Lactation performance of Awassi ewes fed diets containing either *Atriplex halimus* L. or olive cake

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**ABSTRACT**

The objective of the two studies was to evaluate the effects of feeding on lactating Awassi ewes (study 1) and lambs (study 2), fed a diet of *Atriplex halimus* L. (ATR) or olive cake (OC), as a foraging source substitute for wheat straw. In study 1, 33 newly lambed ewes and their lambs were randomly assigned one of three diets: The control diet (CON), 250 g/kg of OC, or 250 g/kg of ATR dry matter (DM). Ewes and lambs were housed in individual pens. Ewes fed CON diet had greater DM, neutral detergent fibre, and acid detergent fibre intakes than OC and ATR groups. Ether extract (EE) intake was greater (*p* < .0001) in OC diet compared to CON and ATR diets. Milk yield was similar (*p* = .99) among treatments. Content of milk total solids and fat were greater in ATR diet than CON and OC diets. Milk production cost was lower in the OC and ATR compared to the CON group. In study 2, 18 ewe lambs were assigned the same diets used in study 1 to evaluate the effects of OC and ATR on nutrient digestibility and N balance. Dry matter digestibility was greater in ATR compared to CON and OC groups. The digestibility of EE was greater in the OC group than in CON and ATR groups. Results showed that the inclusion of OC and ATR did not negatively impact lactation performance. Additionally, results proved the economic value of using such products, as they reduced the cost of milk production.

**HIGHLIGHTS**

- Olive cake and *Atriplex halimus* L. were fed to Awassi ewes at a level of 250 g/kg of dietary DM.
- The inclusion of olive cake and *Atriplex halimus* L. at 250 g/kg of dietary DM, as a source of fibre, did not negatively impact the lactation performance of sheep.
- Additionally, results proved the economic value of using such products, as they reduced the cost of milk production.

**Introduction**

Wheat straw is commonly used as a foraging source in small ruminant diets; however, it contains high levels of fibre and low levels of protein, which result in lower digestibility and productivity (Obeidat et al. 2014). Obeidat (2017) suggested that olive cake (OC) – the agro-industrial byproduct of olive oil extraction – and *Atriplex halimus* L. (ATR) – a Mediterranean saltbush – are suitable alternative foraging sources to wheat straw (Obeidat et al. 2016).

Olive cake is the byproduct of the extraction of oil from olive fruits; about 65% of the world's olive trees are cultivated in Mediterranean countries (Garcìa et al. 2003), making this a major industry in the region. As only 200–270 g/kg of the whole olive fruit can be used to produce olive oil, the rest is a byproduct, mainly in the form of OC (Awawdeh and Obeidat 2013). Weinberg et al. (2008) showed that OC contains around 80 g/kg of crude protein (CP), 580 g/kg of nutrient detergent fibre (NDF), 460 g/kg of acid detergent fibre (ADF), and 90 g/kg of ether extract (EE) dry matter (DM) basis. In a recent study, Obeidat (2017) showed that the inclusion of 150 g/kg of OC in the diet of Awassi lambs may be a cost-effective dietary inclusion compared to traditional feed sources, with no adverse effects on animal performance.

*Atriplex halimus* L. is a shrub native to Jordan and represents almost 65% of the saltbush ranch in the Middle East; it tolerates drought and salinity and is well-adapted to live in semi-arid and arid conditions (Shawket et al. 2010; Walker et al. 2014). Lambs that...
receive ATR have a higher daily milk yield than lambs that only receive berseem hay (Shawket and Ibrahim 2013). In contrast, the replacement of barley straw with 300 g/kg of ATR leaves does not stimulate higher milk yields in the feeding of Awassi ewes (Abbeddou, Rischkowsky, Hilali, et al. 2011). The rate of milk production remains the same in Awassi ewes receiving 50% of saltbush as those ewes receiving 100% of the same saltbush (Abu-Zanat and Tabbaa 2006).

The hypothesis of this study was that developing alternative feedstuffs for small ruminants would decrease production costs and, ultimately, improve profitability. The objective of the current study is to evaluate the effect of the inclusion of OC and ATR, as a dietary forage source in substitution of wheat straw, on the lactating performance of newly lambed Awassi ewes and the growth rates of their male lambs.

Material and methods

Two studies were conducted in the Animal Field at the Research and Training Department, Faculty of Agriculture, Jordan University of Science and Technology (JUST). OC was purchased from a local olive fruits mill. Atriplex halimus L. (ATR) was collected from the university campus. Both OC and ATR were sundried before preparing the diets. The diets were prepared specifically to meet the nutrient requirements of newly lambed ewes, according to the NRC (2007), and contained 150 g/kg of dietary DM CP. The dietary groups are as follows: Control diet (CON) containing no ATR or OC, 250 g/kg of OC, and 250 g/kg ATR dietary DM, as a substitute for wheat straw. The content of nutrients and dietary ingredients can be found in Table 1.

Study 1

Intravaginal sponges were used to estrually synchronise 75 ewes for lambing consistency among the experimental animals. Of those synchronised, 33 ewes (initial body weight (BW) = 56.5 ± 2.13 kg; age = 4 to 5 years) expecting single male lambs were randomly assigned into three dietary groups (11 ewes/diet). The chosen ewes gave birth within four days of each other. Ewes were housed with their lambs in individual, shaded pens measuring 0.75 x 1.5 m and equipped with plastic feed and water troughs, allowing them free access to clean water and their assigned diets. Feeds were offered daily at 08:00. The nutrient intake was measured daily throughout the experiment, which lasted 9 weeks. The first week was deemed the adaptation period (to both their diet and their pens), and the following 8 weeks were designated for data collection.

The BW of ewes and their lambs (TCS-SS stainless steel, waterproof electronic platform scale, Gromy Industry Co., Ltd., China) was measured at the commencement of the trial and every 2 weeks until the end of the trial. At the same time of weighing, their milk yield and composition were also evaluated. To determine milk yield, ewes were given 0.75 mL oxytocin intravenously, milked by hand at 08:00 by trained personnel, and lambs were separated from their dams for 4 h after the first milking. Ewes were then given a second dose of oxytocin, milked again, and the milk yield weighed. Milk yield was adjusted over a 24-h period. A 125 mL sample was collected from each ewe and analysed for total solids (in a forced-air oven at 55 °C), fat (Gerber method), and CP (Kjeldahl procedure: N x 6.38).

For chemical analysis, diets and feed-refusal samples were analysed for DM (method #967.03), CP (method #976.06), and EE (method #920.29) according to procedures described by AOAC AOAC AOAC (1990). Fibre parameters (NDF and ADF) were analysed using an ANKOM2000 fibre analyser (ANKOM Technology

| Item                                      | CON | OC | ATR |
|-------------------------------------------|-----|----|-----|
| Ingredients, g/kg dry matter (DM)         |     |    |     |
| Barley grain, whole                       | 580 | 610| 645 |
| Soybean meal, 440 g/kg CP (solvent)       | 150 | 120| 85  |
| Wheat straw                               | 250 | 0  | 0   |
| Olive cake                                | 0   | 250| 0   |
| Atriplex halimus L.                       | 0   | 0  | 250 |
| Salt                                      | 10  | 10 | 10  |
| Limestone                                 | 9   | 9  | 9   |
| Vitamin–mineral premix                    | 1   | 1  | 1   |
| Feed cost/t, US$                          | 353 | 282| 269 |
| Ingredients, g/kg DM                      |     |    |     |
| Dry matter                                | 912 | 908| 909 |
| Crude protein (CP)                        | 153 | 155| 154 |
| Neutral detergent fibre (NDF)             | 317 | 281| 249 |
| Acid detergent fibre (ADF)                | 134 | 125| 89  |
| Ether extract (EE)                        | 10  | 53 | 14  |
| Ash                                       | 8.15| 5.78|7.14|

\*Diets were: The control diet (CON), 250 g/kg olive cake (OC), and 250 g/kg Atriplex halimus L. (ATR) of dietary DM. \*\*Contained 16 g/kg CP, 689 g/kg NDF, 380 ADF, 5 g/kg EE and 88 ash of DM basis. \*\*\*Contained 80 g/kg CP, 508 g/kg NDF, 332 g/kg ADF, 203 g/kg EE and 67.0 g/kg ash of DM. \*\*\*\*Contained 114 g/kg CP, 524 g/kg NDF, 322 g/kg ADF, 22 g/kg EE and 72.8 g/kg ash of DM. \*\*Composition per kg contained: vitamin A, 600,000 UI; vitamin D<sub>3</sub>, 200,000 UI; vitamin E, 75 mg; vitamin K<sub>3</sub>, 200 mg; vitamin B<sub>1</sub>, 100 mg; vitamin B<sub>5</sub>, 500 mg; lysine, 0.5%; DL-methionine, 0.15%; manganese oxide, 4000 mg; ferrous sulphate, 15,000 mg; zinc oxide, 7000 mg; magnesium oxide, 4000 mg; potassium iodide, 80 mg; sodium selenite, 150 mg; copper sulphate, 100 mg; cobalt phosphate, 50 mg; dicalcium phosphate, 10,000 mg. Calculated based on the prices of diet ingredients for the year 2019.
Data were analysed in a completely randomised design, using the MIXED procedure of the Statistical Analysis System (version 8.1, 2000, SAS Inst. Inc., Cary, NC). Milk yield and composition were analysed for the variance of repeated measures in a model including treatment, week, and the treatment × week interaction. The appropriate covariance structure of the data was chosen for each analysis from the structures of compound symmetric, autoregressive order one, and unstructured (based upon the Schwarz Bayesian criterion). As no treatment × week interaction was detected, only the treatment effects are discussed. For the different diets, nutrient intakes, and ewe and lamb BWs, milk yield cost the only fixed effect was treatment. A probability of $p < .05$ was considered a significant difference.

**Study 2**

Eighteen Awassi lambs (BW = $33.5 \pm 0.69$ kg; age = 6 to 7 months) were randomly assigned the same diets used in study 1 (six ewe lambs/diet) to evaluate the effect of OC or ATR on nutrient digestibility and N balance. The experiment lasted 21 days with an adaptation period of 14 days, housed individually in shaded pens ($0.75 \times 1.5$ m) and a collection period of seven days in metabolic cages ($0.8 \times 1.05$ m). From days 15 to 21, lambs were placed in metabolic cages equipped with trays for faecal and urinary collections. Daily faecal output was collected, weighed, and recorded, with 10% kept for subsequent analyses. Urine was collected in containers, weighed, and recorded, with 5% kept at $-20^\circ$C to evaluate NB. Each bottle contained 50 mL of 6 N HCL to prevent ammonia losses. At the end of the study, faecal and urinary samples were composited for each lamb. Faecal and dietary samples were dried in a forced-air oven at $55^\circ$C for several days to reach a constant weight and weighed to determine DM content. The samples were then ground in a Wiley mill (Brabender OHG, Duisburg, Kulturstrasse 51–55, type 880845, Nr 958084, Germany), passed through a 1 mm screen, and stored in plastic bags at room temperature for subsequent analyses, using the procedures described by AOAC (1990).

For the determination of N balance, the collected urinary samples were composited for each lamb and analysed for nitrogen (N) content using the Kjeldahl procedure. The intake of N was calculated by multiplying DM intake by the N content of each diet. Loss of N was calculated by multiplying N content in faeces and urine by faecal and urinary output, respectively. Retained N (g/day) was then calculated by subtracting faecal and urinary output from the N intake. The retention of N (g/100 g) was calculated by dividing the retained N by N intake.

Data were analysed using the MIXED procedure of SAS (version 8.1, 2000, SAS Institute Inc., Cary, NC), where the lamb was the random variable. For all data, treatment was the fixed effect. The least-square means of the MIXED procedures of SAS was used to further identify significant differences among means. Significant differences were considered at ($p < .05$).

**Results**

Dry matter, NDF, and ADF intakes were greater ($p < .04$) in ewes fed the CON diet than the OC and ATR diets (Table 2). Intake of EE was greater ($p < .0001$) in those ewes fed the OC diet, compared to the CON and ATR diets.

No significant differences ($p > .80$) were detected in the final BW, total gains, and average daily gain of the ewes and lambs across the three diets (Table 3).

**Table 2.** Effects of feeding olive cake (OC) or *Atriplex halimus* L. (ATR) on the nutrient intake of Awassi ewes fed lactation diets (Study 1).

| Item                  | CON (n = 11) | OC (n = 11) | ATR (n = 11) | SEM | p-Value |
|-----------------------|-------------|-------------|-------------|-----|---------|
| Nutrient intake, g/d  |             |             |             |     |         |
| Dry matter            | 2534a       | 2333b       | 2394b       | 86.0| .04     |
| Crude protein         | 388         | 362         | 353         | 13.3| .07     |
| Neutral detergent fibre| 803a       | 656b       | 571c        | 25.3| <.0001 |
| Acid detergent fibre  | 340a         | 292b       | 204c        | 10.9| <.0001 |
| Ether extract         | 28b          | 124a       | 32b         | 3.2 | <.0001 |

1Diets were: The control diet (CON), 250 g/kg OC, and 250 g/kg ATR of dietary DM. *Means within a row, without a common superscript, differ significantly ($p < .05$).

Abbreviations. SEM: Standard error mean; CON: control diet; OC: olive cake; ATR: *Atriplex halimus* L.; DM: dry matter.

**Table 3.** Effect of feeding olive cake (OC) or *Atriplex halimus* L. (ATR) on the body weight of ewes and the growth rate of lambs (Study 1).

| Item                  | CON (n = 11) | OC (n = 11) | ATR (n = 11) | SEM | p-Value |
|-----------------------|-------------|-------------|-------------|-----|---------|
| Ewes                  |             |             |             |     |         |
| Initial body weight, kg| 56.6        | 56.1        | 56.7        | 2.3 | .97     |
| Final body weight, kg  | 56.0        | 55.0        | 56.0        | 1.2 | .90     |
| Body weight change, kg | −0.7        | −1.1        | −0.7        | 1.5 | .97     |
| Lambs                 |             |             |             |     |         |
| Initial body weight, kg| 5.3         | 5.5         | 5.3         | 0.2 | .80     |
| Final body weight, kg  | 17.6        | 17.8        | 17.4        | 0.8 | .93     |
| Total gain, kg         | 20.3        | 23.8        | 24.6        | 1.6 | .97     |
| Average daily gain, g  | 220          | 221         | 217         | 13.2| .98     |

4Diets were: The control diet (CON), 250 g/kg OC, and 250 g/kg ATR of dietary DM.

Abbreviations. SEM: Standard error mean; CON: control diet; OC: olive cake; ATR: *Atriplex halimus* L.; DM: dry matter.
The milk production did not differ ($p = .99$) among diets (Table 4). The total solids and fat content were greater ($p < .01$) in ewes fed the ATR diet compared with the CON and OC diets. The cost of milk production was lower ($p < .04$) in diets containing OC and ATR than in the CON diet.

The nutrient intake, digestibility and N balance parameters are shown in Table 5. No significant differences were detected in CP, NDF, and ADF digestibility among the treatments. Digestibility of EE was greater ($p < .001$) in the OC group compared to the CON and ATR groups. No differences ($p \geq .47$) in N intake, N loss in faeces and urine, N retained (g/d), and N retention (g/100 g) were observed among the three treatment groups.

### Discussion

In agreement with previous studies dealing with alternative feedstuffs (Obeidat 2018, 2020; Aloueedat et al. 2019; Hatamleh and Obeidat 2019), the cost of diets diminished by 20 and 24% in the OC and ATR diets, respectively, compared to the CON diet. These findings could be due to the fact that the cost of alternative feeds is cheaper than that of conventional feeds. As a result, the use of alternative feeds reduces the cost of feeding, which – assuming it does not affect the health and performance of the animals consuming these feeds – will positively affect the profitability of owning these animals.

In this current study, nutrient intake is the highest among the control group, with the exception of EE intake, which was the highest among the OC group (Table 2). These results are different from other similar research; for example, one study showed that animal feed treatment with ATR resulted in a higher intake of EE, compared to the CON – it referred to the differences in the nutritional composition between ATR and wheat straw, as ATR showed higher protein and energy levels than wheat straw (Abu-Zanat and Tabbaa 2006). The nutrient intake of the ruminants positively correlated with digestibility. This contrasts with the low energy and protein content in the wheat
low level of CP in the ATR diet was enough to maintain these animals (1050 g of feed). However, the decent stop eating after they ingested 800 g of herbage concentration of 205 g/kg of DM. The animals fed on this diet research, as it was reported that the feed intake pounds. This is consistent with results from other content and the presence of secondary chemical com-

The presence of tannins in the plant, at a level of 100 g/kg DM, is considered toxic. Tannins may inhibit cellulolytic and proteolytic enzymes and, as a result, decrease the rate of fermentation and volatile fatty acid production in the rumen. Moreover, the high level of salt in ATR encourages the animal to consume increased amounts of water, which negatively impacts the physiology and metabolism of rumen. In the current study, the feed intake among the ATR group decreased, mainly due to the high salt content and the presence of secondary chemical compounds. This is consistent with results from other research, as it was reported that the feed intake decreased in diets containing ATR with an ash concentration of 205 g/kg of DM. The animals fed on this diet stopped eating after they ingested 800 g of herbage DM, which is less than the normal requirements for these animals (1050 g of feed). However, the decent level of CP in the ATR diet was enough to maintain the animals’ requirements. (Freer et al. 1997).

Our results indicate that the reduced intake for those animals in the OC group, compared to those being fed a regular dietary formula, maybe extrapolated by the issue of palatability (Abbeddou, Rischkowsky, Richte, et al. 2011) or the high level of lignin (Hadjipanayiotou 1999) in the OC feed. The existing results corroborate the literature. For example, Cabiddu et al. (2004) disclosed that OC silage may reduce the intake in Sarda ewes once added in amounts equal to 250 or 500 g DM/head/day. However, the performance of these animals remained constant. This current study also found that the intake of EE is highest in the OC silage group, which may be a result of the residual oils used in OC production and, therefore, influences the EE in the OC group ewes (Hadjipanayiotou 1999).

Table 3 demonstrates the role CON, OC, or ATR diets play in inducing changes in the BW of ewes and the growth performance of lambs. According to this current experiment, there were no differences between initial BW and final BW among the three diets. These findings are in line with the research conducted by Abu-Zanat and Tabbaa (2006), who reported that the increase of DM intake in the saltbush-supplemented group did not affect BW. The same results were observed in Chios ewes and Damascus goats fed OC silage, as the final BW was not altered (Hadjipanayiotou 1999). Notably, the residual oil in OC enhanced the energy in the diet of Sarda ewes, thus, helping to maintain the weight of these animals (Cabiddu et al. 2004).

The results of this current study represent an improvement in growth and the weight gain of lambs across the three groups; however, there are no significant differences across the groups in the average daily gain. The recent results agree with another study that showed the role of high CP content in ATR in enhancing milk production and growth in lambs (Abu-Zanat and Tabbaa 2006). The administration of saltbush, in combination with annual pasture, barley, and lupin grain during ewes’ feedings, did not affect the lamb birth weight or the pre-weaning growth rate (Chadwick et al. 2009).

The ATR treatment showed no significant changes in milk production, despite the higher energy and protein content, compared to wheat straw. This could be due to the presence of secondary chemical compounds that decrease feed intake (El-Shakhret et al. 1996), but this study proposes that milk production is unaffected as a result of insufficient intake that is unable to maintain the animals’ requirements and normalise the milk yield. These results agree with several previous studies (Abu-Zanat and Tabbaa 2006; Abbeddou, Rischkowsky, Hilali, et al. 2011). In this study, the total solid content and fat content were the highest among the ATR group. These results agree with Abbeddou, Rischkowsky, Hilali, et al’s (2011) study, in which he reported that ATR had many positive effects on the nutritional composition of milk, increasing protein, fat, and total solids. Moreover, the ash increases the total solids due to the high concentration of potassium, sodium, and chloride in ATR, leading to an increase in the concentration of these minerals in the milk (Abbeddou, Rischkowsky, Hilali, et al. 2011). According to our findings, OC does not affect the rate of milk production. These results are consistent with a study on Awassi ewes – the replacement of barley with 300 g/kg OC does not affect milk yield, but it may trigger a reduction in milk protein (Abbeddou, Rischkowsky, Hilali, et al. 2011). Similarly, Chiofalo et al. (2004) reported that the use of 200 g/kg of OC to feed ewes decreased the casein and protein percentages, compared to the CON. This could be explained by the higher milk production in the OC group, leading to a decrease in the concentration of these nutrients at a higher volume of milk. Chiofalo
et al. (2004) indicated that the lactose and fat contents in milk were unaffected when the amount of OC in the diet reached 200 g/kg. Abbeddou, Rischkowsky, Hilali, et al. (2011) reported that replacing 300 g/kg of barley straw with OC in the feeding of Awassi ewes did not affect the milk fat and protein, compared to the CON, whereas the OC group had higher lactose – the total solids and solids-not-fat in the milk were similar to the control. Similarly, Cabiddu et al. (2004) reported that OC silage did not affect the fat and protein content of milk during the feeding of Sarda ewes (250 and 500 g DM/head/day).

Concurrent with the results of the current study, Al-Shdaifat and Obeidat (2019) observed that milk cost was reduced when dried distillers’ grains and soluble byproducts were included in the diets of Awassi ewes at 200 and 300 g/kg of DM as an alternative to other feedstuff ingredients. In addition, Obeidat (2020) reported similar findings when a black cumin meal was fed to Awassi lambs at 150 g/kg of DM. The results of this current study and results from previous studies confirm that the use of alternative feeds has a positive impact on profitability in its use in feeding small ruminants.

Many previous studies showed that ATR can negatively affect digestibility (Salem et al. 2010). However, other research shows that there was no effect of ATR on the nutrient’s digestibility (Al-Owaimer et al. 2008, 2011). The results in this current study demonstrated an increase in the digestibility of DM, which could be explained by differences in the nutritional content between ATR and wheat straw. The higher protein and energy levels in ATR enhance the digestibility in rumen. Conversely, the inclusion of ATR may increase the digestibility of protein due to the high solubility of N in the ATR, which increases the digestible CP in the rumen (Salem et al. 2010). The presence of secondary compounds could have a positive effect on animals, at a certain level, by protecting dietary proteins from rumen degradation, which leads to decreased methane production and improves nutrient utilisation (Salem et al. 2010). Moreover, our research indicates no significant differences in the N balance between the three groups. Similarly, a study by Al-Owaimer et al. (2008) also showed no significant differences in the NB between the CON and the ATR diets, although it did remain higher in the CON group. Al-Owaimer et al. (2011), however, showed significant differences between the ATR and the CON groups. Moreover, ATR supplementation combined with a source of energy may increase the utilisation of N, N retention, and N absorption and decrease the animal’s urinary N excretion (Salem et al. 2005). In this study, no effect of this diet on the N balance. These results are supported by Obeidat (2017), who reported that feeding OC did not attenuate the N intake or N loss and retention. However, in his study, the OC does positively affect the N balance if the diet contains 150 g/kg OC (Obeidat 2017).

One limitation that should be considered during the use of OC in the nutrition of ruminants is its low digestibility. This may be due to the polymerisation that occurs between different phenols, proteins, and cellulose during oil extraction (Molina-Alcaide and Nefzaoui 1996). The resulting polymers as lignin are unavailable for digestion in ruminants, and they may interfere with the digestibility of other nutrients (Abbeddou, Rischkowsky, Richte, et al. 2011); for example, the apparent digestibility of CP and organic matter decreases upon polymer formation. In contrast, the digestibility of EE increases (Molina-Alcaide and Nefzaoui 1996).

**Conclusions**

Under the conditions of the current study, the inclusion of OC and ATR at 250 g/kg of dietary DM, as a substitution for wheat straw, did not have a negative impact on ewe lactation performance and offspring growth rate. Instead, the results showed a beneficial economic effect by reducing production costs, compared to the costs of the CON group.

**Ethical approval**

All procedures were performed after obtaining the approval of the Institutional Animal Care and Use Committee of JUST.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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