Almond Hulls: Chemical Composition and Feeding Value

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INTRODUCTION

Almond (*Prunus dulcis*) belongs to the family Rosaceae that is related to stone fruits including peaches and cherries. Field weight yields of almonds at harvest are 23% meats (nuts), 13% debris, 14% shells, and 50% hulls (EPA 1995). The Almond Board of California reported the fruit weight to be 31% kernels, 20% shells and 49% hulls on an As Is basis and 32% kernels, 20 shells, and 48% hulls on a DM basis (Huang 2018 unpublished). Almond hulls are a byproduct in the production of almond nuts. Almond hulls (AH) are anatomically similar to the fleshy portion of a peach that humans consume, and hulls contain the mesocarp and exocarp (Figure 1). Consequently, almond hulls are high in sugars and a byproduct feedstuff high in nutritive value that is fed to ruminants in various regions of the world.

The story of almond hulls as a byproduct feedstuff in California has an interesting history. In the 1940s, almond hulls were not used as a livestock feed. Instead, the majority were burned while the remainder were plowed under in fields (Cruess 1949). Velasco et al. (1965) stated “As recently as 1948, almond hulls were considered of little or no value, and most of them were burned or otherwise destroyed. Then as a result of work by University of California researchers (1948-1951), hulls were found to have an energy value 65 to 90% of barley”. The early research at the University of California clearly demonstrated the nutritive value of almond hulls for ruminants (Weir, 1951; Velasco et al. 1965). Subsequently, the research of Aguilar et al. (1984) was of paramount importance to expanding the use of almond hulls as a feedstuff for dairy cattle. Almond hulls are now a common, highly valued byproduct feedstuff that are used in the diets of lactating dairy cows in California. A survey (Castillo et al. 2012) of 40 dairy farms in California found almond hulls to be an ingredient in 39 out of 104 TMR evaluated with an average feeding rate of 1.5 kg/cow/day and a range of feeding from 0.2 to 3.0 kg. A more recent survey (Heguy 2019, unpublished) found that the feeding amount had increased to approximately 2.3 kg (5 pounds) per lactating cow daily. Even though almond hulls are commonplace in diets of lactating cows, there is a paucity of data on the chemical composition and nutritive value of almond hulls. To achieve higher amounts of feeding to lactating dairy cows, more comprehensive information is required on the nutritive value and chemical composition of almond hulls.

California is the world’s leading producer of almond nuts with a production of 1.16 billion kg in crop year 2019/2020 (Almond Almanac 2020). Associated with the yield of nuts (kernels) was 1.83 billion kg of hulls and 0.75 billion kg of shells. For the 2019/2020 crop year, almond tree fruit weight was 31% kernels (nuts), 49% hulls, and 20% shells. Almond nut production in the 2019/20 crop year increased by 63% from the 630 million kg produced in 2007. Orchard plantings of almond trees are increasing rapidly. In 2019, there were 1.18 million acres of bearing orchards and 350,000 acres of nonbearing orchards. Almond nut production can be expected to increase dramatically when the nonbearing orchards come into production in the next 5 to 10 years, which will create a large supply of almond hulls for feeding to livestock. The focus of the current research was/is to evaluate the feeding potential of almond hulls.

This paper is a brief review of the past and current work on assessing the nutritive value of almond hulls. The approach will be:

1. Nutrient Composition of Almond Hulls
2. Survey of California Nutritionists on Almond Hull Usage
3. *In Vitro* Assessment of Almond Hulls
4. Feeding Value of Almond Hulls
5. Variation in Composition and Regulatory Issues
6. Current and Future Research
7. Summary

1. Nutrient Composition of Almond Hulls (AH)

The aim was to begin an evaluation of the chemical composition and nutritive value of almond hulls and to investigate differences in the chemical composition of almond hulls as it relates to the contribution of debris that includes shells and sticks. A concern about almond hulls as a feedstuff is the variability in nutrient (chemical) composition. The variability in nutrient composition can be attributed to a number of factors, but of utmost importance are the variety of almond, the harvesting methods, and the age of the orchard (trees). Nutritionists know that Nonpareil almond hulls are superior in nutritional quality to Pollinator (varieties other than Nonpareil) almond hulls. Consequently, Nonpareil almond hulls are preferred for feeding high producing dairy cows. Most almond varieties are not self-pollinating so two or more varieties are planted in an orchard with consideration to when each variety blooms. Nonpareil produces a high quality nut for human consumption. There is a tendency to refer to the “other” varieties as pollinators because often their role is to pollinate the Nonpareil variety in an orchard. That is how the terms “other variety” and “pollinators” are referred to in this paper with the two descriptions being synonymous.

The harvesting of almonds involves the shaking of trees so the fruit falls to the orchard floor where the hulls dry. However, along with the almond fruit that falls in response to tree shaking, there are sticks and leaves that also fall from the trees. Sweepers with brushes put the fruit, along with sticks, into windrows on the orchard floor. Sweepers have blowers to remove some of the leaf material. Next, the harvester picks up the fruit from the orchard floor to be placed into a reservoir cart. The harvester does remove leaf material, dirt/rocks, and the sticks of large size, but there are considerable amounts of sticks of short length that remain in the fruit. A shuttle cart follows the reservoir cart, and the fruit is transferred to the shuttle cart. This action all happens on the go, in swift motion and precise timing. Once loaded the shuttle cart races off to an elevator at the edge of the orchard where the fruit is transferred to semi-trailer containers that will transport the fruit to an almond huller. The harvester will remove large sticks.

Age of orchard has not been critically evaluated as far as we are aware.
Antidotal information indicates that older trees have more foliage so that the amount of sticks in the almond fruit on the orchard floor is greater than the amount of sticks for younger orchards. A contributing factor with older trees is that the current agronomic practices often do not involve the pruning of trees so the potential for more sticks (debris) contributing to the harvest of almonds may have increased. This debris contributes to the variation in chemical composition or what nutritionists refer to as "variation in quality".

Nutritionists were asked what influenced the decision to include almond hulls in diets. The #1 consideration was price, but consistency was a close 2nd (Heguy 2019; unpublished survey). Frequently overlooked is the publication by Aguilar et al. (1984) that reported the variation in composition of three varieties of almond hulls that were varieties of major production at the time the study was conducted (**Table 1**). Variability was high even for Nonpareil almond hulls, which are viewed as high quality almond hulls because of their hull size and chemical composition (nutritive value).

Table 1. Variation in chemical composition of hulls from three almond varieties (Aguilar et al. 1984).

Item	Merced[1]	Nonpareil[2]	Neplus[3]
Crude fiber, %	14.4	14.3	21.1
range[4]	14.0 – 14.8	12.1 – 16.6	17.4 – 24.9
ADF, %	21.5	27.3	29.9
range	20.6 – 22.5	19.9 – 34.8	24.6 – 35.2
Cellulose, %	13.3	15.5	18.3
range	12.8 – 13.8	12.9 – 18.1	15.9 – 20.7
Lignin, %	7.9	12.1	11.7
range	7.5 – 8.4	7.7 – 16.6	7.9 – 15.6
Soluble sugars, %	26.4	31.7	23.9
range	19.6 – 33.2	20.8 – 33.7	18.5 – 29.4
Crude protein, %	5.4	6.7	6.1
range	4.9 – 5.8	4.7 – 8.8	5.4 – 6.7
Ash	7.3	6.1	7.6
range	7.0 – 7.7	5.2 – 7.0	6.8 – 8.3

[1] Merced: mid to late season variety with papery shell.
[2] Nonpareil: early season variety with thin shell.
[3] Neplus: requires a pollinator, soft shell.
[4] Range refers to the chemical component listed above it.

Our research was an extension of the previous work (Aguilar et al. 1984) conducted at UC Davis. Commercial almond hulls that are available in the market are often a mix of varieties, Nonpareil variety mixed with Pollinator varieties. Commercial almond hulls are a “commodity” that contains debris composed predominately of sticks and shells and are often a mix of Nonpareil and Pollinator varieties. Chemical analysis of commercial almond hulls does not look specifically at the composition of the “hull” because of the debris component. Our approach was to hand-sort commercial almond hulls to separate the hulls from the debris (sticks and shells). This created what we referred to in our research as “Pure” Hulls.

Twelve different samples of almond hulls were obtained. Samples included 5 Nonpareil, 2 Butte/Padre pollinator mixes, 1 Butte/Mission pollinator mix, and 4 pollinators that had no variety designation. For our research, the “Other Variety” designation included the seven samples that were designated by the source supplier as not a Nonpareil variety. Each sample of almond hulls was thoroughly mixed and divided into two samples. One sample was retained for chemical analysis and represented Total almond hulls (TAH) while the other half was hand sorted to separate hulls from debris (sticks and shells) to create samples of Pure almond hulls (PAH) and Debris (wood sticks and shells). Thus, in our research study, TAH represented commercial almond hulls because TAH contained debris. The PAH represented the hull material that is the important fraction with respect to nutritional value of commercial almond hulls. The methods of chemical analysis were described previously (DePeters et al. 2020a).

The proportion of debris in the 5 Nonpareil almond hull samples was 4.7% As-Is basis (S.D. = 3.08) while for the Other Variety, the debris was 6.8% and more variable (S.D. = 4.07) As Is basis. Our results agree with those of Offeman et al. (2014) who sorted 36 samples of Nonpareil and found 4.5% debris. In our study there were two samples of the Monterey variety that averaged 5.1% debris while Offeman et al. (2014) found 7.4% debris in 21 samples. There were also two samples of Butte/Padre mixed varieties with 9.1% average debris. These two samples were numerically lower in debris than the 14.7% for Butte and 13.0% for Padre reported previously (Offeman et al. 2014). Offeman et al. (2014) noted that some varieties, including Butte and Padre, tended to have a portion of the shell adhering to the hull so it might be assumed that there is likely more debris in the almond hull fraction from these varieties. In more recent work in our research program, in contrast to Offeman et al. (2014), we found that some samples of Nonpareil almond hulls had shell retained to the hull. We wish to acknowledge here that Mr. Dave Phippen (Travaille & Phippen, Inc. Manteca, CA) has and is a valuable resource for us with respect to providing information about all aspects related to the production of almonds. Shell that is closely associated with the hull is often referred to as “stick-tights”. In our hand-sorting process, it was extremely difficult to remove the shell “stick-tights” from the hull of the Nonpareil almond hulls. Why stick-tights occur is unknown, and it seems to vary with season of harvest and variety of almond. For our research, it was an interesting observation that probably deserves further study since “stick-tights” will impact the nutritional value of commercial almond hulls. Overall, our data agree with the literature that Nonpareil are large in size and contained the lowest amount of debris numerically.

Our study did not evaluate growing region in California. Information on the impact of growing region on the chemical composition of almond hulls is lacking and deserves attention. Offeman et al. (2015) evaluated one sample of Nonpareil almond hulls each from two counties in CA as a descriptive measure for their leaching study. The sample from Kern Co. contained 94.39% hulls, 3.94% shell, 1.43% twigs, and 0.24% other material (As Is basis). The sample from Colusa Co. contained 92.46% hulls, 2.52% shell, 2.43% twigs, and 2.59% other material (As Is basis). The almond hulls were from different harvest seasons, and other information on hulling methods and age of orchard was not provided. The difference in total debris was 5.61 versus 7.54% for Nonpareil. We are unaware of any other data for California with respect to the impact of growing region, variety, harvest and hulling practices, and agronomic practices on debris contribution to almond hulls.

Dry matter content was highest for Debris and lowest for PAH. The sticks and shells were low in moisture content so when these were removed from the TAH, the DM content of PAH decreased for both the Nonpareil (**Table 2**) and the Other Variety (**Table 3**). This difference in moisture content could be important since the legal definition of almond hulls in California states not higher than 15% crude fiber (CF; As Is basis) and not higher than 13% moisture. Moisture impacts the estimate of CF on an As Is basis. The Nonpareil almond hulls were 14.64% CF (DM basis) and 12.7% CF (As Is basis). The proportion of CF As Is basis to CF DM basis was 86.8% for TAH. In contrast, the proportion of CF As Is basis to CF DM basis was 85.2% for PAH. A similar pattern occurred for the Other Variety where the proportion of CF As Is basis to CF DM basis was 88.1% for TAH and 87.4% for PAH.

Table 2. Chemical composition (DM basis) of total almond hulls (TAH), pure almond hulls (PAH), and debris for Nonpareil variety.

	TAH				PAH				Debris			
Chemical Composition, % DM	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
DM	86.82	1.41	85.60	88.50	85.20	1.91	83.50	87.70	91.54	1.16	90.20	93.00
OM	92.97	0.51	92.29	93.56	92.54	1.21	91.17	93.90	95.68	0.44	95.03	96.18
CP	5.08	1.10	3.80	6.40	5.14	1.14	3.80	6.70	6.94	1.94	4.50	9.00
Soluble Protein	2.12	0.71	1.50	3.10	2.26	0.77	1.40	3.30	1.84	1.05	1.10	3.60
NDF	21.40	1.83	18.50	22.90	19.26	1.19	18.00	21.20	62.28	6.39	55.90	72.30
NDFom	20.98	1.71	18.20	22.40	18.84	1.15	17.50	20.60	60.72	6.49	54.20	71.00
ADF	15.36	1.33	13.50	16.70	13.38	0.76	12.60	14.60	46.44	4.96	41.20	53.70
ADFom	15.04	1.05	13.50	16.00	13.04	0.64	12.60	14.10	45.48	4.69	41.20	52.70
CF	14.64	0.89	13.20	15.40	12.96	1.05	12.10	14.60	44.36	4.83	39.10	52.20
CF (As Is)	12.71	0.77	11.46	13.37	11.04	0.89	10.31	12.44	40.61	4.42	35.79	47.78
Lignin	8.59	0.71	7.64	9.41	7.63	0.70	7.02	8.78	22.38	2.73	19.40	25.81
Ash	7.03	0.51	6.44	7.71	7.46	1.21	6.10	8.83	4.32	0.44	3.82	4.97
EtOH Soluble CHO	32.57	4.00	27.32	36.39	33.56	4.32	28.03	39.88	7.87	3.32	4.80	13.41
Starch	0.32	0.18	0.10	0.60	0.44	0.46	0.00	1.20	0.44	0.29	0.20	0.90
NFC	65.43	3.07	62.10	69.37	67.20	2.79	63.99	70.96	22.14	7.59	14.07	34.12
NSC	32.88	3.86	27.90	36.50	34.00	4.38	28.20	40.40	8.30	3.26	5.70	13.90
TDN	68.56	0.74	67.80	69.80	69.46	1.02	68.60	70.80	49.26	9.71	37.50	63.60
NEL (Mcal/lb)	0.71	0.03	0.68	0.74	0.74	0.01	0.73	0.75	0.47	0.14	0.31	0.68
Ca	0.21	0.03	0.16	0.25	0.19	0.02	0.17	0.21	0.55	0.23	0.26	0.80
P	0.12	0.03	0.09	0.16	0.12	0.03	0.10	0.16	3.09	6.66	0.06	15.00
Mg	0.09	0.02	0.07	0.11	0.09	0.02	0.07	0.11	2.89	6.21	0.07	14.00
K	2.81	0.35	2.42	3.27	2.88	0.34	2.53	3.34	1.19	0.15	0.98	1.36
Na	0.02	0.00	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.04
Fe (PPM)	196.0	21.5	168.0	217.0	209.8	68.1	136.0	282.0	378.8	202.2	252.0	734.0
Mn (PPM)	13.40	2.79	11.00	18.00	12.80	1.30	12.00	15.00	26.60	2.70	23.00	30.00
Zn (PPM)	11.60	1.95	9.00	14.00	10.60	3.78	7.00	16.00	42.40	10.55	28.00	55.00
Cu (PPM)	3.80	1.30	3.00	6.00	2.80	1.30	1.00	4.00	11.60	7.70	5.00	20.00

Abbreviations: SD = standard deviation; DM = Dry matter; OM = organic matter; CP = Crude protein; ADF = Acid detergent fiber; ADFom = Acid detergent fiber on an organic matter basis; NDF = Neutral detergent fiber; NDFom = Neutral detergent fiber on an organic matter basis; CF = crude fiber; EtOH Soluble CHO = ethanol soluble carbohydrates; NFC = non-fiber carbohydrates calculated by: NFC% = 100 – (CP% + Fat% + Ash% + NDF% + NDFICP%); NSC = non-structural carbohydrates calculated by: NSC% = EtOH CHO% + Starch% ; TDN = total digestible nutrients; NEL = net energy of lactation; Ca = calcium; P = phosphorus; Mg = magnesium; K = potassium; Na = sodium; Fe = iron; PPM = parts per million; Mn = manganese; Zn = zinc; Cu = copper.

Table 3. Chemical composition (DM basis) of total almond hulls (TAH), pure almond hulls (PAH), and debris for Other varieties.

	TAH				PAH				Debris			
Chemical Composition, % DM	Avg	SD	Min	Max	Avg	SD	Min	Max	Avg	SD	Min	Max
DM	88.09	1.70	85.60	89.90	87.26	2.10	84.20	90.20	92.47	1.09	91.00	94.00
OM	92.44	1.00	90.94	93.66	91.54	0.89	90.04	92.63	96.37	0.51	95.85	97.10
CP	5.04	1.36	4.00	8.00	4.87	1.44	3.80	8.00	5.39	2.02	3.30	9.60
Soluble Protein	2.06	1.15	0.90	4.40	1.97	1.18	1.00	4.50	1.77	1.71	0.70	5.40
NDF	25.54	3.76	20.40	31.70	22.07	1.33	19.60	23.60	69.23	6.44	59.20	78.10
NDFom	24.90	3.63	20.00	31.30	21.54	1.08	19.50	22.90	68.27	6.10	59.10	77.10
ADF	18.11	3.52	13.60	24.10	15.89	1.55	14.00	18.40	50.54	5.78	43.00	58.20
ADFom	17.84	3.57	13.60	24.10	15.57	1.41	13.60	17.50	50.29	5.60	43.00	57.60
CF	18.10	1.46	15.90	19.70	15.07	1.33	13.30	17.20	49.39	5.57	39.80	54.80
CF (As Is)	15.94	1.29	14.01	17.35	13.15	1.16	11.61	15.01	45.67	5.15	36.80	50.67
Lignin	9.74	2.44	6.94	12.45	8.69	1.88	7.30	12.84	22.70	2.61	17.92	26.22
Ash	7.56	1.00	6.34	9.06	8.46	0.89	7.37	9.96	3.63	0.51	2.90	4.15
EtOH Soluble CHO	27.98	3.43	21.38	31.19	29.49	3.66	23.31	35.01	5.39	2.06	3.70	9.61
Starch	0.26	0.11	0.10	0.40	1.66	3.68	0.20	10.00	0.20	0.14	0.10	0.40
NFC	60.69	3.36	55.55	64.43	63.31	1.94	60.08	65.81	18.33	6.81	6.00	28.36
NSC	28.23	3.47	21.60	31.60	29.71	3.64	23.50	35.20	5.59	2.17	3.80	10.00
TDN	65.80	2.86	62.50	69.60	67.00	1.77	63.60	68.60	44.61	10.73	37.30	66.90
NEL (Mcal/lb)	0.65	0.04	0.61	0.70	0.66	0.02	0.62	0.68	0.43	0.14	0.33	0.74
Ca	0.26	0.04	0.22	0.31	0.24	0.03	0.19	0.29	0.40	0.14	0.21	0.56
P	0.12	0.04	0.07	0.18	0.12	0.04	0.07	0.19	0.09	0.05	0.04	0.19
Mg	0.11	0.01	0.10	0.13	0.11	0.02	0.09	0.13	0.10	0.03	0.06	0.17
K	3.25	0.40	2.83	3.88	3.45	0.40	2.93	3.98	1.08	0.48	0.57	2.00
Na	0.02	0.01	0.01	0.03	0.07	0.15	0.01	0.40	0.01	0.00	0.01	0.02
Fe (PPM)	201.9	70.2	119.0	322.0	229.4	57.3	163.0	304.0	258.4	251.1	118.0	822.0
Mn (PPM)	17.86	5.61	11.00	25.00	17.43	6.11	10.00	26.00	20.86	8.86	10.00	38.00
Zn (PPM)	14.29	4.50	9.00	22.00	13.71	5.77	7.00	24.00	46.00	36.13	17.00	122.00
Cu (PPM)	4.57	1.27	2.00	6.00	3.71	1.11	2.00	5.00	13.71	9.11	4.00	26.00

Abbreviations: SD = standard deviation; DM = Dry matter; OM = organic matter; CP = Crude protein; ADF = Acid detergent fiber; ADFom = Acid detergent fiber on an organic matter basis; NDF = Neutral detergent fiber; NDFom = Neutral detergent fiber on an organic matter basis; CF = crude fiber; EtOH Soluble CHO = ethanol soluble carbohydrates; NFC = non-fiber carbohydrates calculated by: NFC% = 100 – (CP% + Fat% + Ash% + NDF% + NDFICP%); NSC = non-structural carbohydrates calculated by: NSC% = EtOH CHO% + Starch%; TDN = total digestible nutrients; NEL = net energy of lactation; Ca = calcium; P = phosphorus; Mg = magnesium; K = potassium; Na = sodium; Fe = iron; PPM = parts per million; Mn = manganese; Zn = zinc; Cu = copper.

The issue of using the chemical component of CF on an As Is basis and not on a DM basis for regulatory purposes should be reassessed. CF As Is may not adequately reflect changes in moisture content with due to weather or storage. For instance, the CF content of a sample of almond hulls obtained from the outside of a pile may differ from a sample obtained from deep within the pile. In addition, the CF method does not adequately reflect the cellulose, hemicellulose, and lignin composition of the cell wall fraction. A more appropriate chemical method might be neutral-detergent fiber.

The fiber (aNDF, aNDFom, ADF, ADFom, and CF) and lignin compositions followed a pattern similar to DM content with highest content of fiber fractions and lignin in Debris and lowest content of fiber fractions and lignin in PAH. The TAH was intermediate but only slightly higher in fiber and lignin content than PAH.

There was large variation in fiber composition for our study. A summary from the literature (**Table 4**) also showed that the fiber composition of almond hulls was quite variable.

Table 4. Chemical composition of almond hulls reported in the literature. All values are on a DM basis.

	1	2	3	4a	4b	4c	4d	5a	5b	6	7	8	9	10	11
NDF	28.0	-	62.0	27.5	31.3	27.1	26.7	36.2	34.7	-	37.1	33.9	33.7	21.1	16.0
ADF	28.8	-	30.4	25.7	21.7	17.9	18.6	24.0	23.8	29.2	24.3	28.7	26.2	13.7	22.3
CF	-	10.6	-	13.2	13.3	13.3	12.2	-	-	15.1	-	-	-	13.5	-
CP	2.7	4.1	10.3	6.0	6.6	6.7	5.7	2.7	2.2	62.0	2.9	6.0	5.7	7.0	2.9
Ash	6.1	6.1	9.9	-	-	-	-	7.7	5.3	7.4	6.5	7.1	5.0	12.0	9.0

Lignin	7.1	-	-	10.6	7.9	6.6	6.3	11.2	10.6	11.9	11.8	12.4	10.2	4.1	11.4
Sugars	26.6	26.6	14.1	-	-	-	-	-	-	30.2	-	-	-	-	56.9
Crude Fat	3.3	3.3	2.7	2.4	3.3	2.7	-	1.6	3.4	-	1.7	3.6	2.4	2.5	-
Pectins	4.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-

1. Saura-Calixto et al. 1983
2. Saura-Calixto and Cañellas 1982
3. Elahi et al. 2017
4. Alibes et al. 1983
    a-d: 1976-1979 samples
5. Yalchi and Kargar 2010
    a. Stone shell variety (hard shell)
    b. Paper shell variety (soft shell)
6. Aguilar et al. 1984
7. Yalchi 2011
8. DePeters et al. 2000
9. Arosemena et al. 1995
10. Norollahi et al. 2006
11. Jafari et al. 2011

In California commercial almond hulls are often a mix of Nonpareil and Other Varieties (Pollinator varieties). Nonpareil TAH contained 15.04% ADFom (S.D. 1.05; Range 13.5 to 16.0%). The variation in ADFom was much larger numerically for Other Variety with a S.D. of 3.57 for an average content of 17.84%. Average CF content for Nonpareil TAH was 14.64% (S.D. = 0.89) while the CF for Other Variety was higher numerically (Avg. = 18.1%) and more variable (S.D. = 1.46). The higher fiber content of Other Variety was likely related to smaller hull size (lower weight contribution to the total sample) relative to the debris, but also it could be related to shell adhering to the almond hulls.

Aguilar et al. (1984) studied three varieties of almond hulls and found considerable variation in chemical composition within each variety. In their work, Nonpareil contained on average 27.3% ADF (Range: 19.9 to 34.8%) while Neplus averaged 29.9% ADF (Range: 24.6 to 35.2%). Variation in chemical composition was also noted for almond hulls of different varieties in Iran (Jafari et al. 2011; Jafari et al. 2015).

In a study of byproduct feedstuffs common to California (DePeters et al. 2000), almond hulls that were collected at various hullers contained on average 33.9% NDF (S.D. = 4.5) and 28.7% ADF (S.D. = 4.2). In that study, variety was not considered. In addition, harvesting practices and hulling methods have changed in recent years to remove more debris from almond hulls (Dave Phippen, personal communication). Indeed, the fiber content of almond hulls was lower in our current study compared with DePeters et al. (2000). Nonpareil contained 21.4% aNDF (S.D. = 1.82) and the Other Variety contained 25.5% aNDF (S.D. = 3.76) in the current study.

Nonpareil TAH contained 21.4% aNDF (S.D. = 1.83) and 21.0% aNDFom (S.D. = 1.71). Both average content and variation of aNDF were higher for the Other Variety with 25.5% aNDF (S.D. = 3.76) and 24.9% aNDFom (S.D. = 3.63) compared with Nonpareil. A similar pattern was observed for ADF. Nonpareil TAH contained 15.4% ADF (S.D. = 1.33) and 15.0% ADFom (S.D. = 1.05). The fiber content and variation were higher for the Other Variety with 18.1% ADF (S.D. = 3.52) and 17.8% aNDFom (S.D. = 3.57).

Almond hulls were low in CP content. The CP content of TAH was similar Nonpareil compared with Other Variety. Removing debris did little to change the CP of PAH although the difference was larger for the Other Variety where debris accounted for a larger proportion of the TAH weight. Average CP of almond hulls was previously reported to be 6.0% (DePeters et al. 2000) for California. However, Elahi et al. (2017) reported 10.3% CP while Saura-Calixto et al. (1983) reported 2.7% CP and Saura-

Calixto and Cañellas (1982) reported 4.11% CP for almond hulls in different growing regions of the world.

Ethanol-soluble carbohydrates (EtOHSC) were lower in Debris compare with both TAH and PAH. Sequeira and Lew (1970) analyzed two samples of AH of unknown variety, and reported that almond hulls contained 31.5% total carbohydrates. The predominant sugars found were glucose (10.4%), fructose (8.8%), and sucrose (5.25%). Holtman et al. (2015) reported that Nonpareil almond hulls (not sorted) contained 37.3% fermentable and 9.0% nonfermentable sugars in close agreement to Nonpareil almond hulls (sorted) in the study of Offeman et al. (2014) that contained 32.7% fermentable sugars and 9.3% nonfermentable sugars. However, Nonpareil almond hulls contained 6.1% glucose, 5.9% fructose, and 1.9% sucrose in Holtman et al. (2015) compared with 15.8% glucose, 13.0% fructose, and 3.9% sucrose in Offeman et al. (2014).

Pectins were not measured in our research. Offeman et al. (2014) reported that about 60% of the DM in almond hulls was extracted with water while total sugars across varieties ranged from a low of 30.6% for Fritz to a high of 42.0% for Nonpareil. The 60% water extracted material agrees with the 55 to 62% reported by Jafari et al. (2015) and the 58.8 to 63.9% reported by Offeman et al. (2015). Offeman et al. (2014) suggested that the difference between total water soluble content and total sugar content represented other water-soluble components including pectins, gums, tannins, and ash. Saura-Calixto et al. (1983) reported 3.98% total pectins, 0.09% gums, and 6.02% polyphenols measured as D-catechin while Jafari et al. (2015) reported 2.32 to 2.84%

tannins and 3.2 to 3.57% total phenolic compounds. Holtman et al. (2015) reported AH contained 3.5% ash and 2.1% soluble ash. Using an average value for tannins and phenolics from Jafari et al. (2015), the total would be 18.07% for other water-soluble components, which agrees with Nonpareil (60% – 42% = 18%) for Offeman et al. (2014).

Variety plays a major role in the chemical composition of commercial almond hulls. In an orchard, two or more varieties are planted in alternating rows for pollination (**Figure 1**) since most varieties are not self-pollinating.

Figure 1. Almond orchard with different varieties.

Each variety is harvested separately because both the quality of the nut and the harvest time of each variety differ. Nonpareil has a large size hull so as a proportion of the total sample weight, the debris (shells and sticks) can be a lower proportion of the almond hull weight compared with a pollinator variety that typically has a smaller hull size. Another complicating factor is that the shell type also differs with variety with soft shell and hard shell almond varieties. The proportion of sticks and shells in the hull product of pollinators can be high compared with Nonpareil almond hulls. Even though Nonpareil hulls are the highest quality based on fiber and sugar composition, many hullers blend the hulls from different varieties to create commercial almond hulls that meet the California legal definition of almond hulls of 15% CF or less on an As Is basis. This blending of almond hull varieties tends to minimize the importance of understanding what factors impact the chemical composition and nutritive value of commercially available almond hulls.

The most complete comparison of composition (**Table 5**) with respect to variety of almond that we are aware of was conducted by the Almond Board of California (Huang 2018 unpublished). Total sugar content varied from a low of 13.4% for Aldrich to a high of 32.2% for Independence. Nonpareil and Independence were both greater than 30% total sugar, but the total sugar content was more variable for Nonpareil than Independence. Crude protein content was low for all varieties with the exception of Wood Colony at 9.7%. Moisture content was low for all varieties except for Padre (15.9%) and Carmel (14.8%), which were above the CDFA definition of not more than 13% moisture. The variability in moisture content was also high for Carmel. For NDF content only Independence averaged below 20% NDF. Acid detergent lignin ranged from a low of 2.8% for Price to a high of 5.3% for Fritz. Potassium varied with variety, but calcium, magnesium, and phosphorus varied little with variety.

Table 5. Composition of California Almond Hulls by Variety- G. Huang, Associate Director, Food Research and Technology, ABC unpublished data, 2018

Composition of Clean Almond Hulls by Variety on Dry Matter Basis (%)

Analyte	Aldrich	Butte	Butte/ Padre	Carmel	Fritz	Independence	Mission
Moisture	12.6±9.9	11.3±4.8	10.1±2.1	14.8±10.6	11.8±6.0	8.2±3.4	11.7±8.5
Protein	6.4±1.5	4.6±1.4	5.0±1.1	7.0±1.3	5.0±1.1	5.5±0.5	4.2±0.9
Fat	2.2±0.6	2.4±0.4	2.5±1.0	2.0±0.7	2.1±0.6	1.9±0.1	2.3±0.7
Ash	10.8±1.4	10.5±2.5	8.5±1.1	11.0±1.3	9.4±1.2	10.1±1.8	10.9±1.6
Fructose	3.8±1.0	6.4±1.8	7.8±0.8	3.7±0.7	7.2±2.0	6.3±1.0	4.8±0.8
Glucose	6.4±1.5	10.6±2.7	12.1±1.6	6.6±2.4	9.1±1.9	14.6±2.7	7.0±2.2
Sucrose	3.4±2.2	3.1±1.9	3.4±1.1	0.9±0.8	2.4±1.3	11.3±1.6	1.9±1.3
Total Sugar	13.4±4.3	20.1±4.7	23.3±1.7	10.8±3.9	18.6±3.4	32.2±1.4	13.5±4.2
NDF	28.1±1.8	26.1±2.7	23.9±2.1	28.9±3.1	25.7±2.3	19.2±1.4	26.3±2.3
ADF Seq	19.0±1.7	18.1±2.0	17.3±1.2	19.9±2.1	16.9±2.8	14.1±0.5	17.9±1.4
AD Lignin	4.2±0.8	4.1±0.9	3.6±0.4	4.7±0.7	5.3±1.1	3.0±0.5	4.4±0.5
Potassium	4.1±0.5	3.7±0.9	3.1±0.4	4.0±0.3	3.3±0.3	3.1±0.4	3.8±0.1
Calcium	0.3±0.0	0.2±0.0	0.2±0.0	0.3±0.0	0.2±0.0	0.2±0.0	0.3±0.1

Magnesium	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.2±0.0
Phosphorus	0.2±0.0	0.1±0.1	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.1	0.1±0.0

Composition of Clean Almond Hulls by Variety on Dry Matter Basis (%) continued

Analyte	Monterey	Nonpareil	Padre	Price	Sonora	Wood Colony	Average
Moisture	11.5±10.2	8.3±3.1	15.9±6.5	12.8±6.0	10.9±7.2	12.4±7.9	11.6±6.6
Protein	5.1±0.7	4.0±0.8	4.4±1.8	5.5±1.2	7.3±2.7	9.7±3.6	5.6±2.2
Fat	2.5±0.9	2.0±1.0	2.0±1.0	2.2±1.1	1.5±0.6	2.1±0.7	2.2±0.7
Ash	10.8±1.8	8.1±2.0	9.7±2.7	9.5±0.8	9.6±0.8	12.3±3.3	10.1±2.1
Fructose	5.8±1.3	8.5±1.0	8.5±1.4	8.6±1.5	7.1±0.8	5.4±2.0	6.5±2.0
Glucose	8.5±1.8	16.9±2.9	13.4±3.8	13.2±2.0	10.6±2.4	6.1±2.5	10.5±4.0
Sucrose	2.6±1.4	5.1±1.5	4.6±3.0	3.1±1.9	5.4±2.4	3.8±1.7	3.8±2.7
Total Sugar	16.9±3.8	30.5±4.3	26.3±6.8	24.8±2.3	23.1±3.6	15.3±5.2	20.7±7.3
NDF	26.6±2.6	21.2±3.3	22.0±2.6	20.9±1.2	23.6±1.6	26.2±3.5	24.6±3.6
ADF Seq	16.9±4.2	15.1±2.1	15.8±1.5	15.0±1.2	16.0±1.2	17.9±2.3	17.0±2.5
AD Lignin	4.2±0.7	3.1±0.6	3.4±0.8	2.8±0.1	3.1±0.4	3.6±1.1	3.8±1.0
Potassium	3.8±0.7	2.6±0.6	4.1±1.1	3.0±0.4	3.4±0.6	4.2±1.1	3.6±0.8
Calcium	0.2±0.0	0.2±0.0	0.3±0.1	0.2±0.0	0.2±0.0	0.3±0.1	0.2±0.1
Magnesium	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0
Phosphorus	0.1±0.1	0.1±0.0	0.1±0.1	0.1±0.0	0.1±0.1	0.2±0.1	0.1±0.1

The predominate sugar (**Table 6**) in almond hulls was glucose at approximately 50% of the total sugar content (Huang 2018), which agrees with Sequeira and Lew (1970). Fructose and sucrose were found in lower concentrations.

Table 6. Composition of Almond Hulls by Types- G. Huang, Associate Director, Food Research and Technology, ABC unpublished data, 2018

Composition of Almond Hulls (%, 2017)

Analyte	California	Hardshell	Nonpareil	Average
Moisture	13.0±3.3	10.3±1.8	10.1±4.0	10.9±3.2
Protein	6.0±2.2	3.7±0.8	4.9±0.9	4.7±1.5
Fat	2.6±0.8	2.0±0.5	2.6±1.0	2.4±0.8
Ash	8.7±2.3	8.6±2.3	7.1±1.6	8.1±2.1
Fructose	6.9±1.4	7.2±2.3	8.3±1.3	7.5±1.8
Glucose	11.3±2.0	11.5±4.6	15.8±2.8	13.1±3.9
Sucrose	4.1±1.3	3.5±1.7	5.6±2.5	4.4±2.1
Total Sugar	22.2±3.7	22.3±8.2	29.7±3.6	25.1±6.6
NDF	31.3±6.5	34.3±14.2	22.4±2.6	29.1±10.4
ADF Seq	21.1±5.1	24.6±10.0	15.6±2.3	20.3±7.5
AD Lignin	5.1±1.7	6.6±3.5	3.4±0.9	5.0±2.7
Potassium	3.0±0.8	2.5±0.7	2.3±0.4	2.6±0.7
Calcium	0.2±0.0	0.2±0.1	0.2±0.0	0.2±0.0
Magnesium	0.1±0.0	0.1±0.0	0.1±0.0	0.1±0.0
Phosphorus	0.0±0.1	0.1±0.0	0.1±0.1	0.1

Take Home Messages: The chemical composition/nutritional value of almond hulls was influenced by the Debris fraction and by the variety of almond. Reducing the proportion of Debris in almond hulls decreased the fiber and ash content. Nonpareil hulls were superior in quality as measured by higher sugar content and lower content of ash, lignin, and NDF in the hulls compared with Other Varieties. Almond hulls are an excellent source of readily available carbohydrates (sugars) in the diet of ruminants.

2. Survey of California Nutritionists on Almond Hull Usage

Members of the California Chapter of the American Registry of Professional Animal Scientists (ARPAS) were surveyed on almond hull usage practices. In February 2019, an electronic survey was emailed to the entire California ARPAS membership list. Forty-two surveys were returned by 40 nutritionists and two feed suppliers.

In the previous five years (2014 – 2018), almond hull usage increased (41%) or remained the same (44%), while only 15% of respondents reported decreased usage. Average feeding rates for lactating cows across herds and almond hull feeding levels in nutritionists' highest almond hull fed herds are presented in **Table 7**. The reported average feeding rate depicts an increase from a previous California survey (Castillo et al. 2012) that reported an average feeding rate of 1.5 kg/lcow/day, with a range of 0.2 to 3.0 kg.

Table 7. Average and maximum almond hull feeding rates (kg/lactating cow/day) in California lactating rations.

	Average	Range
Average feeding rate	2.3 kg	0.5 – 4.5 kg
Maximum feeding rate	4.6 kg	0.9 – 8.2 kg

Table 8 describes almond hull utilization in lactating cow, dry cow, and heifer growing rations. Sixty-two percent of respondents said that changes in the price of almond hulls affected how the hulls were utilized in ration formulations, and was mostly dependent on the price of almond hulls compared with forage/silage prices. Price, consistency, mold,

and quality were variables that respondents felt they were “very responsive” to addressing when including almond hulls in rations (**Table 9**).

Table 8. Almond hull utilization in California dairy rations.

	Forage	Concentrate	Forage & Concentrate
Lactating Cow Ration	30%	0%	70%
Dry Cow Ration	31%	7%	62%
Heifer Growing Ration	29%	9%	62%

Table 9. Responsiveness of inclusion of almond hulls in diets related to different variables.

	Very	Somewhat	Not
Price (n=38)	32	6	0
Consistency (n=38)	30	7	1
Mold (n=35)	29	5	1
Quality (n=37)	27	9	1
Crude Fiber Levels (n=36)	15	16	5
ADF (n=35)	15	16	4
Ash (n=34)	14	16	4
Sugar (n=36)	13	19	3
NDF (n=36)	11	21	3

Other results of potential interest include 79% of respondents tested almond hulls for chemical composition. Frequency of lab testing varied between monthly and yearly, or when there was reason for concern. Most nutritionists reported concerns when including almond hulls in lactating cow rations (66%) and in dry cow/heifer growing rations (70%).

Quality issues were a top concern for feeding almond hulls, and most concerns related to the amount of stick and shell that impact the nutritional quality of the hulls.

Take Home Messages: Almond hull feeding is an important topic in California as rising almond orchard acreage increases hull availability for feeding to dairy cattle and other livestock. The topic of byproduct feeding will become increasingly important as decreased water availability impacts forage production in the State. Given the large range in reported feeding rates, results from this survey suggest there may be opportunity to increase almond hull inclusion rates in California dairy rations.

3. *In Vitro* Assessment of Almond Hulls

The aim of this study was to determine the *in vitro* digestibility and *in sacco* disappearance of dry matter (DM) and neutral detergent fiber (NDF) in total almond hulls (TAH), pure almond hulls (PAH), or Debris. The TAH were used because there are no data on the effect of debris (non-hull material) on the nutritional value of almond hulls. The hulling process yields commercial AH (< 15.0% crude fiber) that are predominately hulls, with the amount of debris (sticks and shells) varying, at least, for the variety of almond (DePeters et al., 2020a). We know from previous research (DePeters et al., 2020a) that the contribution of debris impacts the chemical composition of AH by increasing the fiber, lignin, and ash content.

The few in vitro studies with AH did not adequately describe the AH used (Arosmena et al., 1995; Jafari et al., 2011; Elahi et al., 2017). In the case of Arosemena et al. (1995), the AH were commercial AH and therefore contained debris. Based on the lignin and fiber content, it is unlikely that the AH used in other studies (Jafari et al., 2011; Jafari et al., 2015; Elahi et al., 2017) were pure AH. To the best of our knowledge, there are no reports in the literature for the in vitro fermentability of pure AH.

The aim of this study was to investigate the impact of debris on the in vitro and *in sacco* rumen fermentability of AH by evaluating 12 samples of commercial AH (Total almond hulls; TAH) of which a portion of each was hand sorted to create Pure almond hulls (PAH) and Debris (non-hull material).

Twelve different samples of AH were obtained from five hullers throughout California. Samples contained 5 Nonpareil, 2 Butte/Padre pollinator mixes, 1 Butte/Mission pollinator mix, and 4 pollinators that had no variety designation. Each huller supplied a sample of Nonpareil hulls as well as 1-2 samples of “other” varieties. Samples were designated either Nonpareil or Other Variety. Each sample of AH was thoroughly mixed and divided into two samples. One sample represented TAH while the other half was hand sorted to separate AH from debris to create samples of PAH and Debris (wood sticks and shells). Three samples from one of the hullers did not have enough Debris to be used for in vitro analysis, so only the PAH and TAH samples were used from that huller. This resulted in 12 PAH samples, 12 TAH samples, and 9 Debris samples.

In vitro gas production was measured by incubating 33 samples using the syringe method (Menke & Steingass, 1988). In addition, total gas produced at 24 h was used to calculate metabolizable energy (ME) values with the equation determined by Melesse et al. (2018). *In vitro* true digestibility on a dry matter (DM) basis (IVTD) and neutral detergent fiber digestibility (NDFD) determinations were carried out using multilayer polyethylene polyester cloth bags in the ANKOM Daisy incubator. Bags were incubated for 12, 24, 48, or 72 h and the ANKOM fiber analyzer was used to determine remaining NDF. More detailed methods and statistical analysis can be found in Swanson et al., 2021b.

In vitro total estimated gas production (**Table 10**) was overall significantly higher for PAH (270 ml/g) compared with both TAH and Debris (261 and 79 ml/g respectively).

The rate of gas production was significantly higher for PAH and TAH (0.10098 and 0.101 /h respectively) compared with Debris (0.074 /h), but there was no difference between PAH and TAH. Estimated gas production was significantly greater for PAH (283 ml/g) than TAH (267 ml/g) for Nonpareil but the difference was not significant for the Other Variety. As anticipated, total estimated gas production was significantly lower for Debris (94 ml/g Nonpareil and 69 ml/g Other) compared with both PAH and TAH for both varieties. Estimated rate of gas production was similar for PAH and TAH for both varieties but was significantly lower for Debris compared with TAH. There was a greater numerical difference between Nonpareil and Other Variety for PAH (283 ml/g and 261 ml/g, respectively) than for TAH (267 ml/g and 257 ml/g, respectively). A similar pattern was observed with the estimated rate of gas production, with the Nonpareil Debris having a numerically greater estimated rate (0.0989 /h) than Other Variety (0.061 /h).

Table 10. Estimated potential gas production (ml/g) of almond hulls (AH) for each Type (Total AH, Pure AH, Debris) and Variety (Nonpareil or Other). The effects of Type (Total AH, Pure AH, Debris) on parameters of the gas production function are shown. The estimate is the asymptote or total volumes (ml/g) of gas produced for each Type and Variety from the model. The corresponding rate constants for each Type and Variety are expressed as /h.

					P-value[1]		
	Total AH	Pure AH	Debris	S.E.M.	Total AH vs Pure AH	Total AH vs Debris	Pure AH vs Debris
Asymptote (ml/g)							

Nonpareil	267	283	94	3.3	0.006	<0.001	<0.001
Other	257	261	69		0.463	<0.001	<0.001
Type Avg	261	270	79	3.2	0.009	<0.001	<0.001
Rate Constant (/h)							
Nonpareil	0.11	0.10	0.09	0.003	0.627	0.007	0.067
Other	0.10	0.10	0.06		0.796	<0.001	<0.001
Type Avg	0.10	0.10	0.07	0.003	0.320	<0.001	<0.001

The contribution of debris was reflected in the significantly lower amount of estimated total gas produced for TAH compared with PAH even though the overall estimated rate was not significantly different. Jafari et al. (2011) evaluated the impact of AH variety on in vitro rumen fermentation. Total gas produced (ml/g DM), rate of gas production (ml/h), and organic matter coefficient of digestibility differed by variety as seen with Rabei (79.5, 0.13, 0.823), Mamaei (78.9, 0.13, 0.815), Shahroud15 (63.1, 0.11, 0.68), and Shokoufe (70.1, 0.12, 0.715) respectively. Similar to the results in this study, the Rabei variety that had the greatest gas production also had the highest non-fiber carbohydrates (NFC) and lowest acid detergent lignin (ADL) concentrations (Jafari et al., 2011; DePeters et al., 2020a). The Nonpareil variety in our study also had numerically the highest estimated amount and rate of gas production along with greater NFC and lower lignin content for all types when compared with the Other Variety (DePeters et al., 2020a). Offeman et al. (2014) also found that Nonpareil AH had the highest fermentable sugar content when compared with other varieties grown in California. Rumen microorganisms are able to easily break down and ferment NFC, while lignin is mostly undegradable, so greater NFC content could lead to an overall increase in fermentation and improved digestibility (Nocek and Russell, 1988).

The calculated metabolizable energy (ME) concentration was numerically greater for PAH (9.3 MJ/kg and 8.7 MJ/kg) than TAH (9.0 MJ/kg and 8.5 MJ/kg) while both were significantly greater than Debris at approximately half the energy content (4.7 MJ/kg and 3.8 MJ/kg) for both Nonpareil and Other Variety respectively. There were small numerical differences within Variety between TAH and PAH, but over all Types, Nonpareil had significantly higher calculated ME content compared with the Other Variety. The Other Variety had a greater numerical proportion of Debris (6.8%) compared with Nonpareil (4.7%) (DePeters et al., 2020a).

The lower ME concentration of Debris contributed to the numerically lower energy content of TAH compared with PAH. The larger difference in estimated ME content for Nonpareil compared with the Other Variety was likely due to the differences in aNDF, lignin, ash, and NFC content. As reported previously (DePeters et al., 2020a), Nonpareil TAH contained 21.4% aNDF, 8.6% lignin, 7.0% ash, and 65.4% NFC compared to the Other Variety TAH that were 25.5% aNDF, 9.7% lignin, 7.6% ash, and 60.7% NFC. Similar trends were observed for PAH and Debris for Nonpareil and Other Varieties (DePeters et al., 2020a). These differences in composition would account for the lower ME concentration of Other Variety compared with Nonpareil across all Types.

The IVTD and NDF digestibility were measured at 12, 24, 48, and 72 h (**Table 11**). The IVTD and NDFD were significantly greater for PAH than TAH at 48 and 72 h, and Debris was significantly lower in digestibility than both TAH and PAH for IVTD at every time point and for NDFD at 24, 48, and 72h.

Table 11. Daisy *in vitro* true digestibility on a dry matter (DM) basis (IVTD) and neutral detergent fiber digestibility (NDFD) of almond hulls (AH). The effects of Type (Total AH, Pure AH, Debris) on IVTD and NDFD coefficients at each timepoint measured *in vitro* are shown.

					P-value[1]		
	Total AH	Pure AH	Debris	S.E.M.	Total AH vs Pure AH	Total AH vs Debris	Pure AH vs Debris
Daisy *in vitro* True Digestibility on DM basis coefficient							
12hr	0.79	0.81	0.36	0.010	0.088	<0.001	<0.001
24hr	0.84	0.87	0.37		0.003	<0.001	<0.001
48hr	0.87	0.91	0.40		<0.001	<0.001	<0.001
72hr	0.88	0.92	0.42		<0.001	<0.001	<0.001
Daisy NDFD coefficient							
12hr	0.14	0.11	0.06	0.021	0.244	<0.001	0.072
24hr	0.32	0.36	0.08		0.148	<0.001	<0.001
48hr	0.46	0.57	0.11		<0.001	<0.001	<0.001
72hr	0.51	0.61	0.13		<0.001	<0.001	<0.001

[1] Pure vs Total = contrast between Pure almond hulls and Total almond hulls; Debris vs Total = contrast between Debris and Total almond hulls; Pure vs Debris = contrast between Pure almond hulls and Debris samples.

Total AH = contains AH and Debris; Pure AH = sorted to contain only hulls; Debris = sticks and shells sorted from TAH.

The lower IVTD and NDFD for Debris contributed to the lower digestibility of TAH compared with PAH at 24, 48, and 72h for IVTD and 48 and 72h for NDFD. The digestibility of aNDF for PAH compared with TAH at 12 h of does not agree with changes in IVTD, but could be linked to the greater amount of aNDF due to the presence of sticks and shells in TAH compared with PAH. Lignin, a fraction of aNDF, was measured as ADL in this study. The ADL does not include soluble lignin, unlike Klason lignin, which is usually measured at greater amounts than ADL (Hatfield et al., 1994). Queirós et al. (2020) found that almond shells had between 5-9% soluble lignin and 27.9-30.5% Klason lignin. Hall (2000) reported that AH have 16.9% soluble fiber, which would include soluble lignin. It is possible that some of the greater aNDF (24.3% TAH; 20.9% PAH) observed in TAH in this study was soluble lignin, which quickly solubilized within the first 12 hours of incubation. This would lead to a deceptively high aNDF digestibility amount at 12 hours for TAH compared with PAH. At this time more research still needs to be done on the type and amount of lignin in AH.

In addition to the *in vitro* digestibility measurements, two nonlactating, nonpregnant, rumen cannulated Holstein cows were used to measure *in sacco* dry matter and NDF digestibility. The TAH and PAH samples were weighed into monofilament nylon bags that were heat sealed before being placed in the rumen of the cannulated cows. Two series of *in sacco* incubations were conducted with bags of TAH or PAH incubated in the rumen for 0, 1, 2, 4, 8, 16, 32, and 64 h as described by Nocek (1988). Bags were then analyzed for DM and NDF disappearance. A non-linear mixed effects model was used to analyze the rate and extent of digestibility for both DM and NDF of the TAH and PAH.

The estimated asymptote for the coefficient of DM disappearance was significantly greater for PAH (0.3547) and TAH (0.3435; **Table 12**). The estimated fractional rate of *in sacco* DM disappearance was 0.064 /h for TAH and 0.0768 /h for PAH, which was not significantly different. The calculated coefficient for the proportion of DM disappearance (P) was numerically higher for PAH (0.9325) than TAH (0.8985). A similar response was observed for estimated potential disappearance of NDF (Table 12). The estimated asymptote for the proportion of NDF disappearance was 0.80796 for TAH and 0.892 for PAH, which was significantly different. The estimated rate of NDF disappearance was also significantly greater for PAH (0.060 /h) compared with TAH (0.052 /h). The calculated coefficient for the proportion of NDF disappearance (P) was numerically higher for PAH (0.7439) than TAH (0.6659).

Table 12. *In sacco* dry matter (DM) and neutral detergent fiber (NDF) disappearance for each Type (Pure almond hulls (AH) or Total AH). Effects of Type (Pure AH or Total AH) on coefficients of the *in sacco* disappearance function. The estimates were determined from the model. A are the estimated asymptote for the coefficient of disappearance for each Type. k are the corresponding rate constants (/h) for each Type. Int are the corresponding intercepts of time 0 with the coefficient of disappearance on the y-axis for each Type. P are the estimated Asymptote (A) + Intercept (Int) or total estimated proportion of disappearance for each Type.

			P-value[1]
Variable	Estimate	S.E.M.	Pure AH vs Total AH
DM Disappearance			
A- Pure AH	0.35	0.008	0.018

A- Total AH	0.34		
k- Pure AH	0.07	0.002	0.195
k- Total AH	0.06		
Int- Pure AH	0.58	0.008	<0.001
Int- Total AH	0.55		
P- Pure AH[2]	0.93		
P- Total AH[2]	0.89		
NDF Disappearance			
A- Pure AH	0.89	0.032	<0.001
A- Total AH	0.80		
k- Pure AH	0.06	0.003	0.007
k- Total AH	0.05		
Int- Pure AH	-0.15	0.023	0.071
Int- Total AH	-0.14		
P- Pure AH[2]	0.74		
P- Total AH[2]	0.66		

[1] Pure vs Total = contrast between Pure almond hulls and Total almond hulls.
[2] These are calculated values: A + Int = P (proportion of disappearance).
Total AH = contains AH and Debris; Pure AH = sorted to contain only hulls.

Yalchi and Kargar (2010) compared stone shell and paper shell (similar to soft shell of Nonpareil and hard shell of Other Variety) AH in the rumens of four sheep. Degradation rate of DM for stone shell (0.067 /h) and paper shell (0.063 /h) differed. Proportion of degradation of DM was also greater for stone AH (0.81) compared with paper AH (0.77). Degradation rate of NDF was 0.054 and 0.046 /h and degradation coefficients were 0.56 and 0.52 for stone shell and paper shell AH, respectively. Yalchi (2011) evaluated PAH in the rumen of three sheep at seven time points ranging from 2 to 96 h. Digestibility coefficients of DM for PAH were 0.47 at 2 h and 0.77 at 96 h compared with 0.24 at 2 h and 0.67 at 96 h for alfalfa hay. Interestingly, the digestibility of NDF in PAH was lower than in alfalfa hay at all times points except for the 96 h time point. The perception is that the fiber fraction of AH is highly digestible. However, the findings of Yalchi (2011) question this view. In fact, earlier work by DePeters et al. (1997) reported that for three samples of AH, the proportion of NDF remaining after 72 h of in situ digestion averaged 0.14, for a digestibility coefficient of 0.86. In contrast, the proportion of NDF remaining for beet pulp was 0.036 and 0.042 for soy hulls. The NDF digestibility of AH deserves further study

> **Take Home Messages:** Overall, Debris was not as digestible as PAH and TAH, and Debris contributed to TAH having significantly lower IVTD and NDF digestibility at 48 and 72h, along with numerically lower calculated ME and significantly lower gas production when compared with PAH. This is important for dairy producers in California who need high quality, digestible feeds to support milk production. Reducing the amount of Debris contamination in commercial AH is one important approach to improving the nutritive value of AH for ruminants and to improving the overall monetary value of the hulls for almond hullers.

4. Feeding Value of Almond Hulls

In vitro rumen fermentation data (Section 3) indicate that digestibility of fiber (NDF) in almond hulls is low (Swanson et al. 2021b), and the fiber in almond hulls may not be as high in digestibility as the fiber in alfalfa hay (Swanson, unpublished). Early research in our lab (DePeters et al. 1997) observed lower fiber digestibility in almond hulls compared with other by-product feedstuffs including soy hulls and citrus pulp measured using an *in sacco* (*in situ*) disappearance study (**Table 13**).

Table 13. Estimated and calculated *in sacco* digestion parameters for DM and NDF from DePeters et al., 1997.

Feed	DM Disappearance	DM kd	NDF Disappearance	NDF kd
Almond hulls	29.2	0.062	16.5	0.043
Soy hulls	87.2	0.047	59.7	0.038
Beet pulp	63.1	0.084	39.1	0.083
Wheat Mill Run	36.7	0.135	19.8	0.122

kd = rate constant for disappearance (h^{-1})

Jafari et al (2015) evaluated almond hulls from four different almond varieties as well as alfalfa and sugar beet pulp for in situ rumen degradability using steers. These researchers found high levels of rumen DM degradability. Extent of ruminal DM degradation of almond hulls ranged from 77.4% to 84.7%. The reason the difference between studies (Jafari et al. 2015 and DePeters et al., 1997) is not apparent.

Norollahi et al. (2006) measured *in vivo* digestibility of almond hulls in sheep. It appears that the diet was 100% almond hulls, but it was not stated as such in the paper. Apparent digestibility was 73.1%, 29.6%, 40.6%, and 84.4% for DM, crude protein, crude fiber, and nitrogen-free extract, respectively. Yalchi (2011) determined in sheep the apparent digestibility of two diets, 100% alfalfa hay (Basal diet) and 70% alfalfa hay/30% almond hulls (Mixed diet). Compared with the 100% alfalfa hay diet, when almond hulls were added to the basal diet (100% alfalfa hay) the apparent digestibility of NDF and CP decreased and there was a tendency for the apparent digestibility of ADF and hemicellulose to also decreased when almond hulls were added to the basal diet (100% alfalfa hay).

The aim of the following study was to evaluate the *in vivo* apparent digestibility of almond hulls. One lot of commercial almond hulls was obtained, which is a limitation of the study. The chemical composition is reported in **Table 14**. Almond hulls (unprocessed) were cubed with alfalfa hay in the following proportions, 0:100, 10:90, 20:80, and 40:60 almond hulls:alfalfa hay (wt:wt As Is basis), to create four experimental diets. The cubes were broken apart by hand. Eight wether sheep were used in a replicated 4 x 4 Latin square design with 4 wethers, 4 periods with each period 14 d in length, and 4 diets. Apparent digestibility was determined using a total feed and fecal collection approach. Each wether was fitted with a fecal harness. Sheep were fed twice daily, and feed intake recorded. Feces were collected and weighed twice daily. A regression approach was used to estimate the digestibility of almond hulls.

Table 14. Chemical composition of almond hulls used in sheep digestibility study. All values are on percentage of DM basis unless otherwise noted.

	Almond hulls
CP	4.4
ADF	21.1
ADFom	20
aNDF	27.3
aNDFom	26.7
Crude Fiber	19.6
Lignin	7.8
EtOH soluble CHO	31
Water soluble CHO	36
Starch	0.2
Ether Extract	1.55
Ash	6.33
TDN	65.9
NEL (Mcal/lb)	0.68
NFC	62
NSC	31.2

Abbreviations: CP = Crude protein; ADF = Acid detergent fiber; ADFom = Acid detergent fiber on an organic matter basis; NDF = Neutral detergent fiber; NDFom = Neutral detergent fiber on an organic matter basis; CF = crude fiber; EtOH Soluble CHO = ethanol soluble carbohydrates; NFC = non-fiber carbohydrates calculated by: NFC% = 100 – (CP% + Fat% + Ash% + NDF% + NDFICP%); NSC = non-structural carbohydrates calculated by: NSC% = EtOH CHO% + Starch% ; TDN = total digestible nutrients; NEL = net energy of lactation

The apparent DM digestibility of almond hulls was 60.9%, significantly lower than the 63.3% for alfalfa hay (**Table 15**). Apparent digestibility of NDFom was 23.5% for almond hulls and 44.4% for alfalfa hay. Apparent digestibility of crude protein was 32.6% for almond hulls and 73.7% for alfalfa hay. This study only evaluated one lot of commercial almond hulls. But, based on this study, the *in vivo* digestibility of fiber (NDFom) and crude protein were low compared with alfalfa a hay. The low fiber (NDFom) digestibility should be considered when almond hulls are used to replace a portion of the forage, for example corn silage, in the diet of high producing dairy cows.

Table 15. Calculated apparent digestibility of nutrients from almond hulls and alfalfa in sheep.

Apparent Digestibility	Almond Hulls	Alfalfa Hay
DM	60.9	63.3
NDFom	23.5	44.4
ADFom	17.7	45.6
Crude Protein	32.6	73.7

Aguilar et al. (1984) used steers to determine apparent digestibility of three varieties of almond hulls including Nonpareil (NP), Neplus (NE), and a commercial mix (CM). Almond hulls replaced a portion of the control diet (**Table 16**).

Table 16. Diets for digestibility (Aguilar et al 1984)

Ingredient	Control	20% AH	40% AH
Alfalfa	25.0	19.8	14.7
Oat hay	35.0	27.75	20.55
Barley	40.0	31.7	23.50
Almond hulls		20.0	40.00
Urea		0.75	1.25

As the proportion of almond hulls in the diet increased, apparent digestibility of dry matter, ADF, cellulose, and energy decreased (**Table 17**).

Table 17. Apparent digestibility in sheep of various diets and almond hull varieties as reported in Aguilar et al. 1984.

Item	Control	20%CM	40%CM	20%NP	40%NP	20%NE	40%NE
DM	70.3	67.3	65.4	68.7	66.3	69.4	66.4
ADF	51.3	38.9	33.3	40.7	28.3	51.1	40.2
Cellulose	63.4	57.7	54.9	60.4	51.3	66.0	57.3
Energy	69.7	65.8	63.9	67.6	64.6	67.9	64.0

Calculated digestibility of almond hull varieties using regression analysis is reported in **Table 18**.

Table 18. Apparent digestibility and DE concentration of almond hull varieties from Aguilar et al. 1984.

Item	Nonpareil	Neplus	Commercial Mix
DM, %	61.2	62.1	59.6
ADF, %	19.4	23.3	14.8
Energy, %	57.0	56.3	54.5
DE, Mcal/kg	2.52	2.45	2.38

The DE content of the Control diet was 3.08 Mcal/kg. Replacing a portion of the Control diet with commercial almonds reduced the energy concentration to 2.91 Mcal/kg (5.5% reduction) and 2.82 Mcal/kg (8.4% reduction) with 20% and 40% inclusion of commercial almond hulls in the diet, respectively. The decrease in DE concentration with the inclusion of almonds hulls likely reflected the low digestibility of fiber in almond hulls since the soluble sugars should be highly digestible. Aguilar et al. (1984) found that the correlation between ADF (%) and DE (Mcal/kg) was -0.99 while the correlation between soluble sugars (%) and DE (Mcal/kg) was +0.49. Lignin and crude fiber contents were also negatively correlated to DE concentration.

The apparent digestibility of DM for commercial almond hulls (59.6%) observed with steers by Aguilar et al. (1984) agrees closely with our observation (60.9%) with sheep. Likewise, Aguilar et al. (1984) observed fiber (ADF) digestibility of 14.8% while we observed fiber digestibility of 17.7% (ADFom) and 23.5% (NDFom).

There are a few studies with lactating dairy cows. Aguilar et al. (1984) included almond hulls in a TRM for lactating cows as a forage ingredient, replacing alfalfa hay at 12.5 and 25%. The Control diet was 61% alfalfa hay so the TMR was high forage. There was no difference in animal performance. The inclusion of almond hulls with associated fiber content had no impact on any milk component although milk fat % was low across all diets in their study as seen in **Table 19**.

Table 19. Milk composition of cows from the Aguilar et al. 1984 study.

Item	Control	12.5% AH	25% AH
DM Intake, kg/d	19.4	20.1	19.8
Milk, kg/d	25.3	25.5	24.8
Fat, %	3.2	3.2	3.2
Protein, %	3.2	3.2	3.2
SNF, %	8.8	8.8	8.8
Solids, %	12.0	12.0	12.0

More recently Williams et al. (2018) replaced 27.5% of alfalfa cubes in the diet with almond hulls. The average intake of almond hulls was 3.9 kg DM (8.6 pounds) daily. Intake of DM did not differ with diet. However, yields of milk, energy-corrected milk, milk protein, and milk lactose decreased with the feeding of almond hulls (**Table 20**).

Table 20. Feed intake and milk production performance (Williams et al. 2018)[1].

Item	Control	Almond Hull
DM Intake, kg/d	22.3	22.6
Milk yield, kg/d	27.4^{a}	24.6^{b}
Energy-correct milk yield, kg/d	26.4^{a}	24.6^{b}
Fat, kg/d	1.04	1.00
Fat, %	3.81	4.14
Protein, kg/d	0.87^{a}	0.78^{b}
Protein, %	3.22	3.20
Lactose, kg/d	1.36^{a}	1.19^{b}
Lactose, %	4.99	4.88

$^{a–b}$ Means in the same row followed by different superscripts differ significantly ($P < 0.05$).

[1] Control cows consumed 14.2 kg alfalfa cube DM and Almond hull cows consumed 10.5 kg alfalfa cube DM + 3.9 kg almond hull DM.

In 2019, a dairy cattle feeding study was conducted at UC Davis where increasing amounts of almond hulls were added to the TMR to replace the concentrates (Swanson et al., 2021a). As previously stated, almond hulls are low in crude protein but high in fermentable carbohydrates. The highly fermentable sugars, such as sucrose and glucose, in AH could make them a better replacement for concentrates in a lactating cow diet instead of forages that offer more digestible fiber. The aim of this study was to determine if 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 if there are changes in production with different AH levels substituted for concentrates.

The study used 12 lactating Holstein dairy cows averaging 96 ± 30 days-in-milk that were assigned to dietary treatments using a 4 x 4 Latin square experimental design.

Healthy cows were assigned to their respective Latin square based on parity with 4 primiparous cows 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 21 days in length, with the last 7 days of each period used for data collection, with feed offered and milk production recorded twice a day during the study and feed refusals recorded every morning. There were four diets fed where the TMR composition was based on formulating a diet for 28 kg DM intake per cow that would provide cows with 0, 1.8, 3.6, or 5.5 kg/d of commercial AH. This created 4 TMR's with 0, 7, 13, or 20% AH (**Table 21**). As the amount of AH increased in the diet, corn and soyhull pellets decreased while soybean meal increased. Details for the experimental design were reported previously (Swanson et al. 2021a).

Table 21. Composition of total mixed ration for lactating cows.

	0% AH	7% AH	13% AH	20% AH
Ingredient and % of TMR on DM basis				
Alfalfa	38.7	38.7	38.7	38.5
Rolled Corn	32.5	30.1	28.3	23.3
Soy Hulls	11.5	8.0	2.0	0.0
Almond Hulls	0.0	7.0	13.2	20.0
Oat Hay	3.3	2.5	2.5	2.5
Soybean Meal	1.5	1.8	2.9	3.7
DDG	6.2	6.2	6.2	6.2
Cottonseed	3.8	3.8	3.8	3.8
Limestone / Oystershell	1.3	0.3	0.3	0.3
Sodium Bicarb	0.6	0.6	0.6	0.6
Mineral[1]	0.2	0.2	0.2	0.2
Mag ox	0.2	0.2	0.2	0.2
Salt	0.1	0.1	0.1	0.1

[1] Nutrius LLC, Kingsburg, CA Provides to the diet 0.56 % DM Crude Protein, 0.92 % DM ADF, 0.48 % DM NDF, 0.02 Mcal/ lb NE lactation, 1.7 % DM TDN, 12.37 % DM of Calcium, 5.33 % DM Phosphorus, 9.15 % DM Sodium, 0.08% DM Potassium, 4.28 % DM Magnesium, 2.16 % DM Sulphur, 25.06 ppm DM Cobalt, 668.80 ppm DM Copper, 58.54 ppm DM Iodine, 2664.5 ppm DM Manganese, 22.79 ppm DM Selenium, 4473.59 ppm DM Zinc, 1982.07 ppm DM Iron, 933.33 g/Ton of Monensin, 242.68 KIU/ lb of

DM Vitamin A, 84.0 KIU/ lb of DM Vitamin D-3, 1.9 KIU/ lb of DM Vitamin E, 26.67 mg/ lb of Biotin, 0.0103 % DM Lysine, and 0.246 % DM of Methionine, 0.24 % DM Methionine-3, 13.31 mg/ lb EDDI, 0.02 % DM Diflubenzuron, 13.30 lbs Live BCFU's, 1.55 % DM Almond shells, 0.23 % DM Rice Hulls.

The chemical composition of the almond hulls used is shown in **Table 22**. Sampling almond hulls was difficult because of the size of the hulls as well as the distribution and particle size of the debris, which included sticks and shells. The variation in crude protein was small while there was larger variation in the fiber fractions, water soluble carbohydrates, and lignin compositions. The almond hulls were high quality, sometimes referred to in the industry as "prime". The crude fiber on an As Is basis was 12.78%, and crude fiber ranged from a low of 11.88% to a high of 15.06% with sampling.

Table 22. Chemical composition of 4 grab samples of almond hulls added to total mixed-rations in this study.

	Avg	SD	Min	Max
Chemical Composition (% of DM basis unless otherwise noted)				
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
CF	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
EtOH soluble CHO	32.0	2.16	29.7	34.1
Water soluble CHO	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
NEL (Mcal/kg)[1]	1.6	0.02	1.5	1.6

[1] NEL was calculated based on the equation outlined in the Dairy NRC (2001).

Abbreviations: ADFom = Acid detergent fiber on an organic matter basis; aNDF = Neutral detergent fiber from alpha-amylase; aNDFom = Neutral detergent fiber on an organic matter basis; CF = crude fiber; EtOH Soluble CHO = ethanol soluble carbohydrates; Water soluble CHO = water soluble carbohydrates

The inclusion of AH in the diet resulted in lower intake of NDF for the 13% AH and 20% AH diets compared with 0% and 7% AH diets (**Table 23**). Intake of ADF was lower for the 13% AH compared with the other diets. There were no differences in DM, crude protein, calcium, phosphorus, or estimated net-energy intake due to diet. As anticipated, the intakes of DM, CP, ADF, NDF, and NEL were different for parity.

Table 23. Intake of dry matter and chemical components for cows consuming each almond hull (AH) diet.

						P-value[1]				
	0% AH	7% AH	13% AH	20% AH	SEM	Diet	Parity	L	Q	C
Intake in kg/d										
Dry Matter	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	7.5	7.5	6.6	6.5	0.19	<0.01	0.01	<0.01	0.53	<0.01
Calcium	0.29	0.31	0.29	0.34	0.02	0.06	0.10	0.10	0.27	0.05
Phosphorus	0.08	0.08	0.08	0.08	0.003	0.44	0.04	0.66	0.62	0.14
NEL (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

[1] Diet = effect of different AH % diets on intake; Parity = effect of parity on intake; L, Q, C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period; There were no significant Diet x Parity interactions for any measurements

Actual milk yield (**Table 24**) tended to decrease at the higher amount of AH feeding, with the 7% AH diet numerically the highest milk yield (39.3 kg). There was no effect of diet on yields of ECM, fat, lactose, and total solids. Protein yield was greater for the 7% almond hull diet resulting in the highest protein production (1.34 kg). For fat percentage, there was a significant effect of diet with the 13% and 20% almond hull diets higher than the 0% and 7% almond hull diets. Protein percentage was significantly different due to diet, with the 0% and 7% almond hull diets higher in protein content compared with the 13% and 20% almond hull diets. Milk urea nitrogen (MUN) concentration was lower for the 13% and 20% almond hulls diets compared with the 0% and 7% almond hull diets.

Table 24. Yield and composition of milk and components for cows consuming each almond hull (AH) diet.

						P-value[1]				
	0% AH	7% AH	13% AH	20% AH	SEM	Diet	Parity	L	Q	C
Yield (kg/d):										
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
Total Solids	4.85	4.91	4.63	4.73	0.15	0.09	0.01	0.17	0.89	0.03
Concentration (%):										
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
Total solids	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 (1000's cells/mL)	47.82	31.42	47.33	49.25	1.25	0.47	0.18	0.76	0.16	0.54

[1] Diet = effect of different AH % diets on production; Parity = effect of parity on production; L, Q, C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period; There were no significant Diet x Parity interactions for any measurements

[2] ECM = energy-corrected milk: [(0.327 x lbs of milk) + (12.95 x lbs of fat) + (7.65 x lbs of total protein)]

The decrease in aNDF intake 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 to that of 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, 22.7 kg/day for 0, 12.5, and 25% AH diets respectively), milk yield (24.9, 25.2, and 24.7 kg/day 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 since the forage proportion of the diet was 61% alfalfa hay for the control (no 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/day 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 were replacing 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. There was a decrease in both milk protein percentage and yield 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 non-protein nitrogen in the 25% AH diet, although all diets likely exceeded nitrogen requirements, resulting in higher blood and milk urea nitrogen concentrations as the 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 (BCS) 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 long term.

Dry matter, OM, and ADF, aNDFom, and crude protein apparent digestibilities were affected by diet (**Table 25**). For DM and OM digestibility, the AH diets were greater compared with the 0% AH diet, with the 20% AH diets having the highest digestibility for DM and OM. A similar pattern was seen with CP apparent digestibility with the 20% AH diet having a higher digestibility than the 0% AH diet. Digestibility of ADF was significantly higher for the 20% AH diet (46.9%) when compared with the 0% AH diet (41.6%). For ADFom digestibility, the 20% AH diet was numerically greater than that of the other diets. For aNDF digestibility, all of the AH diets were numerically higher than the 0% AH diet. For aNDFom apparent digestibility, the 7% AH diet was higher than the 0% AH diet. There were no interaction effects of diet and parity for any digestibility parameters.

Table 25. Apparent total-tract digestibility for cows consuming each almond hull (AH) diet.

						P-value[1]				
	0% AH	7% AH	13% AH	20% AH	SEM	Diet	Parity	L	Q	C
Apparent Digestibility (%)										
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

[1] Diet = effect of different AH % diets on digestibility; Parity = effect of parity on digestibility; L, Q, C = linear, quadratic, and cubic contrasts of diets averaged over levels of parity and period; There were no significant Diet x Parity interactions for any measurements

Abbreviations: ADFom = Acid Detergent Fiber on an Organic Matter Basis; aNDF = Neutral detergent fiber from alpha-amylase; aNDFom = Neutral detergent fiber on an organic matter basis

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 hour *in situ* DM digestibility of 70-71% with *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 64-70% 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 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 decreased (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 were AH are mainly replacing 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). Dried citrus pulp, a fibrous but carbohydrate-rich by-product, when added to the diet of goats to replace corn grain, resulted in an increase in ADF digestibility, 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 carbohydrate rich by-product, was added to replace barley in lactating Holsteins' 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 non-fiber carbohydrates (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.

Time spent in activities associated with resting, eating, and ruminating was affected by diet with the cows receiving the 20% AH diet resting less and eating and ruminating more when compared with the other three diets. As the amount of almond hulls in the diet increased, the number of minutes a cow spent ruminating increased. Cows on the 20% almond hull diet spent approximately 60 minutes more each day ruminating. This increase in chewing likely supported a rumen environment that supported high milk fat percent.

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. While normally lignin 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 (about 35cm in diameter) compared to chopped forage 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.

Take Home Messages: Almond hulls are an excellent, palatable feedstuff for lactating dairy cows. Almond hulls fed in our study were approximately 13% Crude Fiber As Is Basis so the hulls were high quality. Almond hulls of high quality replaced up to 20% of the concentrate ingredients in a TMR with no negative effects in production performance (feed intake, milk yield, milk composition, rumination time). Higher levels of feeding may be possible depending on the level of milk production. Higher amounts of feeding will be based on various factors identified in our survey of nutritionist, but cost of competitive ingredients and the consistency of the chemical composition of almond hulls are of utmost importance.

5. **Variation in Composition and Regulatory Issues**

The harvesting methods and current agronomic practices impact the contribution of debris to commercial AH. The almond huller removes a large portion of this debris although it is challenging to remove the sticks that are shorter than about 2 inches (Phippen, personal communication).

Commercial feed laws and regulations (CDFA validation 2773.5) define AH hulls as: "*Almond hulls are obtained by drying that portion of the almond fruit which surrounds the nut. They shall not contain more than 13.0 percent moisture, nor more than 15.0 percent crude fiber, and not more than 9 percent ash. If they contain more than 15.0 percent but less than 29.0 percent crude fiber, they shall be labeled "Almond Hulls and Shell" …*".

We conducted a descriptive study to evaluate a 5-year period of information for commercial AH analysis using data from the CDFA to determine if there were differences associated with month and year and if any differences in the percent CF were related to moisture content of the AH.

Data for a 5-year period, 2014 to 2018, were obtained from the CDFA. The data included month and year of sampling, the percent CF As Is basis, and the percent moisture. The number of samples collected each year for analysis varied. The CDFA does not establish a priori the number of samples that will be collected during any given year. The CDFA Commercial Feed Program is not based on a statistical sampling approach with random sampling of AH. The CDFA Commercial Feed Program is focused on feed safety and label compliance, in the case of this study with AH, for percent CF As Is and percent moisture.

For the purpose of our research, a percent CF As Is basis greater than 15% CF was designated as a violation. A moisture content greater than 13% was designated as a violation. A description of the statistical analysis approaches is described (DePeters et al. 2020b)

There were 673 samples of AH analyzed during the 5-year period studied. The percentage of total AH samples analyzed that were found to be in violation were 62.1, 54.3, 39.3, 51.4, and 45.2%, for 2014, 2015, 2016, 2017, and 2018, respectively (**Table**

26). There was no obvious trend across years for the proportion of AH samples analyzed that were a violation for the percent CF As Is basis.

Table 26. Number of samples with no crude fiber (CF) violation (<15% CF), number of samples with crude fiber violation, total samples, and percent of samples that were a violation by year.

Year	Samples with No CF Violation	Samples with CF Violation	Total Samples	Percent that were Violation
2014	61	100	161	62.1
2015	85	101	186	54.3
2016	71	46	117	39.3
2017	51	54	105	51.4
2018	57	47	104	45.2

The percent CF (17 % CF As Is basis) in AH that were in violation was similar across years as was the percent CF (13 % CF As Is basis) for samples with no violations (**Table 27**).

Table 27. Count of violations by year including the average percent crude fiber (CF; As Is basis) for almond hull samples that were and were not a violation. A crude fiber greater than 15% is a violation.

Year	Number of violations	%CF in Violations	SD	%CF in No Violations	SD
2014	100	17.6	2.4	13.5	1.2
2015	101	17.4	2.3	13.7	1.0
2016	46	17.2	1.7	13.1	1.2
2017	54	17.4	1.8	13.0	1.4
2018	47	17.6	2.7	13.0	1.3

There was no obvious trend or difference found number of violations for percent CF As Is basis by month (**Table 28**). These violations were based on percent CF expressed on an As Is basis. A sample greater than 15% CF As Is basis was a violation.

Table 28. Count of violations by month and the average percent crude fiber (CF; As Is basis) for almond hulls samples that were a violation (> 15%CF) and were not a violation averaged over 5 years.

Month	Number of violations	Total samples	%CF in Violation	SD	%CF with No violations	SD
1	30	55	17.8	2.4	13.6	1.2
2	26	62	16.8	1.8	13.1	1.2
3	24	57	18.0	1.8	13.3	1.4
4	40	108	17.5	2.0	13.3	1.2
5	36	62	17.6	2.1	13.7	1.3
6	52	74	17.4	2.2	13.5	1.1
7	39	54	17.5	1.9	13.7	1.0
8	16	29	17.7	3.8	12.7	1.5
9	16	38	18.2	3.0	13.0	1.1
10	26	50	17.2	1.6	13.3	1.1
11	15	30	17.2	1.5	13.4	1.4
12	28	54	16.9	2.9	13.3	1.5

The percent moisture in AH samples that were a violation was similar to the percent moisture of samples that were not violations. Interestingly, the evaluation of violations adjusted for percent moisture provided the best statistical model fit to these data. From the statistical model, the coefficient for the percent moisture was -0.07 (± 0.04), the negative slope indicating that as the percent moisture increased, the risk of violation declined.

Across all years, AH samples found in violation were 4.1 percentage units higher in CF As Is basis than those samples that were not in violation.

Analysis of percent CF As Is basis adjusted for percent moisture had a coefficient for percent moisture that was -0.14 (± 0.05), the negative slope indicating that as the percent moisture increased in the AH, the percent CF As Is basis decreased.

The number of AH samples hulls found in violation of percent moisture content (> 13% moisture) were too few counts for statistical analysis. Summer months had no violations while the moisture violation occurred during the winter months. Moisture content can be a concern for the growth of fungi since AH are high in sugar content.

The aim of the CDFA program of sampling and analyzing feeds is to ensure feed safety. Only a small portion of the AH marketed were actually sampled and tested for crude fiber and moisture during the 5-year period of review so it is difficult to know what quality of AH that were actually fed to lactating cows on dairy farms.

Take Home Messages: The rank from most to least violations (violation stated as > 15% CF As Is basis) as a proportion of total samples was 2014> 2015 > 2017 > 2018 > 2016.The percent crude fiber differed by year, but across all years crude fiber content was highest in summer compared with other seasons. When moisture content was included in the statistical model for predicting the number of violations, as the percent moisture increased, the risk of a percent crude fiber (As Is basis) violation decreased.

Including moisture in the model for predicting percent crude fiber by month and year indicated that as the percent moisture increased, the percent crude fiber decreased. From a legal definition perspective, setting a maximum percent moisture of 13% moisture prevents the intentional addition of moisture to almond hulls to reduce the risk of a violation. Almond samples in violations were 4.1 percentage units higher in percent crude fiber (17%CF) compared with samples found not to be in violation (13 %CF). From a practical perspective of feeding animals and purchasing almond hulls, it is likely wise to periodically obtain a respective sample from lots of almond hulls delivered to a dairy farm for chemical analysis. For commercial almond hulls: ***Test, Don't Guess*** when it comes to the chemical composition of AH.

6. Current and Future Research

We are currently looking at the chemical composition of almond hulls collected during the 2021 harvest season. This involves both wet chemistry analysis and NIR (near infrared) analysis. One aim is to assess the lignin content of almond hulls. The fiber in almond hulls is less digestible than might be expected. The question being addressed is does the type of lignin have an effect. We are measuring both the acid detergent lignin (ADL) and the Klason lignin (KL) content of commercial almond hulls and “pure” almond hulls (sorted to remove sticks and shells). Klason lignin content is great than ADL. The difference between ADL and KL is often times referred to soluble lignin. We are studying the difference in lignin type/methodology as it relates to the digestibility of hulls.

A lactation study with Holstein cows will evaluate the feeding of cubes that contain both alfalfa hay and almond hulls. The justification for this approach was to include almond hulls with lower quality alfalfa hay for the international export-market.

Almond hulls effectively replaced concentrate ingredients in the diets of lactating cows. However, how high can almond hulls go in a lactating cow diet as a forage ingredient is yet to be studied. Water is a scare resource in California, and that is not likely to change in the near future. In fact, with climate change and a growing human population, water will only become more restrictive to both plant and animal agriculture in California. How much of the diet silage can almond hulls replace?

Future research is yet to be determined. However, information on chemical composition of almond is need as agronomic practices evolve. The almond industry is exploring harvesting methods that do not involve the ground floor in the orchard. New, self-pollinating varieties will be developed and well as more water efficient almond varieties. The form of the almond hull product will also be explored. Pelleting, for example, is an approach to increasing the density for shipping almond hulls nationwide. However, pelleting, similar to cubing, changes the physical form of the hulls. In addition, pelleting, in particular, but also cubing reduce the ability of cows to sort the debris, sticks and shells, from the diet.

7. Summary

Almond hulls are a byproduct created in the production of almonds for human consumption. Almond hull composition is high in sugars and fiber, but low in protein. The chemical composition of almond hulls is quite variable as reflected by the high proportion of samples collected by CDFA Inspectors that were found in violation, greater than 15% CF As Is Basis. Almond hulls are high in energy content based on in vitro and in vivo determinations. The fiber content of almond hulls may not be as high as generally viewed. Almond hulls can successfully be used as either a concentrate and/or a forage ingredient in the diet of lactating dairy cows and for this reason almonds are a unique and important byproduct feedstuff for dairy cattle.

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