Feeding high amounts of almond hulls to lactating cows

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ABSTRACT

California is the leading state for the production of almonds, with more than 400,000 bearing hectares of orchards that produced approximately 1 billion kilograms of shelled nuts in 2017. Almond hulls (AH) are a regional by-product feedstuff fed predominantly to dairy cattle in California. A 2012 study surveyed 40 dairy farms in California and found that 39 out of 104 total mixed rations contained AH, with a mean daily feeding rate of 1.45 kg/cow. In 2017, approximately 2 billion kilograms of AH was produced. At a feeding rate of 1.45 kg/cow daily, even if all 1.7 million lactating cows in California are consuming AH, there will be a surplus of AH on the market as the approximately 130,000 nonbearing hectares come into nut production. Therefore, the potential of feeding varying amounts of AH to lactating dairy cows was investigated using 12 Holstein cows with 4 primiparous and 8 multiparous cows. The dietary treatments were 4 total mixed rations containing 0, 7, 13, or 20% AH. The AH used contained 12.8% crude fiber (as-is basis), which was below the 15% legal limit set by state feed regulations. Diets were formulated so that as the inclusion rate of AH increased, the amount of steam-flaked corn and soyhull pellets decreased and soybean meal inclusion increased. Experimental design was a replicated 4 × 4 Latin square. Diet had a cubic effect on actual milk yield, energy-corrected milk yield, and dry matter intake, with the 7% AH diet having the highest values and the 13% AH diet having the lowest. The percent and yield of total solids and the yields of lactose and fat did not differ with diet, but percent and yield of protein declined linearly with increased AH inclusion, and fat percent increased linearly. Apparent total-tract digestibilities of dry matter and organic matter were higher with the inclusion of AH in the diet. Total percentage of the day spent ruminating increased linearly with higher amounts of AH. Overall, this work demon-

strated that AH can be fed at varying amounts, up to 20% of the diet, to lactating dairy cows to support high levels of milk production and that increasing amounts of AH (up to 20%) in the diet could lead to improved digestibility and milk fat percentage but decreased milk protein production.

Key words: almond hulls, dairy nutrition, concentrate replacement, California

INTRODUCTION

California produces 82% of the world's almonds, with more than 1 billion kilograms produced in 2017–2018 alone (Almond Board of California, 2018). Field weight during harvest is 23% nuts, 13% debris, 14% shells, and 50% hulls, meaning that approximately 2.05 billion kilograms of almond hulls (AH) was produced in 2017–2018 (EPA, 1995; Almond Board of California, 2018). Almonds are related to peaches, where the hull of an almond is anatomically similar to the fleshy portion of the peach that humans consume. Although AH are not consumed by humans, they can serve as a viable feedstuff for dairy cows and goats (Aguilar et al., 1984; Reed and Brown, 1988).

Almond hulls are high in sugars and NDF but low in protein content (Cruess et al., 1947; Saura-Calixto and Cañellas, 1982; DePeters et al., 2000). Almond hulls that are sold as by-product feed must contain ≤15% crude fiber (CF; as-fed basis) to be classified as “almond hulls”; if they contain >15% CF, they are classified as “hull and shell” (CDFA, 2013). The feed industry often refers to AH that are <15% CF as “prime hulls,” but this is not a legal term. Much of the NDF in AH can be degraded by ruminant microbes, with lignin (ADL; the undegradable portion of NDF) percentages ranging from only 6 to 11% on a DM basis (Aguilar et al., 1984; Yalchi and Kargar, 2010). In addition to NDF, AH supply ruminants with an excellent source of highly fermentable carbohydrates in the form of sucrose, fructose, glucose, inositol, and sorbitol (Saura-Calixto and Cañellas, 1982; Offeman et al., 2014). This high content of fermentable carbohydrates could make AH a good substitute for concentrate ingredients, such as corn. In addition, AH are dried in the orchard during

Received June 17, 2020.

Accepted January 15, 2021.

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the harvesting process, making them an easy feed for dairies to store (Reed and Brown, 1988).

A survey conducted in California in 2012 found that of the 104 TMR sampled, 39 contained AH, with an average of 1.45 kg/d per cow being fed (Castillo et al., 2012). The California Department of Agriculture estimated that there were 1.75 million dairy cows in California in 2017. Even if every cow consumed AH, there would still be a sizable surplus of AH on the market. Given this estimated surplus along with the high amounts of fermentable carbohydrates in AH and the affordability of AH as a by-product feed for lactating dairy cows, feeding higher amounts of AH to lactating cows would contribute to the sustainability of both the dairy and almond industries in California.

Little recent research has focused on feeding AH to dairy cows. Aguilar et al. (1984) found that AH could be fed to lactating dairy cows at up to 25% of the TMR with no negative effects on milk production or feed intake. In contrast, Williams et al. (2018) found that feeding AH to lactating dairy cows at 17.6% of their diet resulted in a decrease in CP and NDF intake along with a decrease in the yields of milk and milk protein. For both of these previous studies AH were used as a replacement for alfalfa hay, with urea being supplemented in the Aguilar et al. (1984) study. As previously stated, AH are low in CP but high in fermentable carbohydrates. The highly fermentable sugars, such as sucrose and glucose, in AH could make them a better replacement for concentrates instead of forages in a lactating cow diet.

The aim of this study was to determine whether AH could be fed in varying amounts as a replacement for corn and soyhulls in a lactating cow diet to support production performance and digestibility and whether changes in production occur with different AH levels substituted for concentrates. We hypothesized that AH could serve as a viable ingredient at levels up to 20% of the diet with no negative effects on either production performance or diet digestibility. The results from this study will provide guidance for producers and nutritionists on how a given AH level in the diet will affect production performance for lactating cows.

MATERIALS AND METHODS

In February 2019, 12 lactating Holstein dairy cows averaging 96 ± 30 DIM were assigned to dietary treatments using a 4×4 Latin square experimental design. Healthy cows were assigned to their respective Latin square based on parity, with 4 primiparous cows assigned to square 1, 4 multiparous second-lactation cows assigned to square 2, and 4 multiparous third-lactation cows assigned to square 3. There were 4 periods, with

each period being 21 d in length. The last 7 d of each period was used for data collection, with feed offered and milk production recorded twice a day during the study and feed refusals recorded every morning. The ingredient composition of the 4 TMR is presented in Table 1, and the chemical composition of each TMR is shown in Table 2. The TMR composition was based on formulating a diet for 28 kg of DMI/cow that would provide cows with 0, 1.8, 3.6, or 5.5 kg of commercial AH/d. This created 4 TMR with 0, 7, 13, or 20% AH. The chemical composition of the AH used in this study is presented in Table 3. As the amount of AH increased in the diet, corn and soyhull pellets decreased and soybean meal increased. Soyhull pellets, which are high in NDF from α -amylase (**aNDF**) and ADF, were added to balance for the lower amount of aNDF and ADF in corn; steam-flaked corn is roughly 9.5% aNDF and 3.4% ADF, whereas the AH fed were roughly 24% aNDF and 15% ADF (NRC 2001; Table 3). Soybean meal was added as AH increased to account for the lower protein in AH (4.5%) compared with steam-flaked corn (9.4%; NRC, 2001; Table 3).

Cows were housed in an open corral with access to 24 covered, sand-bedded freestalls and a concrete exercise yard at the UC Davis Dairy. Water was available ad libitum from a water trough. Cows had ad libitum access to trace mineral blocks. Cows were individually fed using Calan Broadbent feeding doors (C system; American Calan Inc.). Cows were fed twice daily after

Table 1. Composition (% on a DM basis) of TMR for lactating cows with 4 varying amounts of almond hulls (AH)

Ingredient	Amount of AH			
	0%	7%	13%	20%
Alfalfa hay, chopped	38.72	38.71	38.71	38.51
Corn, steam-flaked	32.49	30.07	28.34	23.28
Soyhull pellets	11.53	7.97	2.01	0.00
AH	0.00	6.59	13.18	19.67
Oat hay, chopped	3.30	2.47	2.47	2.46
Soybean meal	1.50	1.75	2.85	3.70
Distillers grains, dried	6.24	6.24	6.24	6.24
Cottonseed, whole fuzzy	3.77	3.77	3.77	3.77
Limestone/oyster shell	1.29	1.29	1.29	1.29
Sodium bicarbonate	0.64	0.64	0.64	0.64
Mineral ¹	0.23	0.23	0.23	0.23
Magnesium oxide	0.16	0.16	0.16	0.16
Salt, white	0.13	0.13	0.13	0.13

¹Nutris LLC. Provides (on a DM basis) 0.56% CP, 0.92% ADF, 0.48% NDF, 0.04 Mcal/kg NE_L, 1.7% TDN, 12.37% Ca, 5.33% P, 9.15% Na, 0.08% K, 4.28% Mg, 2.16% S, 25.06 mg/kg Co, 668.80 mg/kg Cu, 58.54 mg/kg I, 2,664.5 mg/kg Mn, 22.79 mg/kg Se, 4,473.59 mg/kg Zn, 1,982.07 mg/kg Fe, 933.33 g/t of monensin, 535.12 kIU/kg vitamin A, 185.2 kIU/kg vitamin D₃, 4.19 kIU/kg vitamin E, 58.81 mg/kg biotin, 0.0103% lysine, 0.246% methionine, 0.24% methionine-3, 29.35 mg/kg ethylene diamine dihydroiodide, 0.02% diflubenzuron, 29.33 kg of live bacterial colony-forming units, 1.55% almond shells, and 0.23% rice hulls.

Table 2. Chemical composition (% on a DM basis unless otherwise noted) of TMR containing varying amounts of almond hulls (AH) from 4 grab samples

Item ¹	0% AH	SD	7% AH	SD	13% AH	SD	20% AH	SD
DM	86.7	0.61	86.6	0.67	86.4	0.31	86.7	0.78
CP	17.2	0.78	16.3	0.95	17.0	1.31	17.2	1.05
ADF	19.3	1.25	18.6	1.54	18.2	1.07	19.0	0.65
ADFom	18.8	0.93	18.0	1.12	17.6	0.98	18.5	0.90
aNDF	28.0	0.92	27.3	0.50	25.2	1.35	24.5	1.93
aNDFom	27.0	1.03	26.8	0.89	24.5	1.05	24.1	1.73
Lignin	3.4	0.15	3.7	0.36	4.0	0.37	4.4	0.65
Starch	24.6	1.97	23.8	0.91	22.6	3.27	19.3	0.45
Ca	1.2	0.16	1.2	0.05	1.2	0.18	1.3	0.32
P	0.3	0.02	0.3	0.02	0.3	0.03	0.3	0.04
Mg	0.5	0.04	0.5	0.05	0.5	0.05	0.5	0.05
K	1.2	0.02	1.4	0.04	1.4	0.09	1.5	0.07
Na	0.3	0.05	0.4	0.04	0.3	0.06	0.4	0.13
Fe (mg/kg)	476	68.4	520	83.7	507	126.5	522	73.2
Mn (mg/kg)	36	4.4	37	6.4	34	3.5	37	2.5
Zn (mg/kg)	34	3.1	38	6.8	36	0.6	37	4.0
Cu (mg/kg)	7.7	0.58	8.7	0.58	8.7	0.58	8.7	0.58
NE _L ² (Mcal/kg)	1.69	0.05	1.65	0.03	1.65	0.02	1.64	0.01

¹ADFom = ADF on an OM basis; aNDF = NDF from α -amylase; aNDFom = NDF on an OM basis.²Calculated based on the equation outlined in the Dairy NRC (2001).

they returned from the milking parlor at approximately 0730 and 1930 h. Feed refusals were collected from each cow's bunk and weighed before the morning feeding. During the last 7 d of each period, 2 separate samples of feed refusals were taken daily for each cow. Each sample

retained 5% of the total as-fed weight of the feed refusal in plastic bags for each cow. One sample was used for determination of DM, and the other sample was used for chemical analysis. Dry matter was determined by drying duplicate samples in a forced-air oven for 15

Table 3. Chemical composition (% on a DM basis unless otherwise noted) of 4 grab samples of almond hulls added to TMR in this study

Item ¹	Average	SD	Minimum	Maximum
DM	86.1	2.03	83.6	88.3
CP	4.5	0.24	4.2	4.7
Soluble protein	1.5	0.05	1.5	1.6
aNDF	23.8	2.04	22.2	26.6
aNDFom	23.5	2.08	21.9	26.4
ADF	14.9	2.17	12.9	16.8
ADFom	14.0	2.35	11.5	16.1
Crude fiber	14.9	1.77	13.8	17.5
Lignin	7.2	0.78	6.3	8.1
Ash	5.9	0.33	5.6	6.3
OM	94.1	0.33	93.7	94.4
Ethanol-soluble carbohydrates	32.0	2.16	29.7	34.1
Water-soluble carbohydrates	34.7	2.24	31.8	37.2
Ca	0.2	0.02	0.2	0.2
P	0.1	0.01	0.1	0.1
Mg	0.1	0.01	0.1	0.1
K	2.5	0.08	2.4	2.6
Na	0.02	0.01	0.02	0.03
Fe (mg/kg)	225	103	161	378
Mn (mg/kg)	17	2.4	15	20
Zn (mg/kg)	17	3.4	12	20
Cu (mg/kg)	4	0.5	4	5
NFC	64.0	3.04	60.0	66.7
NSC	32.0	2.16	29.7	34.1
NE _L ² (Mcal/kg)	1.6	0.02	1.5	1.6

¹aNDF = NDF from α -amylase; aNDFom = NDF on an OM basis; ADFom = ADF on an OM basis.²Calculated based on the equation outlined in the Dairy NRC (2001).

h at 100°C to a constant weight. Two grab samples of each TMR were also collected during each morning feeding and placed in separate plastic bags to create a composite sample for each TMR. A shovel was used to get samples of each TMR from the feed piles every 2 wk throughout the study. From these large samples, a grab sample of each TMR was used for determination of DM similar to the feed refusals, and the rest of the sampled TMR was ground coarsely in a hammer mill before being sent for chemical analysis. All TMR were stored at room temperature until further processing or analysis. In addition, 4 grab samples were taken from the AH pile used for the TMR throughout the study for chemical analysis.

Cows were milked daily at 0700 and 1900 h in a single-6 herringbone parlor. Westfalia milk meters and proportional milk samplers were used to measure milk yield and to collect individual milk samples. Milk samples were taken at the evening milking on d 17 through the morning milking on d 19 of each period for a total of 4 samples per cow per period. All milk samples were preserved with Broad Spectrum MicroTabs (Advanced Instruments) and stored at 4°C. Following milk sampling on the morning of d 21, all 48 samples were taken to the laboratory for analysis, where samples were warmed to 40°C in a water bath. At 40°C, each sample was analyzed for percent fat, total protein, lactose, and SNF using an infrared milk analyzer (Bentley 150, Bentley Instruments) calibrated with milk standards provided by the California Department of Food and Agriculture. After analysis, the samples from the evening of d 18 and morning of d 19 for each cow were mixed thoroughly and approximately 20 mL of each sample was transferred to a plastic snap vial and shipped to Central Counties DHIA for MUN and SCC using a MilkoScan FT3 and a Fossomatic FC (Foss), respectively.

Fecal grab samples were taken rectally at approximately 0600 and 1800 h on d 16 through d 19 of each period. Feces were stored at -20°C. Feces were later thawed and mixed. A subsample of each cow's mixed feces was dried in a forced-air oven for 15 h at 100°C for the determination of DM. A second subsample was dried for 48 h at 55°C for subsequent chemical analysis.

All experimental procedures used for the animals as well as general management practices were approved by the Institutional Animal Care and Use Committee of the University of California at Davis before the start of this project. One primiparous cow was removed from the study during period 4 while on the 0% AH diet due to developing mastitis that became septic. This resulted in a sample size of 12 for the diets including AH but a sample size of 11 for the 0% AH diet.

Analytical Procedures

Each sample of as-fed TMR was coarsely ground through a Montgomery Ward hammermill (model no. WB 6A) using a 3-mm screen followed by mixing and subsampling. Samples of TMR were analyzed for DM using AOAC International (2000) method 934.01. Each TMR and AH sample was sent to Cumberland Valley Analytical Services (Waynesboro, PA) for laboratory analysis following methods outlined in AOAC International (2000). Crude protein was determined using AOAC International (2000) method 990.03. Soluble protein was determined using the borate-phosphate procedure as detailed by Krishnamoorthy et al. (1982). Acid detergent fiber was determined using AOAC International (2000) method 973.18. Ash-free acid detergent fiber (**ADFom**) was determined by running AOAC International (2000) method 973.18 followed by ashing the ADF residue at 535°C for 2 h. Neutral detergent fiber was determined using the method described by Van Soest et al. (1991) and modified to use Whatman 934-AH glass microfiber filters (Global Life Sciences Solutions USA LLC) with 1.5- μ m particle retention, held in Buchner funnels. This method includes the use of α -amylase and sodium sulfite, so it is referred to as aNDF. Ash-free NDF (**aNDFom**) was determined by ashing the aNDF residue at 535°C for 2 h. Sulfuric acid lignin was determined using a method described by Goering and Van Soest (1970). Briefly, the modifications included using a 7-cm Whatman glass fiber filter in a California Buchner funnel instead of a Gooch crucible to allow for greater surface area. After this step, the fiber residue and filter were agitated in a tube with 72% sulfuric acid for 2 h. These contents were then filtered again, rinsed, dried, and weighed. The filter and lignin residue were then ashed for 2 h and weighed. Total ash was determined using AOAC International (2000) method 942.05, modified to use 1.5-g samples with a 4-h ash time followed by hot weighing. Organic matter was determined by disappearance of sample during the ashing process. Using the ash value reported, percent OM was determined as follows: $[\text{sample DM (g)} - \text{ash (g)}] / \text{sample DM (g)}$. Ethanol-soluble carbohydrates (80% ethanol) were measured as described by Hall (2000). Starch was determined according to Hall (2009) using the acetate buffer method. Calcium, phosphorus, magnesium, potassium, sodium, iron, manganese, zinc, and copper were all determined using AOAC International (2000) method 985.01, modified to ash 0.35 g of sample for 1 h at 535°C and digest in open crucibles for 20 min in 15% nitric acid atop a hot plate. Samples were then diluted to 50 mL and analyzed using inductively coupled plasma atomic emission spectroscopy. The NE_L

was calculated based on the equation outlined in the Dairy NRC (2001), where NE_L (Mcal/kg) = $(0.0245 \times TDN - 0.12)$.

Rumination Data

Rumination collars (Heattime PR TC500, SCR, Allflex USA) were used on each cow for the duration of the trial to collect data regarding time spent each day performing specific activities. The activities measured included resting, medium activity, high activity, eating, rumination, side lying, walking, and panting. Medium activity consisted of the cows walking to and from the feed bunks (calmly walking), whereas high activity included cows in heat or instances where cows were being moved for pen cleaning (instances of higher stress). To normalize data for analysis, each activity is reported as a percentage based on the time of that activity divided by the total time recorded (24 h).

Statistical Analysis

All feed intake, milk production, digestibility, and rumination data were averaged for each cow during each sample period analyzed in R version 3.6.2 (R Core Team, 2019). Averages were used so that the data analyzed would have normal distributions. A linear mixed-effects model was used in the “lme4” package, and *P*-values were calculated using a type III ANOVA with Satterthwaite’s method (Bates et al., 2015). Polynomial effects (linear, quadratic, and cubic) of diet were determined using the linear mixed-effects model below and the “emmeans” package in R (Lenth, 2020), with results averaged over levels of period and parity. The linear mixed-effects model used was

$$y_{ijk} = \mu + \text{diet}_i + \text{period}_j + \text{parity}_m + \text{cow}_k + e_{ijkm},$$

where y_{ijk} is an observation of the k th cow of the m th parity fed the i th diet during period j , μ is a constant, and e_{ijkm} is residual error. Overall, there were 4 diets ($i = 0, 7, 13$, and 20% AH), 3 parities ($m = \text{first, second, and third lactations}$), and 4 periods ($j = 1, 2, 3$, and 4) as fixed effects, with cow ($k = 1, \dots, 12$) as the random effect. Because square was assigned based on parity (e.g., square 1 = first-lactation cows), square was not added as an effect. This final linear mixed-effects model, which does not include the interaction of parity and diet, was determined using the Akaike information criterion (Faraway, 2016). For TMR and AH composition, averages, standard deviation, and ranges were calculated in R using the “Rmisc” package (Hope, 2013). For all data analysis, a *P*-value of <0.05

was considered significant, and a *P*-value of <0.1 but >0.05 was considered a tendency.

RESULTS

AH Composition

One load of AH was used for the study, and the AH were stored in a 3-sided, covered commodity barn. There was variation in chemical composition for the 4 samples of AH collected during the study (Table 3). Sampling AH is difficult because of the size of the hulls as well as the distribution and particle size of the debris, which includes sticks and shells. In addition, AH piles can be quite large and dense, making it impossible to sample throughout the pile. In our AH, we did not find plastic that would be associated with an orchard drip line. The variation in CP was numerically small, whereas there was larger numeric variation in the fiber fractions, water-soluble carbohydrates, and lignin content. The AH used in this study were high quality, sometimes referred to in the industry as “prime.” The CF was 12.8% on an as-fed basis, much lower than the legal limit of 15% CF on an as-fed basis. The CF in the 4 subsamples ranged from a low of 11.9% to a high of 15.1% , which illustrates the difficulty associated with sampling AH for regulatory purposes as well as chemical composition for ration formulation.

DMI and Nutrient Intake

The inclusion of AH in the diet had a cubic effect on DM ($P = 0.05$), ADF ($P = 0.03$), and aNDF ($P < 0.01$) intakes, as seen in Table 4. The 13% AH diet had the lowest intake of ADF, whereas the 20% AH diet had the lowest intake of aNDF. There were no significant differences in CP, Ca, or P intakes due to diet. Intakes of aNDF ($P < 0.01$) and NE_L ($P = 0.03$) decreased in a linear fashion as the amount of AH in the diet increased. The intakes of DM, CP, ADF, aNDF, P, and NE_L differed ($P < 0.05$) by parity, with the greatest intake for all measures in third-lactation cows (Supplemental Table S1, https://osf.io/jc5z6/?view_only=bdb4264822ab4131a60404d58296d3f2). When DMI was expressed as a percentage of BW, no differences were detected.

Milk Yield and Milk Composition

Actual milk yield (Table 5) had a cubic effect ($P = 0.03$) due to diet, resulting in the 7% AH having the highest milk yield (39.3 kg). There was no effect of diet for yield of fat ($P > 0.1$), but there was a cubic

Table 4. Intake (kg/d unless otherwise noted) of DM and chemical components for cows consuming TMR containing varying amounts of almond hulls (AH)

Item	Amount of AH				SEM	P-value ¹				
	0%	7%	13%	20%		Diet	Parity	L	Q	C
DM	26.7	27.6	26.4	26.6	0.72	0.16	0.01	0.35	0.50	0.05
CP	4.6	4.5	4.5	4.6	0.13	0.41	0.02	0.96	0.10	0.83
ADF	5.1	5.1	4.8	5.0	0.14	0.02	<0.01	0.15	0.07	0.03
aNDF ²	7.5	7.5	6.6	6.5	0.19	<0.01	0.01	<0.01	0.53	<0.01
Ca	0.29	0.31	0.29	0.34	0.02	0.06	0.10	0.10	0.27	0.05
P	0.08	0.08	0.08	0.08	0.003	0.44	0.04	0.66	0.62	0.14
NE _L (Mcal)	45.8	45.6	43.9	43.9	0.57	0.11	0.02	0.03	0.90	0.23
DMI/BW %	4.1	4.2	4.0	4.1	0.11	0.30	0.61	0.69	0.64	0.07

¹Diet = effect of diets with different AH percentage on intake; parity = effect of parity on intake; L, Q, and C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period. There were no significant diet × parity interactions for any measurement.

²aNDF = NDF from α-amylase.

effect for ECM ($P = 0.05$), with the 7% AH diet having the highest ECM production. Lactose and TS yields had similar cubic effects ($P = 0.03$), with the 7% AH diet being highest for both. Protein yield had both linear and cubic effects ($P < 0.01$) due to diet. The 7% AH diet had the highest protein production (1.34 kg), whereas the 13% AH diet had the lowest (1.23 kg). Milk fat percentage increased ($P < 0.01$) in a linear fashion as the AH amount increased in the TMR. In contrast, protein percentage decreased linearly ($P < 0.01$) with increased AH in the diet. Milk urea N concentration followed a similar pattern as milk protein, decreasing linearly ($P < 0.01$) as AH amount in the diet increased. For yields of milk, ECM, fat, protein, lactose, and TS, parity had an effect ($P < 0.05$), with yields increasing as parity number increased (Supple-

mental Table S2, https://osf.io/jc5z6/?view_only=bdb4264822ab4131a60404d58296d3f2).

Apparent Total-Tract Digestibility

Dry matter ($P < 0.01$), OM ($P < 0.01$), ADF ($P = 0.01$), and CP ($P = 0.02$) increased linearly with increasing AH inclusion (Table 6). Digestibility of ADFom, aNDF, and aNDFom did not exhibit a linear effect ($P > 0.1$) due to diet, although both measures of aNDF and aNDFom tended ($P = 0.06$ and 0.07 , respectively) to display a cubic response, with the 7% AH diet being highest for both. There was no effect ($P > 0.1$) of parity for any measures (Table 6, Supplemental Table S3, https://osf.io/jc5z6/?view_only=bdb4264822ab4131a60404d58296d3f2).

Table 5. Yield (kg/d) and composition (% unless otherwise noted) of milk and components for cows consuming TMR containing varying amounts of almond hulls (AH)

Item	Amount of AH				SEM	P-value ¹				
	0%	7%	13%	20%		Diet	Parity	L	Q	C
Yield										
Milk	38.8	39.3	36.9	37.7	1.37	0.05	0.01	0.09	0.99	0.03
ECM ²	41.8	42.2	40.1	41	1.22	0.20	<0.01	0.36	0.96	0.05
Fat	1.46	1.47	1.44	1.48	0.05	0.65	0.02	0.47	0.99	0.29
Protein	1.33	1.34	1.23	1.25	0.04	<0.01	0.02	<0.01	0.85	<0.01
Lactose	1.95	1.99	1.86	1.9	0.07	0.07	0.02	0.16	0.84	0.03
TS	4.85	4.91	4.63	4.73	0.15	0.09	0.01	0.17	0.89	0.03
Composition										
Fat	3.81	3.78	3.95	3.97	0.12	<0.01	0.70	<0.01	0.92	0.13
Protein	3.46	3.43	3.35	3.33	0.07	<0.01	0.35	<0.01	0.78	0.11
Lactose	5.02	5.06	5.04	5.04	0.05	0.48	0.87	0.44	0.26	0.39
TS	12.58	12.58	12.65	12.64	0.20	0.49	0.65	0.16	0.74	0.57
MUN (mg/dL)	10.65	10.13	8.62	8.08	0.58	<0.01	0.77	<0.01	0.98	0.29
SCC (×1,000 cells/mL)	47.82	31.42	47.33	49.25	1.25	0.47	0.18	0.76	0.16	0.54

¹Diet = effect of diets with different AH percentage on intake; parity = effect of parity on intake; L, Q, and C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period. There were no significant diet × parity interactions for any measurement.

²Calculated as ECM = (0.148 × kg of milk) + (5.87 × kg of fat) + (3.47 × kg of total protein).

Table 6. Apparent total-tract digestibility (%) for cows consuming TMR containing varying amounts of almond hulls (AH)

Item ¹	Amount of AH				SEM	P-value ²				
	0%	7%	13%	20%		Diet	Parity	L	Q	C
DM	69.1	72.8	72.2	75.1	0.76	<0.01	0.40	<0.01	0.66	0.03
OM	70.8	74.0	73.5	76.2	0.74	<0.01	0.39	<0.01	0.72	0.04
ADF	41.6	43.5	43.4	46.9	1.24	0.03	0.16	0.01	0.41	0.31
ADFom	42.2	44.2	43.1	46.4	1.58	0.28	0.19	0.12	0.62	0.30
aNDF	47.5	51.4	49.0	50.1	1.19	0.13	0.27	0.34	0.26	0.06
aNDFom	47.9	52.6	50.5	51.6	1.24	0.07	0.28	0.13	0.16	0.07
CP	66.2	68.1	66.8	70.0	0.97	0.03	0.53	0.02	0.42	0.06

¹ADFom = ADF on an OM basis; aNDF = NDF from α -amylase; aNDFom = NDF on an OM basis.

²Diet = effect of diets with different AH percentage on intake; parity = effect of parity on intake; L, Q, and C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period. There were no significant diet $\times$ parity interactions for any measurement.

Rumination Data

Time spent resting, eating, and ruminating was affected linearly by diet ($P < 0.01$), with the cows resting less and eating and ruminating more as the amount of AH in the diet increased (Table 7). There were no differences due to diet ($P > 0.1$) for high and medium activity, side lying, walking, or panting. There were no differences due to parity ($P > 0.1$) for any of the measures (Table 7, Supplemental Table S4, https://osf.io/jc5z6/?view_only=bdb4264822ab4131a60404d58296d3f2).

DISCUSSION

The effect of parity for DMI and milk production was anticipated because primiparous cows tend to eat more slowly compared with second- and third-parity cows and tend to weigh less than full-grown multiparous cows (D'Mello, 2000). In this study the average BW for primiparous cows was 621 kg, and second- and third-lactation cows weighed 636 and 717 kg, respectively.

The amount of AH in the diet did not affect DMI linearly in this study, although there was a cubic effect ($P = 0.05$), with the 7% AH cows eating the most. Even with this effect, the cows on each diet ate approximately the targeted amount of AH based on DMI (Supplemental Table S5, https://osf.io/jc5z6/?view_only=bdb4264822ab4131a60404d58296d3f2). Our results mostly agree with those of Aguilar et al. (1984) and Williams et al. (2018), who reported no issues with cows going off feed when AH were fed to dairy cows. In contrast, when AH replaced hay in the diet of goats, DMI actually increased significantly (Reed and Brown, 1988; Can et al., 2007). For the diets in the current study, AH were used as a concentrate ingredient due to high values of NFC reported previously (DePeters et al., 2000), which meant that as the proportion of AH in the diet increased, the proportions of steam-flaked corn and soyhull pellets decreased. Soybean meal proportion increased with increasing AH in the diets to balance protein concentration. This kept the overall TMR CP between 16.3 and 17.2%, which is well

Table 7. SCR Rumination Collar (Allflex USA) data for time (%/d) spent doing each activity from total time recorded each day for cows consuming TMR containing varying amounts of almond hulls (AH)

Item ¹	Amount of AH				SEM	P-value ²				
	0%	7%	13%	20%		Diet	Parity	L	Q	C
Resting	37.2	34.7	35.6	32.4	1.15	<0.01	0.26	<0.01	0.48	0.02
Medium activity	10.2	9.8	9.7	9.7	0.79	0.67	0.16	0.28	0.53	0.92
High activity	1.1	0.99	1.1	1.1	0.15	0.64	0.80	0.39	0.50	0.54
Rumination	31.5	32.7	32.9	34.4	1.01	<0.01	0.93	<0.01	0.26	0.19
Eating	16.3	18.1	17.4	18.8	0.66	<0.01	0.77	<0.01	0.76	0.02
Side lying	0.18	0.19	0.19	0.16	0.01	0.51	0.56	0.75	0.15	0.92
Walking	0.36	0.39	0.39	0.39	0.04	0.60	0.75	0.24	0.56	0.63
Panting	2.3	2.3	1.9	2.0	0.31	0.17	0.53	0.15	0.96	0.09

¹High activity includes when cows are in heat, moved to the milking parlor, and moved for pen cleaning. Medium activity is normal walking to the feed bunk, walking to get water, and so on.

²Diet = effect of diets with different AH percentage on intake; parity = effect of parity on intake; L, Q, and C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period. There were no significant diet $\times$ parity interactions for any measurement.

within the NRC (2001) requirements for CP intake for high-producing dairy cows. This was reflected in the lack of CP intake differences due to diet in this study. Although CP intake did not differ, MUN concentration decreased as AH inclusion increased (Table 5). This is similar to what was observed by Can et al. (2007), where replacing wheat straw with AH in the diets of goats resulted in a significant decrease in serum urea N concentration even though the diets were balanced for CP. There are at least 2 possible explanations for why MUN concentration decreased as the amount of AH consumed increased (DePeters and Ferguson, 1992). One explanation is that the high sugar content of AH provided the rumen microbial population with a readily available energy source that increased the conversion of ruminal ammonia N to microbial protein. Improving ammonia N conversion to microbial protein would decrease the amount of ammonia N absorbed across the rumen wall to be converted to urea N in the liver. Because urea will equilibrate across water, a lower blood urea N would be reflected in lower MUN as well as lower urinary urea N. A second explanation is that the AA composition of the metabolizable protein, microbial protein, and feed protein resulted in less AA used for energy. A better balance of AA delivered postruminally would reduce the use of AA energy. This would result in lower conversion of N to urea and, thus, lower MUN.

The decrease in aNDF intake ($P < 0.01$) seen in this study was likely due to the decrease in soyhull pellets (60.3% aNDF and 44.6% ADF compared with 23.8% aNDF and 14.9% ADF for AH) in the diet. Even though aNDF intake decreased as AH inclusion increased, ADF intake had a cubic response to diet, with the 13% AH diet resulting in the lowest intake. The smaller numeric differences in ADF intake compared with aNDF intake were likely due to the smaller differences in ADF content of AH and soyhull pellets compared with aNDF content.

Aguilar et al. (1984) found that feeding a TMR with up to 25% AH had no negative effects on DMI (21.8, 23, and 22.7 kg/d for 0, 12.5, and 25% AH diets, respectively), milk yield (24.9, 25.2, and 24.7 kg/d for 0, 12.5, and 25% AH diets, respectively), and milk composition of fat and protein. These researchers added urea to the diets containing AH so that diets were isonitrogenous. Their approach to diet formulation was different than the current study because the forage proportion of the diet was 61% alfalfa hay for the control (0% AH diet) and the forage decreased with each addition of AH to a high-AH diet with 35% forage and 25% AH. More recently, in an approach similar to Aguilar et al. (1984), AH were used to supplement alfalfa for dairy cows, with no urea added, which resulted in a decrease

in CP intake, an increase in aNDF intake, and no effect on DMI (Williams et al., 2018). However, yields of milk (27.4 and 24.6 kg/d for control and AH diets, respectively), ECM, milk protein, and milk lactose decreased in response to replacing alfalfa cubes with AH (Williams et al., 2018). In the current study, AH replaced concentrate ingredients and not the forage ingredients. Numerically, ECM and milk yield were lowest for the 13% AH diet but highest for the 7% AH diet, showing a cubic effect of diet ($P = 0.05$ and 0.03 , respectively). There was a decrease in both milk protein percentage and yield ($P < 0.05$) as the amount of AH in the diet increased. When lactating goats were fed diets containing varying amounts of AH supplemented with urea, milk protein percentage was the highest for the 25% AH diet but lowest for the 35% AH diet, with no change in milk protein yield (Reed and Brown, 1988). This was potentially due to the higher amount of NPN in the 25% AH diet, although all diets likely exceeded N requirements, resulting in higher blood N and MUN concentrations as AH and urea supplementation increased (Reed and Brown, 1988). Both ECM production and DMI responses followed a similar cubic pattern as AH inclusion in the diet increased, so it is possible that the changes in DMI could have been a primary driver in ECM production. Body condition score was not analyzed in this study. Without BCS for the cows, it is difficult to say whether maintaining this level of ECM production would be sustainable for cows consuming 20% AH in the long term.

Previous studies reported that AH were highly digestible both in situ and in vivo (Alibés et al., 1983; Norollahi et al., 2006; Yalchi and Kargar, 2010). Commercial AH were reported to have 24 h in situ DM digestibility of 70 to 71% and in vivo DM apparent digestibility of approximately 73% (Norollahi et al., 2006; Yalchi and Kargar, 2010; Yalchi, 2011). In diets where AH were added to account for up to 40% of the total ration, in vivo DM digestibility still ranged from 64 to 70% depending on the diet. In the present study, DM and OM apparent digestibilities ranged from 69 to 76%. Apparent digestibilities of DM, OM, ADF, and CP increased ($P < 0.05$) as the amount of AH in the diet increased. The results from this study contradict some of the previous work done on AH digestibility. Digestibility studies conducted with sheep and goats found decreases in CP, aNDF, and ADF digestibilities when AH were added to the diet in place of alfalfa, but DM digestibility was decreased in the feeding study with goats (Reed and Brown, 1988; Yalchi, 2011). When steers were used to assess the digestibility of AH substituted for both grain and forage, researchers found no difference in DM digestibility, but ADF digestibility was significantly de-

creased (Aguilar et al., 1984). In these previous studies, AH were mostly replacing forages (mainly alfalfa hay) in the diets, which could account for the differences in diet effect seen in the current study, where AH mainly replaced the concentrates in the diet.

The increase in DM, OM, ADF, and CP digestibilities seen in our study could be due to various factors. When goats were fed soybean hulls, a fibrous by-product, instead of corn grain, aNDF and ADF digestibilities increased, although DM and CP digestibilities decreased (López et al., 2014). When added to the diet of goats to replace corn grain, dried citrus pulp, a fibrous but carbohydrate-rich by-product, resulted in an increase in ADF digestibility and a decrease in CP digestibility, but no change in either DM or aNDF digestibilities (López et al., 2014). The authors also noted an increase in acetic acid production with a decrease in propionic acid when feeding citrus pulp (López et al., 2014). This increase in acetic acid production could be the result of increased microbial activity from fermentable carbohydrates such as pectin, which in turn could account for the higher digestion of fiber. Similarly, when beet pulp, a fibrous but carbohydrate-rich by-product, was added to replace barley in lactating Holstein diets, there was an increase in DM and aNDF digestibilities along with an increase in acetic acid production (Poorkasegaran and Yansari, 2014). Like beet pulp and citrus pulp, AH are high in NFC as well as soluble fiber that includes pectin (Saura-Calixto et al., 1983; Yalchi and Kargar, 2010). The NFC content is highly fermentable by rumen microorganisms, and this increased substrate availability could contribute to microbial growth, increasing fermentation, which in turn could potentially increase fiber digestibility (Nocek and Russell, 1988). The easily fermentable carbohydrates, including pectin, in AH that can increase acetate and butyrate production could result in increased milk fat production (Poorkasegaran and Yansari, 2014; Urrutia and Harvatine, 2017), similar to what we saw with the cows consuming 20% AH in this study along with the increased amount of chewing.

The fiber in AH is associated with lignin at a somewhat high percentage compared with typically fibrous feeds such as alfalfa (Yalchi and Kargar, 2010). This likely is reflected in the increasing amount of lignin in our diets as the percent of AH increased. Although lignin normally would be associated with decreased digestibility, it could aid in fiber digestibility by increasing the fiber mat in the rumen, which in turn would increase retention time of the AH, thereby decreasing passage rate (Poorkasegaran and Yansari, 2014). In addition, commercial AH have a relatively large particle size (~35 cm in diameter) compared with chopped for-

age or grain. This larger particle size could also lead to an increase in retention time (Poorkasegaran and Yansari, 2014). This is reflected in the increased percentage of time spent ruminating and eating for the cows consuming increasing amounts of AH. The increased time spent ruminating and chewing could have been a result of decreased passage rate, which would lead to increased fiber digestibility (Poorkasegaran and Yansari, 2014). Given the lack of a linear decrease in aNDF digestibility seen in this study, it is more likely that the size of the AH, not the lignin content, played a role in the increased rumination and chewing.

The presence of condensed tannins in AH could decrease CP digestibility, as seen in some studies, but did not appear to affect CP digestibility in our study (Cruess et al., 1947; Alibés et al., 1983; Siriwardhana and Shahidi, 2002; Yalchi, 2011). The composition of AH is still not fully described, especially in the cases of water-soluble carbohydrates and lignin, which can drastically affect digestibility (DePeters et al., 2020). These inadequately described composition data could also explain why in this study the increasing digestibilities of OM and CP as AH inclusion increased are not reflected in the NE_L values for the AH diets; NE_L is calculated using TDN, so as digestibility increases, so should the available energy. The NE_L of the 4 TMR decreasing as AH inclusion increased would suggest that some digestible component of AH is not being accounted for.

In addition, although data are not reported, the AH fed in this study were tested for pesticide concentration by the California Department of Food and Agriculture to confirm that all pesticides present were below tolerance levels, which they were. Overall, the high sugar content and large particle size of the AH could have resulted in the higher DM and ADF digestibility along with an increase in milk fat percentage and an increase in rumination and eating time seen in the cows in this study.

Regarding study limitations, replacing a portion of the concentrate ingredients with AH changed the type of NSC in the diet, with starch concentration decreasing and sugar concentration increasing with increasing AH inclusion. This study should be repeated and rumen samples collected to determine the effect of the type of NSC on the composition of the rumen microbial community.

CONCLUSIONS

Substituting AH at varying amounts for a portion of the concentrate ingredients in a lactating cow TMR had no negative linear effects on DMI, ECM milk yield, milk fat, or lactose yield. Cubic effects of diet were observed

for DMI, milk yield, ECM, lactose yield, and aNDF and ADF intake, with the 7% AH diet having the highest values for these measurements. Apparent digestibility of DM, OM, ADF, and CP increased with increasing amount of AH in the diet. Milk protein percentage and yield significantly decreased with increasing amount of AH in the diet. In contrast, milk fat percentage increased with increased AH in the diet with no change in milk fat yield. The findings from this study indicate that AH can be fed as a concentrate supplement up to 20% of the diet to potentially help improve milk fat percentage and DM digestibility, although milk protein could decrease. Including AH at 7% of the diet could help optimize DMI and milk, protein, and fat yields. The AH used in the current study were what is often referred to in the industry as “prime” because of their CF content. Responses to feeding high amounts of AH may differ in practice because the compositional quality of AH can vary greatly and component digestibilities can differ if different basal forages are used. When traditional concentrate ingredients (e.g., steam-flaked corn) become expensive, the economics for California dairy producers to feed higher amounts of AH could be considered.

ACKNOWLEDGMENTS

The authors acknowledge the financial support of the Almond Board of California, Biomass Workgroup (Modesto, CA), and the advice of K. Lapsley and G. Huang. We thank the dairy staff (D. Gisi, M. Patino, J. Hernandez, and P. Domer), the feed mill staff (D. Gall and J. Villaseñor), and the student research assistants (K. Kennicutt and S. Anderson) of the University of California, Davis, for their support. We acknowledge the input of J. G. Fadel as well as the members of the California chapter of the American Registry of Professional Animal Scientists. Research was supported by the California Agricultural Experiment Station at the University of California, Davis, through Multistate NC-2042. The authors declare no conflicts of interest.

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