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Rocket seed meal (*Eruca sativa*) can replace soybean meal in fattening lamb diets improving performance, protein metabolism, and economic balance

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Abstract

The study determined the effects of replacing different levels of soybean meal (SBM) with rocket seed cake (RSC) in the diets of growing lambs on feed utilization and growth performance. Twenty-eight male lambs (180 ± 5 d old) were divided into four groups in a complete randomized design with repeated measures for 105 d. Soybean meal was replaced with RSC at 0% (RSC0), 25% (RSC25), 50% (RSC50), and 75% (RSC75). The RSC75 group had the lowest final weight, total weight gain, and daily weight gain. The RSC25 increased ($P < 0.001$) the intakes of DM, starch value (SV), total digestible nutrients (TDN), digestible energy (DE), and digestible crude protein (DCP) compared to the other diets, while the RSC75 decreased these values. Moreover, the RSC25 decreased ($P < 0.05$) feed conversion of DM compared to other diets. Treatments did not affect nutrient digestibility or diet's nutritive values expressed as true SV, TDN, DCP, and DE. The RSC linearly increased albumin and urea and lowered the high-density lipoprotein concentrations in lamb's blood. The inclusion of RSC in the diet increased economic efficiency, with the highest relative percentages of net revenue with the RSC25. Overall, RSC can replace SBM at 25% in the diet of growing lambs.

KEYWORDS
growth performance, lambs, nutritive value, protein feeds, rocket seed meal

1 | INTRODUCTION

Mediterranean countries suffer from the availability and the cost of conventional protein feeds. Therefore, exploring alternative protein feeds with considerable amounts of protein is recommended (Ebeid et al., 2020; Hassan, El-Garhy, et al., 2024; Kholif et al., 2016). One of the recommended alternatives is rocket (*Eruca sativa*). Rocket is an oilseed crop native to Southern Europe and is cropped in many areas of the world (Al-Taey et al., 2023). Seeds and leaves of rocket have been used for therapeutic uses (Altwaijry et al., 2020; Hassan et al., 2023). Rocket seed cake contains a considerable concentration of crude protein (∼ 27 to 35%), which makes it a suitable protein feed for ruminants (Al-Taey et al., 2023; Das et al., 2003; Pagnotta et al., 2022). Additionally, the seeds contain 19–28% carbohydrates, 15–20% crude fibers, and 20–30% crude protein (Hassan et al., 2023; Nail et al., 2017; Pagnotta et al., 2022). The rocket seeds are rich in omega-3, vitamins such as A, E, C, and K, and many secondary metabolites including flavonoids, saponin, gums, and soluble and insoluble phenol and alkaloids (Al-Rawe et al., 2023; Al-Taey et al., 2023; Pagnotta et al., 2022).

Rocket seed cake contains a group of thioglucosides (108–125 μmol/g) with gallic acid at about 44.24 mg/g (Akcicek et al., 2021) which produce for example isothiocyanate, nitrile, and thiocyanate because of hydrolysis (Al-Rawe et al., 2023; Al-Taey et al., 2023; Pagnotta et al., 2022). Thioglucosides are toxic and reduce the palatability of feed and depress the function of the thyroid (T_3 and T_4) causing negative effects on the productivity of animals (Al-Taey et al., 2023). Glucosinolates have several biological activities including anticarcinogenic, antifungal, antibacterial, and antioxidant action (Al-Taey et al., 2023; Cavaiuolo & Ferrante, 2014). Moreover, the rocket seeds contain a high content of erucic acid (*cis*-13-docosenoic acid), which is an anti-nutritional compound and limits the use of the whole seed, rich in oil, in applications for food and feed purposes, even if at very low concentrations (Kumar et al., 2022).

A few experiments evaluated rocket seed cake as a protein concentrate in ruminants. Consuming rocket promotes feed digestion, stimulates bile production, and enhances liver function (Al-Shammari & Batkowska, 2021; Al-Taey et al., 2023; Nowfel & Al-Okaily, 2017; Pagnotta et al., 2022). Al-dain and Jarjeis (2015) fed male Awassi lambs on a diet containing rocket at 600 mg/kg body weight daily for 4 months. They reported that the supplementation increased red cell count, hemoglobin, and packed cell volume, and decreased glucose, cholesterol, and triglycerides. Thus, the present experiment was performed to determine the nutritive value of rocket to replace soybean meal at different levels in diets of growing Ossimi lambs on feed utilization and growth performance. The hypothesis was that rocket seeds contain a considerable amount of CP and phytochemicals will provide lambs with high amounts of protein that will support their growth and feed efficiency.

2 | MATERIALS AND METHODS

2.1 | Experimental protocol

The study was conducted on the farm and laboratories of the Faculty of Agriculture, Fayoum University, Fayoum Governorate, Egypt during the winter of 2022. The farm of the current study is situated in Damou, (29°17′49 N and 30°55′21E), Fayoum, with dry weather in the winter and rare rain and daily temperatures ranging from 9 to 22 °C. The protocol of the experiment and treatment of animals were approved by the Institutional Animal Care and Use Committee (FU-IACUC), Fayoum University with proposal code number: AEC2201.

2.2 | Rocket seed cake

Rocket seed cake was obtained from a local supplier in Egypt (Al Jasmine factory for natural oils, Fayoum Governorate, Egypt). Rocket seed cake was prepared after the mechanical cold pressing extraction of oil from crushed ripe rocket seeds considering the notes of Çakaloğlu et al. (2018).

Polyphenols concentrations in SBM and RSC were measured using an Agilent 1,260 series HPLC (Santa Clara, CA, USA). An eclipse C18 column (4.6 mm × 250 mm i.d., 5 μm) was used for the separation process. Water (A) and 0.05% trifluoroacetic acid in acetonitrile (B) at a flow rate 0.9 ml/min were used for the mobile phase. The mobile phase was programmed consecutively in a linear gradient as follows: 0 min (82% A); 0–5 min (80% A); 5–8 min (60% A); 8–12 min (60% A); 12–15 min (82% A); 15–16 min (82% A), and 16–20 min (82%A). The multi-wavelength detector was monitored at 280 nm. The injection volume was 5 μl for each of the sample solutions. The column temperature was maintained at 40°C. A standard of polyphenols (Sigma-Aldrich GmbH, Steinheim, Germany) was used.

Amino acid profiles in SBM and RSC were measured using an Agilent 1,260 series HPLC (Santa Clara, CA, USA) as described by Jajic et al. (2013) using an Eclipse Plus C18 column (4.6 mm × 250 mm i.d., 5 μm). Amino acids standard (Sigma, Product #A6282, MO, USA) was used.

2.3 | Animals, management, and experimental design

Twenty-eight, healthy and clinically free of internal and external parasites, male Ossimi lambs were used. Lambs with 38 ± 0.7 kg BW and 180 ± 5 d old were used in a completely randomized design with repeated measures in time. Lambs were divided randomly into four experimental groups ($n = 7$) based on their live body weight. Before starting the experiment 'the adaptation period', lambs were vaccinated against clostridium using Covaxin 10 (Merck & Co., Inc., Rahway, NJ, USA) at 1 ml/lamb subcutaneously, and repeated after 21 d, then every 6 months. Moreover, lambs were treated with Ivomec Super (Boehringer Ingelheim, Bracknell, UK) at 2 ml/lamb subcutaneously. During the day, lambs were kept outdoors with shelter while at night were housed in semi-open barns under the same environmental and management conditions. Light bulbs were used to provide lighting of 12 h of light per day for all lambs. Each lamb in the trial was kept in an area of 2 × 1.5 m^2. Lambs were fed a control diet consisting of berseem clover (*Trifolium alexandrinum*) and concentrate feed mixture at 30:70, DM basis. The concentrate feed mixture contained (DM basis): 55% yellow corn, 23% wheat bran, 20% soybean meal, 1% limestone, 0.5% premix, and 0.5% NaCl. In the control diet (RSC0 treatment), soybean meal was replaced with RSC at 25% (RSC25 treatment), 50% (RSC50 treatment), or 75% (RSC75 treatment). Diets were prepared according to the NRC (2007) recommendations. Table 1 shows the ingredients and composition of diets. The experiment lasted for 105 d consisting of 15 d for adaptation and 90 days for measurements. Lambs were offered the concentrate mixture at 08:00 h, while berseem clover was offered at 16:00 h, with free access to fresh water. Samples of feeds were taken daily, composited weekly, and dried at 60°C in a forced-air oven for 48 h and stored for later chemical analysis. The difference between the offered diets and refusals from the previous day

TABLE 1 Ingredients and chemical composition of feeds and diet fed to the Ossimi lambs.

	Diet[a]				Ingredients				
	RSC0	RSC25	RSC50	RSC75	Berseem clover	Rocket seed cake	Soybean meal	Yellow corn	Wheat bran
Ingredients (g/kg DM)									
Yellow corn	385	385	385	385					
Wheat bran	161	154	147	140					
Soybean meal	140	105	70	35					
Rocket seed cake	0	42	84	126					
Limestone	7.0	7.0	7.0	7.0					
Premix	3.5	3.5	3.5	3.5					
NaCl	3.5	3.5	3.5	3.5					
Egyptian clover	300	300	300	300					
Chemical composition (g/kg DM)									
Organic matter	889	888	888	887	840	924	940	929	917
Crude protein	171	170	169	167	158	343	420	111	137
Ether extract	41.5	43.4	45.2	47.0	37.5	69.7	22.5	52.1	43.9
Non-structural carbohydrates	473	468	463	458	297	265	377	683	413
Neutral detergent fiber	204	208	211	215	347	246	121	83.0	322
Acid detergent fiber	110	111	112	113	196	95.0	66.0	20.0	121
Hemicellulose	94.0	97.0	99.0	102	151	151	55.0	63.0	201

[a] The control diet contained (per kg DM): concentrates feed mixture and berseem clover at 70:30 (RSC0 diet). Rocket seed cake was included at 4.2%, 8.4%, or 12.6% to replace soybean meal at 25% (RSC25 diet), 50% (RSC50 diet), or 75% (RSC75 diet), respectively.

was recorded and considered as the daily feed intake. Lambs were individually weighed biweekly before the morning feeding.

2.4 | Digestibility trial

A digestibility trial was conducted at the end of the experiment. Lambs were individually maintained in metabolic cages (70 cm width × 120 cm high × 150 cm length) for 10 days where the first three consecutive days (i.e., d 96–98) were considered as the adaptation period, and the last seven consecutive days (i.e., d 99–105) were considered as the collection period for the total collection of feces and urine for nutrient digestibility and ruminal fermentation determinations. Beneath each cage were 4 mm stainless steel screens to retain feces but let the urine through to enable the separate and total collection of feces and urine. Feed refusals and total fecal and urinary outputs were daily collected separately in labeled polyethylene bags and weighed. About 10% of fresh feces were taken and dried to determine the DM content of the feces. Composite samples of feces for each individual lamb were formed, mixed, ground, and stored in a refrigerator at −20°C for subsequent chemical analysis. Feed and feces samples were analyzed for DM, ether extract (EE), ash, and N contents (Kjeldahl method 955.04) according to the official methods of AOAC (2019). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) of feed were determined using a Fibertect 2010 (Tecator, Sweden) as described by Van Soest et al. (1991). The concentrations of non-structural carbohydrates (NSC), hemicellulose, and organic matter (OM) in feed ingredients and feces were calculated. Acid-insoluble ash was used as an internal indigestibility marker. The digestibility coefficients were calculated according to Van Keulen and Young (1977). The equations of NRC (2001) were used to calculate the total digestible nutrient (TDN), starch value (SV), digestible crude protein (DCP), and digestible energy (DE).

2.5 | Blood sampling and analysis

Lambs were sampled for blood samples at the end of the experiment before the morning feeding. Approximately 10 ml of fresh blood was withdrawn from the jugular vein of all lambs. Each blood sample was divided into two aliquots: (1) one with sodium fluoride and potassium oxalate for analyzing glucose and (2) one without any additives for serum separation. Clear blood serum samples were decanted into 2-mL Eppendorf tubs and frozen at −20°C pending analysis using specific kits (Stanbio Laboratory, Boerne, Texas, USA) for each single parameter according to manufacturer instructions. For the concentrations of total protein (g/dL), albumin (g/dL), globulin (mg/dL), total cholesterol (mg/dL), high-density lipoprotein (HDL, mg/dL), triglycerides (mg/dL), urea-N (mg/dL), creatinine (mg/dL), alanine aminotransferase (ALT, IU/L), and aspartate aminotransferase (AST, IU/L) were measured in each sample. Globulin samples were calculated as the difference between total protein and albumin.

2.6 | Economic evaluation

The economic return of the evaluated values was calculated based on the price of feed ingredients during the experiment assuming that the price of 1 kg live body weight gain of lambs was $7 USD and the cost of 1 ton of berseem clover (*T. alexandrinum*; 15% DM) in all the tested rations was $20.6 USD. While the costs of 1 ton of concentrate feed mixture were $585.8 USD, $552.5 USD, $519 USD, and $485 USD for the rations containing RSC at 0%, 25%, 50%, and 75%, respectively (on DM basis).

2.7 | Statistical analyses

Lambs were divided randomly into four experimental groups in a completely randomized design with repeated measures in time. Before the statistical analysis, data was tested for the normal distribution, where all measurements showed normal distributions. Data generated weekly were analyzed using the PROC MIXED procedure of the Online Version of SAS, with period as a repeated measure and individual lambs as the experimental unit. The model was: $Y_{ijkl} = \mu + D_i + A_j (D_i) + P_k + (D \times P)_{ik} + e_{ijkl}$ where Y_{ijkl} = observation of the *j*th lamb in the *k*th sampling time given *i*th treatment, D_i = diet effect, $A_j (D_i)$ = animal within treatments, P_k = sampling period effect, $(D \times P)_{ik}$ = interaction between the diet and sampling week and e_{ijkl} = experimental error. Data collected once (i.e., blood and digestibility) was analyzed using the following model: $Yijk = \mu + D_i + L_j (D_i) + e_{ijk}$ where Y_{ijk} = observation of the j^{th} lamb given i^{th} treatment, D_i = treatments effect, $L_j (D_i)$ = lamb within treatments and e_{ijk} = experimental error. Polynomial (linear and quadratic) contrasts were used to examine level responses to increasing levels of RSC and for comparison between control vs. the average of RSC treatments. Significance was declared at $P < 0.05$.

3 | RESULTS AND DISCUSSION

The inclusion of rocket seed cake in the diets of lambs as a protein feed was extensively evaluated in fish and poultry, with almost no information on ruminant feeding. Therefore, comparing the present results with those in other experiments in ruminants was not available. More experiments to explore the effects of rocket seed cake on the diets of animals are recommended. Moreover, exploring the effects of feeding RSC to animals in the gastrointestinal tract of ruminants should be evaluated.

3.1 | Chemical composition

Rocket seed cake had more EE (69.7 vs. 22.5 g/kg DM), NDF (246 vs. 121 g/kg DM), and ADF (95 vs. 66 g/kg DM) concentrations compared to soybean meal, which had more CP (420 vs. 343 g/kg DM) and NSC (377 vs. 265 g/kg DM) concentrations (Table 1). The replacement of soybean meal with rocket seed cake had minimal effects on the concentrations of the different nutrients in the diets. This may be due to the low level of RSC inclusion in all diets, which were 4.2%, 8.4%, and 12.6% for RSC25, RSC50, and RSC75 treatments, respectively.

Rocket seed cake contained higher concentrations of polyphenols including caffeic acid, naringenin, methyl gallate, chlorogenic acid, ellagic acid, ferulic acid, catechin, quercetin, daidzein, Apigenin, and cinnamic acid; however, SBM contained more rutin, kaempferol, and vanillin (Table 2). As mentioned before, higher concentrations of gallic acids and other phenols are toxic reduce the palatability of feed, and depress the function of the thyroid (Al-Taey et al., 2023). However, glucosinolates and other phenols are anticarcinogenic, antifungal, antibacterial, and antioxidants (Al-Taey et al., 2023; Cavaiuolo & Ferrante, 2014). Further attention to the concentrations of phenols in RSC especially in growing animals should be considered.

Regarding the essential amino acids, soybean meal contained 16.6% more total essential amino acids, threonine, phenylalanine, isoleucine, and leucine compared to rocket seed cake (Table 3). Moreover, rocket seed cake contained 11% more methionine compared to soybean meal. Methionine is one of the most important amino acids in animal feeding. Ruan et al. (2017) stated that methionine not only serves as a constituent of body protein but also is involved in the development of the digestive tract and the growth of animals. Regarding the nonessential amino acids, soybean meal contained 21.1% more total nonessential amino acids, aspartic acid, glutamic acid, serine, glycine, arginine, alanine, tyrosine, cystine, and proline compared to rocket seed cake.

TABLE 2 Concentration[a] (μg/g) of polyphenols of soybean meal (SBM) and rocket seed cake (RSC) identified by HPLC analysis.

Polyphenol	SBM	RSC
Gallic acid	79.1	1,380
Coffeic acid	63.2	615
Naringenin	28.3	572
Methyl gallate	18.0	317
Chlorogenic acid	36.4	189
Catechin	ND	166
Ellagic acid	ND	22.3
Coumaric acid	ND	12.5
Vanillin	86.0	11.5
Ferulic acid	2.0	11.2
Rutin	48.3	9.6
Kaempferol	38.0	7.89
Quercetin	ND	7.37
Daidzein	ND	5.67
Apigenin	ND	1.68
Cinnamic acid	ND	1.02

ND = not detected.
[a]Concentration based on the total areas of the identified peaks.
[b]Identification based on authentic standards, the National Institute of Standards and Technology (NIST) library spectra, and literature.

3.2 | Growth performance

The initial weight did not differ between treatments (Table 4), which reflects the random distribution of animals into treatments. The RSC25 treatment showed quadratically increased final weight by 5.6% (P = 0.046), total weight gain by 19.1% (P = 0.001), and daily weight gain by 18.7% (P = 0.008) compared to the control treatment. The RSC75 treatment decreased final weight by 3%, total weight gain by 5.6%, and daily weight gain by 6.1% compared to the control treatment. Data on growth performance are paralleled with those of feed intake and reflect their cumulative effects. Increasing the replacement level caused the negative effects on the performance which may be due to the low concentrations of total and individual essential amino acids in soybean meal compared to RSC (Hassan, El-Garhy, et al., 2024; Hassan, Hassaan, et al., 2024; Mousa et al., 2024). Recently, Hassan, El-Garhy, et al. (2024) stated that the complete replacement of cottonseed meal with wheat germ meal in diets of growing lambs improved their performance.

Generally, rocket seeds are rich in vitamins including B_1, B_2, C, and A, as well as pro-vitamin, folic acid, glucosinolates (the precursors of isothiocyanates and sulfaraphene), and minerals, including iodine, Fe, Ca, and S (Al-Rawe et al., 2023; Al-Taey et al., 2023; Cavaiuolo & Ferrante, 2014; Pagnotta et al., 2022). Such nutrients may be responsible for the improved growth performance. Moreover, rocket consumption improves liver functions and raises the hepatic antioxidant glutathione. Such effects protect cells from free radical damage and inhibit potential pathogens in the digestive system (Ponnampalam et al., 2022). On the other hand, the crude fat content of RSC was higher than that of soybean meal. Therefore, the feed crude fat content increases with the RSC ratio (approximately 13.2%), and the crude fat content at RSC75 is close to 4.2% is a possible reason for the affected growth performance. Increasing the fat content in the consumed diet is expected to have a negative impact on growth performance due to the potential increase in feed passage rate in the digestive tract (Mir et al., 2006). Moreover, it is important to note that an increase in dietary crude fat leads to a decrease in microbial activity in the rumen (Wang et al., 2021). However, at an appropriate level, it will enhance the energy concentration in the diet and consequently improve animal performance (Bahramkhani-Zaringoli et al., 2022).

As observed in many experiments (Hassan, Hassaan, et al., 2024; Morsy et al., 2022; Salem et al., 2014), increasing the consumption of secondary metabolites showed negative effects on ruminal fermentation and depressed nutrient digestion and animal performance (Kholif & Olafadehan, 2021). However, we did not measure the effect of treatments and their phytochemicals on ruminal fermentation and microbes, we can speculate that the antimicrobial activity of phytochemicals in rocket seeds depressed microbial activity and the fermentability and digestibility of diets, causing negative effects on animal performance (Kholif & Olafadehan, 2021). The used ingredient (i.e., rocket seeds) contains thioglucosides, the main active compounds

TABLE 3 Amino acid (AA) profile of rocket seed cake (RSC) and soybean meal (SBM) (g/kg DM).

	SBM	RSC	SBM vs. RSC (change %)
Essential AA			
Histidine	9.4	9.3	1.1
Threonine	13.6	12.0	11.8
Valine	15.5	14.9	3.9
Methionine	5.40	5.99	−10.9
Phenylalanine	17.2	12.6	26.7
Isoleucine	16.1	12.1	24.8
Leucine	30.5	20.9	31.5
Lysine	11.7	11.7	0.0
Nonessential AA			
Aspartic acid	37.9	23.4	38.3
Glutamic acid	69.2	57.4	17.1
Serine	16.5	12.5	24.2
Glycine	15.4	15.7	−1.9
Arginine	24.0	21.2	11.7
Alanine	14.8	12.9	12.8
Tyrosine	10.0	7.7	23.0
Cystine	1.64	0.88	46.3
Proline	14.5	8.96	38.2
Σ essential AA	119.4	99.6	16.6
Σ nonessential AA	203.8	160.7	21.1

TABLE 4 Growth performance of Ossimi lambs fed diets with different levels of rocket seed cake (RSC) replacing soybean meal as a protein feed.

	Diet[a]					P value			
	RSC0	RSC25	RSC50	RSC75	SEM	Diet	RSC0 vs. others	Linear	Quadratic
Initial weight (kg)	39.2	39.0	39.1	38.5	0.83	0.947	0.789	0.659	0.792
Final weight (kg)	57.0	60.2	56.8	55.3	1.12	0.038	0.732	0.109	0.046
Total weight gain (kg/lamb)	17.8	21.2	17.7	16.8	0.55	<0.001	0.279	0.013	0.001
Daily gain (g/lamb)	198	235	197	186	6.2	<0.001	0.279	0.013	0.008

[a]The control diet contained (per kg DM): concentrates feed mixture and berseem clover at 70:30 (RSC0 diet). Rocket seed cake was included at 4.2%, 8.4%, or 12.6% to replace soybean meal at 25% (RSC25 diet), 50% (RSC50 diet), or 75% (RSC75 diet), respectively.
P-value is the observed significance level of the *F*-test for diet; SEM = standard error of the mean.

of rocket seeds. Higher consumption of rocket increases the consumption of thioglucosides and erucic acid which are considered toxic substances and cause lower palatability of feed and depress the function of the thyroid (T_3 and T_4) causing negative effects on the growth of lambs (Das et al., 2003). Myrosinases hydrolyze glucosinolates into various hydrolysis products with a variety of growth-promoting biological activities (Cavaiuolo & Ferrante, 2014; Chen & Andreasson, 2001). More research on feeding RSC and other feeds rich in specific substances (e.g., thioglucosides and erucic acid) is recommended to provide strong evidence of their expected effects on ruminal fermentation, microbial activity, feed digestion, and animal performance.

3.3 | Feed intake and conversion

The RSC25 treatment increased ($P < 0.001$) the intakes of DM, SV, TDN, DCP, and DE compared to RSC0 by 6.9%, 7.6%, 8.2%, 8.9%, and 8.4%, respectively, while the RSC75 treatment decreased these values by 4.8%, 9.8%, 9.2%, 11.7%, and 9.1%, respectively (Table 5) indicating a lower nutritional value of the diets at higher levels of replacement. These results indicate that the palatability of the diet was enhanced with the RSC25 treatment (the low level of inclusion) compared to the high levels of replacement. The presence of the secondary metabolites (e.g. thioglucosides) at suitable levels, and the pleasant aroma and flavor of rocket (Al-Rawe et al., 2023; Al-Taey et al., 2023) may be a possible reason for the affected intake. The concentration of thioglucosides may be responsible for the observed effects (both negative and positive effects on feed intake), and thioglucosides and erucic acid were high enough to impair feed intake in the RSC75 treatment. Theoretically, consuming high levels of thioglucosides (e.g. bioactive compounds with a high antimicrobial activity will decrease microbial activity and negatively affect feed intake (Al-Taey et al., 2023; Pagnotta et al., 2022). Such effects were not measured in the present experiment; therefore, more research is recommended to confirm or refute such effects on ruminal microbes, and consequently on ruminal digestion and fermentation.

Additionally, the RSC25 treatment decreased feed conversion calculated as kg DM intake/kg gain, kg TDN intake/kg gain, kg SV intake/kg gain, g DCP intake/g gain, and Mcal DE intake/kg gain compared to RSC0 by 10.1%, 8.9%, 8.6%, 7.7%, and 8.8%, respectively. Results of the enhanced feed intake and feed efficiency with the RSC25 treatment, and the impaired ones with the RSC75 treatment may be due to the probably affected ruminal fermentation.

3.4 | Diet digestibility and nutritive value

The rationale of this experiment was to use rocket seed meal as an alternative to soybean meal and thus the objective was to determine the effect of feeding lambs rocket seed cake on feed utilization and growth performance. This objective was fulfilled as treatments did not affect OM, CP, EE, NDF, and ADF digestibility (Table 6). Moreover, diet's nutritive values expressed as true SV ($P = 0.092$), TDN ($P = 0.090$), DCP ($P = 0.093$), and DE ($P = 0.331$) were not affected by the dietary treatments.

The weak effects of different treatments on nutrient digestibility indicate that rocket seeds have almost the same or better digestion compared to soybean meal. It was expected that the RSC at the low level would enhance nutrient digestibility while the high levels of inclusion would impair nutrient digestion. It is expected that rocket

TABLE 5 Feed intake and feed conversion in Ossimi lambs fed diets with different levels of rocket seed cake (RSC) replacing soybean meal as a protein source.

	Diet[a]					*P* value			
	RSC0	RSC25	RSC50	RSC75	SEM	Diet	RSC0 vs. others	Linear	Quadratic
Feed intake									
Dry matter (kg/lamb/day)	1.45	1.55	1.42	1.38	0.052	0.037	0.039	0.643	0.004
SV (kg/lamb/day)	0.92	0.99	0.88	0.83	0.012	<0.001	0.010	0.001	0.007
TDN (kg/lamb/day)	0.98	1.06	0.94	0.89	0.010	<0.001	0.023	<0.001	0.003
DCP (g/lamb/d)	179	195	169	158	2.1	<0.001	0.067	<0.001	0.002
DE (Mcal/lamb/d)	4.29	4.65	4.11	3.90	0.051	<0.001	0.024	<0.001	0.006
Feed conversion									
kg DM intake/kg gain	7.35	6.61	7.22	7.43	0.275	0.022	0.435	0.509	0.012
kg TDN intake/kg gain	4.95	4.51	4.76	4.78	0.178	0.037	0.237	0.764	0.023
kg SV intake/kg gain	4.65	4.25	4.47	4.49	0.167	0.039	0.228	0.723	0.024
g DCP intake/g gain	0.91	0.84	0.86	0.85	0.031	0.045	0.140	0.312	0.038
Mcal DE intake/kg gain	21.7	19.8	20.9	21.0	0.78	0.041	0.231	0.735	0.038

[a] The control diet based on (per kg DM): 700 g of concentrates feed mixture and 300 g berseem clover (*Trifolium alexandrinum*) (RSC0 diet). Rocket seed cake was included at 4.2%, 8.4%, or 12.6% to replace soybean meal at 25% (RSC25 diet), 50% (RSC50 diet), or 75% (RSC75 diet), respectively.
P-value is the observed significance level of the *F*-test for diet; SEM = standard error of the mean. DCP = digestible crude protein, DE = digestible energy, SV = starch value, TDN = total digestible nutrients.

TABLE 6 Nutrient digestibility and diet's nutritive value in Ossimi lambs fed diets containing rocket seed cake (RSC) replacing soybean meal at different levels as a protein feed.

	Diet[a]					*P* value			
	RSC0	RSC25	RSC50	RSC75	SEM	Diet	RSC0 vs. others	Linear	Quadratic
Digestibility (g/kg DM)									
Organic matter	707	724	701	685	8.1	0.058	0.736	0.044	0.076
Crude protein	723	742	705	685	8.8	0.100	0.270	0.057	0.005
Ether extract	709	742	675	670	10.0	0.343	0.281	0.097	0.003
Neutral detergent fiber	612	642	619	600	13.9	0.264	0.600	0.386	0.116
Non-structural carbohydrates	737	734	720	705	8.9	0.111	0.131	0.024	0.512
Nutritive values (g/kg DM)									
True starch value	634	641	619	604	7.8	0.092	0.216	0.196	0.214
Total digestible nutrients	674	682	658	644	7.9	0.090	0.222	0.189	0.113
Digestible crude protein	124	126	119	115	1.5	0.093	0.058	0.060	0.099
Digestible energy (Mcal/kg)	2.96	3.00	2.89	2.82	0.35	0.331	0.206	0.165	0.120

[a] The control diet contained (per kg DM): concentrates feed mixture and berseem clover at 70:30 (RSC0 diet). Rocket seed cake was included at 4.2%, 8.4%, or 12.6% to replace soybean meal at 25% (RSC25 diet), 50% (RSC50 diet), or 75% (RSC75 diet), respectively.
P-value is the observed significance level of the *F*-test for diet; SEM = standard error of the mean.

seeds can stimulate the activity of digestive enzymes, boost the secretion of digestive enzymes, and promote the activity of the beneficial microflora in the digestive tract to create a healthy environment for feed digestion (Al-Shammari & Batkowska, 2021).

No detrimental effects were found on nutrient digestibility from those animals fed on RSC; however, total weight gain and daily gain were improved with RSC inclusion. This may be partly explained due to the presence not only of digestible crude protein but also to the contents of carotenoids, vitamin C, glucoerucin, and flavonoids (Morshedy et al., 2021; Rahmy et al., 2024). One limitation of our experiment is that we did not determine rumen microbiome composition, and further studies should analyze that to improve our understanding of the mechanisms behind RSC active molecules in the digestive system.

3.5 | Blood measurements

The measured blood parameters were within the established reference ranges for healthy animals (Boyd, 1984). Feeding RSC did not affect the concentrations of blood total protein, globulin, creatinine, glucose, ALT, AST, cholesterol, and triglycerides (Table 7). However, the RSC-containing diets linearly ($P < 0.05$) increased the concentrations of blood albumin and urea-N. Weak effects on blood total protein, globulin, and creatinine may be related to the minor effects of treatments on CP digestibility. Such results suggest the absence of negative effects of the bioactive compounds in rocket seed on the nutritional status of lambs (Kholif et al., 2021). Another evidence of the positive effects of treatments on the nutritional status of lambs is the increased concentrations of blood albumin by 33.3%, 27.8%, and 16.7% with the RSC25, RSC50, and RSC75 treatments, respectively. However, CP digestibility was not affected by the treatments, the increased serum albumin may reflect the quality of protein and amino acid profile of rocket seed compared to soybean meal. The RSC diets increased blood urea-N by 4.3%, 10.0%, and 12.3% for the RSC25, RSC50, and RSC75 treatments, respectively. The increased blood urea-N was not paralleled with the observed CP digestibility, without a clear reason. The starch content in the feed has appeared to have decreased due to the increase in RSC substitution rate and its digestibility has also decreased. The reduced starch intake and digestibility decreased ammonia availability to microorganisms in the rumen, and the increased blood urea-N was probably due to an increase in unused ammonia in the rumen (de Oliveira Franco et al., 2016). Such effects may be regarded as potential reasons for the observed changes.

The minimal effects of the diets on liver enzymes (i.e. ALT and AST), and their value within normal range for healthy lambs (Pettersson et al., 2008) indicate improved/unaffected liver functions due to the protective effects of rocket seed on liver cells from free radical damage. The unchanged glucose with the feeding rocket may be due to the unaffected OM and NSC digestibility. Additionally, the rocket has a high efficiency in promoting the transfer of glucose to cells to be used as a source of energy and prevents its accumulation in the blood (Khoobchandani et al., 2010).

The RSC decreased ($P = 0.023$) the concentration of HDL compared to the control diet. Minimal effects on blood cholesterol and triglycerides were observed with the treatments; however, RSC contained more fat and free fatty acids. Vitamin C in the seeds of rocket minimizes the biotransformation of unsaturated fatty acids into cholesterol esters (Khoobchandani et al., 2010). RSC-containing diets decreased the concentrations of blood HDL by 29.1%, 19.2%, and 28.4% for the RSC25, RSC50, and RSC75 diets. This effect confirms the ability of phytogenic feeds/additives containing phenolic acids to lower blood HDL (Kholif et al., 2015). Kurmukov (2013) stated that

TABLE 7 Blood measurements in Ossimi lambs fed diets containing different levels of rocket seed cake (RSC) replacing soybean meal as a protein feed.

	Diet[a]					*P* value			
	RSC0	RSC25	RSC50	RSC75	SEM	Diet	RSC0 vs. others	Linear	Quadratic
Total protein (g/dL)	7.70	7.87	7.33	7.40	0.378	0.729	0.713	0.421	0.898
Albumin (g/dL)	1.8	2.4	2.3	2.1	0.09	0.012	0.004	0.004	0.105
Globulin (g/dL)	5.9	5.5	5.0	5.3	0.41	0.578	0.263	0.283	0.475
Urea-N (mg/dL)	30.0	31.3	33.0	33.7	1.10	0.019	0.032	0.013	0.028
Creatinine (mg/dL)	1.15	1.17	1.23	1.04	0.100	0.609	0.985	0.569	0.319
Glucose (mg/dL)	60.3	59.7	56.7	55.3	2.49	0.473	0.311	0.145	0.897
Alanine transaminase (IU/L)	14.7	15.3	14.0	14.2	2.01	0.964	0.944	0.760	0.904
Aspartate transaminase (IU/L)	91.0	92.0	88.7	93.3	3.26	0.781	0.932	0.808	0.590
Cholesterol (mg/dL)	90.0	87.7	89.0	85.7	4.91	0.930	0.664	0.609	0.921
Triglycerides (mg/dL)	53.7	54.7	54.0	52.0	2.43	0.881	0.969	0.616	0.554
High-density lipoprotein (mg/dL)	43.7	31.0	35.3	31.3	1.44	0.023	0.062	0.013	0.035

[a] The control diet contained (per kg DM): concentrates feed mixture and berseem clover at 70:30 (RSC0 diet). Rocket seed cake was included at 4.2%, 8.4%, or 12.6% to replace soybean meal at 25% (RSC25 diet), 50% (RSC50 diet), or 75% (RSC75 diet), respectively.
P-value is the observed significance level of the *F*-test for diet; SEM = standard error of the mean.

TABLE 8 Economic evaluation of replacing soybean meal with different levels of rocket seed cake (RSC) as a protein feed in diets of Ossimi lambs.

	Diet[a]			
	RSC0	RSC25	RSC50	RSC75
Total weight gain (kg/lamb/90 day)	17.8	21.2	17.7	16.8
Dry matter consumed (kg/lamb/90 day)	131	140	128	124
Price of 1 kg DM of the ration ($USD)[b]	0.6	0.6	0.5	0.5
Cost of feed consumed ($USD/lamb/90 day)	77	77	66	61
Total revenue ($ USD)	126	149	125	119
Net revenue ($USD)	49	72	59	58
Relative percentage of net revenue	100	147	120	118

[a] The control diet contained (per kg DM): concentrates feed mixture and berseem clover at 70:30 (RSC0 diet). Rocket seed cake was included at 4.2%, 8.4%, or 12.6% to replace soybean meal at 25% (RSC25 diet), 50% (RSC50 diet), or 75% (RSC75 diet), respectively.
[b] All price values are in $ USD which is equal to 17 EGP (Egyptian pound) during this study.

plant secondary metabolites can minimize the synthesis and absorption of all types of cholesterol and form insoluble complexes with them to reduce their concentration in blood serum (Adriani et al., 2016).

3.6 | Economic evaluation

The RSC25 treatment showed the highest relative percentage of net revenue compared to the other treatments (Table 8). The highest net profit measured as $USD/lamb through the experiment was $ 72 USD with the RSC25 diet, followed by the RSC50, RSC75, and RSC0 diets, whose values were $59 USD, $58 USD, and $49 USD, respectively. Compared to the control, feeding the RSC25, RSC50, and RSC75 diets increased the net revenue by 47%, 20%, and 18%, respectively. Feed cost is the highest recurrent cost in livestock production, with the highest cost for protein feeds. Reducing the cost of animal feeding will be positively reflected as net revenue for producers. In fattening systems of lambs, decreasing the cost of feed intake or enhancing the feed efficiency are the major ways to increase farmer's profit. Therefore, these objectives can be achieved by enhancing feed conversion and weight gain (Mousa et al., 2022). Therefore, substituting costly feeds with cheap alternatives should be used to reduce the cost of feeding. In the present experiment, replacing soybean meal with the RSC showed better economic efficiency with the highest relative percentages of net revenue with the RSC25 treatment containing soybean meal. This could be attributed to either the increase of most nutrient digestibility caused by the inclusion of RSC at 25% and/or the low price of RSC ($412 USD/ton) compared to that of soybean meal ($1,235 USD/ton).

In conclusion, rocket seed cake can replace soybean meal as a protein feed in the diets of growing lambs at different levels. The inclusion of rocket seed cake to replace one-quarter of soybean meal in the diet (equals to 4.2% of total diet DM) is the recommended level to improve feed utilization, diet's nutritive value, and growth performance under the current experiment conditions. Long-term studies on animals are needed to verify their effects and explore the specific mechanism of action on the performance of animals at different growth stages.

CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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