Effects of alternative feedstuffs on growth performance, carcass characteristics, and meat quality of growing Awassi lambs

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ABSTRACT
Twenty-seven Awassi lambs were used to evaluate the effects of dietary inclusion of selected (dry bread, carob pods, olive cake, and sesame meal) alternative feedstuffs (AF) on performance, carcass characteristics, and meat quality. Lambs were assigned to one of three treatment diets. Diets contained (g/kg on DM basis) no (0AF; n = 9), 250 (25AF; n = 9), or 500 (50AF; n = 9) of AF, respectively. Lambs fed the 50AF diet had the least (p < .05) intake of DM, OM, NDF, and ME. Crude protein digestibility was lowest (p < .01) in lambs fed the 50AF diet. The digestibility of NDF and ADF was highest (p < .01) for the 0AF diet. Hot and cold carcass weights tended to be greater (p ≤ .10) for lambs fed with the 0AF than the 50AF diet. Dressing percentage tended to be lower (p = .07) in lambs fed with the 50AF compared to the 0AF and 25AF diets. No substantial differences were observed among dietary treatments in carcass and non-carcass cut weights. Composition (muscle, fat, and bone) of dissected legs were not different (p ≥ .10) among dietary treatments. No substantial differences (p ≥ .37) were observed among dietary treatments in all meat quality parameters except for higher redness of the 0AF diet. Dietary inclusion of AF at 250 or 500 g/kg decreased production cost with similar feed conversion ratio. However, at high level (500 g/kg) AF could negatively affect nutrients intake, digestibility, and performance.

HIGHLIGHTS
• Replacing conventional feedstuffs from lamb diets with two levels (250 or 500 g/kg) of alternative feedstuffs reduced production cost without causing any health problems to lambs.

ARTICLE HISTORY
Received 26 September 2018
Revised 23 January 2019
Accepted 31 January 2019

KEYWORDS
Alternative feedstuffs; digestibility; meat quality

Introduction
One of the major constraints of sheep industry in the Middle Eastern countries (i.e. Jordan) is limited availability of feedstuffs and insufficient natural pastures (Awawdeh 2011). Natural pastures are available only in limited times (Awawdeh and Obeidat 2011) and, in most cases, do not meet maintenance requirements of livestock animals (Salem and Nefzaoui 2003). Grains are commonly imported with expensive prices in Jordan, thus, finding cheap alternative (non-conventional) feedstuffs (AF) should reduce production cost and increase farmers’ profitability.

Numerous studies have included different AF in sheep diets to support meat and milk production (Awawdeh 2011). Those studies have shown that AF can successfully replace part of the traditional feedstuffs by certain percentages (<250 g/kg). At a higher percentage, such replacement might negatively impact sheep performance. Previous studies (Hindiyeh et al. 2011; Obeidat et al. 2012) indicate that dietary inclusion of dry bread (DB) up to 200 g/kg will not probably cause negative effects on lamb performance. Similarly, dietary inclusion of carob pods (CB) up to 200 g/k did not negatively affect sheep performance (Obeidat et al. 2011).

Although differences present between the type (crude, pelleted, de-stoned, acid-treated, etc.), dietary inclusion of crude olive cake (OC) up to 100 g/kg was fairly safe without negative effects on lamb performance (Omar et al. 2012; Awawdeh and Obeidat 2013; Tufarelli et al. 2013). Previous studies demonstrate
that sesame meal (SM) can be included in lamb diets at 80–200 g/kg without detrimental effects on performance (Omar 2002; Obeidat et al. 2009; Hassan et al. 2013).

Almost all previous studies included only one type of AF (Awawdeh 2011), combination of AF only in the supplement concentrate (Mahgoub et al. 2005) or as feed blocks (Salem and Nefzaoui 2003). In the current study, we included combination of four types of AF at the time. Choosing four types allowed us to include AF at higher levels (500 g/kg) without drastically affecting nutrient composition of treatment diets and to make treatment diets isocaloric and isonitrogenous. Based on nutrients composition (Table 1), DB and CB were selected as alternative energy source, SM as alternative protein source, and OC as alternative fibre source.

The objective of this study was to evaluate the effects of dietary inclusion of DB, CB, OC, and SM (at 250 or 500 g/kg) on performance (nutrient intake, digestibility, growth rate, and production cost), carcass characteristics, and meat quality of growing Awassi lambs.

### Materials and methods

The study was conducted at the Agricultural Research and Training Unit at Jordan University of Science and Technology (JUST). The Institutional Animal Care and Use Committee at JUST approved all procedures used in this study.

#### Obtaining alternative feedstuffs

Dry bread (waste bread) was obtained from JUST cafeteria. Bread was collected and sun-dried over several weeks. Carob pods were collected from in-campus (JUST) trees and allowed to sun-dry. Olive cake was obtained from a local olive oil-extraction mill (Irbid, Jordan). Olive cake was dried by spreading it into a thin layer and manually turned over, mixed, and re-spread every week to prevent spoilage. Sesame meal was collected from a local sesame-pressing factory (Amman, Jordan) for oil extraction and dried similar to drying OC. After drying, DB, CB, and SM were milled to ease the mixing process of diets.

#### Animals, dietary treatment, experimental design, and analytical methods

Lambs were purchased from a local farm and upon arrival at the study site, lambs were individually ear tagged, weighed, treated for internal (Mebendazole, Mebendole, Lebanon) and external (Ivermectin, Huvepharma, Altius, Romania) parasites, and vaccinated against enterotoxemia (COGLAVAX, Ceva, Sante Animal, Libourne, France). Lambs were housed individually in shaded pens (1.5 m × 0.75 m).

### Table 1. Chemical composition (g/kg DM) of the alternative feedstuffs used in treatment diets.

| Item a | Dry bread | Carob pods | Olive cake | Sesame meal |
|--------|-----------|------------|------------|-------------|
| DM, g/kg as fed | 880.0 | 854.0 | 812.0 | 841.0 |
| OM     | 980.0 | 960.0 | 950.0 | 930.0 |
| CP     | 146.0 | 77.0 | 72.0 | 457.0 |
| NDF    | 24.0 | 213.0 | 533.0 | 158.0 |
| ADF    | 6.0 | 150.0 | 345.0 | 85.0 |
| Ether extract | 16.0 | 35.0 | 170.0 | 117.0 |
| ME, MJ/kg b | 13.8 | 12.0 | 4.2 | 12.3 |

DM: dry matter; OM: organic matter; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; ME: metabolisable energy.

### Table 2. Ingredient and chemical composition of dietary treatments containing different levels of alternative feedstuffs fed to growing male Awassi lambs.

| Dietary Treatments a | 0AF | 25AF | 50AF |
|----------------------|-----|------|------|
| Barley, g/kg DM      | 513.0 | 408.0 | 303.0 |
| Soybean meal, g/kg DM| 150.0 | 75.0 | 0.0 |
| Wheat bran, g/kg DM  | 90.0 | 90.0 | 90.0 |
| Wheat straw, g/kg DM | 220.0 | 150.0 | 80.0 |
| Carob, g/kg DM       | 0.0 | 50.0 | 100.0 |
| Sesame meal, g/kg DM | 0.0 | 80.0 | 160.0 |
| Olive Cake, g/kg DM  | 0.0 | 70.0 | 140.0 |
| Dry bread, g/kg DM   | 0.0 | 50.0 | 100.0 |
| Na bicarbonate, g/kg DM| 5.0 | 5.0 | 5.0 |
| Salt, g/kg DM        | 10.0 | 10.0 | 10.0 |
| Limestone, g/kg DM   | 10.0 | 10.0 | 10.0 |
| Vitamin/minerals premix b | 1.00 | 1.00 | 1.00 |
| Toxin binder, g/kg DM| 1.00 | 1.00 | 1.00 |

Chemical composition, g/kg of DM

| Item | 0AF | 25AF | 50AF |
|------|-----|------|------|
| DM, g/kg as fed | 914.0 | 897.0 | 879.0 |
| OM    | 904.0 | 909.0 | 910.0 |
| CP    | 160.0 | 160.0 | 159.0 |
| NDF   | 308.0 | 288.0 | 264.0 |
| ADF   | 127.0 | 128.0 | 135.0 |
| Ether extract | 13.00 | 34.00 | 56.00 |
| ME, MJ/kg DM c | 9.75 | 9.75 | 9.79 |
| Tannins d | 5.20 | 10.50 | 15.80 |
| Cost, US$/ton as fed e | 309.00 | 230.00 | 156.00 |

DM: dry matter; OM: organic matter; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; ME: metabolisable energy.

aAlternative feedstuffs were added at 0 (0AF), 25% (25AF), or 50% (50AF) on DM basis. Four composite samples per dietary treatment.

bComposition per 1 kg of the diet contained (vitamin A: 8000 U; vitamin D3: 15,000 U; vitamin E: 1 U; Mn: 0.40 μg; Zn: 0.15 μg; Fe: 0.50 μg; Cu: 0.50 μg; Co: 0.01 μg).

cDetermined based on tabular values (NRC 2007), Obeidat et al. (2009) for sesame meal, and Awawdeh and Obeidat (2013) for olive cake.

dTannins contents (g/kg) for carob, sesame meal, and olive cake were 61 (Obeidat et al. 2011), 15 (Olude et al. 2016), and 14 Sadeghi et al. 2009, respectively.

The study was conducted at the Agricultural Research and Training Unit at Jordan University of Science and Technology (JUST). The Institutional Animal Care and Use Committee at JUST approved all procedures used in this study.
Twenty-seven male Awassi lambs averaging 90 days of age and 20.0 ± 0.5 kg BW were randomly assigned to one of three dietary groups (9 lambs/group). Group one was fed the control diet (0AF), group two (25AF) and three (50AF) contained 250 and 500 g/kg (on DM basis) of the selected AF (DB, CB, OC, and SM), respectively (Table 2). Alternative feedstuffs were included in treatment diets by partially replacing barley, soybean meal, and wheat straw from the control diet. All diets were formulated to be isonitrogenous, isocaloric, and to meet nutrient requirements of growing lambs (NRC 2007). Diets were prepared every two weeks and samples of dietary ingredients and final diets were obtained and stored (−20 °C) for later analysis.

One-week adaptation period was allowed prior to offering the experiment diet. Diets were offered at ad libitum (10% refusal) once daily as a total-mixed ration. Animals had free access to fresh water throughout the study. Before the next-day feeding, refused feed for each lamb was weighed and a sample was taken. At the end of the study (69 days), all refused-feed samples were composited for each lamb and stored (−20 °C) for later analysis to evaluate nutrient intake. Lambs were weighed at the beginning of the study and every two weeks before the morning feeding throughout the study.

Offered and refused feed samples were dried (forced-air oven for 24 h at 55 °C) and then ground (1 mm; Brabender OHG, Duisburg, Germany). Following the AOAC (1990) standard procedures, feed samples were analysed for DM (100 °C in air-forced oven for 24 h; method 967.03), OM (550 °C in ashing furnace for 6 h; method 942.05), CP (Kjeldahl procedure; method 976.06), EE (Soxtec procedure, Tecator, Hoganas, Sweden; method 920.29), NDF and ADF were determined according to the procedures described by Van Soest et al. (1991) with modifications for ANKOM2000 fibre analyser (ANKOM Technology Cooperation, Fairport, NY). NDF analysis was conducted using heat-stable alpha-amylase and sodium sulphite and values were expressed with residual ash content.

Digestibility and nitrogen balance

On day 52, six lambs from each dietary group were randomly selected and individually housed in metabolism crates (1.05 m x 0.80 m designed to allow separate urine and faeces collection) to evaluate nutrient digestibility and nitrogen balance. Animals were given 4 days to adapt to metabolism crates and then followed by a collection period of 3 days. During the collection period, samples of offered and refused feed were collected, composited, ground, and saved (−20 °C) for later analyses.

For each lamb, daily faeces were collected, weighed, sampled (10%), composited, dried (55 °C), and saved (−20 °C) for later analysis. Samples of offered and refused feed and dried faeces were analysed (using the AOAC standard procedures) for DM (method 967.03), OM (method 942.05), N (method 976.06), EE (method 920.29), and NDF and ADF (ANKOM) to calculate nutrient digestibilities. Urine was collected in plastic buckets containing 10 ml 6 N HCl. For each lamb, daily urine was weighed, sampled (5%), and saved (−20 °C) for later analysis to calculate N retention as a per cent and as amount of intake N.

Slaughtering procedure, carcass characteristics and meat quality

At end of the study (after 18 h fasting) all lambs were slaughtered at 0900 h by trained personnel according to a standard slaughter procedure (Abdullah et al. 1998). Fastig live weight was recorded immediately before slaughter and hot carcass weight was recorded immediately after slaughter. Carcasses were then chilled (at 4 °C for 24 h) and then weighed to determine cold carcass weights. Dressing percentage was calculated as cold-carcass weight percentage of the fasting live weight. Non-carcass components (lungs and trachea, liver, heart, spleen, testes, kidneys, kidney fat and mesenteric fat) were removed and weighed.

The day after slaughter, chilled carcasses were split in halves and further into four commercial cuts (i.e. shoulders, racks, loins and legs) and the following linear dimensions were measured: leg fat depth (L3), tissue depth (GR), rib fat depth (J), eye muscle depth (D), eye muscle width (A), rib-eye area, fat depth (C) and shoulder fat depth (S2) as described by Abdullah et al. (1998) and Abdullah and Musallam (2007).

Upon cutting, the right loin cut was dissected and the longissimus muscle (rib eye) was excised, immediately vacuum-packed, and stored (−20 °C) for 2 weeks for meat quality assessment. Also, right legs from each carcass were dissected to measure total lean, bone, and fat contents. At the time of meat quality assessment, frozen longissimus muscles were thawed (in a cooler at 4 °C overnight) and divided into pieces where each piece was used for specific meat quality measurement (pH, water holding capacity-WHC, color-CIE L*a*b* coordinates, shear force, and cooking loss) as described by Abdullah and Musallam (2007).
Table 3. Performance and nutrient intakes of growing male Awassi lambs fed different levels of alternative feedstuffs.

| Item            | 0AF  | 25AF | 50AF | SEM  | p-value |
|-----------------|------|------|------|------|---------|
| n               | 9.00| 9.00| 9.00|      |         |
| Initial BW, kg  | 20.00| 20.30| 19.70| 0.50| .68     |
| Final BW, kg    | 33.10| 32.10| 30.20| 1.18| .23     |
| Total gain, kg  | 13.10| 11.80| 10.50| 1.15| .30     |
| ADG, g/d        | 190.00| 171.00| 152.00| 14.40| .30     |

Nutrient intake, g/d

| Item            | 0AF  | 25AF | 50AF | SEM  | p-value |
|-----------------|------|------|------|------|---------|
| DM              | 1059.00a| 993.00a| 817.00b| 50.50| <.01    |
| OM              | 955.00a| 900.00b| 748.00b| 48.50| <.01    |
| CP              | 211.00a| 177.00b| 131.00b| 9.80 | <.01    |
| EE              | 24.00a| 66.00b| 85.00b| 4.10 | <.01    |
| NDF             | 256.00a| 262.00a| 207.00b| 15.30| .03     |
| ADF             | 85.00a| 105.00a| 98.00b| 7.10 | .16     |
| ME, MJ/d        | 10.20a| 9.54b| 7.87b| 0.50| <.01    |
| FCRd            | 5.80| 6.20| 5.80| 0.48| .81     |
| ME efficiency3  | 77.60| 73.80| 80.20| 5.80| .74     |
| Cost of gain, US$/kgg | 1.83a| 1.44b| 0.92b| 0.11| <.01    |

DM: dry matter; OM: organic matter; CP: crude protein; NDF: neutral detergent fibre; ADF: acid detergent fibre; ME: metabolisable energy.
a,b,cWithin row, means with different superscript are different at p value <.05.
dAlternative feedstuffs were added at 0 (0AF), 25% (25AF), or 50% (50AF) on DM basis.

Results

Ingredient and chemical composition of dietary treatments

Chemical composition of AF is presented in Table 1. Crude protein content was greatest for SM (457 g/kg) and least for CB and OC (< 80 g/kg) with 146 g/kg for DB. Olive cake contained the greatest amount of NDF (533 g/kg) and ADF (345 g/kg) and DB contained the least amount (24 and 6 g/kg, respectively). The ether extract was substantially greatest for OC and SM (170 and 117 g/kg, respectively). Olive cake provided the least amount of metabolisable energy (4.18 MJ/kg).

Nutrient intake and lamb performance

Throughout the study, all lambs were healthy and no health issues related to treatment diets were observed. Performance and nutrients intake of lambs fed different levels of AF are shown in Table 3. No significant (p > .23) differences were observed among dietary treatments in final body weight, total gain, and ADG. Numerically, lambs fed the 50AF diet had lower final BW than those fed the 0AF or 25AF diets.

Lambs fed the 50AF diet had the least (p < .01) intake of CP and EE increased with increasing AF in treatment diets. No significant (p = .16) differences were observed in ADF intake among dietary treatments. Feed conversion ratio and efficiency of ME use were not different (p > .74) among treatment diets. Cost of gain was lowest (p < .01) for lambs fed the 50AF diet, intermediate for those fed the 25AF diet, and highest for lambs fed the 0AF diet.

Statistical analysis

Data were analysed using the MIXED procedure of SAS (2002) and lamb was included as a random variable. Initial body weight was used as a covariate for analysing growth performance. Cold carcass weight was included as a covariate for analysing carcass components and cuts weight. For leg composition, leg weight was included as a covariate. Treatment means were computed using the LSMEANS option and separated using preplanned pair-wise comparisons of least squares means using t-tests. Significant effects were considered at p-value ≤.05 and tendency was considered at p-value ≤.10.
Table 5. Carcass and non-carcass components of growing male Awassi lambs fed different levels of alternative feedstuffs.

| Item                             | 0AF    | 25AF   | 50AF   | SEM    | p-value |
|----------------------------------|--------|--------|--------|--------|---------|
| n                                | 9.00   | 9.00   | 9.00   | 1.00   | .19     |
| Fasting live, kg                 | 31.70  | 31.00  | 29.20  | 0.96   | .19     |
| Hot carcass, kg                  | 15.20  | 14.50  | 13.00  | 0.66   | .07     |
| Cold carcass, kg                 | 14.80  | 14.30  | 12.80  | 0.67   | .11     |
| Dressing percentage, %          | 46.60  | 46.10  | 43.50  | 0.96   | .07     |
| n                               | 7.00   | 7.00   | 7.00   | 8.00   |          |
| Carcass cuts, kg                 |        |        |        |        |         |
| Shoulders                        | 5.60   | 5.40   | 5.40   | 0.08   | .17     |
| Legs                             | 5.30a  | 5.20b  | 5.50a  | 0.12   | .04     |
| Racks                            | 1.10   | 1.10   | 1.10   | 0.10   | .93     |
| Loins                            | 1.10   | 1.10   | 1.00   | 0.07   | .62     |
| Tail fat                         | 0.60   | 0.87   | 0.72   | 0.10   | .06     |
| Non-carcass components, kg       | 1.36   | 1.38   | 1.26   | 0.13   | .61     |

a,b Within row, means with different superscript are different at p < .05.

Table 6. Carcass linear dimensions and fat measurements of growing male Awassi lambs fed different levels of alternative feedstuffs.

| Item                     | 0AF    | 25AF   | 50AF   | SEM   | p-value |
|--------------------------|--------|--------|--------|-------|---------|
| n                        | 7.00   | 7.00   | 8.00   | 1.00  | .02     |
| Leg fat depth (L3), mm    | 2.10a  | 4.10a  | 2.60a  | 0.46  | .02     |
| Tissue depth (GR), mm     | 11.10a | 14.60a | 10.90a | 0.83  | <.01    |
| Rib fat depth (J), mm     | 2.70   | 4.10   | 2.70   | 0.65  | .06     |
| Eye muscle width (A), mm  | 51.90  | 51.60  | 47.20  | 1.60  | .10     |
| Eye muscle depth (B), mm  | 24.10  | 23.20  | 21.70  | 1.10  | .27     |
| Fat depth (C), mm         | 1.60a  | 2.80a  | 1.70b  | 0.24  | <.01    |
| Shoulder fat depth (S2), mm| 2.30  | 2.60   | 1.90   | 0.32  | .29     |
| Rib-eye area, cm²         | 11.10  | 10.20  | 9.40   | 0.54  | .12     |

a,b Within row, means with different superscript are different at p < .05.

Table 7. Leg characteristics of growing male Awassi lambs fed different levels of alternative feedstuffs.

| Item, g                    | 0AF    | 25AF   | 50AF   | SEM   | p-value |
|----------------------------|--------|--------|--------|-------|---------|
| n                          | 7.00   | 7.00   | 8.00   | 1.00  | .24     |
| Leg weight, g              | 2485.00| 2419.00| 3550.00| 123.00| .24     |
| Total muscle, g            | 1555.00| 1545.00| 1509.00| 112.00| .10     |
| Total muscle, g/100 g      | 66.80  | 63.00  | 64.90  | 4.40  | .10     |
| Total fat, g               | 194.00 | 264.00 | 227.00 | 100.00| .32     |
| Total fat, g/100 g         | 6.60   | 9.40   | 7.90   | 4.40  | .34     |
| Subcutaneous fat, g        | 157.00 | 227.00 | 190.00 | 88.90 | .31     |
| Subcutaneous fat, g/100 g  | 5.20   | 7.90   | 6.30   | 4.00  | .33     |
| Intermuscular fat, g       | 59.00  | 63.00  | 63.00  | 10.10 | .82     |
| Intermuscular fat, g/100 g | 2.30   | 2.50   | 2.50   | 0.50  | .78     |
| Total bone, g              | 542.00| 566.00 | 531.00 | 31.10 | .72     |
| Total bone, g/100 g        | 22.70  | 23.90  | 22.20  | 1.60  | .76     |
| Others, g                  | 127.00 | 190.00 | 151.00 | 22.10 | .18     |
| Others, g/100 g            | 5.40   | 7.70   | 6.30   | 0.80  | .17     |

aAlternative feedstuffs were added at 0 (0AF), 25% (25AF), or 50% (50AF) on DM basis.

Table 8. Loin meat quality data of growing male Awassi lambs fed different levels of alternative feedstuffs.

| Item                        | 0AF    | 25AF   | 50AF   | SEM    | p-value |
|-----------------------------|--------|--------|--------|--------|---------|
| pH                          | 7.00   | 7.00   | 8.00   | 0.00   | .37     |
| Cooking loss, %             | 38.80  | 38.80  | 37.70  | 1.70   | .46     |
| Water holding capacity, %   | 28.50  | 29.30  | 30.90  | 1.40   | .47     |
| Shear force, kg/cm²         | 4.90   | 4.70   | 4.90   | 0.32   | .81     |
| Color coordinates           |        |        |        |        |         |
| Lightness, L*               | 36.00  | 38.30  | 37.30  | 1.90   | .71     |
| Redness, a*                 | 3.10a  | 1.90b  | 1.90p  | 0.20   | <.05    |
| Yellowness, b*              | 18.70  | 23.10  | 19.30  | 2.70   | .50     |

a,b Within row, means with different superscript are different at p < .05.

Digestibility and nitrogen balance

Nutrient digestibilities and N balance results are presented in Table 4. Digestibility of DM and OM were not different (p ≥ .54) among dietary treatments. Crude protein digestibility was lowest in lambs fed the 50AF diet (p < .01) and did not differ between the 0AF and 25AF diets. The digestibility of NDF and ADF was highest (p < .01) for the 0AF diet and did not differ between the 25AF and 50AF diets. Ether extract digestibility was greatest (p < .01) for the 50AF, intermediate for the 25AF, and least for the 0AF diet.

Intake, faecal, urinary, and retained N were not significantly (p ≥ .08) affected with dietary treatments. Numerically, N intake was lower and N excreted in faeces was higher in lambs fed the 50AF diet compared to those fed the 0AF diet, subsequently, retained N (g/d) was numerically lower.

Carcass characteristics and meat quality

There were no differences among dietary treatments in fasting live weight (Table 5). Hot and cold carcass weights tended (p < .11) to be greater for lambs fed the 0AF than the 50AF diet. Dressing percentage tended to be lowest (p = .07) for the 50AF diet, with no differences between the 0AF and 25AF diets.

No significant differences (p ≥ .17) were observed among treatment diets in carcass cuts except for the legs and tail fat weights. Lambs fed the 50AF had (p = .04) greater legs weight and tended (p = .06) to have lower fat tail weights than those fed the 25AF diet, but not different from the 0AF diet. Non-carcass components were not different (p = .61) among treatment diets.

Carcass linear-dimensions and fat measurements of lambs fed different levels of AF are presented in Table 6. No significant differences (p ≥ .10) in eye
muscle width (A) and depth (B), shoulder fat depth (S2), and rib-eye area were observed among dietary treatments. However, leg fat depth (L3), tissue depth (GR), and fat depth (C) were greatest \((p ≤ .02)\) for the 25AF diet, with no differences between the 0AF and the 50AF diets.

Leg characteristics of lambs fed different levels of AF are presented in Table 7. No significant differences \((p > .10)\) were observed among treatment diets in leg composition (muscle, fat, and bone weights and percentages) or fat composition (subcutaneous and intermuscular fat weights and percentages). Meat quality data of lambs fed different levels of AF are presented in Table 8. No significant differences \((p > .37)\) were observed among dietary treatments in all meat quality parameters except for the redness coordinate, which was highest \((p < .05)\) for the 0AF diet.

**Discussion**

**Ingredient and chemical composition of dietary treatments**

The chemical composition of AF used in this study was within the average values reported previously for DB (Hindiyeh et al. 2011), CB (Obeidat et al. 2011), OC (Awawdeh and Obeidat 2013), and SM (Obeidat et al. 2009). Ether extract contents of the 25AF and 50AF diets increased linearly as a result of replacing low-EE feedstuffs (soybean meal and wheat straw < 20 g/kg) with higher-EE feedstuffs (OC and SM > 110 g/kg).

**Nutrients intake and lamb performance**

Depression in nutrients (DM, OM, NDF, and ME) intake of lambs fed the 50AF diet was probably due to high dietary contents of EE and tannins. dos Santos et al. (2016) suggested that increased EE content may depress diet palatability of lambs. An inverse relationship exists between diet content of tannin and palatability (Kumar and Vaithiyanathan 1990). It is known that OC and CB have high content of tannins (Chiofalo et al. 2004).

We observed that dietary inclusion of AF at 250 g/kg did not affect nutrients intake of lambs but at higher levels (500 g/kg) it depressed nutrients intake. Consistent with our results, dietary inclusion of Prosopis juliflora at 250 g/kg had no effects on DM intake, but higher levels (350 and 450 g/kg) depressed nutrient intake of Awassi lambs (Abdullah and Hafes 2004). Nutrients intake of sheep was not affected when DB was included in the diet up to 300 g/kg (Afzalzadeh et al. 2007; França et al. 2012; Obeidat et al. 2012) or when CB was included up to 250 g/kg (Priolo et al. 1998; Obeidat et al. 2011). Additionally, dietary inclusion of OC up to 250 g/kg (Omar et al. 2012; Awawdeh and Obeidat 2013; Ozdogan et al. 2017) or SM up to 200 g/kg (Omar 2002; Obeidat et al. 2009; Hassan et al. 2013) did not affect nutrients intake of Awassi lambs. Ether extract intake of lambs increased linearly as the level of AF increased in treatment diets. This is simply a result of higher contents of EE in AF (namely, OC and SM). Similar to our results, dietary inclusion of SM up to 200 g/kg (Omar 2002) or up to 160 g/kg (Obeidat et al. 2009) increased EE intake of lambs.

In our study, no significant effects of feeding AF at 250 g/kg on lamb performance (total gain, final weight, ADG, and feed conversion ratio) were observed. Similar to our results, no effects on lamb performance were detected when diets contained up to 250 g/kg of DB (Afzalzadeh et al. 2007; Obeidat et al. 2012), 250 g/kg of CB (Priolo et al. 1998; Obeidat et al. 2011), 400 g/kg of SM (Obeidat et al. 2009; Hassan et al. 2013), or up to 200 g/kg OC (Al Jassim et al. 1997; Owaimer et al. 2004; Mioc et al. 2007; Omar et al. 2012; Awawdeh and Obeidat 2013).

On the other hand, it has been demonstrated that performance was depressed in lambs fed diets containing up to 300 g/kg of DB (Hindiyeh et al. 2011), 560 g/kg of CB (Priolo et al. 2000; Vasta et al. 2007), or 300 g/kg of OC (Al Jassim et al. 1997; Mioc et al. 2007). In the current study we observed that at the high inclusion level (500 g/kg), AF numerically reduced lamb performance (i.e. final body weight). Although lambs fed the 50AF diet had numerically the lowest ADG, feed conversion ratio was not different as a result of lower DM intake.

**Digestibility and nitrogen balance**

Digestibility of DM and OM did not differ among dietary treatments in the current study. This is consistent with previous studies that included CB at 250 g/kg (Obeidat et al. 2011), OC at 120 g/kg (Owaimer et al. 2004), or SM at 160 g/kg (Obeidat et al. 2009). Other studies have shown depression in DM digestibility with dietary inclusion of CB at 560 g/kg (Priolo et al. 2000) or urea-treated OC at 300 g/kg (Al Jassim et al. 1997).

Crude protein digestibility was lower in lambs fed the 50AF than those fed the 0AF and 25AF diets. Consistent with this result, CP digestibility decreased in sheep fed diets containing 560 g/kg of CB (Priolo et al. 2000) or 128 g/kg of OC (Yañez-Ruiz and Molina-
Decreased CP digestibility of the 50AF diet was probably due to a greater proportion of protein associated with cell wall components. Digestibility of NDF and ADF were depressed in lambs fed the 25AF or 50AF diets compared to the 0AF group. Similar results were reported in sheep fed diets containing peach palm meal (dos Santos et al. 2016), CB (Priolo et al. 2000), or OC (Yáñez-Ruiz and Molina-Alcaide 2007). According to Kumar and Vaithiyananathan (1990), an inverse relationship exists between tannin contents of the diet and nutrient digestibility. It has been suggested that tannins in feeds could potentially bind with dietary proteins, cellulose, and hemicellulose and making them unavailable to ruminal microbes and/or the animal. The high tannin in AF could be the reason behind the low digestibility of CP, NDF and ADF. Additionally, high contents of fat (especially unsaturated fatty acids) in the diet could reduce nutrient digestibilities (especially fibre and protein) due to the possible toxic effect on ruminal microbes (dos Santos et al. 2016). Furthermore, the cell wall components and/or structure of AF (especially OC) could have been more resistant to fermentation by ruminal microbes.

In the current study, EE digestibility increased linearly with increasing the level of AF in the diet, simply due to higher EE intake. This is consistent with dos Santos et al. (2016). Numerically, N intake was lowest and N excreted in faeces was highest for lambs fed the 50AF diet. This is a direct result of lower DM intake and depressed CP digestibility in lambs fed the 50AF diet.

**Carcass characteristics and meat quality**

In the current study, lambs fed the 50AF diet tended to have lower hot and cold carcass weights compared with those fed the 0AF diet, subsequently; dressing percentage was numerically lower for the 50AF diet. Consistent with our results, dietary inclusion of 200 g/kg CB (Priolo et al. 1998), 300 g/kg OC (Mioč et al. 2007), or 160 g/kg SM (Obeidat et al. 2009) decreased dressing percentage of lambs. In contrast, dietary inclusion of CB at 250 g/kg (Obeidat et al. 2011), OC at 150 g/kg (Mioč et al. 2007), or SM at 150 g/kg (Hassan et al. 2013) had no effects on hot and cold carcass weights or dressing percentage of lambs.

In our study, treatment diets had no effects on shoulders, racks, and loins weights. This is consistent with other studies (Obeidat et al. 2011; Hassan et al. 2013; Afzalzadeh et al. 2007) that used similar AF (CB, SM, and DB, respectively). Lambs fed the 25AF diet in our study tended to have heavier tail fat. Similarly, inclusion of DB at 200 g/kg in fattening Awassi lambs diets increased tail fat weights (Hindiyeh et al. 2011).

In the current study, non-carcass components weights were similar among treatment diets. Similarly, Obeidat et al. (2011) found that dietary inclusion of CB up to 250 g/kg did not affect non-carcass components weights of Awassi lambs. In contrast, inclusion of 80 and 160 g/kg SM decreased non-carcass components of Awassi lambs (Obeidat et al. 2009).

In the current study, eye muscle width, depth, and rib-eye area were similar among treatment diets. These results are consistent with previous studies that used SM (Obeidat et al. 2009), CB (Obeidat et al. 2011), or OC (Owaimer et al. 2004) as AF in feeding lambs. Inconsistent with previous studies that used SM (Obeidat et al. 2009) or CB (Obeidat et al. 2011), lambs fed the 25AF diet in the current study had the highest leg fat depth, tissue depth, and fat depth compared with lambs fed the 0AF or 50AF diets.

It is known that low intake and/or digestibility of dietary fibre leads to low ruminal production of acetate (a major precursor for fatty acid synthesis) and this would affect fat accumulation in different body tissues (Hanson and Ballard 1967). Neutral detergent fibre intake and digestibility was lower for the 50AF than the 25AF diet in the present study. Additionally, EE intake was greater for lambs fed the 25AF and 50AF diets compared to the 0AF diet. Thus, the observed high leg fat and fat depths in lambs fed the 25AF diet were probably a combination of greater EE (compared to the 0AF diet) and NDF (compared to the 50AF diet) intake.

Consistent with previous studies (Awawdeh et al. 2009; Obeidat et al. 2011), treatment diets had no effects on leg composition. Consistent with our results, treatment diets had no effects on meat quality parameters (Awawdeh et al. 2009; Obeidat et al. 2009; 2011), except for lower redness values for the 25AF and 50AF diets. We did not observe changes in blood haemoglobin levels (data not shown) in response to treatment diets. Thus, low redness values observed in our study could be related to mechanisms other than a direct change in blood haemoglobin/myoglobin concentrations as suggested by Priolo et al. (1998).

**Conclusions**

Lambs fed diets containing 250 g/kg alternative feedstuffs (dry bread, carob pods, olive cakes, and sesame meal) had similar growth rate to those fed the conventional diet. Dietary inclusion of alternative...
feedstuffs at 500 g/kg could negatively impact lamb performance (nutrient intake, carcass weight, and dressing percentage) with similar feed conversion ratio to the conventional diet.

Carcass characteristics and meat quality were not substantially affected by both inclusion levels (250 or 500 g/kg). Cost of gain was least for lambs fed the 50AF diet, intermediate for the 25AF diet, and highest for the control diet.

Replacing conventional feedstuffs from lamb diets with two levels (250 or 500 g/kg) of alternative feedstuffs was successful and reduced production cost without causing any health problems to lambs. Under the condition of our study, it is recommended to include alternative feedstuffs in lambs diet at 250 g/kg which supported similar performance obtained by the conventional diet but with lower cost.

Although 500 g/kg dietary inclusion of alternative feedstuffs could negatively affect lamb performance, it is a recommended approach in terms of cost of gain. Future research investigating methods (mechanical, chemical, and biological) to improve the utilisation of alternative feedstuffs by lambs should be encouraged. This will lead to efficient use of such feedstuffs in sheep diets even at higher inclusion levels.

Acknowledgements

Thanks are due to the manager and staff of ARTU at JUST.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was supported by the Deanship of Scientific Research at JUST (#24/2016).

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