Title: Development of New Alfalfa Products in Combination with Almond Hulls for Emerging Domestic and International Markets

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Abstract:

There are large quantities of almond hulls available in California that can be fed to cattle as an economical carbohydrate-rich feed, but they are low in protein, unlike alfalfa. This project aimed to analyze combinations of different qualities of alfalfa hay mixed with almond hulls for forage quality characteristics and digestibility that would capitalize on the strengths of both feeds and create new market opportunities for alfalfa growers. Four qualities of alfalfa (low, low/medium, medium, and high) were mixed with 0, 25, 50, 75% almond hulls. Samples were analyzed via wet chemistry for quality parameters and were tested for *in vitro* digestibility using both the gas production over 72 hours and Daisy *in vitro* methods. In a separate sheep feeding trial, *in vivo* digestibility was determined using eight wethers with fecal collection harnesses fed a diet of a low/medium quality alfalfa hay cubed with 0, 10, 20, or 40% almond hulls. For all mixes, addition of the almond hulls increased the TDN, RFV, and non-fiber carbohydrates while CP, ADF, and NDF decreased (see text box for abbreviations). Almond hulls improved the fermentability, ME, and quality of low-quality alfalfa but had less effect on the high-quality alfalfa. *In vitro* results showed that inclusion of almond hulls improved DM and OM digestibility of alfalfa mixes, but the NDF digestibility was either unchanged or decreased by the addition of almond hulls. Calculated ME values were comparable to that of high-quality alfalfa. In sheep, a diet consisting of Low/Medium quality alfalfa mixed with almond hulls also significantly improved DM and OM digestibility. Alfalfa cubed with 10% almond hulls was found to have the highest dry matter, organic matter, and crude protein digestibility with only small decreases in fiber digestibility compared with 100 % alfalfa cubes. Inclusion of modest amounts (10-20%) of almond hulls packaged with alfalfa has the potential to improve energy content, NFC, TDN, RFV, and DM digestibility of the alfalfa, especially for low quality alfalfa hays.

Introduction:

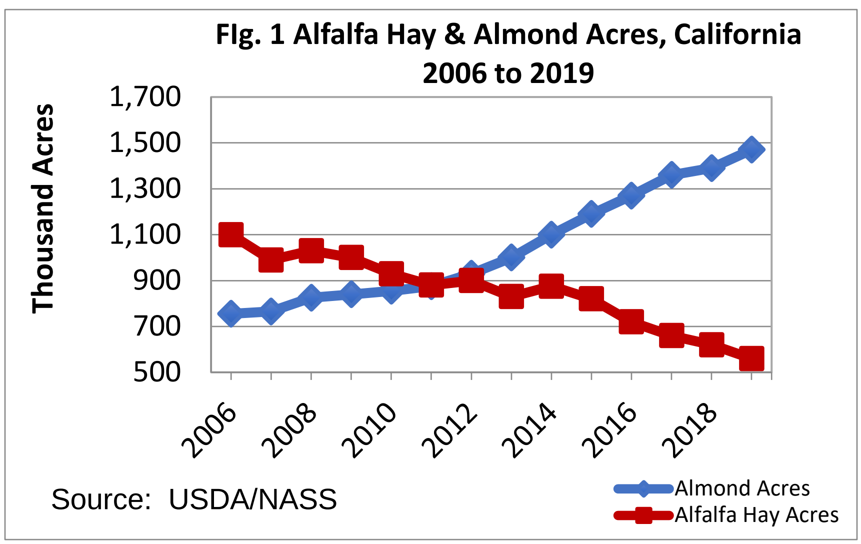
There are over two million tons of almond hulls produced each year as a by-product of the over 1.5 million acres of almonds currently being grown in California (Almond Almanac, 2020, Figure 1). The production of almond hulls is likely to increase since currently about 22% of the CA acres are non-bearing young trees, even if the increase in acreage stabilizes (Almond Almanac, 2020). In many cases almonds have taken over land previously occupied by alfalfa, and many alfalfa growers and dairy producers grow almonds on the same ranch. The phenomenal change in land-use from alfalfa and other agronomic crops to almond (and other permanent crops such as walnut and grape) has been a phenomenon worrisome to alfalfa growers in California (Figure 1, NASS, 2021). The large quantities of almond hulls have challenged other feedstuffs, including alfalfa, due to their status as an inexpensive high energy-containing by-product feedstuff.

Abbreviations:
DM- Dry Matter
CP-Crude Protein
ADF-Acid Detergent Fiber
NDF-Neutral Detergent Fiber
NDFD - NDF Digestibility
OM-Organic Matter
ADF_{om}- ADF on an OM basis
NDF_{om}- NDF on an OM basis
NSC-Non-structural Carbohydrates
EE- Ether Extract
ME-Metabolizable Energy
TDN-Total Digestible Nutrients
(Western States Equation from ADF)
RFV-Relative Feed Value
RFQ-Relative Feed Quality
NFC-Non-Fiber Carbohydrates

Profitability has been the main driving force for the expansion of almond acreage in California, with approximately 70% of the almond nuts going for export (Almond Almanac, 2020). Labor and the need for more precise water stewardship are other factors. Although alfalfa acreage has been reduced in recent years, alfalfa is still produced on over 580,000 acres in California in 2021, driven by domestic dairy demand, horse demand and export markets. California remains one of the nation's leading alfalfa producers and the nation's leading dairy producer, and western states currently produce about 50% of the nation's milk (NASS, 2021).

Almond hulls (the soft fleshy exocarp by-product of harvesting the almond nuts) were previously given away, but currently are purchased primarily for California dairy markets, and have become a highly valued, economical, palatable, energy-dense by-product feedstuff, often competing with alfalfa hay in the ration (Swanson et al., 2021).

While almond hulls serve as an excellent high-energy and fiber rich by-product feed, they lack sufficient protein and effective fiber for optimum rumen function (DePeters et al., 2020). Alfalfa has many of the characteristics required by ruminants and is highly valued in diets, particularly for its digestible energy, effective fiber, and digestible protein. Is it possible that combinations of almond hulls and alfalfa hay could provide a unique package of nutrients and energy desired by feed buyers?



Alfalfa growers are very interested in new uses and new markets for their crop, as are almond growers. We hypothesized that combinations of alfalfa with various amounts of almond hulls might produce synergistic nutritional values that would be of strong interest to dairy or other livestock producers, regardless of their location (domestically or overseas). Exports of alfalfa are estimated to be >17% of the 7 western states' production (Putnam et al., 2019), and there is a strong export demand for other high energy feeds as well (e.g. corn grain). These markets are primarily in the Far East (China, Korea, Japan), and the Middle East (Saudi Arabia, UAE). Hay exports from the west coast, primarily from CA and WA have exceeded 4 million metric tons in recent years (about 50% alfalfa and 50% grasses), and valued at over $1.3 billion in 2020 (Mathews and Sumner, 2021).

Pricing of such alfalfa-almond hull combinations would also be different, with alfalfa being generally more expensive, and almond hulls less, with the potential for high energy, high protein forage products with digestible fiber to be attractive to buyers. The data from this project provides the preliminary analysis and testing of such concepts that then could be considered by nutritionists as a choice in the feeds market. The strongest interest may be in improving the lower-quality alfalfa hay types, which are typically available in greater quantity and would presumably benefit more from a combination with high-energy feeds.

Cubing or other modes of re-combination (double compression, pellets) could be used to deliver such products, suitable for long-distance transport, either domestically or internationally. Applications are likely to be primarily dairy purchasers, but could also include horse and beef markets. Since a considerable market for 'grinder' hay exists for beef producers in the US, this may be an attractive market providing a potentially higher energy content and better livestock health. This research included laboratory testing of a range of combinations of different qualities of alfalfa and almond hulls, with a range of percentages, from 100% to 0% alfalfa-almond hull mixes. These were tested in the lab for common composition analyses as well as in vitro gas production and NDF digestibility. A sheep feeding trial on selected mixes measured the digestibility and energy yield of various mixtures of alfalfa and almond hulls. Research was conducted at UC Davis, Davis, CA.

Materials and Methods:

This project began in the fall of 2020. Alfalfa of three qualities (high, medium, low/medium, and low quality) were obtained by the California Alfalfa and Forage Association and the San Joaquin Valley Haygrowers Association (a grower marketing cooperative). Almond hulls of excellent quality suitable for livestock were obtained from the Almond Board of California. These samples were used for NIR, wet chemistry, and *in vitro* digestibility analysis as well as a digestion study that used sheep as the model for ruminants.

Sample Treatment Mixes for Forage Analysis Studies (with 4 different qualities of alfalfa):
100% alfalfa, 0% almond hulls
75% alfalfa, 25% almond hulls
50% alfalfa, 50% almond hulls
25% alfalfa, 75% almond hulls
0% alfalfa, 100% almond hulls

Wet Chemistry and NIRS Analysis. Samples for lab analysis were ground using a hammer mill with a 3 mm screen, followed by grinding in a Udy cyclone mill with a 1 mm screen. Finely ground samples were mixed to get the desired proportions of almond hulls with each alfalfa quality. Almond hulls were added to subsamples of each alfalfa quality to obtain mixes that were 0, 25, 50, or 75% almond hulls (see box). There was also one sample of 100% almond hulls. These 17 samples were analyzed using a near-infrared reflectance (NIR) spectroscopy by Cumberland Valley Analytical Services. In addition, wet chemistry was performed by Cumberland Valley to determine DM, CP, NDF, NDFom, ADF, ADFom, lignin, starch, EE, OM, NSC, and NFC for each sample mix. Equations were used to estimate TDN, NEL, RFV, and RFQ (see box for abbreviations). Calculated estimates of TDN ranged from 45.3 to 58 TDN, with TDN determined using ADF concentration and the Western States equation: TDN (% of DM) = 82.38 - (0.7515 * ADF [% of DM]). Relative feed value (RFV) was calculated using the following equation: RFV = (((88.9 - (0.779 * ADF [% of DM])) * (120 / NDF [% of DM])) / 1.29). The RFV ranged from 100 to 233 for the Low to High quality alfalfa hay samples.

***In Vitro* Lab Studies.** *In vitro* gas production was measured at UC Davis by incubating various combinations of alfalfa hay and almond hulls in mixed rumen fluid at the aforementioned percentages (See box). Two methods were used: the gas method and the Daisy method. With the four different quality alfalfa hays mixed with almond hulls, there were five combinations at four different percentage levels along with one pure almond hull sample, for a total of 17 unique samples.

Gas production was measured by using the syringe system (Menke et al., 1979). Ground samples of the different alfalfa hay to almond hull mixes were weighed into syringes and incubated with a mixture of rumen fluid and buffers. Rumen fluid was collected from two UC Davis fistulated nonlactating cows fed a high forage diet. The rumen fluid from both cows was mixed to minimize variation in the microbial population of the rumen fluid since the *in vitro* fermentation runs were performed over a number of weeks. At the laboratory, the rumen fluid from the two cows was mixed, filtered through eight layers of cheesecloth, and flushed with carbon dioxide (CO_2) before being mixed with the appropriate buffer. The rumen fluid/buffer mix was then measured and added to each individual syringe. Gas production was recorded every 2 h for the first 10 h period and incubation continued for 72 hours. The incubation run was repeated three times. All samples were measured in triplicate, so data includes nine replications per treatment. The 24 h gas production values for each sample were used to calculate metabolizable energy (ME) using a previously determined equation (Melesse et al., 2018).

The samples were also fermented *in vitro* using the Ankom Daisy system. The Daisy system uses four, 1- gallon fermentation containers. Rumen fluid from two rumen-fistulated, nonlactating dairy cows was collected and mixed to create a pooled source of rumen fluid to which buffer was added. Fermentation incubation time points included: 12, 24, 30, and 48 h. Samples at each time point were done in duplicate for each run. Samples were weighed into monofilament bags (Ankom). These monofilament bags were placed in the fermentation jars of the Daisy system and one jar of samples was removed and rinsed for each incubation time point. The bags were then dried at 55°C for at least 15 h before being weighed to determine dry matter (DM) disappearance. The bags were then analyzed for NDF to determine the amount of NDF remaining at each fermentation time point. The disappearance of both DM and NDF was determined at UC Davis using the methods reported previously (DePeters et al., 1997). Disappearance was determined as the extent of digestion at the specified incubation four time points.

Sheep Feeding Study. From the *in vitro* results and wet chemistry data, three combinations of alfalfa hay and almond hulls were chosen, along with pure alfalfa, to be used in a sheep digestibility study. Weed-free low/medium quality (approximately 53 TDN) alfalfa hay was chosen. Almond hulls were added to the low/medium alfalfa hay to create mixes containing 0, 10, 20, or 40% almond hulls (wt:wt basis, see box). Mixes were cubed by Harlan Feed (Woodland, CA) using a standard cubing technique with a 7/8-inch dye. Core samples of the alfalfa hay bales were obtained before cubing. Each bale was sampled 5-6 times using a Star Quality 7/8 in sampler with a gas-powered drill. The almond hulls were sampled by taking multiple grab samples from the same lot used for the cubes.

Cubed Mixtures for Sheep Feeding Trial (low-medium alfalfa):
100% alfalfa, 0% almond hulls
90% alfalfa, 10% almond hulls
80% alfalfa, 20% almond hulls
60% alfalfa, 40% almond hulls

Eight wethers were fed the four cubes mixes (see box). The experimental design was a replicated 4x4 Latin square, allowing for each sheep to consume each diet over four experimental periods. Each sheep consumed all four cube treatments which were: 1) pure low/medium quality alfalfa, 1) alfalfa with 10% almond hulls, 3) alfalfa with 20% almond hulls, and 4) alfalfa with 40% almond hulls.

Sheep were housed in elevated pens at UC Davis. Each animal was housed individually to allow for individual feed intake. The pens were elevated and there was no bedding. Feed offered and refused were weighed and recorded twice daily. There were four 14-day periods with the first seven days of each period being used as adjustment to the diet and the last seven days used for data collection. During week two of each period, at the morning feeding, grab samples of each cube mix were collected. There were two samples (two separate sample bags) collected for each diet. One sample was used for dry matter determination. The other sample was used for chemical analysis. A fecal-collection harness was put on each animal on day six of each period. Fecal collection was from day eight to 14 (seven days of fecal collection). Feces from each animal was weighed in the morning (8-9 a.m.) and the evening (4-5 p.m.) and weights recorded per animal. At the conclusion of each period the feces for each animal (14 samples: 2 samples/day for 7 days) was combined to create a weekly composite and then mixed by hand. Two (2) subsamples were collected for each animal. One subsample was used for dry matter (DM) determination at 100ºC. The other subsample was dried at 55ºC and were sent to Cumberland Analytical for wet chemistry analysis. Apparent total-tract digestibility was determined by total fecal collection. Apparent digestibility was determined for DM, OM, CP, ADFom, and aNDFom.

Statistical Analysis:

All statistical analyses were performed using R version 3.6.2 (R core team, 2019). For the *in vitro* and feed data, averages and standard deviations were calculated using the R*misc* package in R (Hope, 2013). For the sheep digestibility data, a linear mixed effects model using the lme4 package was used and *P*-values were calculated using a Type III Analysis of Variance with Satterthwaite's method (Bates *et al*., 2015). Individual contrasts were analyzed for the main effects using the Emmeans package and P-values were adjusted using the Tukey method (Lenth, 2020). The model used as follows:

$$y_{ijk} = \mu + diet_i + period_j + sheep_k + e_{ijk} \quad (2)$$

where y_{ijkm} is the digestibility of each nutritional component of the i^{th} diet for the j^{th} period for the k^{th} sheep, µ is a constant, and e_{ijk} is residual error. $Diet_i$ is the fixed effect of i^{th} cube type (i = 0%, 10%, 20%, or 40% AH); $period_j$ is the fixed effect of j^{th} period (j = 1-4); $sheep_k$ is the random effect of the k^{th} sheep (m = 1,…,8). The interaction of diet and period was not significant so it was not included in the model.

Project Objectives and Corresponding Results:

***Objectives*:**

- To measure the forage quality characteristics of various combinations of alfalfa-almond hull mixtures in the lab and in cube form and develop innovative products centered upon alfalfa
- To evaluate the potential DM and NDF digestibility as well as gas production and energy values for various mixtures of four qualities of alfalfas with almond hulls using *in vitro* methods.
- To evaluate the *in situ* digestibility and palatability of alfalfa-almond hull cubed mixes compared with a pure alfalfa utilizing sheep digestibility studies.

Corresponding Results:

- The alfalfa samples ranged from 45 to 58 TDN while the almond hulls had a high NFC and TDN but only 5.6% crude protein. For all mixes, as the percentage of almond hulls increased, the TDN, RFV and NFC increased while CP and NDF concentration decreased.
- Almond hulls improved the fermentability, ME, and quality of low-quality alfalfa but had less effect on high quality alfalfa. Inclusion of almond hulls improved DM and OM digestibility of alfalfa mixes, but the NDF digestibility was either unchanged or decreased. Calculated ME values that were comparable to that of the pure high-quality alfalfa.
- In sheep, mixes were highly palatable. Diets consisting of Low/Medium quality alfalfa cubed with 10% almond hulls was found to have the highest dry matter, organic matter, and crude protein digestibility with only small decreases in ADF and NDF digestibility compared with the 0% almond hull diet.
- Inclusion of modest amounts of almond hull (10-20%) mixed with mid-lower quality alfalfa hays in various packages should be of interest for different markets due to improvement in energy, DMD, TDN, and RFV, while maintaining high protein.

Results and Discussion:

Forage Quality Measurements. The alfalfa samples used for these studies ranged from high forage quality (low-fiber, high protein) to low forage quality (low protein, high fiber; Table 1). Addition of various quantities of almond hulls reduced the crude protein concentrations but also decreased ADF and NDF concentrations (Table 1). The addition of almond hulls improved the RFV and TDN values of medium and low-quality hays, but did not affect the higher quality hay samples to the same extent (Figure 1). Crude protein (CP) values for these hays ranged from 14.3 to 25% of DM, ADF values ranged from 42.4 to 23.6% of DM, NDF ranged from 52 to 28.1% of DM, and lignin ranged from 9.9 to 5.4% of DM for Low to High quality hay samples, respectively (Table 1). The almond hulls were only 5.6% CP, 22.8% ADF, 22.6% NDF, and 7.1% lignin (all on a DM basis), but they were 63.4% NFC and had a calculated TDN of 60 (Western States Equation) and a calculated RFV index of 299.

For all qualities of alfalfa, as the percentage of almond hulls increased, the TDN, RFV, NFC, and water- and ethanol-soluble carbohydrates increased while the CP, ADF, and NDF percentages decreased (Figure 1, Table 1). The amount of lignin increased as the percentage of almond hulls increased for all qualities of alfalfa except the Low sample. Given the low amount of CP in almond hulls, it was not surprising to see the CP drop as the amount added increased. These were high-quality almond hulls, with lower NDF, ADF, and lignin values that would typically be fed to lactating dairy cows. The chemical composition of the almond hulls sampled for this study is typical for high quality hulls in California (DePeters et al., 2020).

In Vitro Measurements. In vitro gas production was highest at the 72-h time point for the almond hulls (344.3 ml/g) but the Medium and Low/Medium with 75% almond hulls were similar (334.7 and 328.6 ml/g, respectively, data not shown). Compared with 100% high-quality alfalfa (282.4 ml/g at 72 h), the Medium quality alfalfa with 25% almond hulls was slightly higher (285.5 ml/g) and the Low/Medium quality alfalfa with 25% almond hulls was slightly lower (278.3 ml/g). A similar trend was seen with the 24 h gas production values (Table 2). For ME values calculated from 24 h gas production, the high-quality alfalfa with 25% almond hulls was the highest at 10.8 MJ/kg, while 100% high-quality alfalfa was similar at 10.5 MJ/kg (Table 2). The Low/Medium alfalfa with 25%

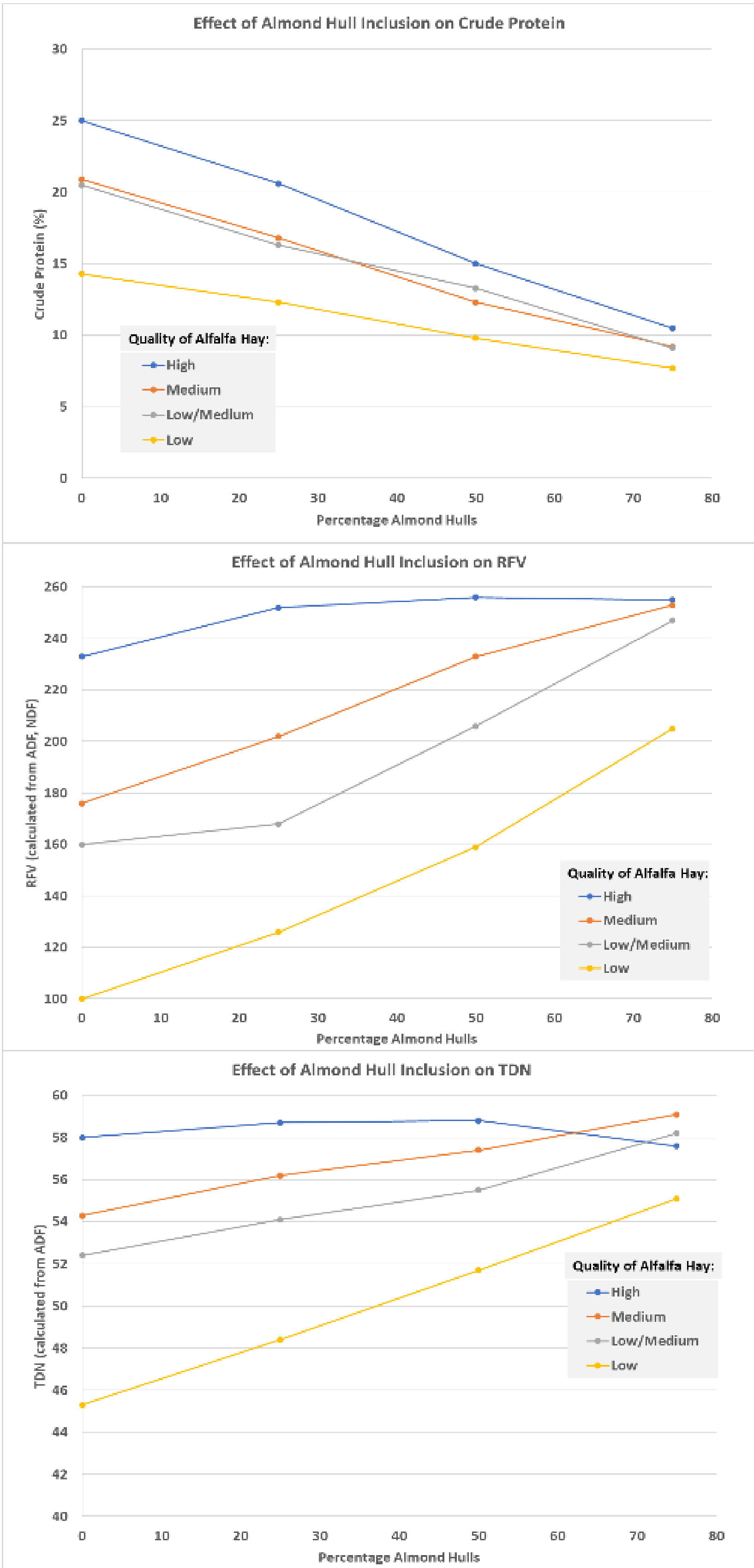


Figure 1. *Effect of four initial qualities of alfalfa mixed with varying amounts of almond hulls on Crude Protein (CP), Relative Feed Value (RFV), and Total Digestible Nutrients (TDN). For reference, almond hulls had 5.6% CP, 20.9% ADF, 22.9% NDF, 7.1% lignin, 299 RFV, and 60.1% TDN (90% DM), and 64.3% Non-Fiber Carbohydrates (NFC).*

almond hulls had 9.7 MJ/kg ME, while the same Low/Medium quality hay with 50 or 75% almond hulls improved to 10.3 MJ/kg. While the Low-quality hay had the greatest improvement in ME as the % almond hulls increased (8.3 MJ/kg to 9.9 MJ/kg for Low with 0 to 75% almond hulls), even with 75% almond hulls added it still resulted in much lower ME than other hay qualities with that percentage of almond hulls (10.4, 10.5, and 10.3 MJ/kg for High, Medium, and Low/Medium respectively- Table 2).

Table 1. Chemical composition for all alfalfa samples mixed with various almond hull percentages. Samples were analyzing utilizing wet chemistry.

		Forage Quality[1]						
Alfalfa Quality	Almond Hulls %	CP	ADF	NDF	Lignin	NFC	TDN	RFV
		%	%	%	%	%	%	%
None (Almond Hulls)	100	5.6	20.8	22.6	7.1	64.3	60.1	299
High	75	10.5	24.4	25.7	7.3	56.3	57.6	255
	50	15.0	22.7	26.1	6.3	50.4	58.8	256
	25	20.6	22.8	26.4	5.4	43.7	58.7	252
	0	25.0	23.8	28.1	5.4	37.0	58.0	233
Medium	75	9.2	22.2	26.5	7.8	56.8	59.1	253
	50	12.3	24.8	27.9	6.9	51.5	57.4	233
	25	16.8	26.6	31.5	6.8	42.1	56.2	202
	0	20.9	29.3	35.3	6.3	34.3	54.3	176
Low/Medium	75	9.1	23.5	26.7	7.3	56.4	58.2	247
	50	13.3	27.6	30.7	7.1	46.8	55.5	206
	25	16.3	29.6	36.6	6.8	40.2	54.1	168
	0	20.5	32.1	37.4	7.0	30.7	52.4	160
Low	75	7.7	28.2	30.5	8.7	53.8	55.1	205
	50	9.8	33.2	37.0	9.1	45.7	51.7	159
	25	12.3	38.1	43.8	9.3	35.9	48.4	126
	0	14.3	42.7	52	9.9	25.5	45.3	100

1. CP-Crude Protein; ADF=Acid Detergent Fiber; NDF=Neutral Detergent Fiber; Lignin=Acid Detergent Lignin; NFC=Non-Fiber Carbohydrates by difference; TDN= Calculated from ADF (Western States); RFV= Relative Feed Value. All Values on a 100% Dry Matter Basis except TDN (90%).

Daisy DMD was highest for almond hulls at 24 h (67%) and inclusion of almond hulls with all the alfalfa samples improved Dry Matter Digestibility of the alfalfa samples (Table 2). DMD was dramatically improved for the lower-quality alfalfa samples but only modestly improved the high-quality samples (Table 2). Fiber Digestibility (NDFD) was greatest in the high-quality alfalfa samples with no almond hulls, and generally the almond hull samples were lower in fiber digestibility. Inclusion of almond hulls had either no effect on NDFD or decreased fiber digestibility compared with the 100% alfalfa treatments (Table 2). This would indicate that almond hulls are overall quite digestible *in vitro*, but the fiber in almond hulls is not as digestible as the fiber in alfalfa. This is likely due to the higher lignin values in almond hulls relative to their ADF and NDF content, meaning the fiber in almond hulls is more highly lignified as a percentage of the NDF, thus less digestible compared with alfalfa hay. The key value of almond hulls nutritionally is the high concentration of non-fiber fermentable carbohydrates (NFC, Table 1), which improves fermentability (Gas), dry matter digestibility (DMD), and ME when mixed with alfalfa hay, especially lower qualities of hay (Table 2).

Table 2. *In vitro* gas production, Metabolizable Energy (ME), Dry Matter Digestibility (DMD) at 24 hours, and Neutral Detergent Fiber Digestibility (NDFD) at 24 hours for alfalfa, almond hull, and alfalfa-almond hull mixtures. Initial Quality was based upon NDF, ADF, and CP content (Table 1).

Alfalfa Quality*	**Almond Hulls**	**24-hr gas Production**	**ME**	**DMD 24hr**	**NDFD 24hr**
	%	ml/g	(MJ/kg)	%	%
None (Almond Hulls)	100	294.8	10.5	67.0	26.8
High	75	277.3	10.4	62.4	32.5
	50	271.9	10.6	57.0	29.8
	25	262.5	10.8	56.5	37.7
	0	240.5	10.5	56.4	37.4
Medium	75	283.8	10.5	60.6	27.3
	50	268.2	10.2	54.1	25.6
	25	243.7	9.9	51.6	28.7
	0	231.8	9.8	49.1	32.6
Low/Medium	75	280.0	10.3	64.4	31.0
	50	266.2	10.3	56.2	23.1
	25	240.0	9.7	53.6	32.4
	0	224.4	9.6	52.1	29.4
Low	75	268.8	9.9	61.2	22.3
	50	246.9	9.4	52.9	15.2
	25	225.5	9.0	49.6	25.0
	0	195.9	8.3	44.4	26.9

Sheep Feeding Trials. The *in vivo* sheep feeding study results showed a similar trend to that seen *in vitro*. The cubes that were fed included low/medium quality alfalfa combined with almond hulls in cubes (almond hulls:alfalfa 0:100. 10:90, 20:80, and 40:60 proportions, Table 3). Due to the low CP in almond hulls, the CP in the 40% almond hulls cubes was much lower compared with the cubes containing 0 or 10% almond hulls (14.9% CP compared with 20 and 20.7%, respectively, Table 3). The NDF and ADF were lower in cubes containing almond hulls, but the lignin concentration was higher in the cubes with 20 and 40% almond hulls. The calculated TDN was slightly higher for the cubes containing almond hulls, but the RFV for all cubes containing almond hulls was much higher than the 100% low/medium alfalfa hay (Table 3). Even modest inclusion of almond hull in the cubes resulted in over 20-point improvement in RFV, due to the lower NDF and ADF concentrations (Table 3).

In the sheep-feeding study, digestibility of DM, OM, and CP was highest when the sheep were consuming cubes containing 10% almond hulls (Table 4). For the 20% and 40% almond hull containing cubes, there were significant decreases in NDFom and ADFom digestibility, but no difference between the cubes containing 0 and 10% almond hulls. This reflects the reduced fiber digestibility of almond hulls observed in the lab studies (Table 2). The higher DM and OM

Table 3. Chemical composition of the cubed Low/Medium quality alfalfa mixed with 0, 10, 20, or 40% almond hull for the sheep-feeding trial. All values are on a DM basis except for TDN (90%DM), as previously described (see box p. 2 for abbreviations).

	0% Almond Hull		10% Almond Hull		20% Almond Hull		40% Almond Hull	
Composition	Avg	SD	Avg	SD	Avg	SD	Avg	SD
				%				
CP	20.0	0.82	20.7	0.42	19.0	0.59	14.9	0.31
ADF	33.6	1.13	30.3	0.71	31.5	0.29	31.1	1.25
NDF	42.2	1.24	37.7	1.22	37.4	0.79	36.7	1.89
aNDFom	41.1	1.31	36.5	1.25	36.5	0.75	36.0	1.89
Lignin	6.8	0.29	6.7	0.27	7.0	0.12	8.1	0.29
Starch	0.7	0.61	1.5	1.03	1.2	1.12	0.6	0.74
Fat	1.9	0.47	1.6	0.36	1.8	0.36	2.0	0.27
Ash	10.4	0.42	8.8	0.43	8.7	0.81	8.1	0.40
TDN	57.1	0.85	59.6	0.54	58.7	0.22	59.0	0.94
RFV	138.4	5.83	161.6	6.38	160.0	3.69	164.4	11.20

digestibility seen when the sheep were consuming cubes with almond hulls was anticipated given that almond hulls contained 64.3% NFC, which are highly fermentable carbohydrates by rumen microbes. The decrease in CP digestibility was also expected since we know that the digestibility of CP is highly correlated to the concentration of CP in the diet (Holter and Reid, 1959). In addition, almond hulls were previously shown to have low CP digestibility compared with alfalfa hay (Yalchi,

Table 4. Sheep *in situ* digestibility of dry matter, organic matter, crude protein, ADFom, NDFom for low/medium quality alfalfa cubed with 0, 10, 20, or 40% almond hulls.

	0% Almond Hulls	10% Almond Hulls	20% Almond Hulls	40% Almond Hulls	SE
			% Digestibility		
DM	59.5[a]	62.9[b]	61.7[b]	61.3[b]	0.65
OM	60.9[a]	64.1[b]	62.3[a]	61.5[a]	0.66
CP	70.8[a]	72.1[a]	67.6[b]	55.6[c]	0.83
ADFom	45.8[a]	43.0[a]	39.1[b]	34.8[c]	1.13
NDFom	44.7[a]	42.8[a]	38.9[b]	36.6[b]	1.38

[a-c] Different lettered superscripts denote significant differences between treatments ($p<0.05$) for each nutritional component.

2011). The lower ADFom and NDFom digestibilities seen in the cubes containing almond hulls was likely due to the higher content of lignin in the almond hulls compared with alfalfa. Yalchi (2011) found that NDF was significantly less digestible in diets containing 30% almond hulls when fed to sheep compared with 100% alfalfa diets. Conversely, a feeding study done with dairy cattle found that feeding almond hulls up to 20% of the diet had slight improvements in NDFom and ADFom compared with that of the basal diet that contained 0% almond hulls (Swanson et al., 2021). The data in this study would suggest that the NDF and ADF in almond hulls are not as digestible in sheep as the NDF and ADF found in alfalfa hay, even low/medium quality alfalfa hay. However, examination of fiber digestibility in full total-mixed rations in dairy diets would be helpful in understanding the differences in fiber digestibility between alfalfa of various qualities and almond hulls.

Conclusions:

Overall, this research suggests that there were potential benefits of added almond hulls to alfalfa hay mixes based on *in vitro* and *in vivo* digestibility estimates when low amounts (e.g.10-20%) of almond hulls are mixed with Low/Medium quality alfalfa hay, but this relationship was less important for higher qualities of alfalfa hay. Mixes with almond hulls had the effect of lowering NDF and ADF concentrations, thereby improving RFV and TDN, which should be of strong interest to hay marketers. The sheep digestibility study suggests that the fiber in almond hulls was not highly digestible. A decreased fiber digestibility was observed when the proportion of almond hulls in the cube mixes increased. Mixing modest amounts of almond hulls with low to medium quality alfalfa (e.g. 38-48% NDF) could be beneficial by increasing the overall dry matter and crude protein digestibility and RFV and TDN, with only slight decreases in fiber digestibility. Additional studies to examine these types of mixes in dairy production studies that measure performance (milk yield and feed intake) would provide useful information, as well as modelling various mixtures at different price-points.

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