J. Trop. Agric. and Fd. Sc. 46(1)(2018): 25 – 37

The effects of varying levels of *Nigella sativa* seed meal supplementation on nutrient digestibility and rumen fermentation characteristics in goats

(Kesan nilai berbeza-beza suplemen diet hampas biji *Nigella sativa* ke atas pencernaan nutrien dan ciri fermentasi rumen pada kambing)

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Abstract
The supplementations of various herbal feed additives with many nutritional properties have been widely investigated. The present study aims to investigate the effects of *Nigella sativa* seed meal (NSM) supplementation on nutrient digestibility and rumen fermentation characteristics of goats. In doing so, five mixed breed adult male goats were fed ad libitum with guinea grass hay (as basal diet), supplemented with NSM (DMI based on 1.5% of body weight) at 0% (NSM0), 0.8% (NSM8), 1.6% (NSM16) and 2.4% (NSM24). A mixture of Feral with Boer and Katjang breed of goats were used in this study. This study was carried out as a cross-over design of a 3-week cycle (2-weeks of adaptation and 1-week of experimental) and resumed after 1-week of washout period. It was revealed that there were no significant differences in nutrient digestibility of DM, OM, CF, DE, ADF, ADL and NDF, rumen pH, total VFA, individual VFA proportions and acetate: propionate ratio between control and NSM supplemented groups. Therefore, the results has proven that the addition of 0.8%, 1.6% and 2.4% NSM supplementation did not cause any adverse impact on feed digestibility and rumen fermentation characteristics of the goats. However, a larger number of replicates on the tolerance levels of NSM concentration in the dietary treatment of goats should be studied further.

Keywords: *Nigella sativa*, goats, nutrient digestibility, pH, volatile fatty acids

Introduction

Small ruminants such as goats play an imperative role in the agricultural systems particularly in the economic and ecological cycle of developing countries (Handekar et al. 2010). By and large, the performance of ruminants is influenced by the type and amount of feed supplementation (Ngwa et al. 2003), depending on the feed digestibility and rumen fermentation characteristics. A symbiotic relationship has been established between ruminants with microbes that are present in their gut. The microbes in the rumen ferment the carbohydrates to produce volatile fatty acids (VFAs), which account for more than half of the total metabolisable energy provided to ruminants. VFAs are weak acids, which disintegrate in

Article history
Received:26.9.16
Accepted:1.9.17

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the rumen and thus, releasing protons that leads to pH reduction (Penner et al. 2009). Following the fermentation of fibre, sugar and starch, among the major short chain VFAs in rumen, which are formed, include acetic acid, propionic acid and butyric acid (Moran 2005).

Over the past decade, numerous investigations have been carried out with regards to the utilisation of suitable plant extracts (with high concentration of secondary metabolites) as additives in enhancing the nutrient utilisation in order to improve ruminant performance and reduce stress in ruminants (Wanapat et al. 2008; Frankic et al. 2009; Kholif et al. 2012).

Commonly known as black cumin or 'Habbah Al-Sauda', *Nigella sativa* is a small herbal plant (30 – 70 cm in height) belonging to the Ranunculaceae family, which originates from the Middle East (Matthaus and Ozcan 2011). *Nigella sativa* seeds have been widely used in view of their medicinal properties. In addition, they are essential for the growth and development of skin tissues and skeletal muscle, as they possess high nutritional value and abundance in polyunsaturated omega-6 fatty acids (Connor et al. 1992; Matthaus and Ozcan 2011). Fatty acid supplements is introduced with the objective to regulate the antimicrobial effects of fatty acids to ensure that ruminal fermentation as well as digestion process is maintained, and the biohydrogenation is controlled in order to enhance the animal production system (Jenkins 1993).

Nigella sativa seed meal (NSM) is the residual by-product of pressed *Nigella sativa* seed that is believed to contain nutrients, which are not completely obtained from the whole seed (Silvia et al. 2012). Numerous studies have been carried out in relation to the utilisation of *Nigella sativa* seed as a feed supplement. However, its residual seed meal as a supplemental source of polyunsaturated fatty acid in the diet of ruminants has not been widely studied. Owing to their high nutritional properties, a number of studies have highlighted the effect of NSM supplementation in poultry such as broiler (Tollba and Hassan 2003; Abdo 2004; Hassan et al. 2007; Al-Muffarrej 2014; Ghasemi et al. 2014) and quail (Hassan and Alaqil 2014). The NSM is believed to be rich in phytochemical content of saponin and flavonoid (Michel et al. 2010). Additionally, it is a rich source of fatty acid that is able to control the antimicrobial effects of fatty acids so that the addition of these supplements will enable regulation of biohydrogenation process in order to improve the feed digestibility (Jenkins 1993). The supplementation of NSM in ruminant diets has not been widely investigated and mainly focused on poultry diets despite the beneficial nutritional properties of the NSM.

Feed digestibility and rumen fermentation characteristics are highly variable since they depend on the nature, type and quantity of fatty acid supplemented to the ruminant diet (Fiorentini et al. 2013). Apart from that, the type of VFA is formed based on the microorganism population and rumen environment (Bannink et al. 2008). It is noteworthy that ruminants require fats as an energy source. Small ruminants such as goats lack the Δ12 and Δ15 desaturase enzymes that are important for their growth. Polyunsaturated fatty acids (omega-3 and omega-6) are fundamental fatty acid components in ruminant diets (Innis 2005). Common source of omega-3 fatty acids is marine fish and common sources of omega-6 fatty acids are animal fat and vegetable oils (Wallace 2004). The addition of dietary lipids to ruminant diets increased their energy density (Oldick and Firkins 2000). Given such a background, the main purpose of this study was to investigate the effect of NSM supplementation as a source of fatty acid on feed digestibility, as well as rumen VFAs in goats.

Materials and methods

Animals, experimental runs and diets

A total of five mixed breed rumen fistulated adult male goats (an average of 2 – 3 years of age) with body weight ranging between 18 and 20 kg were utilised in this study. A mixture of Feral with Boer and Katjang breed of goats were used in this study. A cross over experimental design was employed with four periods: two weeks of adaptation period, one week of experimental period and one week washout period in between dietary treatment periods. The control diet was observed in the goats to allow any effects from dietary treatments to dissipate. All goats were fed basal diets (guinea grass hay, *ad libitum* feeding) and formulated dietary treatments (iso-nitrogenous and isocaloric) supplemented with NSM 0% (NSM0), 0.8% (NSM8), 1.6% (NSM16) and 2.4% (NSM24). *Table 2* presents the feed formulations with dietary treatments. These values were ensured iso-nitrogenous and isocaloric due to the fact that the NSM is only a feed additive and it does not affect the level of crude protein and energy content. The total estimated crude protein provided from the total concentrate and guinea grass hay for NSM0, NSM8, NSM16 and NSM24 are 15.38%, 15.39%, 15.4% and 15.42% respectively. As for the estimated energy content for NSM0, NSM8, NSM16 and NSM24, the values are 19.01 MJ/kg, 19.01 (MJ/kg), 19.03 MJ/kg and 19.03 MJ/kg, respectively.

Since this is the very first study carried out with regards to the effect of NSM supplementation in goats, the determination of inclusion rates were based on values employed in the literature for *Nigella sativa* seed supplementation in other types of small ruminants such as sheep (Zanouny et al. 2013). In the present study, the amount of NSM supplemented in the dietary treatment was proportionately calculated by means of using the basis of 100 mg/kg *Nigella sativa* seed containing about 30% oil content (Zanouny et al. 2013). Also, other studies have employed the minimum inclusion rate, which was fixed at 0.8% for herbal feed supplementation (Najafi and Taherpour 2013).

All dietary treatments were fed twice daily at 0900 and 1500. Following the 2 weeks of adaptation period, the total feed intake and total amount of faeces of each goat were collected and weighed daily for seven days. The total feed intake and the total faecal output were estimated using metabolic cage. From the total feed and faeces residue collected, three replicates were then sub-sampled, oven-dried at 60 °C and then refrigerated at 4 °C until further analysis.

Sample analysis and measurements

Ground NSM, feed and faecal samples were determined for dry matter (DM), organic matter (OM), crude fat (CF), crude protein (CP), ether extract (EE), gross energy (GE), acid detergent fibre (ADF), and neutral detergent fibre (NDF) according to the standard methods of AOAC (2007). On the other hand, acid detergent lignin (ADL) was determined based on the method described by Van Soest et al. (1991). The analysis of ether extract was employed to determine the crude fat. The apparent digestibility percentages of DM, OM, CF, CP, NDF, ADL, ADF and digestible energy (DE) were calculated according to the following equation:

Apparent digestibility (%)

$$= \frac{\text{Nutrient intake - Nutrient in faeces}}{\text{Nutrient intake}} \times 100$$

Modified method by Sanbongi et al. (1998) was used to defat the NSM and this is followed by the determination of the total saponin content based on vanillin-sulfuric acid colorimetric reaction (Makkar et al.

2007). A spectrophotometer with absorbance of 544 nm was utilised to obtain a standard curve to calculate the concentrations of saponin, which were expressed as mg diosgenin equivalent/g dry weight (DW).

Tables 1-3 demonstrate the chemical composition (%), feed formulation (%) and nutrient composition (%) of the dietary treatments supplemented with different levels of NSM.

Rumen sampling and analysis

The rumen contents were collected through the rumen fistula using a PVC pipe with holes during the last three days of the experimental period at 0, 2, 6, and 12 h after morning feeding. First, the pH of rumen fluid was measured and a portion of the rumen fluid that was filtered through four layers of cheesecloth was then subjected to VFA analysis. The method designed by Erwin et al. (1961) was employed for

Table 1. Chemical compositions of *Nigella sativa* seed meal

Chemical composition	% DM
Dry matter	92.12
Organic matter	93.49
Gross energy (Mcal/kg)	5.53
Crude fat	19.23
Crude protein	31.62
Ash	6.51
Neutral detergent fibre	23.49
Acid detergent fibre	14.56
Acid detergent lignin	4.15
Saponin (mg/100 g)	0.14

Table 2. Feed formulation of diets supplemented with different levels of *Nigella sativa* seed meal

Ingredients (% DM)	*Nigella sativa* Seed Meal Diets*			
	NSM0 (n = 5)	NSM8 (n = 5)	NSM16 (n = 5)	NSM24 (n = 5)
Corn grain	44.7	43.9	43.1	42.3
Soya bean meal	32.0	32.0	32.0	32.0
Rice bran	18.0	18.0	18.0	18.0
Molasses	2.8	2.8	2.8	2.8
Calcium carbonate	1.0	1.0	1.0	1.0
Sodium chloride (NaCl)	0.5	0.5	0.5	0.5
Dicalcium phosphate	0.5	0.5	0.5	0.5
Vitamin-mineral premix**	0.5	0.5	0.5	0.5
Nigella sativa seed meal	0	0.8	1.6	2.4

Note:
NSM: *Nigella sativa* seed meal
*Supplemented with NSM at 0%: NSM0/Control; 0.8%: NSM8; 1.6%: NSM16 and 2.4%: NSM24 (DMI based on 1.5% of body weight)
**Contained (g/kg) $FeSO_4.7H_2O$ 170; $CuSO_4.5H_2O$, 70; $MnSO_4.5H_2O$, 290; $ZnSO_4.7H_2O$, 240; (mg/kg) $CoCl_2.6H_2O$ 510; KI, 220; NaSeO, 130; vitamin K_3, 150; vitamin B_1, 450; vitamin B_{12}, 0.9; vitamin B_5, 1,050; pantothenic acid, 750; folic acid, 15; (IU) vitamin A, 620,000; vitamin D_3, 324,000.
n = number of replicates

Table 3. Nutrient composition of diets supplemented with different levels of *Nigella sativa* seed meal

Chemical composition (% DM)	*Nigella sativa* Seed Meal Diets*				Guinea hay**
	NSM0 (n = 5)	NSM8 (n = 5)	NSM16 (n = 5)	NSM24 (n = 5)	
Dry matter	89.89	89.96	89.81	89.62	93.29
Organic matter	92.57	92.57	92.56	92.54	92.55
Gross energy (Mcal/kg)	4.82	4.82	4.83	4.83	4.23
Crude fat	3.50	3.53	3.57	3.60	0.72
Crude protein	24.21	24.23	24.25	24.28	6.55
Ash	7.43	7.43	7.44	7.46	7.45
Neutral detergent fibre	16.40	16.41	16.42	16.38	84.41
Acid detergent fibre	4.69	4.63	4.61	4.67	50.13
Acid detergent lignin	1.61	1.55	1.55	1.58	8.16

Note:
NSM: *Nigella sativa* seed meal
*Supplemented with NSM at 0%: NSM0/Control; 0.8%: NSM8; 1.6%: NSM16 and 2.4%: NSM24 (DMI based on 1.5% of body weight)
**Guinea grass hay (%) was offered after feeding the concentrates
n = number of replicates

the quantification of VFA. A drop of 98% sulphuric acid was added into the freshly filtered rumen fluid and the portion was stored at -20 ºC before further analysis. The VFA of the rumen fluids were determined using gas chromatography system (Agilent 6890, Mississauga, ON, Canada) fitted with a flame ionisation detector (FID) and nitrogen as a carrier gas with a flow rate of 2.0 mL/minute. Supelco SP-2330 (Supelco, Inc. USA) capillary column with 0.32 mm i.d. and 0.50 mm film thickness was used to analyze VFA and the running conditions of the oven were maintained at 180 ºC, with FID at 250 ºC and injector at 220 ºC.

Statistical analysis

By means of using the SAS statistical software package version 9.10, the data were subjected to analysis of variance (ANOVA). Duncan Multiple Range Test was used to separate significant means, in which the statistical mean values of p >0.05 were considered to be not significant. Hence, only mean values of p <0.05 were considered statistically significant (Greenland et al. 2016).

Results and discussion

Digestibility study results

Table 4 summarises the results of the digestibility study. The average daily dry matter intake for all dietary treatment groups was 542 g/day. However, no significant difference was found in apparent digestibility of DM, OM, DE, CF, CP, NDF, ADF and ADL between l dietary treatments.

According to Abubakr et al. (2013), the presence of fat could decrease cell wall degradation by physical coating of the

Table 4. Dry matter intake and apparent digestibility of nutritive portions supplemented with different levels of *Nigella sativa* seed meal

Item	*Nigella sativa* Seed Meal Diets*			
	NSM0 (n = 5)	NSM8 (n = 5)	NSM16 (n = 5)	NSM24 (n = 5)
Total dry matter intake (g/day)	542.1 ± 6.66	544.4 ± 3.22	538.0 ± 9.95	547.2 ± 1.55
Apparent digestibility (%)				
Dry matter	66.1 ± 1.03	66.5 ± 0.68	66.3 ± 1.81	67.1 ± 1.52
Organic matter	67.4 ± 1.08	67.7 ± 0.67	67.7 ± 1.64	68.5 ± 1.52
Digestible energy	66.5 ± 0.98	67.1 ± 0.56	66.7 ± 1.74	67.6 ± 1.47
Crude fat	80.3 ± 1.02	83.2 ± 0.59	80.6 ± 3.28	82.2 ± 1.51
Crude protein	76.5 ± 0.29	77.7 ± 0.40	76.0 ± 1.45	77.1 ± 0.93
Neutral detergent fiber	58.3 ± 1.49	59.4 ± 1.02	58.9 ± 2.34	60.8 ± 2.13
Acid detergent fiber	42.5 ± 3.02	42.3 ± 2.17	42.6 ± 3.33	38.5 ± 1.90
Acid detergent lignin	10.7 ± 0.40	9.8 ± 0.31	10.5 ± 0.65	10.4 ± 0.62

Note:
NSM: *Nigella sativa* seed meal
*Supplemented with NSM at 0%: NSM0/Control; 0.8%: NSM8; 1.6%: NSM16 and 2.4%: NSM24 (DMI based on 1.5% of body weight)

fibre and thus, affecting fibre digestion. For instance, Salem et al. (2011) discovered that supplementation of *L. leucocephala* and *S. babylonica* tree plant leaves in the dietary feed of crossbreed male lambs increased the digestibility of DM, OM, CP and CF. The authors attributed the increase in nutrient digestibility to the presence of plant secondary metabolites in the diet.

Zeweil et al. (2008) reported that NSM has the potential to improve nutrient digestibility. The addition of herbal additives in the improved quality of feedstock, such as NSM has aided in increasing the production of goats. As regards the present study, similar values of digestibility ($p > 0.05$) between the control and dietary supplement groups suggested that the addition of the NSM up to 2.4% as a source of fatty acid did not affect the rate of degradation or nutrient digestibility in goats. Similar results were reported by Zhou et al. (2012) whereby tea saponin from tea leaves extract of the Ilex kudingcha C.J. Tseng species (a traditional Chinese tea, rich in plant secondary metabolites) was supplemented in the diet intake of black wethergoats (a local breed from South China). It was found that different concentrations of tea saponin (up to 800 mg/kg feed DM) did not affect the apparent nutrient digestibility of the goats. Moreover, Wanapat et al. (2008) reported that supplementation of garlic powder did not alter nutrient digestibility, with the exception of an increase in CP and NDF. Maia et al. (2012) reported that there were no significant changes on the nutrient digestibility supplementing canola, castor or sunflower oils to roughage diet for the intake of rumen-cannulated sheep. Also, the results of the present study are in agreement with the findings of Nasri et al. (2011) whereby no changes were recorded on the total intake, OM and CP digestibility of lambs fed with dietary supplements of *Quillaja saponaria*.

Therefore, it is deemed that the addition of NSM up to 2.4%, as a source of fatty acid in the dietary treatment of goats in this study was not sufficient to cause significant changes in the nutrient digestibility. Besides, the supplemented amount of NSM could still maintain the nutrient digestibility without causing any adverse effects and thus, preserving the balance of ruminal microorganisms in the rumen environment of the goats as suggested by Maia et al. (2012).

Rumen pH

The rumen pH values of the experimented goats obtained following the feeding of dietary treatment supplemented with NSM are shown in *Table 5*. Ruminal pH is an important index of rumen ecosystem function (Zhou et al. 2012). In this study, the rumen pH values were maintained at 6.5 to 7 in all dietary treatment groups throughout the day. Mould and Orskov (1983) highlighted that the best range of pH for optimum fibre digestion is between 6.7 and 7.0. In fact, an inhibitory effect is expected when rumen pH values are less than 6.1 (Mould and Orskov 1983).

In determining the rumen pH values, the active molecules in herbal feed additives play an important role (Spanghero et al. 2008). One of the important active molecules of the herbal feed additives is the secondary compounds such as saponin. Saponins are steroid or triterpenoid glycosides that are found in plant products and used in livestock diets (Nasri et al. 2011). The effects of saponin on ruminal pH and volatile fatty acid concentrations are highly mutable (Nasri et al. 2011). The rumen pH is also dependent on the quantity of incoming saliva and accretion of VFA (Cantalapiedra-Hijar et al. 2011). The supplementation of saponin to heifer diets has made the manipulation of rumen fermentation successfull (Hu et al. 2005). In addition, saponin is also believed to enhance the production of propionic acid in rumen (Wina et al. 2005), and daily supplementation of dietary tea saponin was found to increase daily gain and feed conversion efficiency of goats (Hu et al. 2006).

The mean saponin content of NSM employed in this study was 0.14 mg/100 g (*Table 1*). Even though the saponin concentration of NSM was quite significant, the rumen pH values were not affected because the pH values were stabilised to be near-neutral in the rumen environment. The results of the present study correlated well with the findings of several other research. For instance, Castillejos et al. (2008) reported that the use of lavender oil as a feed additive did not cause any pH modification in the beef cattle rumen. Ozturk et al. (2012), on the other hand, found that olive leaf extract supplementation using

Table 5. Rumen pH after feeding diets containing different levels of *Nigella sativa* seed meal

Hours after feeding	*Nigella sativa* Seed Meal Diets*			
	NSM0 (n = 5)	NSM8 (n = 5)	NSM16 (n = 5)	NSM24 (n = 5)
0	6.9 ± 0.03	7.0 ± 0.04	7.0 ± 0.07	7.0 ± 0.04
2	6.6 ± 0.03	6.6 ± 0.04	6.7 ± 0.04	6.6 ± 0.04
6	6.7 ± 0.04	6.8 ± 0.06	6.8 ± 0.06	6.8 ± 0.05
12	6.5 ± 0.05	6.6 ± 0.06	6.5 ± 0.05	6.5 ± 0.07

Note:
NSM: *Nigella sativa* seed meal
*Supplemented with NSM at 0%: NSM0/Control; 0.8%: NSM8; 1.6%: NSM16 and 2.4%: NSM24 (DMI based on 1.5% of body weight)
n = number of replicates

the rumen simulation technique yielded no difference in pH between treatments. Manasri et al. (2012) also observed no effects in the ruminal pH values (which were maintained at 6.7 to 6.9) based on their study of supplementing garlic pellet to the diet of crossbreed beef cattle. Similarly, Aazami et al. (2013) observed that the supplementation of *Quillaja saponaria* powder did not produce any effect on the rumen pH.

To summarise, the pH values which were nearly constant at almost neutral range in this study demonstrated that fiber digestion was not affected by the dietary supplementation of NSM to the experimented goats.

VFA

The total VFA concentration of the experimented goats obtained after feeding diets supplemented with NSM is presented in *Table 6*. The molar proportions of the individual VFAs reached the maximum after 2 h of feeding (*Table 7*). The total VFA concentration is a significant parameter due to the fact that VFAs (comprising predominantly of short chain fatty acids

Table 6. Total VFA concentration (mol/100 mL) of rumen fluid after feeding diets containing different levels of *Nigella sativa* seed meal

Hours after feeding	*Nigella sativa* Seed Meal Diets*			
	NSM0 (n = 5)	NSM8 (n = 5)	NSM16 (n = 5)	NSM24 (n = 5)
0	73.7 ± 0.72	73.4 ± 0.70	73.7 ± 0.62	74.4 ± 0.72
2	95.5 ± 0.69	94.7 ± 0.55	95.3 ± 0.43	95.6 ± 0.46
6	86.0 ± 0.59	85.4 ± 0.59	86.3 ± 0.53	84.7 ± 0.57
12	82.8 ± 0.50	82.9 ± 0.48	84.2 ± 0.68	83.9 ± 0.42

Note:
NSM: *Nigella sativa* seed meal
*Supplemented with NSM at 0%: NSM0/Control; 0.8%: NSM8; 1.6%: NSM16 and 2.4%: NSM24 (DMI based on 1.5% of body weight)
n = number of replicates

Table 7. Volatile fatty acids of rumen fluid at 2 h after feeding diets containing different levels of *Nigella sativa* seed meal

Item	*Nigella sativa* Seed Meal Diets*			
	NSM0 (n = 5)	NSM8 (n = 5)	NSM16 (n = 5)	NSM24 (n = 5)
Proportion of VFA (%)	95.5 ± 0.69	94.7 ± 0.55	95.3 ± 0.43	95.6 ± 0.46
Acetate (%)	61.9 ± 0.48	62.7 ± 0.55	62.7 ± 0.42	62.0 ± 0.57
Propionate (%)	21.0 ± 0.38	21.1 ± 0.37	20.9 ± 0.22	21.1 ± 0.45
Butyrate (%)	12.9 ± 0.28	13.4 ± 0.29	13.1 ± 0.23	12.8 ± 0.27
Acetate to propionate ratio	3.0 ± 0.06	3.0 ± 0.05	3.0 ± 0.05	2.9 ± 0.08

Note: NSM: *Nigella sativa* seed meal
*Supplemented with NSM at 0%: NSM0/Control; 0.8%: NSM8; 1.6%: NSM16 and 2.4%: NSM24 (DMI based on 1.5% of body weight)
n = number of replicates

such as acetate, propionate and butyrate) are the major source of energy (particularly derived from butyrate) for the ruminants (Moran 2005). The VFAs mainly present in the epithelium of the colon and are produced from microbiological activities in the rumen (Tagang et al. 2010). The results presented in *Table 6* exhibited that the total VFA concentration ranged from 73.4 to 74.4 mol/100 mL at 0 h before morning feeding. It reached a maximum of 94.7 to 95.6 mol/100 mL 2 h after feeding. Thereafter, the total VFA ranged between 82.8 to 86.3 mol/100 mL from 6 to 12 h after morning feeding. It is noteworthy that no significant differences (p >0.05) in total VFA concentrations were observed with the addition of NSM for all dietary treatment groups. Similar to the rumen pH values, which were almost invariable with the different dietary treatments supplemented with NSM, the total VFA concentrations showed similar trend, with no significant differences observed. Notably, low pH in the rumen environment is closely associated with changes in the production of VFA (Spanghero et al. 2008). As has been pointed out earlier, the rumen pH values recorded in the present study were mostly in the optimal near neutral region, which correlated with the observed indifferences in VFA production.

Szumacher-Strabel et al. (2009) underscored that feed containing linoleic acid has profound influence on rumen fermentation, in which excess amounts have been generally found to inhibit rumen fermentation process and decrease VFA production. However, decrease in VFA production was not observed in this study and hence, showing that the concentration of NSM used was within the acceptable limits. In a similar vein, Zhou et al. (2012) found that concentrations of acetate, propionate and butyrate were not altered upon the supplementation of tea saponin to goat diet. This showed that tea saponin had minor effects on the pattern of rumen fermentation.

Some studies were carried out on different types of ruminant such as cattle steers supplemented with herbs such as lemon grass in the diet also disclosed that total VFA concentrations were not altered (Hosoda et al. 2006; Wanapat et al. 2008). The results of the present study corresponded with Dentinho et al. (2014) who found similarity in total VFA concentrations in cannulated rams fed with soybean meal supplemented with *Cistus ladanifer* L. According to Hart et al. (2008), lower concentrations of herbal feed supplements may possibly be the contributing factor in causing little difference in the total VFA concentrations.

As tabulated in *Table 7*, data obtained on individual molar proportions of VFA 2 h after feeding showed no changes in acetate, propionate, butyrate and acetate:propionate ratio among the different NSM dietary supplemented groups. This finding is in agreement with Cieslak et al. (2013) that the addition of feed rich in omega-6 fatty acid did not significantly alter rumen fermentation. It was also observed by Fiorentini et al. (2013) that the supplementation of dietary lipid sources did not affect pH, molar concentration of propionate and total VFA (p >0.05). Furthermore, the findings of the present study are also in agreement with Szumacher-Strabel et al. (2009), in which the addition of up to 5% of herbs rich in omega-6 fatty acids like borage (*Boragoofficinalis*) and evening primrose (*Oenotherabiennis*) in the dietary treatment for sheep, goats and dairy cows did not cause a change in the total VFA concentration and the ratio of acetate and propionate and thus, implying that fiber digestion was not disturbed. The findings of this study are also consistent with the research done by Miri et al. (2013, 2015), which concluded that supplementation of cumin seed extract in the dietary intake of lactating goats did not cause changes in molar proportions of VFA, particularly molar acetate proportion in comparison to the control treatment. Miri et al. (2015) suggested that it is possible that the complex microbial consortium in the rumen may affect the action of bioactive secondary metabolites of the feed supplied. Therefore, the findings of this study showed no significant changes (p >0.05) in the rumen fermentation parameters can be attributed to a variety of factors, which include ruminal condition and dosage of feed supplements. It has to be noted that the inclusion rates were based on literature on the effect of NS seeds on small ruminants (Zanouny et al. 2013). Using the literature values as a benchmark, the inclusion rate of NS seed meal employed in this study was fixed at about 30% higher since almost 30% of the oil has been removed from the seed meal.

The concentration of the treatment levels was based on doubling (1.6%) and tripling (2.4%) the minimum inclusion rate (0.8%) reported in previous studies (see Najafi and Taherpour 2014). When calculated based on the total DM intake, the values of the double and triple amount of the minimum inclusion rate of 0.8% (1.6% and 2.4%) were found to be within the required range. These values were found to be suitable and conservative enough for use in experimental study. In addition, the basal diet without the supplementation of the NSM is sufficient to meet the dietary requirements of the animals.

Additionally, the tested animals were adult goats and there is a possibility that goats in that growth phase may have the potential to display greater significance in the parameters tested. However, the number of animal replicates used should also be increased. Greater variability and better results may be attainable by means of increasing the sample data sets using a larger number of animal replicates.

Conclusion

To conclude, the supplementation of NSM as a source of fatty acid did not significantly affect nutrient digestibility and rumen fermentation parameters of the experimented goats. The low dosage of NSM supplementation is one of the possible causes of these findings. Another factor is the small number of replicates of goats employed in the study. Nevertheless, the results obtained have proven that rumen fermentation characteristics could be maintained and were not adversely affected with the supplementation of NSM.

Acknowledgments

The authors would like to extend their gratefully thanks to Universiti Putra Malaysia for lending generous support to this research.

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Abstrak
Penggunaan bahan sampingan herba yang mengandungi pelbagai jenis nutrien telah banyak dikaji. Tujuan utama kajian ini adalah untuk menilai kesan hampas biji jintan hitam (NSM) sebagai makanan tambahan ke atas pencernaan nutrien dan ciri-ciri fermentasi rumen pada kambing yang diberi makanan berasaskan mil biji jintan hitam. Lima ekor kambing dewasa baka campuran diberi diet yang berasaskan diet rumput guinea kering secara ad libitum dan diet tambahan NSM (pengambilan bahan kering berasaskan 1.5% daripada berat badan) pada 0% (NSM0), 0.8% (NSM8), 1.6% (NSM16) dan 2.4% (NSM24). Campuran kambing baka *Feral* dengan *Boer* dan *Katjang* digunakan untuk kajian ini. Semua kambing tertakluk kepada kitaran selama tiga minggu (merangkumi dua minggu untuk adaptasi dan satu minggu untuk eksperimen). Kitar pemakanan kambing diteruskan selepas satu minggu *washout*. Dapatan kajian menunjukkan suplemen mil biji jintan hitam tidak memberi kesan signifikan kepada semua bahagian asid lemak, pH rumen serta keseluruhan kepekatan asid lemak meruap (VFA), perkadaran molar VFA individu atau nisbah asetik kepada propionik keseluruhannya. Kesimpulannya, tiada kesan signifikan terhadap pencernaan nutrien dan ciri-ciri fermentasi rumen pada kambing didapati daripada suplemen mil biji jintan hitam pada 0.8%, 1.6% dan 2.4% dalam diet. Walau bagaimanapun, kajian lanjut diperlukan untuk sampel saiz yang lebih besar dan juga kadar toleransi konsentrasi NSM yang lebih besar di dalam kajian nutrisi kambing.