crude protein	25.81 ± 0.13	3.26 ± 0.18	4.77 ± 0.13	4.33 ± 0.11
Crude fat	2.29 ± 0.03	0.88 ± 0.02	1.07 ± 0.02	0.85 ± 0.03
Crude ash	10.40 ± 0.02	6.29 ± 0.07	8.26 ± 0.22	7.12 ± 0.13
Crude fibre	17.50 ± 0.16	9.17 ± 0.04	10.88 ± 0.03	10.01 ± 0.01
ADF	24.95 ± 0.05	22.02 ± 1.24	20.25 ± 1.38	28.05 ± 1.02
NDF	30.35 ± 0.09	26.85 ± 1.51	24.69 ± 1.69	34.20 ± 1.25
Lignin	6.86 ± 0.16	10.20 ± 0.57	9.38 ± 0.64	13.00 ± 0.47
ADICP	1.87 ± 0.05	1.01 ± 0.06	1.48 ± 0.04	1.34 ± 0.03
NDICP	2.89 ± 0.08	1.24 ± 0.07	1.81 ± 0.05	1.65 ± 0.04
Starch	3.21 ± 0.04	3.38 ± 0.03	4.33 ± 0.05	3.37 ± 0.04
NFC	31.16 ± 0.21	62.72 ± 1.38	61.21 ± 1.85	53.50 ± 1.29
DDM	69.46 ± 0.04	71.75 ± 0.97	73.13 ± 1.08	67.05 ± 0.8
DMI <sub>BW</sub> %	3.95 ± 0.01	4.48 ± 0.25	4.88 ± 0.33	3.51 ± 0.13
TDN <sub>1X</sub>	62.24 ± 0.10	63.23 ± 1.17	62.74 ± 1.49	56.75 ± 1.08
NE <sub>L</sub> , mkal/kg	1.58 ± 0.00	1.40 ± 0.04	1.39 ± 0.04	1.21 ± 0.03
NE <sub>M</sub> , mkal/kg	1.62 ± 0.01	1.39 ± 0.05	1.39 ± 0.06	1.15 ± 0.04
NE <sub>G</sub> , mkal/kg	1.02 ± 0.00	0.81 ± 0.04	0.80 ± 0.05	0.59 ± 0.04
Fructose	2.04 ± 0.02	6.47 ± 0.25	3.41 ± 0.08	3.40 ± 0.06
Glucose	0.08 ± 0.01	15.55 ± 0.21	9.53 ± 0.11	7.38 ± 0.02
Sucrose	0.00 ± 0.00	4.11 ± 0.05	1.28 ± 0.02	0.78 ± 0.02
Maltose	0.00 ± 0.00	1.25 ± 0.01	0.00 ± 0.00	0.02 ± 0.01
Total sugar	2.11 ± 0.01	27.38 ± 0.36	14.23 ± 0.18	11.58 ± 0.13
Ca	0.63 ± 0.01	0.05 ± 0.01	0.11 ± 0.01	0.10 ± 0.00
Mg	1.01 ± 0.00	0.17 ± 0.00	0.29 ± 0.01	0.29 ± 0.01
K	1.89 ± 0.01	1.25 ± 0.00	1.64 ± 0.01	1.86 ± 0.01
P	1.49 ± 0.01	0.56 ± 0.01	0.77 ± 0.00	0.77 ± 0.01
S, ppm	108.40 ± 0.51	1.60 ± 0.25	17.40 ± 0.28	2.70 ± 0.16
Zn, ppm	16.80 ± 0.29	1.80 ± 0.14	3.70 ± 0.14	1.20 ± 0.16
Na, ppm	235.10 ± 0.32	133.40 ± 1.05	177.40 ± 0.43	135.30 ± 0.67
Mn, ppm	433.20 ± 0.57	57.60 ± 1.82	101.50 ± 1.97	90.00 ± 0.16
Fe, ppm	399.70 ± 1.36	165.00 ± 3.11	281.10 ± 5.85	292.90 ± 0.65
Cu, ppm	3.20 ± 0.16	0.90 ± 0.07	11.80 ± 0.16	4.70 ± 0.16

ADF – acid detergent fibre, NDF – neutral detergent fibre, ADICP – acid detergent insoluble protein, NDICP – neutral detergent insoluble protein, NFC – non fibre carbohydrate, DDM – digestible dry matter, DMI<sub>BW</sub>% – dry matter intake, TDN<sub>1X</sub> – total digestible nutrient, NE<sub>L</sub> – net energy lactation, NE<sub>M</sub> – net energy maintenance, NE<sub>G</sub> – net energy gain, AH – almond hull, Alf – alfalfa, Npr AH – Nonpareil almond hull, Frg AH – Ferragnes almond hull, Tex AH – Texas almond hull; results are given on a dry matter basis

**Table 2.** Hull, shell and kernel proportions in almond fruit (by species)

Species	Hull, %		Shell, %		Kernel, %	
	fresh	dry	fresh	dry	fresh	dry
Npr	77.94 <sup>a</sup> ± 3.74	63.68 <sup>a</sup> ± 4.96	8.94 <sup>c</sup> ± 1.91	14.09 <sup>c</sup> ± 2.64	13.12 <sup>b</sup> ± 2.16	22.24 <sup>a</sup> ± 2.95
Frg	56.53 <sup>c</sup> ± 2.25	51.90 <sup>b</sup> ± 0.03	27.12 <sup>a</sup> ± 1.12	31.44 <sup>a</sup> ± 1.25	15.53 <sup>a</sup> ± 1.23	16.66 <sup>b</sup> ± 1.22
Tex	71.66 <sup>b</sup> ± 8.19	62.13 <sup>a</sup> ± 9.30	16.37 <sup>b</sup> ± 6.04	21.84 <sup>b</sup> ± 7.10	11.97 <sup>b</sup> ± 2.80	16.02 <sup>b</sup> ± 3.24
P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

Npr – Nonpareil, Frg – Ferragnes, Tex – Texas; data are presented as mean value ± SEM; abc – means within a column with different superscripts are significantly different at  $P < 0.05$

**Table 3.** Fermentation profile of almond hull-supplemented alfalfa silage

Treatment groups	pH	NH <sub>3</sub> -N, %	Lactic acid, g/kg	Acetic acid, g/kg	Propionic acid, g/kg	Butyric acid, g/kg
Alf	5.88 <sup>a</sup> ± 0.12	2.73 <sup>a</sup> ± 0.18	37.51 <sup>a</sup> ± 3.40	13.50 <sup>ab</sup> ± 2.18	0.73 <sup>b</sup> ± 0.34	0.25 <sup>a</sup> ± 0.31
NprAH + Alf	5.08 <sup>c</sup> ± 0.19	1.44 <sup>b</sup> ± 0.06	31.91 <sup>b</sup> ± 1.78	9.56 <sup>c</sup> ± 2.22	6.45 <sup>a</sup> ± 2.67	0.17 <sup>a</sup> ± 0.15
FrgAH + Alf	5.09 <sup>c</sup> ± 0.15	1.33 <sup>b</sup> ± 0.29	29.71 <sup>b</sup> ± 2.49	11.18 <sup>bc</sup> ± 0.59	2.71 <sup>b</sup> ± 1.32	0.05 <sup>a</sup> ± 0.04
TexAH + Alf	5.36 <sup>b</sup> ± 0.05	1.31 <sup>b</sup> ± 0.30	19.40 <sup>c</sup> ± 2.55	16.78 <sup>a</sup> ± 2.41	6.00 <sup>a</sup> ± 0.93	0.17 <sup>a</sup> ± 0.15
<i>P</i> -value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05

AH – almond hull, Alf – alfalfa silage, NprAH + Alf – alfalfa 90% + Nonpareil AH 10%, FrgAH + Alf – alfalfa 90% + Ferragnes AH 10%, TexAH + Alf – alfalfa 90% + Texas AH 10%; data are presented as mean value ± SEM; abc – means within a column with different superscripts are significantly different at  $P < 0.05$ ; results are given on a dry matter basis

who reported increased lactic acid levels with rising AH inclusion but did not obtain the ideal lactic/acetic acid ratio. The differences between the studies were attributed to variations in the proportions of AH and alfalfa, which affected the fermentation results.

Table 4 presents the microbiological analysis of alfalfa silage supplemented with almond hulls. All treatment groups showed LAB development, with no statistically significant differences ( $P > 0.05$ ) between them. Enterobacteria were

The fermentation profiles varied significantly depending on the AH variation. In the TexAH + Alf group, lactic acid levels decreased, while acetic and propionic acid production increased, resulting in higher pH values compared to the other groups. The presence of enterobacteria in this application group further confirmed these suboptimal fermentation conditions. The elevated buffering capacity of the silage (Kung et al., 2018) likely explains why the pH did not reach the desired values in all groups.

**Table 4.** Microbiological profiles of almond hull-supplemented alfalfa silages

Treatment groups	Lactic acid bacteria	Enterobacteria	Clostridia	Yeast	Mold
Alf	6.72 <sup>a</sup> ± 0.88	6.24 <sup>a</sup> ± 0.12	5.73 <sup>a</sup> ± 0.12	5.46 <sup>c</sup> ± 0.33	nd
NprAH + Alf	6.61 <sup>a</sup> ± 0.45	nd	4.62 <sup>b</sup> ± 0.13	7.43 <sup>ab</sup> ± 0.77	nd
FrgAH + Alf	6.71 <sup>a</sup> ± 0.65	nd	4.68 <sup>b</sup> ± 0.17	7.67 <sup>a</sup> ± 0.09	nd
TexAH + Alf	6.90 <sup>a</sup> ± 0.73	5.38 <sup>b</sup> ± 0.33	5.62 <sup>a</sup> ± 0.08	6.68 <sup>b</sup> ± 0.07	nd
<i>P</i> -value	>0.05	<0.05	<0.05	<0.05	

AH – almond hull, Alf – alfalfa silage, NprAH + Alf – alfalfa 90% + Nonpareil AH 10%, FrgAH + Alf – alfalfa 90% + Ferragnes AH 10%, TexAH + Alf – alfalfa 90% + Texas AH 10%; “nd” – not detected; data are presented as mean value ± SEM; abc – means within a column with different superscripts are significantly different at  $P < 0.05$ ; results are expressed in log<sub>10</sub> CFU/g

identified in the Alf and TexAH + Alf groups but were absent in NprAH + Alf and FrgAH + Alf silages – a finding consistent with their lower pH values, which likely inhibited enterobacterial proliferation. Clostridia were present in all groups. Their occurrence in untreated Alf silage was expected; however, their presence in the AH-supplemented groups may have resulted from soil contamination of almond hulls collected from the ground. Yeasts were identified in all groups, but no moulds were detected. In a related study, yeast counts were unaffected by increasing AH addition, whereas mould levels in the control group declined with AH supplementation (Aydm et al., 2023). Microbiological data indicated that silage quality differed depending on AH type, with the lack of enterobacteria in the NprAH + Alf and FrgAH + Alf groups representing a significant and favourable outcome.

Table 5 summarises the mineral composition of AH incorporated into alfalfa silage. Both AH and alfalfa contain significant potassium (K) content, with fresh AH K levels of 1.25%, 1.64%, and 1.86% for the NprAH, FrgAH, and TexAH groups, respectively, and 1.89% in fresh alfalfa plants. After ensiling, K proportions were 1.97% in Alf, 1.87% in NprAH + Alf, 2.00% in FrgAH + Alf and 2.01% in TexAH + Alf. The strong cationic influence of K minerals may slow down silage acidification (Goff and Horst, 1997). In the computation of dietary cation-anion difference, when the balance of (Na + K) relative to (Cl + S) favours K and Na, it can elevate the pH value (Umucalılar and Gülşen, 2005). The buffering effect of K in silage production, coupled with the potential risk of hypocalcaemia in pre-calving cows due to elevated K levels, requires careful management of potassium intake.

**Table 5.** Mineral composition of almond hull-supplemented alfalfa silages, dry matter (DM) %

Parameters	Alf	NprAH + Alf	FrgAH + Alf	TexAH + Alf	P-value
Ca, %	0.51 <sup>a</sup> ± 0.01	0.46 <sup>c</sup> ± 0.01	0.47 <sup>bc</sup> ± 0.00	0.48 <sup>b</sup> ± 0.01	<0.05
Mg, %	1.12 <sup>a</sup> ± 0.01	0.90 <sup>c</sup> ± 0.00	0.90 <sup>c</sup> ± 0.01	0.92 <sup>b</sup> ± 0.01	<0.05
K, %	1.97 <sup>b</sup> ± 0.03	1.87 <sup>c</sup> ± 0.01	2.00 <sup>ab</sup> ± 0.01	2.01 <sup>a</sup> ± 0.02	<0.05
P, %	1.08 <sup>b</sup> ± 0.29	1.11 <sup>a</sup> ± 0.02	1.29 <sup>c</sup> ± 0.00	1.39 <sup>c</sup> ± 0.00	<0.05
S, ppm	124.80 <sup>b</sup> ± 0.03	142.30 <sup>a</sup> ± 0.58	96.40 <sup>c</sup> ± 0.43	90.40 <sup>d</sup> ± 0.10	<0.05
Zn, ppm	20.50 <sup>a</sup> ± 0.38	20.30 <sup>a</sup> ± 0.25	16.50 <sup>c</sup> ± 0.21	19.10 <sup>b</sup> ± 0.35	<0.05
Na, ppm	337.04 <sup>a</sup> ± 0.71	292.10 <sup>b</sup> ± 0.32	237.60 <sup>d</sup> ± 0.32	289.10 <sup>c</sup> ± 1.49	<0.05
Mn, ppm	386.30 <sup>a</sup> ± 0.94	355.00 <sup>c</sup> ± 0.81	361.50 <sup>b</sup> ± 6.37	360.80 <sup>bc</sup> ± 0.71	<0.05
Fe, ppm	388.70 <sup>d</sup> ± 0.57	425.10 <sup>b</sup> ± 0.29	438.70 <sup>a</sup> ± 0.93	422.70 <sup>c</sup> ± 0.21	<0.05
Cu, ppm	5.50 <sup>d</sup> ± 0.16	7.00 <sup>b</sup> ± 0.16	6.40 <sup>c</sup> ± 0.07	9.60 <sup>a</sup> ± 0.22	<0.05

AH – almond hull, Alf – alfalfa silage, NprAH + Alf – alfalfa 90% + Nonpareil AH 10%, FrgAH + Alf – alfalfa 90% + Ferragnes AH 10%, TexAH + Alf – alfalfa 90% + Texas AH 10%; data are presented as mean value ± SEM; a–d – means within a column with different superscripts are significantly different at  $P < 0.05$ ; results are given on a DM basis

**Table 6.** Sugar fractions of almond hull-supplemented alfalfa silages, dry matter (DM)%

Parameters	Alf	NprAH + Alf	FrgAH + Alf	TexAH + Alf	P-value
Fructose	3.31 <sup>a</sup> ± 0.03	2.69 <sup>b</sup> ± 0.02	1.97 <sup>d</sup> ± 0.02	2.14 <sup>c</sup> ± 0.03	<0.05
Glucose	0.88 <sup>d</sup> ± 0.02	3.05 <sup>a</sup> ± 0.02	1.22 <sup>b</sup> ± 0.04	0.98 <sup>c</sup> ± 0.02	<0.05
Sucrose	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	<0.05
Maltose	0.00 <sup>b</sup> ± 0.00	0.19 <sup>a</sup> ± 0.01	0.00 <sup>b</sup> ± 0.00	0.00 <sup>b</sup> ± 0.00	<0.05
Total sugar	4.19 <sup>b</sup> ± 0.04	5.93 <sup>a</sup> ± 0.03	3.19 <sup>c</sup> ± 0.05	3.12 <sup>c</sup> ± 0.04	<0.05

AH – almond hull, Alf – alfalfa silage, NprAH + Alf – alfalfa 90% + Nonpareil AH 10%, FrgAH + Alf – alfalfa 90% + Ferragnes AH 10%, TexAH + Alf – alfalfa 90% + Texas AH 10%; data are presented as mean value ± SEM; a–d – means within a column with different superscripts are significantly different at  $P < 0.05$ ; results are given on a DM basis

Table 6 presents the sugar content of almond hulls incorporated into alfalfa silage. Previous research has demonstrated that AH contains substantial sugar concentrations (Offeman et al., 2014; Holtman et al., 2015; Thomas et al., 2019). In this study, total sugar content was 27.38% in Npr, 14.23% in Frg, and 11.58% in Tex hulls, which was consistent with earlier findings. Due to their high sugar content, AH can potentially improve fermentation quality, by lowering pH from 5.88 (control) to 5.08, 5.09, and 5.39 in Npr, Frg, and Tex treatments, respectively. For legume silages with 30–35% dry matter, optimal pH ranges from 4.3 to 4.5 (Kung et al., 2018). Despite the elevated sugar concentration of AH, the pH of the alfalfa silage did not reach the expected threshold. The buffering capacities of Npr, Frg, and Tex almond hulls were 180, 351, and 288 NaOH/kg, respectively. These results indicate that acidic and basic components of almond hulls interact and affect fermentation profiles. Consequently, the anticipated final acidity may not be obtained at the end of the fermentation process.

Table 7 demonstrates the nutritional composition of alfalfa silage supplemented with AH. The dry matter content of the control group was 25.15%, while the NprAH + Alf, FrgAH + Alf, and TexAH + Alf groups reached 31.88%, 30.69%, and 32.54%, respectively. The increase in DM content was expected, as the addition of dry AH naturally elevates silage DM content. Due to their hygroscopic properties, AH are believed to reduce leakage losses by retaining moisture (Asmus, 2015), while simultaneously raising DM to optimal levels. The incorporation of AH lowered the CP and CF content of alfalfa silage and elevated lignin content. These changes reflect the chemical composition of AH and are in line with findings from earlier studies on their use in maize and alfalfa silage (Aydın, 2023; Aydın et al., 2023). Table 7 also includes data on energy and digestibility. As the current and previous studies (Sirakaya and Beyzi, 2025) are part of the same project, the DM, CP and NH<sub>3</sub>-N values reported in Tables 1, 3 and 7 are identical. In an earlier study, the use of AH in alfalfa silage was associated with improved protein utilisation efficiency (Sirakaya and Beyzi, 2025).

**Table 7.** Chemical and nutritional composition of almond hull-supplemented alfalfa silages, dry matter (DM)

Parameters	Alf	NprAH + Alf	FrgAH + Alf	TexAH + Alf	P-value
Dry matter	25.15 <sup>c</sup> ± 0.56	31.88 <sup>ab</sup> ± 1.05	30.69 <sup>b</sup> ± 0.15	32.54 <sup>a</sup> ± 0.73	<0.05
Crude protein	24.33 <sup>a</sup> ± 0.02	19.86 <sup>b</sup> ± 0.05	19.93 <sup>b</sup> ± 0.13	19.14 <sup>c</sup> ± 0.14	<0.05
Crude fat	1.95 <sup>a</sup> ± 0.02	1.65 <sup>c</sup> ± 0.01	1.78 <sup>b</sup> ± 0.01	1.67 <sup>c</sup> ± 0.03	<0.05
Crude ash	10.64 <sup>a</sup> ± 0.17	9.57 <sup>c</sup> ± 0.05	10.01 <sup>b</sup> ± 0.04	9.62 <sup>c</sup> ± 0.03	<0.05
Crude fibre	19.37 <sup>a</sup> ± 0.15	16.86 <sup>b</sup> ± 0.12	17.18 <sup>b</sup> ± 0.18	16.25 <sup>c</sup> ± 0.26	<0.05
ADF	26.00 <sup>b</sup> ± 0.24	26.32 <sup>b</sup> ± 0.71	27.10 <sup>a</sup> ± 0.15	24.13 <sup>c</sup> ± 0.14	<0.05
NDF	31.04 <sup>a</sup> ± 0.20	31.12 <sup>a</sup> ± 0.17	31.28 <sup>a</sup> ± 0.20	29.91 <sup>b</sup> ± 0.07	<0.05
Lignin	6.36 <sup>d</sup> ± 0.26	8.21 <sup>c</sup> ± 0.04	9.91 <sup>b</sup> ± 0.07	11.56 <sup>a</sup> ± 0.16	<0.05
ADICP	1.56 <sup>b</sup> ± 0.07	1.62 <sup>ab</sup> ± 0.04	1.67 <sup>a</sup> ± 0.04	1.67 <sup>a</sup> ± 0.05	<0.05
NDICP	2.05 <sup>a</sup> ± 0.14	2.00 <sup>a</sup> ± 0.07	2.02 <sup>a</sup> ± 0.06	2.05 <sup>a</sup> ± 0.04	>0.05
Starch	2.74 <sup>b</sup> ± 0.04	2.85 <sup>a</sup> ± 0.04	2.25 <sup>d</sup> ± 0.04	2.63 <sup>c</sup> ± 0.02	<0.05
NFC	32.05 <sup>d</sup> ± 0.37	37.80 <sup>b</sup> ± 0.2	37.01 <sup>c</sup> ± 0.11	39.66 <sup>a</sup> ± 0.21	<0.05
DDM	68.65 <sup>b</sup> ± 0.19	68.40 <sup>b</sup> ± 0.55	67.79 <sup>c</sup> ± 0.11	70.10 <sup>a</sup> ± 0.11	<0.05
DMI <sub>BW%</sub>	3.87 <sup>b</sup> ± 0.02	3.86 <sup>b</sup> ± 0.02	3.84 <sup>b</sup> ± 0.02	4.01 <sup>a</sup> ± 0.01	<0.05
TDN <sub>1x</sub>	61.88 <sup>a</sup> ± 0.27	60.42 <sup>b</sup> ± 0.08	58.49 <sup>c</sup> ± 0.13	58.05 <sup>d</sup> ± 0.13	<0.05
NEL, mkal/kg	1.56 <sup>a</sup> ± 0.01	1.47 <sup>b</sup> ± 0.00	1.41 <sup>c</sup> ± 0.00	1.39 <sup>d</sup> ± 0.01	<0.05
NEM, mkal/kg	1.60 <sup>a</sup> ± 0.01	1.48 <sup>b</sup> ± 0.00	1.41 <sup>c</sup> ± 0.01	1.38 <sup>d</sup> ± 0.01	<0.05
NEG, mkal kg	0.99 <sup>a</sup> ± 0.01	0.89 <sup>b</sup> ± 0.00	0.83 <sup>c</sup> ± 0.01	0.80 <sup>d</sup> ± 0.01	<0.05

ADF – acid detergent fibre, NDF – neutral detergent fibre, ADICP – acid detergent insoluble protein, NDICP – neutral detergent insoluble protein, NFC – non fibre carbohydrate, DDM – digestible dry matter, DMI<sub>BW%</sub> – dry matter intake, TDN – total digestible nutrient, NEL – net energy lactation, NEM – net energy maintenance, NEG – net energy gain; AH – almond hull, Alf – alfalfa silage, NprAH + Alf – alfalfa 90% + Nonpareil AH 10%, FrgAH + Alf – alfalfa 90% + Ferragnes AH 10%, TexAH + Alf – alfalfa 90% + Texas AH 10%; data are presented as mean value ± SEM; a–d – means within a column with different superscripts are significantly different at  $P < 0.05$ ; results are given on a DM basis

## Conclusions

The supplementation of almond hulls with alfalfa silage improved its acidity and dry matter content. The analysis suggests that the balance between acid- and base-promoting components in almond hulls may account for the limited fermentation effects observed. Considering their abundant availability, almond hulls represent a reliable feed resource. Their composition, including sugars, structural carbohydrates, and polyphenolic compounds, together with anti-inflammatory and antioxidant properties, make them a valuable material. This study confirms their safe use as a silage additive and as a high-value feed ingredient to mitigate potential issues related to hull storage or utilisation.

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## Conflict of interest

The Authors declare that there is no conflict of interest.

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