Iranian Society of Animal Science

Journal of Livestock Science and Technologies

Shahid Bahonar University of Kerman

ISSN: 2322-3553 (Print) ISSN: 2322-374X (Online)

Digestibility, ruminal characteristics, and meat quality of fattening lambs fed different levels of fennel (*Foeniculum vulgare*) seed powder

Zohre Hajalizadeh, Omid Dayani, Amin Khezri and Reza Tahmasbi

Department of Animal Science, College of Agriculture, Shahid Bahonar University of Kerman, Kerman, Iran.

*Corresponding author,
E-mail address:
odayani@uk.ac.ir

Received: 06 May. 2020,
Accepted: 04 Jun. 2020,
Published online: 01 Jul. 2020.

Abstract The objective of this experiment was to evaluate of effect of fennel seed powder (FSP) on digestibility, ruminal characteristics, and meat quality. In a completely randomized design, three diets containing zero (without FSP), 0.75% and 1.5% FSP were fed to 30 Kermani fattening male lambs (eight months old), with an average initial body weight of 27.5 ± 0.450 kg for 80 days. There was no effect of diets on apparent nutrient digestibility, but dry matter intake (DMI) was higher (P<0.05) for the diets containing FSP. The lambs fed the FSP diets had more final body weight (BW), weight of warm carcass and lean meat than lambs fed control diet (P<0.05). Ruminal pH, and NH_3-N and acetic acid concentrations were higher in lambs on FSP diets than in control group (P<0.05). Ruminal protozoal population and propionic acid concentration were lower (P<0.05) in lambs fed FSP than the control diets. The meat fat content decreased but protein content increased in lambs fed on FSP diets. The malondialdehyde concentration in *Longissimus dorsi* of lambs fed FSP diets was lower compared with the control lambs. The results suggested that fennel seed feeding to fattening lambs, by improving the ruminal fermentation and meat quality, might be a suitable natural antioxidant for the meat production industry.

Keywords: fennel seed, rumen, meat quality, performance

Introduction

Plant extracts have demonstrated an antimicrobial effect *in vitro*, but their influence on growth performance of farm animal species has not been sufficiently documented (Hernandez et al., 2004). The oxidative reaction in meat is important because lead to the deterioration of important sensory properties such as flavor, texture, and color (Decker et al., 1995). Lipid oxidation in meat and meat products can be reduced or inhibited by the use of antioxidants. Natural antioxidants from plants such as herbs and spices (tea, rosemary, oregano, cinnamon, sage, thyme, mint, ginger, and clove) decrease lipid oxidation (Yashin et al., 2017). Plant extracts are secondary metabolites with antimicrobial activity against a wide range of micro-organisms including bacteria, protozoa and fungi (Patra et al., 2010).

Fennel (*Foeniculum vulgare* L.), a perennial herb of the Apiaceae family, possesses antimicrobial activity (Chiej, 1984). Estragole is the major ingredient of fennel essential oil, which also contains trans-anethole, limonene and the cyclic monoterpenes fenchone (Barazani et al., 2002). The fennel antioxidant activities are related to the concentration of trans-anethole and estragole

(Shahat et al., 2011). Saeedi et al. (2016) reported that 0.8% fennel powder in calf starter decreased ruminal fluid pH and increased ammonia nitrogen content and concentration of total short-chain fatty acids, as well as propionate molar percentage. There are no published reports on the antioxidative effect of fennel seeds in lamb meat. Hence, the present study aimed to investigate the effect of fennel seed powder on meat quality, rumen characteristics and rumen fluid volatile fatty acid (VFA) production in fattening lambs.

Materials and methods

Animals and experimental diets

This study was carried out using 30 Kermani fattening male lambs (eight months old), with an average initial body weight of 27.5 ± 0.450 kg. The lambs were divided into three equal groups with ten pens (1.2 × 1.5 m), with bedded straw, in a sheltered, cemented-floor, open-side barn, well-ventilated, and equipped with feeding and watering facilities. The animals, maintained according to the guidelines set by the Iranian Council of Animal Care (1995), were individually fed, twice per day, at 08:00 and 16:00, for *ad libitum* intake to allow 10% orts All lambs were initially shorn, reated with albendazole. (Roacel) for internal parasites, and vaccinated against enterotoxemia (The Razi Vaccine and Serum Research Institute, Iran), and clinically examined during the study during which, no cases of severe clinical diseases were observed.

The experimental diets were: 1) control (without FSP); 2) diet containing 0.75% FSP, and 3) diet containing 1.5% FSP (Table 1). Samples (n = 5) of the experimental diets were ground (1-mm screen), and analyzed for dry matter (DM), crude protein (CP), ether extract (EE) and ash (AOAC, 2000). The NDF and ADF contents were determined according to Van Soest et al. (1991).

Dry matter intake and diet digestibility

Daily feed intake was calculated every day by measuring the orts. From day 5 until the day before slaughter, samples of feces were collected twice daily and stored at –20°C for apparent digestibility estimation. The acid insoluble ash (AIA) content of the feed and the feces was determined using the procedure of Van Keulen and Young (1977).

Ruminal parameters

The day before slaughter, ruminal fluid was collected via

Table 1. The ingredients and chemical composition of three experimental diets (DM basis)

	Diet with specified FSP level (%)		
Ingredients	0	0.75	1.5
Alfalfa hay, chopped	30	30	30
Wheat straw, chopped	10	10	10
FSP	0	0.75	1.5
Barley grain, ground	28	27.25	26.5
Corn grain, ground	9	9	9
Soybean meal	8	8	8
Wheat bran	13	13	13
Vitamin premix[1]	0.6	0.6	0.6
Trace-mineralized salt[2]	0.6	0.6	0.6
Sodium bicarbonate	0.5	0.5	0.5
Limestone	0.3	0.3	0.3
Chemical composition			
Dry matter (%)	89.94	89.96	89.99
Metabolizable energy (Mcal/kg DM)	2.51	2.51	2.51
Crude protein (%)	13.98	14.00	14.02
Organic matter (%)	92.61	92.53	92.46
Ether extract (%)	2.25	2.31	2.37
Neutral detergent fiber	39.39	39.24	39.09
Acid detergent fiber	24.02	23.96	23.91

FSP: Fennel seed powder.
[1] Contained 5,000,000 IU Vitamin A; 5,000,000 IU Vitamin D and 500,000 IU Vitamin E per kg.
[2] Composition: 75.15% NaCl, 3.046% Mn, 1.025% Cu-sulfate, 0.253% Zn-sulfate, 0.015% Ethylenediamine dihydroiodide-80 and 0.011% Na-selenide.

a stomach tube connected to a suction pump approximately 3–4 h after the morning meal. Immediately after sampling, the pH of the ruminal fluid was determined using a digital pH meter (AZ, Model 8601), and the samples were strained through three layers of cheesecloth. A 10 mL sample of the ruminal fluid from each animal was mixed with 1 mL metaphosphoric acid, and another 5 mL were mixed with 0.1 mL 50% sulfuric acid for determination of VFA and ammonia nitrogen, respectively, and the samples stored at -20 °C. A 20- mL sample of the ruminal fluid was centrifuged at 3500 × g for 10 min. After centrifugation, the supernatant samples were mixed with 25% meta-phosphoric acid at a 5:1 ratio and stored at –20°C in 15-mL tubes. Concentration of ruminal fluid VFA was determined by gas chromatography (Model CP 9002). For protozoal enumerations, 4 mL of the ruminal fluid were added to 4 mL of methyl-green formalin saline (MFS) solution (Ogimoto and Imai, 1981) and stored in a dark place. The protozoal population was determined using a light microscope (Olympus CH-2).

At the end of the fattening period, the lambs were fasted for 18h (water was allowed), weighed, and slaughtered on the same day at a slaughterhouse in Kerman city. The weights of the warm and cold (i.e., after 24 h chilling at 4 °C) carcasses, excluding the head, were recorded. The cold carcass was dissected into the leg, loin, shoulder, breast, and neck joints (Kashan et al., 2005). The eye muscle area was determined after tracing the cross-section of the *Longissimus dorsi* muscle between the 12^{th} and 13^{th} thoracic vertebrae (without cover fat) on the graph paper. The back fat depth at the 12^{th}-13^{th} rib cross-section was measured with a caliper. A portion of the *Longissimus dorsi* muscle between the 6^{th} –13^{th} ribs) was then dissected, back fat removed, and stored at -20 °C for determination of pH, chemical composition and lipid oxidation 30 days after storage.

Meat quality

To determine the meat pH, 5 g *Longissimus dorsi* muscle were homogenized with 25 mL distilled water. The homogenates were filtered, and the pH measured with a pH meter at room temperature (Jang et al., 2008).

For dripping loss measurement, the right side of the *Longissimus dorsi* muscle was cut into 2.5-cm thick pieces. Each piece was weighed, rapped into a net made of cotton, transferred into a plastic bag, and stored in a chilling room at 4 °C. After 24 h, each piece of meat was lightly dabbed with a soft tissue, weighed again, and the drip loss calculated (Christensen, 2003).

For determination of the cooking loss, a 1-cm^3 meat sample was cut from the carcass, weighed, and stored for 24 h at 4 °C. Then, the sample was transferred to a water bath at 85 °C for 10 min, gently dabbed, weighed, and the cooking loss calculated (Bertram et al., 2003).

The water holding capacity (WHC) was estimated by centrifuging 1g of the meat placed on tissue paper inside a tube for 4 min at 1500 g. The water remaining after centrifugation was quantified by drying the samples at 70°C overnight (Castellini et al., 2002).

The chemical composition of meat including the crude protein (CP), crude fat (ether extract), DM, and ash was determined by Kjeldahl (BUCHI k370), Suxhelt, oven drying, and burning (Model SEF 202P) the sample in an electric furnace, respectively (AOAC, 2000).

Thiobarbituric acid reactive substances (TBARS) assay performed as described by Tarladgis et al. (1960). Duplicate samples (0.5 g) for all the experimental treatments were mixed with 2.5 mL of stock solution (0.375% thiobarbituric acid (Sigma T5500), 15% trichloroacetic acid (Merck k46451107), and 0.25 N-HCl (Merck k36816017). The mixture was heated for 10 min in a boiling water bath (100°C) until it turned pink. The samples were then cooled in tap water, centrifuged at 2000 g for 25 min, and the absorbance measured spectrophotometrically (HALO, model XB10) at 532 nm against a blank that contained all the reagents except the meat. The MDA concentration was calculated using an extinction coefficient (1.56×10^5 M^{-1} cm^{-1}), and the absorbance values were converted to MDA (in ppm) by using the following equation:

TBA (mg MDA/kg meat) = Sample A_{532} × 2.77

Statistical analyses

The data were analyzed using the Mixed procedure (SAS, 2005) according to a completely randomized design. Data on digestibility, blood and ruminal parameters, etc. were analyzed using the following model:

$Y_{ij} = \mu + T_i + e_{ij}$;

where, Y_{ij} = dependent variable, μ = population mean, T_i = treatment effect and e_{ij} = random error.

The Duncan's multiple range test was used to compare the means. The initial live body weight was used as a co-variate for final BW, and the carcass weight as a co-variate for analysis of carcass components. The effects were considered significant at $P\leq0.05$.

Results

The nutrient digestibility was not affected by feeding FSP but both levels of FSP increased the DMI (Table 2). The data on performance and meat production are given in Table 3. The final BW and warm carcass weight were greater (P<0.05) in lambs fed diet with 1.5% FSP than those fed the control diet (P<0.05). The lambs fed FSP (0.75 and 1.5%) had lower (P<0.05) cold shrinkage than those fed the control diet. The *longissimus dorsi* muscle lean meat weight was increased significantly (P<0.05) in animals fed FSP diet. The lowest back fat depth (mm) was observed in lambs fed 0.75% FSP diet. Lambs fed the 1.5% FSP diet had larger (P<0.05) eye muscle area than other groups. The lambs offered the diet containing FSP had higher pH value and mean ammonia nitrogen than the control group (Table 4; P<0.05). The diet containing 1.5 % FSP resulted in lower (P<0.05) protozoal population than the control diet (Table 4).

Adding FSP to the diet increased acetate and decreased propionate concentrations in the ruminal fluid (Table 5; P<0.05); but no effects were found for other fatty acids and total VFA.

Chemical compositions of the *Longissimus dorsi* are given in Table 6. Meat DM in lambs fed 0.75% FSP in the diet was lower than the control diet (P<0.05). Fat and total protein decreased and increased, respectively, in meat by adding FSP to the diet. The highest fat content in meat was observed in lambs fed the control diet, and the highest protein content was recorded in lambs fed 1.5% FSP. Meat ash was not affected by the experimental diets.

Meat pH at 24 hours, water holding capacity (WHC), and dripping loss after one-month storage were not affected by the experimental diets; however, cooking loss

Table 2. Dry matter intake and nutrient digestibility in lambs fed diets containing fennel seed powder (FSP)

	FSP concentration (% DM)			SEM	*P value*	Contrast	
	0	0.75	1.5			Linear	Quadratic
Dry matter intake (kg)	1.37[b]	1.41[a]	1.43[a]	0.01	0.01	0.003	0.45
Digestibility (%)							
Dry matter	75.18	76.57	78.87	2.52	0.61	0.89	0.34
Crude protein	58.25	66.15	67.04	4.52	0. 50	0.09	0.43
Organic matter	59.60	70.62	64.11	7.76	0.73	0.55	0.68

[a,b] Within row, means with common superscript are not different (P>0.05).
SEM: standard error of the mean.

Table 3. Growth and carcass characteristic of lambs fed diets containing fennel seed powder (FSP)

	FSP concentration (% DM)			SEM	*P value*	Contrast	
Characteristic	0	0.75	1.5			Linear	Quadratic
Final live weight (kg)	44.7[b]	45.8[a]	46.5[a]	0.23	0.02	0.27	0.59
Warm carcass weight (kg)	20.74[b]	21.20[ab]	21.99[a]	0.36	0.03	0.24	0.34
Cold shrinkage (% warm carcass)	2.6[a]	1.81[b]	1.91[b]	0.2	0.01	0.23	0.09
Lean meat (kg)	14.28[b]	14.70[ab]	15.43[a]	0.34	0.02	0.17	0.26
Back fat depth (cm)	4.50[a]	3.10[b]	4.00[a]	0.28	0.01	0.02	0.23
Eye muscle area (cm^2)	17.08[b]	16.96[b]	20.44[a]	0.77	0.03	0.09	0.04

[a,b] Within rows, means with common superscript (s) are not different (P>0.05).
SEM: standard error of the mean.

Table 4. Ruminal pH, NH3-N and protozoa in lambs fed diets containing fennel seed powder (FSP)

	FSP concentration (% DM)					Contrast	
Parameters	0	0.75	1.5	SEM	*P value*	Linear	Quadratic
Ruminal fluid pH	5.72[b]	6.23[a]	6.13[a]	0.123	0.035	0.08	0.05
NH_3-N concentration (mg/dL)	13.04[b]	17.55[a]	17.66[a]	1.24	0.033	0.03	0.84
Protozoa populations (×10^5 cells/mL)							
Entodinium	8.33[a]	7.18[ab]	4.55[b]	0.76	0.02	0.03	0.05
Holotricha	0.10	0.15	0.14	0.06	0. 58	0.62	0.92
Cellulolytica	0.31	0.13	0.13	0.09	0.09	0.01	0.74
Total protozoa	8.80[a]	7.48[ab]	4.83[b]	0.94	0.035	0.05	0.09

[aa,b] Within rows, means with common superscript (s) are not different (P>0.05).
SEM: standard error of the mean.

Table 5. Ruminal volatile fatty acid (VFA) concentration in lambs fed diets containing fennel seed powder (FSP)

	FSP concentration (% DM)					Contrast	
VFA (mmol/L)	0	0.75	1.5	SEM	*P value*	Linear	Quadratic
Acetate	49.56[b]	53.26[b]	60.06[a]	2.09	0.024	0.11	0.28
Propionate	17.20[a]	16.26[a]	14.33[b]	0.777	0.049	0.12	0.54
Butyrate	8.38	10.14	10.10	1.73	0.522	0.66	0.42
Isobutyrate	0.31	0.65	0.30	0.099	0.06	0.11	0.51
Valerate	0.91	1.03	0.90	0.113	0.662	0.34	0.20
Isovalerate	0.17	0.47	0.16	0.148	0.211	0.9	0.19
Total VFA	76.51	82.29	86.02	3.251	0.051	0.64	0.28

[a,b]Within rows, means with common superscript are not different (P>0.05).
SEM: standard error of the mean.

Table 6. Chemical composition of *Longissimus dorsi* muscle in lambs fed diets containing fennel seed powder (FSP)

Traits (%)	FSP concentration (% DM)					Contrast	
	0	0.75	1.5	SEM	*P value*	Linear	Quadratic
Dry matter	32.69[a]	30.05[b]	31.30[ab]	0.644	0.05	0.20	0.03
Ash	1.45	1.80	1.80	0.211	0.44	0.21	0.98
Fat	8.99[a]	6.55[b]	6.35[b]	0.491	0.009	0.08	0.78
Total protein	20.79[b]	21.30[b]	22.39[a]	0.289	0.01	0.02	0.10

[a,b]Within rows, means with common superscript (s) are not different (P>0.05).
SEM: standard error of the mean.

Table 7. Malonaldehyde content and meat quality of lambs fed diets containing fennel seed powder (FSP)

	FSP concentration (% DM)					Contrast	
Traits	0	0.75	1.5	SEM	*P value*	Linear	Quadratic
MDA (nmol/mg protein)	0.501[a]	0.310[b]	0.365[b]	0.031	0.032	0.65	0.13
Cooking less (%)	40.92[a]	38.39[ab]	36.91[b]	0.996	0.047	0.35	0.02
Dripping less (%)	14.44	15.27	14.52	0.864	0.762	0.55	0.68
Water holding capacity (%)	67.16	69.41	68.54	0.977	0.313	0.54	0.16
pH	5.36	5.36	5.28	0.035	0.251	0.15	0.37

[a,b]Within rows, means with common superscript (s) are not different (P>0.05).
MDA: malondialdehyde.
SEM: standard error of the mean.

was lower in the meat of lambs that received 1.5% FSP as compared with the control diet (Table 7). Dietary FSP supplementation decreased (P<0.05) lipid oxidation (MDA formation) in the *Longissimus dorsi* after storage at -20°C for one month (Table 7).

Discussion

Dry matter intake, performance and diet digestibility

The lambs fed 0.75 and 1.5% FSP diets consumed more DM than the control group. This might be due to the antimicrobial effects of FSP on the pathogenic microorganisms in the digestive system and enhancing environment of the rumen (Obeidat, 2020). In addition, Cabuk et al. (2003) noted that anethole and estragole, the ingredients in FSP, had appetite-stimulating effects. Bown (2001) reported that fennel seeds increases appetite and prevents gastrointestinal disorders. Enhanced DM intake in the current study is consistent with the observations of Saeedi et al. (2016) that supplementation of the starter diets with 0.4 and 0.8% (DM basis) FSP increased DMI in Holstein dairy calves. Nutrient digestibility in animal fed FSP not affected. This can be explained by the same percentages of NDF, ADF and moisture in the experimental diets. In addition, several observational studies indicated no effect of adding essential oils on the digestibility of nutrients (Castillejos et al., 2006; benchaar et al., 2007). Zolfaghari Moheb et al. (2015) also reported that nutrient digestibility was not affected by fennel by-product. Derakhshan Nia et al. (2017) showed that organic matter digestibility was highest in the diet containing 12 g fennel powder compared to control diet under *in vitro* conditions.

In this study, FSP in the experimental diet caused to increase the final body weight and warm carcass weight in the lambs. This increase is due to greater DMI in those lambs. In another study, FSP increased BW of Holstein dairy calves (Saeedi et al., 2016). Generally, dietary sup-

plementation with active compounds such as those in fennel, due to increased consumption of DM, improved the energy status and weight gain in livestock (Saeedi et al., 2016; Fazaeli et al., 2018).

Cold shrinkage in lambs fed FSP was lower than lambs fed the control diet. Generally, greater shrinkage indicates poorer water-holding capacity in muscles (More-O'Ferrall et al., 1989); in the present study, the meat water-holding capacity in FSP lambs was numerically but non- significantly greater than the control group. The lean meat weight and eye muscle area were greater and back fat depth was lower for the lambs fed the diet containing 1.5% FSP than those fed the control diet which might be due to phenolic component in fennel (Karami et al., 2010) and greater final body weight of lambs in this group. Adding herbal antioxidants to the diet of goats resulted in numerically decreased back fat depth (Karami et al., 2010).

Ruminal parameters

In the present trial, ruminal fluid pH was higher in lambs on FSP diets; which may reflect the lower concentration of propionic acid and increased acetate ratio. In some studies, plant essential oils, used in *in-vitro* trials with mixed ruminal microorganisms, resulted in a general inhibition of rumen microbial fermentation (Oh et al., 1967; Busquet et al., 2006). Propionate concentration decreased and acetate increased significantly by addition 1.5 % FSP to experimental diets. However, FSP levels had no effect on total VFAs concentration. Several studies (Richardson et al., 1976; Lana and Russell, 1997) demonstrated that growth promoters used in animal diets such as monensin, increased the propionate concentration and reduced the proportion of acetate. In fact, monensin affects some gram-positive bacteria which are involved in fermentation processes that produce acetate. In this experiment, FSP showed a greater inhibitory effect on gram negative bacteria, in contrast to monensin that inhibits mainly gram-positive bacteria (Castillejos et al., 2007). In an *in vitro* study, Cardozo et al. (2004) reported that the addition of 0.22 mg/L of oregano reduced the molar proportion of propionate and increased the molar proportion of acetate and the acetate to propionate ratio during the first 6 days of fermentation. These results were contrary to the observations of Cardozo et al. (2005), who reported that anise (the main component of which is anethole) decreased acetate and increased propionate proportions. Busquet et al. (2006) reported that anethole had a high capacity to modify rumen microbial fermentation and reduced the proportion of acetate and propionate in the rumen. *In-vitro* studies with rumen fluid showed that anethole decreased total VFA production (Calsamiglia et al., 2007; Kilic et al., 2011). The increased rumen VFA concentration with medicinal herbs and their components might be achieved when the undissociated hydrophobic active molecules are more active against microbial membranes (Cardozo et al., 2006). The effect of medicinal herb on volatile fatty acid concentration may depend on the type of substrate fed to ruminants.

In this study, total protozoa and *entodiniomorpha* populations decreased when 1.5 % FSP was added to the experimental diet. This may be due to the lipophilic nature of the compounds, such as anethole which can permeate across the protozoal membrane (Cardozo et al., 2006) and lead to the destruction of the cell membrane, inhibition of enzymes and lack of substrates which are essential for cell metabolism (Goel et al., 2005). Patra et al. (2010) found that fennel extract did not affect the ruminal protozoal. Fandino et al. (2008) reported that anise reduced the concentrations of total protozoa, *entodiniomorphs,* and *holotrichs*, supporting its antiprotozoal effect. The ruminal protozoa in sheep (Newbold et al., 2004) and dairy cattle (Benchaar et al., 2007) were not affected when fed a mixture of essential oils.

Ruminal ammonia-nitrogen was higher in lambs fed the diets containing FSP. Protein degradation is a complex process that includes proteolysis, peptidolysis and deamination (Castillejos et al., 2007). The study discussed demonstrated that proteolysis was not greatly affected by addition of essential oils in the diet (Castillejos et al., 2005). McIntosh et al. (2003) observed that essential oils inhibited degradation of amino acids to ammonia without affecting the proteolytic or peptidolytic activity. Probably these effects might also depend upon the types of protein sources present in the diet.

Several reports indicated that addition of essential oils resulted in a reduction in the number of hyper-ammonia producing bacteria, but only when the animal received low protein diets (McEwan et al., 2002; Wallace et al., 2002). Some essential oil compounds decreased ammonia nitrogen concentrations at low doses. Anethole up to 3000 mg, carvacrol and carvone up to 300 mg (Busquet et al., 2006), limonene and thymol up to 50 mg and eugenol up to 500 mg did not affect ammonia nitrogen concentrations in the rumen (Castillejos et al., 2006). However, ammonia nitrogen concentrations were decreased with oregano oil at 30 and 300 mg and

cinnamon oil at 0.3-300 mg (Cardozo et al., 2005). Sallam et al. (2009) reported the black seed and fennel extract significantly decreased the NH3-N concentration.

Meat quality

Plant extracts rich in polyphenols are good candidates as natural antioxidants, and can prevent lipid oxidation in food products (Brenes et al., 2008). In this study, lambs that consumed fennel seed powder had the lowest MDA content and cooking loss. Antioxidant substrates in fennel seeds, like anethole, could reduce the adverse effects of oxidative deterioration (Gharaghani et al., 2013). Water and ethanol extracts of fennel seeds showed strong antioxidant activity, so that 100 µg of water and ethanol extracts exhibited 99.1% and 77.5% inhibition of peroxidation in the linoleic acid system, respectively (Oktay et al., 2003). Dietary supplementation of turkeys with 200 mg/kg of oregano essential oil significantly decreased lipid peroxidation of cooked and fresh meat during refrigeration storage (Botsoglou et al., 2003). The aqueous extracts of five umbelliferous fruits, such as fennel (*Foeniculum vulgare*), showed strong antioxidant activity that was superior to the known antioxidant ascorbic acid (Satyanarayana et al., 2004). It was found that fennel seeds increased the mice plasma superoxide dismutase, catalase activity and the high-density lipoprotein level, while decreasing the MDA level (Choi and Hwang, 2004).

There were no differences between diets in muscle pH. The main factor determining the quality of meat is its pH, which is related to biochemical processes during the transformation of muscle to meat (England, 2018). Changes in the pH during the post-slaughter period influence the organoleptic characteristics of the meat. So that, stress before slaughter in lambs increase the level of pH (Beriain et al., 2000). The pH (24 h) observed (below 5.8) was similar to that found by Valero et al. (2014) in crossbred bulls fed with essential oils. The muscle pH increased after dietary oregano essential oil incorporation in female sheep that might have reflected different glycogen reserves pre-slaughter (Simitzis et al., 2008). Differences may be related to different utilization of dietary energy or a different reaction to the stress of slaughter, due to the activity of specific muscle enzymes (Hopkins et al., 2001). In chickens, oregano incorporation in feed did not affect the pH values (Young et al., 2003).

Protein contents in muscle were increased in lambs fed the FSP diets, which could be due to lower muscle fat content in FSP lambs; it has been reported that an increase in intramuscular fat might lead to reduced myoglobin and sarcoplasmic protein concentrations in the meat (Kim et al., 2014). Fennel seeds contain polyunsaturated fatty acids (Barros et al., 2010) like linoleic and linolenic acids (56.94 % PUFA). Marinova et al. (2007) investigated the influence of fish oil supplement in the diets of lambs on the fatty acid composition of fat tissues. They showed differences in fat distribution in the carcass, and suggested that polyunsaturated fatty acids could affect the carcass fatness and meat quality. Generally, natural feed supplements from plants such as the essential oils have improved the quality characteristics of meat in lambs (Simitzis et al., 2008).

Conclusions

Feeding FSP to fattening lambs improved the performance and meat yield and had a positive effect on meat quality, meat composition, and fat oxidation. It also increased ruminal ammonia, acetate and nitrogen concentrations. It is suggested that fennel seed may be a good additive for improving the ruminal environment, and a suitable natural antioxidant for the meat production industry.

Disclosure statement

The authors declare that there is no conflict of interest regarding the publication of this article.

References

AOAC, 2000. Official Methods of Analysis, 17th ed. Association of Official Analytical Chemists, Arlington, VA, USA.

Barazani, O., Cohen, Y., Fait, A., Diminshtein, S., Dudai, N., Ravid, U., Friedman, J., 2002. Chemotypic differentiation in indigenous populations of *Foeniculum vulgare* var. vulgare in Israel. *Biochemical Systematics and Ecology* 30, 721-731.

Barros, L., Carvalho, A.M., Ferreira, I.C.F.R., 2010. The nutritional composition of fennel (*Foeniculum vulgare*): shoots, leaves, stems and inflorescences. *Journal of LWT - Food Science and Technology* 43, 814-818.

Benchaar, C., Petit, H.V., Berthiaume, R., Ouellet, D.R., Chiquette, J., Chouinard, P.Y., 2007. Effects of essential oils on digestion, ruminal fermentation, rumen microbial populations, milk production, and milk composition in dairy cows fed alfalfa silage or corn silage. *Journal of Dairy Science* 90, 886-897.

Brenes, A., Viveros, A., Goni, I., Centeno, C., Sáyago-Ayerdy, S.G., Arija, I., Saura-Calixto, F., 2008. Effect of grape pomace concentrate and vitamin E on digestibility of polyphenols and antioxidant activity in chickens. *Poultry Science* 87, 307-16.

Beriain, M.J., Purroy, A., Treacher, T., Bas, P., 2000. Effect of animal and nutritional factors and nutrition on lamb meat quality. In: Ledin, I., Moran, d-Fehr P. (Eds.), Sheep and Goat Nutrition: Intake, digestion, quality of products and rangelands. CIHEAM, Zaragoza, pp. 75-86.

Bertram, H.C., Andersen, H.J., Karlsson, A.H., Horn, P., Hedegaard, J., Norgaard, L., Engelsen, S.B., 2003. Prediction of technological quality (cooking loss and Napole Yield) of pork based on fresh meat characteristics. *Meat Science* 65, 707-712.

Botsoglou, N.A., Grigoropoulou, S.H., Botsoglou, E., Govaris, A. Papageorgiou, G., 2003. The effects of dietary oregano essential oil and [alpha]-tocopherol acetate on lipid oxidation in raw and cooked turkey during refrigerated storage. *Meat Science* 65, 1193-1200.

Bown, D., 2001. New Encyclopedia of Herbs and Their Uses. The Herb Society of America. New York.

Burt, S., 2004. Essential oils: Their antibacterial properties and potential applications in foods-a review. Int. *Journal of Food Microbiology* 94, 223-253.

Busquet, M., Calsamiglia, S., Ferret, A., Kamel, C., 2006. Plant extracts affect *in vitro* rumen microbial fermentation. *Journal of Dairy Science* 89, 761-771.

Cabuk, M.A., Bozhutr, M., Lmre, N., 2003. Antibacterial properties of the essential oils isolated from aromatic plants and using possibility as alternative feed additives. *National Animal Nutrition Congress* 11, 184-187.

Calsamiglia, S., Busquet, M., Cardozo, P.W., Castillejos, L., Ferret A., Fandino, I., 2007. The use of essential oils in ruminants as modifiers of rumen microbial fermentation. Penn State Dairy Cattle Nutrition Workshop. Grantville, PA, pp. 87-100.

Cardozo, P.W., Calsamiglia, S., Ferret, A. Kamel, C., 2006. Effects of alfalfa extract, anise, capsicum and a mixture of cinnamaldehyde and eugenol on ruminal fermentation and protein degradation in beef heifers fed a high concentrate diet. *Journal of Animal Science* 84, 2801-2808.

Cardozo, P.W., Calsamiglia, S., Ferret, A., Kamel, C., 2005. Screening for the effects of natural plant extracts at different pH on in vitro rumen microbial fermentation of a high-concentrate diet for beef cattle. *Journal of Animal Science* 83, 2572-2579.

Cardozo, P.W., Calsamiglia, S., Ferret, A., Kamel, C., 2004. Effects of natural plant extracts on ruminal protein degradation and fermentation profiles in continuous culture. *Journal of Animal Science* 82, 3230-3236.

Castellini, C., Mugnai, C., Dal Bosco, A., 2002. Effect of organic production system on broiler carcass and meat quality. *Meat Science* 60, 219-225.

Castillejos, L., Calsamiglia, S., Ferret, A., 2006. Effect of essential oil active compounds on rumen microbial fermentation and nutrient flow in *in vitro* systems. *Journal of Dairy Science* 89, 2649-2658.

Castillejos, L., Calsamiglia, S., Ferret, A., Losa, R., 2007. Effects of dose and adaptation time of a specific blend of essential oil compounds on rumen fermentation. *Animal Feed Science and Technology* 132, 186-201.

Castillejos, L., Ferret, A., Calsamiglia, S., Losa, R., 2005. Effects of a specific blend of essential oil compounds and the type of diet on rumen microbial fermentation and nutrient flow from a continuous culture system. *Animal Feed Science and Technology* 119, 29-41.

Chiej, R., 1984. The Macdonald Encyclopedia of Medicinal Plants. Macdonald and Co. (Publishers) Ltd., London, P. 448.

Choi, E.M., Hwang, J.K., 2004. Anti-inflammatory, analgesic and antioxidant activities of the fruit of *Foeniculum vulgare*. *Fitoterapia* 75, 557-65.

Christensen, L.B., 2003. Drip loss sampling in porcine M. *Longissimus dorsi*. *Meat Science* 63, 469-477.

Decker, E.A., Chan, W.K.M., Livisay, S.A., Butterfield, D.A., Faustman, C., 1995. Interactions between carnosine and the different redox states of myoglobin. *Journal of Food Science* 60, 1201-1204.

Derakhshan Nia, S., Azarfar, A., Azizi-Shotorkhoft, A., Taghizadeh, M., 2017. Effect of fennel (*Foeniculum vulgare*) and cumin (*Carum carvi*) powder and *Saccharomyces cerevisiae* in comparison with monensin on *in vitro* gas production parameters, protozoa population and microbial enzyme activity of sheep. *Iranian Journal of Animal Science* 48, 399-410.

Fandino, I., Calsamiglia, S., Ferret, A., Blanch, M., 2008. Anise and capsicum as alternatives to monensin to modify rumen fermentation in beef heifers fed a high concentrate diet. *Animal Feed Science and Technology* 145, 409–417.

Fazaeli, H., Shafeyee-Varzaneh, H., Kalvandi, R., Solgi, M., Farahpour, A., Bashiri-Safa, J., 2018. Effect of powder and root extracted of Foeniculum vulgare on the performance of fattening Mehraban lambs. *Journal of Ruminant Research* 6, 69-84 (In Persian).

England, E., 2018. 11 Factors affecting the transformation of muscle to meat. *Journal of Animal Science* 96, 495 (Abstract).

Gharaghani, H., Shariatmadari, F. Karimi Torshizi, M.A., 2013. Comparison of oxidative quality of meat of chickens fed corn or wheat based diets with fennel (Foeniculum vulgare mil.), antibiotic and probiotic as feed additive, under different storage conditions. *European Poultry Science* 77, 199-205.

Goel, G., Puniya, A.K., Aguliar, C.N., Singh, K., 2005. Interaction of gut microflora with tannins in feeds. *The Science of Nature* 92, 497-503.

Hernandez, F., Madrid, J., Garcia, V., Orengo, J., Megias, M.D., 2004. Influence of two plant extracts on broilers performance, digestibility, and digestive organ size. *Poultry Science* 83, 169-174.

Hopkins, D.L., Hall, D.G., Channon, H.A., Holsy, P.J., 2001. Meat quality of mixed sex lambs grazing pasture and supplemented with roughage, oats or oats and sunflower meal. *Meat Science* 59, 277-283.

Iranian Council of Animal Care, 1995. Guide to the Care and Use of Experimental Animals, 1. IUT, Iran.

Jang, A., Liu, X.D., Shin, M.H., Lee, B.D., Lee, S.K., Lee, J.H., Jo, C., 2008. Antioxidative potential of raw breast meat from broiler chicks fed a dietary medicinal herb extract mix. *Poultry Science* 87, 2382-2389.

Karami, M., Alimon, A.R., Yong, M.G., Awis, Q.S., Ivan, M., 2010. Effects of dietary herbal antioxidants supplemented on feedlot growth performance and carcass composition of male goats. *American Journal of Animal and Veterinary Sciences* 5, 33-39.

Kashan, N.E.J., Manafi Azar, G.H., Afzalzadeh, A., Salehi, A., 2005. Growth performance and carcass quality of fattening lambs from fat-tailed and tailed sheep breeds. *Small Ruminant Research* 60, 267-271.

Kilic, U., Boga, M., Gorgulu, M., Sahan, Z., 2011. The effects of different compounds in some essential oils on in vitro gas production. *Journal of Animal Feed Science* 20, 626–636.

Kim Y.H.B., Warner, R.D., Rosenvold, K., 2014. Influence of high pre-rigor temperature and fast pH fall on muscle proteins and meat quality. *Animal Production Science* 54, 375-95.

Lana, R.P., Russell, J.B., 1997. Effect of forage quality and monensin on the ruminal fermentation of fistulated cows fed continuously at a constant intake. *Journal of Animal Science* 75, 224-229.

McEwan, N.R., Graham, R.C., Wallace, R.J., Losa, R., Williams, P., Newbold, C.J., 2002. Effect of essential oils on ammonia production by rumen microbes. *Reproduction Nutrition Development* 42, 62 (Abstract).

McIntosh, F.M., Williams, P., Losa, R., Wallace, R.J., Beever, D.A., Newbold, C.J., 2003. Effects of essential oils on ruminal microorganisms and their protein metabolism. *Applied and Environmental Microbiology* 69, 5011-5014.

Marinova, P., Popova, T., Banskalieva, V., Raycheva, E., Ignatova, M., Vasileva, V., 2007. Effect of fish oil supplemented diet on the performance, carcass composition and quality in lambs. *Bulgarian Journal of Agricultural Science* 13, 729-738.

More-O'ferrall, G.J., Joseph, R.L., Tarrant, P.V., McGloughlin, P., 1989. Phenotypic and genetic parameters of carcass and meat-quality traits in cattle. *Livestock Production Science* 21, 35-47.

Newbold, C.J., McIntosh, F.M., Williams, P., Losa, R., Wallace, R.J., 2004. Effects of a specific blend of essential oil compounds on rumen fermentation. *Animal Feed Science and Technology* 114, 105-112.

Obeidat, B.S., 2020. The inclusion of black cumin meal improves growth performance of growing Awassi lambs. *Veterinary Sciences* 40, 1-8.

Ogimoto, K., Imai, S., 1981. Atlas of Rumen Microbiology. Japan Scientific Societies Press, Tokyo, Japan. p. 231.

Oh, H.K., Sakai, T., Jones, M.B., Longhurst, W.M., 1967. Effect of various essential oils isolated from Douglas Fir needles upon sheep and deer rumen microbial activity. *Journal of Applied Microbiology* 15, 777-784.

Oktay, M., Gulcin, I., Kufrevioglu, O.I., 2003. Determination of *in vitro* antioxidant activity of fennel (*Foeniculum vulgare*) seed extracts. *Lebensmittel-Wissenschaft und Technologie* 36, 263-271.

Patra, A.K., Kamra, D.N., Agarwal, N., 2010. Effects of extracts of spices on rumen methanogenesis, enzyme activities and fermentation of feeds *in vitro*. *Journal of the Science of Food and Agriculture* 90, 511-520.

Richardson, L.F., Raun, A.P., Potter, E.L., Cooley, C.O., Rathmacher, R.P., 1976. Effect of monensin on rumen fermentation in vitro and in vivo. *Journal of Animal Science* 43, 657–664.

Saeedi, S., Dayani, O., Khezri, A., Tahmasbi, R., 2016. The effect of using fennel powder in starter diets on performance, immunity system and biometric parameters of Holstein calves. *Iranian Journal of Animal Science* 46, 371-378.

Salinas-Rios, T., Sánchez-Torres-Esqueda1 M.T., Hernández-Bautista. J., Díaz-Cruz, A., Nava-Cuellar, C., Ortega-Cerrilla, M.E., Cordero-Mora, J.L., Vaquera-Huerta, H., Velasco, J.L.F., 2014. Carcass characteristics, physicochemical changes and oxidative stress indicators of meat from sheep fed diets with coffee pulp. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia* 66, 1901-1908.

Sallam, S.M.A., Bueno, I.C.S., Brigide, P., Godoy, P.B., Vitti, D.M.S.S., Abdalla, A.L., 2009. Investigation of potential new opportunities for plant extracts on rumen microbial fermentation *in vitro*. In: Papachristou, T.G., Parissi, Z.M., Ben Salem, H., Morand-Fehr, P. (Eds.). Nutritional and Foraging Ecology of Sheep and Goats. CIHEAM / FAO / NAGREF, Zaragoza, pp. 255-260.

SAS, 2005. SAS User's Guide. SAS Institute Inc Version 9.1. Cary, NC, USA.

Satyanarayana, S., Sushruta, K., Sarma, G.S., Srinivas N., Subba Raju G.V., 2004. Antioxidant activity of the aqueous extracts of spicy food additives-evaluation and comparison with ascorbic acid in *in vitro* systems. *Journal of Herbal Pharmacotherapy* 4, 1-10.

Shahat, A.A., Ibrahim, A.Y., Hendawy, S.F., Omer, E.A., Hammouda, F.M., Abdel-Rahman, F. H., Saleh, M.A., 2011. Chemical composition, antimicrobial and antioxidant activities of essential oils from organically cultivated fennel cultivars. *Molecules* 16, 1366-1377.

Simitzis, P.E., Deligeorgis, S.G., Bizelis, J.A., Dardamani, A., Theodosiou, I., Fegeros, K., 2008. Effect of dietary oregano oil supplementation on lamb meat characteristics. *Meat Science* 79, 217-223.

Tarladgis, B.G., Watts, B.M., Younatan, M.T., Dudan, L.J., 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. *Journal of the American Oil Chemists Society* 37, 44-48.

Valero, M.V., Torrecilhas, J.A., Zawadzki, F., Bonafé, E.G., Madrona, G.S., Prado, R.M., Passetti, R.A.C., Rivaroli, D.C., Veisentainer, J.V., Prado, I.N., 2014. Propolis or cashew and castor oils effects on composition of *Longissimus* muscle of crossbred bulls finished in feedlot. *Chilean Journal of Agricultural Research* 74, 445-451.

Van Keulen, J.V., Young, B.A., 1977. Evaluation of acid insoluble ash as a natural marker in ruminant digestibility studies. *Journal of Animal Science* 44, 282-287.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and non-starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science* 74, 3583-3597.

Wallace, R.J., McEwan, N.R., McIntosh, F.M., Teferedegne, B., Newbold, C.J., 2002. Natural products as manipulators of rumen fermentation. *Asian-Australasian Journal of Animal Sciences* 10, 1458-1468.

Yashin, A., Yashin, Y., Xia, X., Nemzer, B., 2017. Antioxidant activity of spices and their impact on human health: A Review. *Antioxidants* 6, 1-18.

Young, J.F., Stagsted, J., Jensen, S.K., Karlsson, A.H., Henckel, P., 2003. Ascorbic acid, a-tocopherol and oregano supplements reduce stress-induced deterioration of chicken meat quality. *Poultry Science* 82, 1343-1351.

Zolfaghari Moheb, S., Fatahnia, F., Alipour, D., 2015. Effect of fennel by-product on performance of growing lambs and gas production parameters of their diets. *Iranian Journal of Animal Science* 46, 201-210.