Carcass characteristics and meat quality of male goat kids supplemented by alternative feed resources: Olive cake and cactus cladodes.

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Research

Keywords: olive cake, cactus cladode, goat kid, carcass, meat quality, fatty acid

Posted Date: March 23rd, 2020

DOI: https://doi.org/10.21203/rs.3.rs-18316/v1

Abstract

Background The current study was carried out to evaluate the effect of olive cake and cactus cladodes incorporation on carcass characteristics and meat quality of goat kids.

Methods Forty-eight male goat kids were divided into four groups. The control group received a conventional supplementation and the test groups were supplemented with a concentrate containing, on dry matter basis, 35% of olive cake (OC), 30% of cactus cladodes (CC), or 15% OC and 15% CC (OC+CC) respectively. After 3 months, all animals were slaughtered and the carcass quality was characterized. Samples of Longissimus dorsi and Semimembranosus were collected to determine meat quality.

Results The diets did not affect final body weight and carcass characteristics, except for muscle index that decreases with 35% OC, and redness and yellowness at tail outline and belly ($P < 0.05$). The OC incorporation increased yellowness at tail and decreased redness at belly ($P < 0.05$), while the CC inclusion decreased redness at tail outline ($P < 0.01$), and redness ($P < 0.05$) and yellowness at belly ($P < 0.01$). Meat ultimate pH, color, moisture and tenderness were not affected by diets. In Longissimus dorsi, higher proteins ($P < 0.001$) and lower fat and ash ($P < 0.05$) content were observed with CC, and lower proteins content with OC and OC+CC ($P < 0.001$). In Semimembranosus, a low initial pH ($P < 0.05$) was observed with OC and high protein content ($P < 0.001$) with CC and OC+CC. Generally, groups, ratios, and indexes of fatty acids (FA) were similar between groups, except FA profile that was affected by diet, especially for Semimembranosus. In Longissimus dorsi, the OC and CC introduction decreased C16:1, and C20: 3n3 increased with CC and OC+CC ($P < 0.05$). While in Semimembranosus, OC increased C6, C8, C18:3n3, C20:2 and C22:2, whereas CC incorporation reduced C8, C10, and C15:1, and OC+CC reduced C10 ($P < 0.05$).

Conclusions This study was shown that OC and CC could be introduced in goat kids' diet, without a negative effect on carcass characteristics and meat quality.

Background

Goat (*Capra hircus*) is characterized by a high adaptation capacity in harsh systems and to climate changes [1, 2]. Thus, it provides an important and stable source of red meat and protein for consumers in regions with a harsh environment [3]. Generally, farmers use concentrate feedstuffs in small-ruminants diet to respond to livestock needs, which represents a competition to human food and high additional charges [4]. In these systems, the conventional feed (forage and concentrate) use is expensive [5]. Thus, the reduced production cost became a challenge. It is necessary that breeders adopt some low input strategies, as the use of available alternative feed resources, such as agro-industrial by-products and multi-purpose shrubs [6, 7].

In the Mediterranean area, the olive tree is cultivated on a large surface accounting for 95% of global olive trees cultivation [8]. Olive industrial sector produces, besides olives and olive oil, important quantities of by-products (olive cake (OC) and waste-water) [9]. Frequently rejected in nature, these by-products are

considered as a serious environmental threat due to their negative effects on soil, air and aquatic ecosystems [10]. Many studies reported the opportunity to introduce OC in the ruminant diet to reduce their environmental negative impacts and breeder feed charges [7, 5, 11 –13].

Cactus, this distinguished multi-purpose shrub by its high adaptation to harsh environments, is another alternative feed resource that provides marginal water source for ruminants during drought [14] and high evergreen forage [15]. Many authors recommended the incorporation of cactus pear and cladodes in ruminant diet [16] and others studied their effects on quality of animal products, especially for sheep [15, 17 – 20].

Among ruminants, goat especially is able to valorize by-products and consume such feeds rich in lignin and poor in protein content because of the presence of highly cellulolytic bacterias, and *Streptococcus caprinus* (a bacteria able to degrade tannin-protein complexes) and a high tanninase activity in the rumen [5, 12, 21]. Goat is also characterized by high proteolytic activity and a different microbiota in rumen compared to bovine [22].

Additionally, consumers become more aware of the importance of food quality and its effects on human health and risk of diseases [23, 24]. At this level, goat meat shows a higher dietetic quality compared to sheep. Indeed, goat produces lean carcass and meat with lower intramuscular fat content and thus higher relative proportion of polyunsaturated fatty acids (PUFA) [3, 23]. To meet market and consumer needs, breeders have to warrant sustainable production systems with high-quality products. As known from the literature, diet composition has a deep influence on the sensorial and nutritional quality of animal products [3, 25]. The increase of PUFA in the diet improves fatty acid (FA) profile, desirable FA (DFA) and when appropriate, FA of ω3 group [25]. Moreover, alternative feed resources and by-products are often characterized by a high content in plant secondary compounds (carotenoids, essential oils, antioxidants, flavors polyphenolic compounds, tocopherols, phytosterols, and peptides, etc) , that could have positive effects on ruminant meat quality [4, 6, 7].

Researches on the impact of OC incorporation in the ruminant diet are scarce and were performed only on the sheep and were mainly conducted in the European countries [6, 7, 13]. There are no published studies, to our knowledge, on the OC effect on goat kids meat quality. However, limited researches on cactus cladodes (CC) effect on meat quality were conducted on small ruminant (sheep and goat) [15, 17, 19, 26, 27], meanwhile these studies were focused only on spineless variety of cactus mainly in Brazil and Tunisia. Whereas information regarding the effect of spiny cactus in goat kids diet in other countries is scarce. In this context, the objective of this work was to evaluate the effect of OC and spiny CC introduction in goat kid's diet, on carcass characteristics and meat quality.

Material And Methods

Animals and diets

This study was performed in experimental farm of National Institute of Agricultural Research in Tangier (INRA - Morocco) (35°39'N, 5°51'W; 11 m a.s.l). Forty-eight male goat kids of the indigenous breed called "Beni Arouss", 3-months old with an initial body weight of 10.5 ± 0.1 kg, were divided into four homogeneous groups on a body weight basis. The experiment lasted for 107 days including an adaptation period of 21 days. The goat kids were fed on oat hay complemented by four kinds of supplementation. The control group (Co) received a similar conventional supplementation as distributed by farmers of the region; composed of barley and faba bean (Table 1). The three test (T) groups received either OC, CC or both ones instead of barley. The T_{OC} group was supplemented on a dry matter (DM) basis with 35% OC, the T_{CC} group with 30% CC and the T_{OC+CC} group with 15% of both of them. Table 1 details the ingredients and the chemical and nutritive composition of 1kg DM of each diet. The offered quantities of the diets were adapted to be iso-energetic and iso-proteic. Feed supplement components were ground and mixed, and diet was distributed in two daily meals. The experimental goat kids were kept under similar management and feeding conditions compared to those herded on the regional scale. The CC was provided from shrubs cultivated near the experimental farm. They were daily collected, cut manually to slices with a cutter after removing spines. The OC was provided during the oil extraction period (November to January) from an olive oil mill using a mechanical press process located in Ouazzane town (34°47'N, 5°34'W; 298 m a.s.l) in Northern Morocco. Crude OC was conveyed directly to the experimental farm where it was dried in the air under plastic greenhouse for a few days. Then, it was conserved hermetically in plastic bags. During the experiment, animals had a free access to fresh clean water all the time.

Carcass characteristics

At the end of the trial, all goat kids were weighed and slaughtered as described by Duan et al. [28]. Directly after slaughter, the carcass was weighed before and after the fifth quarter removing to determine hot carcass weight and yield. Also, full and empty digestive tract, skin, pluck (liver, lung, pancreas, heart, spleen, and trachea), paws, head, perirenal, and mesenteric fat were weighed. At the end, the carcass was conserved in a cold room at 4°C for 24 hours.

Twenty four hours after slaughter, the cold carcass was weighed. Also, carcass and thigh length, and thigh thickness were measured to determine compactness (carcass weight on carcass length), muscle (ratio of thigh thickness on thigh length) and conformity indexes (sum of compactness and muscle index).

Carcass color was determined twenty-four hours post-mortem using Konica-Minolta colorimeter CR-400^{Ò} with measurement and illumination area of Ø 8 mm and Ø 11 mm, and 0° viewing angle, calibrated using white calibration plate CR-A43. The color was measured according to CIE [29] L*, a*, b* system, by recording values of lightness index (L*), and two chromatic parameters: redness (a*) and yellowness (b*) intensity indexes. The L* represents the lightness that is variable from 0 for black to 100 for white. The a* and b* are variable from -60 (green and blue) to + 60 (red and yellow) [30]. Values were read in saddle, back middle, tail outline, and belly three times for each sample and the average was recorded.

Longissimus dorsi and *Semimembranosus* muscles of each carcass were removed. These samples were divided into two halves. The first one was used to determine shear force and color, and the second one was ground to homogenize samples for moisture, ash, water retention capacity, protein, fat, and the FA profile analysis. Meat samples were packed and conserved at -25°C until chemical analysis.

Meat analysis

Before sampling, meat pH at 0 and 24 hours post-mortem were determined by using penetration pH-meter (HANNA HI99163) for the two types of muscles. Also, 24 hours post-mortem, muscles color was determined by recording L*, a* and b*. These components were used to determine hue angle (H°) that presents the angle allowing radiation in the yellow-red quadrant (H° = arctangent (b* / a*) × [360° / (2 × 3.14)]) and Chroma (C*) that measures color saturation ($C^* = (a^{*2} + b^{*2})^{0.5}$) [31]. To determine moisture, 5 g of sample was mixed with sand purified with hydrochloric acid 3 N and 95% ethanol and dried in an oven at 102 ± 2°C for 16 hours. Meat ash was obtained by carbonizing 5 g of ground muscle with 1 ml magnesium acetate on heating plate and incinerating the mixture in oven at 550 °C for a period of 1 hour at least. Water retention capacity was determined by exerting during 5 minutes a pressure on sample put between two filter papers [32]. Fat determination method consisted of acid hydrolysis by boiling 5 g sample in 100 ml of 3 N hydrochloric acid during 1 hour and filtering the mixture on double filter paper that was extracted in Soxhlet extractor. Protein was obtained according to Kjeldahl method.

To determine shear force, meat samples were thawed at 4 °C for 24 hours, held in plastic bags and then cooked in water bath programmed at 75 °C with a meat intern temperature of 70 °C during 40 min to determine cooked meat shear force. Then, cooked samples were placed in refrigerator for 24 hours. The raw and cooked texture was obtained by Warner-Bratzler shear force protocol using Texture Analyser "TA.HD plus C®" with a V-shaped cutting blade. Meat tenderness was obtained from *Semimembranosus* muscle, because there were not enough samples left from *L. dorsi* to determine shear force.

Fatty acid profile

The intra-muscular fat was extracted from samples according to Folch et al. [33] method using Chloroform-Methanol. The FA methyl esters (FAME) were prepared by transmethylation described in 969.33 method of AOAC [34]. One ml of n-heptane containing FAME was recuperated in gas chromatograph (GC) vial and preserved in -80°C freezer before injection. The extract was injected in GC (Varian GC CP 3800) equipped with a flame ionization detector and a capillary column type CP- SIL88 capillary column (100 m x 0.25 mm x 0.2 µm). The FA were identified by comparing with a standard analytical mixture of C4 to C24 FA (FAME Sigma-Aldrich) that refers to 37 FA. Detected FA were classified into 13 groups, ratios and indexes:

- Saturated fatty acids (SFA) = C4:0 + C6:0 + C8:0 + C10:0 + C11:0 + C12:0 + C13:0 + C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0 + C21:0 + C23:0 + C22:0 + C24:0;

- Mono-unsaturated fatty acids (MUFA) = C14:1 + C15:1 + C16:1 + C17:1 + C18:1n9t + C18:1n9c + C20:1 + C22:1n9 + C24:1;

- Polyunsaturated fatty acids (PUFA) = C18:2n6t + C18:2n6c + C18:3n6 + C18:3n3 + C20:2 + C20:3n6 + C20:3n3 + C20:4n6 + C22:2 + C22:5n3 + C22:6n3;

- Desirable fatty acids (DFA) = C18:0 + PUFA + MUFA; [23]

- Omega 3 = C18:3n3 + C20:3n3 + C20:5n3 + C22:6n3;

- Omega 6 = C18:2n6t + C18:2n6c + C18:3n6 + C20:3n6 + C20:4n6;

- Omega 9 = C18:1n9t + C18:1n9c + C22:1n9;

- PUFA : SFA ratio = PUFA / SFA;

- MUFA : PUFA ratio = MUFA / PUFA;

- Omega 6 : Omega 3 ratio = Omega 6 / Omega 3;

- Atherogenicity index (AI) = (C12:0 + (4 × C14:0) + C16:0) / (MUFA + PUFA); [35]

- Thrombogenic index (TI) = (14:0 + 16:0 + 18:0) / [0.5 (MUFA) + 0.5 (n-6 PUFA) + 3(n-3 PUFA) + (n-3 PUFA / n-6 PUFA)]; [35]

- (C18:0 + C18:1) / C16:0. [23]

Statistical analysis

The data were processed using SAS® version 9.4 software (SAS Institute Inc., Cary, NC, USA). The effect of the factors was tested by generalized linear models (GLM). Slaughter and carcass measurements were compared using one-way analysis of variance according to the following model:

$$Y_{ik}=\mu+\alpha_i+e_{ik},$$

where Y_{ik}: dependent variable; μ: mean; α_i: effect of i^{th} modality of diet; e_{ik}: residual error.

Meat quality and FA profile results were compared according to a mixed model allowing the inclusion of the compound symmetry structure effect of covariance associated with repeated measures performed on the same animal (PROC MIXED; SAS 9.4) according to the following model:

$$Y_{ijk}=\mu+\alpha_i+\beta_j+\gamma_{ij}+\delta_{ijk}+\varepsilon_{ijk},$$

where Y_{ijk}: the dependent variable; μ: mean; α_i: fixed effect of i^{th} modality of diet; β_j: fixed effect of j^{th} modality of muscle; γ_{ij}: effect of interaction in ij^{th} case; $б_{ijk}$: random effect associated with k repeated observations; e_{ijk}: residual error.

Multiple comparisons of the means were performed when a significant effect of the model was obtained at *P-value* < 0.05.

Results

Carcass parameters

Table 2 presents the effect of OC and CC on body weight and carcass characteristics of each studied groups. After 3 months, animals had the same final body weight in all groups. Also, the hot and cold carcass weight and yield were similar. The full and empty digestive tract was not affected by OC and CC incorporation. They were estimated on average at 4.55 and 1.25 kg, respectively. Gut content thus represented 72% of full digestive tract weight. Pluck, paws and head were the same in control and test groups. Perirenal and mesenteric fats were low and were about 16 g and 41 g, respectively. There was no-effect of OC and CC on the fat deposition. The OC and CC incorporation was without an effect on carcass and thigh length, thigh thickness, and compactness and compliance indexes. However, muscle index was significantly decreased by OC incorporation ($P < 0.05$). Carcass color was affected by diet. No effect was observed on back and saddle color. However, redness and yellowness in tail outline and belly were significantly different ($P < 0.05$). The carcass of goat kids receiving CC and OC+CC were less red than control at tail and belly, and T_{cc} belly was less yellow than control ($P < 0.05$). The OC carcasses were more yellow (b* = 7.9 *vs* 3.6) at the tail outline and less red (a* = 10.1 *vs* 12.7) than that from the control group ($P < 0.05$).

Meat quality

As shown in Table 3, there was no difference in *L. dorsi* pH_0 and pH_{24} between groups. However, *Semimembranosus* of T_{OC} group had a slightly higher pH at slaughter compared to other groups ($P < 0.05$), and no difference was observed on ultimate pH. The initial pH was different according to the muscle (7.05 for *L. dorsi vs* 6.98 for *Semimembranosus)*; however, the interaction between muscle and diet did not affect meat pH_0 and pH_{24}. *Longissimus dorsi* and *Semimembranosus* lightness and color parameters (L*, a*, b*, H° and Chroma) were similar between groups. However, chevon lightness and color differs significantly according to muscle type ($P < 0.01$). The interaction muscle and diet was not significant for the meat lightness and color. The moisture of *L. dorsi* and *Semimembranosus* was similar between groups. A highly significant effect of muscle type was observed on moisture ($P < 0.001$). No-significant effect of muscle and diet interaction was observed on meat moisture. Chevon ash was about 2% and similar between groups in *Semimembranosus.* However, in *L. dorsi*, ash was significantly lower in

CC and OC+CC groups ($P < 0.05$). The muscle type and the interaction between muscle and diet did not affect ash content. Diet did not affect the water retention capacity of *L. dorsi.* In *Semimembranosus,* this capacity was higher in groups receiving CC in the diet (T_{cc} and T_{oc+cc}; $P < 0.001$). Sampled muscle and the interaction muscle and diet had a significant effect on water retention capacity ($P < 0.01$). Meat protein in *L. dorsi* was higher in the T_{CC} group and lower in groups receiving OC (T_{oc} and T_{oc+cc}; $P < 0.001$). However, in *Semimembranosus*, diet did not affect this parameter. The meat protein was similar in the sampled muscles; nevertheless the interaction muscle/diet had a very highly significant effect on meat protein ($P < 0.001$). *Longissimus dorsi* in T_{CC} meat contained a lower intramuscular fat proportion ($P < 0.05$). In *Semimembranosus,* fat was not affected by diet. Nevertheless, intramuscular fat was similar by sampled muscles and also the interaction between muscle and diet. The inclusion of OC and CC did not affect the *Semimembranosus* tenderness.

Fatty acid profile

As detailed in Table 4, chevon in all groups had a high concentration in the oleic acid form cis (C18:1n9c) and C18:0. Generally, sampled muscles had a significant effect on FA profile, groups, ratios and indexes. However, the interaction between muscle and diet had less effect on these parameters. The FA of *L. dorsi* was not affected by diet except for palmitoleic (C16:1) and eicosatrienoic (C20:3n3) acids. The C16:1 was lower in T_{OC} and T_{CC} groups ($P < 0.05$) compared to control. Whereas the C20:3n3 in *L. dorsi* was higher in the T_{CC} group ($P < 0.05$).

In *Semimembranosus* muscle, T_{OC} group meat fat contained higher rates of caproïc (C6), caprylic (C8), capric (C10), α-linolenic (C18:3n3), eicosadienoic (C20:2) and docosadienoic (C22:2) acids ($P < 0.05$), while T_{CC} intramuscular fat had the lowest content in C6, C8, C10 and pentadecenoic (C15:1) acids ($P < 0.05$).

The FA groups (SFA, DFA, MUFA, PUFA, ω-3, ω-6, and ω-9) were not affected by CC and OC incorporation in *L. dorsi* and *Semimembranosus*.

For FA rations, the ω-6 / ω-3 ratio was similar in all groups for *L. dorsi* and *Semimembranosus.* It was from 1.4 to 2.1 in both muscles. Diet was without an effect on PUFA : SFA and MUFA : PUFA ratios. The FA indexes (atherogenicity (AI) and thrombogenic index (TI), and (C18:0 + C18:1) / C16:0) of *L. dorsi* and *Semimembranosus* were similar in all groups.

Discussion

Carcass parameters

Generally, animal performance, carcass traits, and meat composition are influenced by breed and diet [36]. In the present trial, carcass characteristics were lower compared to the ones of sheep because goat carcass is leaner and less compact [3, 37] but also compared to other goat breeds because the growth potential of local and indigenous breeds is lower [38]. Final body weight, hot and cold carcass, and

carcass composition were similar between treatments as expected from the distributed diets quantities that were similar for energy and nitrogen. Roy et al. [39] reported an initial (11 kg) and final body weight (14.7 kg), and hot carcass weight (6 kg) of Black Bengal goat receiving soybean and sunflower bean, similar to the current results. Abidi et al. [17] found a negative effect of spineless CC on weight performances of sheep and goats that disagrees with the current results.

Carcass yield was lower than norm classically reported for goat (49 – 51%) because the studied animals were younger and this parameter is positively correlated to animal age [40]. However, values were similar to those found by Roy et al. [39] for Black Bengal goat kids (42%).

Gut content represented 72% of full digestive tract weight. This could be explained by its low turnover rate because of its high crude fiber content [13].

Perirenal and mesenteric fats were low, which could be explained by diets with low energy contain or by a low allometric rate of fat development in goats (1.26 – 2.25 for subcutaneous and 1.26 – 1.76 for intramuscular fat) [41] and thus a late fat development that is apparent at maturity [3]. The present results are thus not unexpectable in young animals at slaughter. Kotsampasi et al. [12] reported that partially destoned exhausted OC had no effect on body and carcass weight, yield, and visceral organ that is in agreement with the current results. By contrast, Mioč et al. [13] found that 30% of OC decreases final body weight, hot carcass weight, and carcass yield, and increases digestive tract weight of lamb. The obtained goat muscle index was lower than sheep because goat carcass is smaller, leaner, and less compact [3].

For carcass color, the yellowness of OC carcass agrees with Hamdi et al. [11] who reported an increment of fat yellowness in lamb fed OC because of its richness in carotenoids, which deposited in fat. The inferiority of redness in T_{CC} and T_{CC+OC} groups could be caused by a higher conversion of myoglobin to metmyoglobin due to undesirable microbiology [42] developed in meat with high water retention capacity.

Meat quality

Generally, meat quality is affected by many factors as breed, age, sex, weight, and diet [3]. Color, tenderness and pH are the most important meat properties, and the most representative parameter is pH because it affects shear force, water retention capacity, cooking weight loss, flavor and color [3, 19]. The value of pH_0 has to be lower than 6.4 and that of pH_{24} between 5.4 – 5.7 to be commercialized [11, 43] that is lower than the present results. A high ultimate pH (> 5.8) corresponds to dark and tough meat with a reduced shelf-life [41]. The high ultimate pH of chevon (5.8 – 6.2) is a specificity of goat species related to the excitable nature of temperamental species, highly prone to stress in perimortem [3], which leads to glycogen stores decrease and a high pH of meat [44]. Atti et al. [26] reported an ultimate pH of 6.18 – 6.48 for male goat kids receiving spineless CC that is higher than the present results.

Meat color depends on myoglobin content in muscle and its chemical state. It is an essential parameter because consumer selects meat based on its color [19]. Priolo et al. [45] reported the lack of OC blocks

effect on L*, a*, b*, H°, and C* of Barbarine lambs' meat in agreement with the current results for *L. dorsi* and *Semimembranosus*. The lightness was lower in *Semimembranosus* than *L. dorsi* in agreement with that was reported for pigs in intensive and extensive systems by Purchas et al. [46] who found a muscle effect on lightness with *Semimembranosus* inferiority compared to *L. dorsi*. *Semimembranosus* muscle was more red and yellow with a higher hue angle and chroma than *L. dorsi*. Ledward et al. [47] found an effect of electric stimulation of beef on *L. dorsi* and *Semimembranosus* muscles color, which means that color differs according to muscle.

Kotsampasi et al. [12] found moisture of 74 – 75% in lambs meat receiving partly destoned exhausted OC and Webb et al. [3] cited a range of 60 – 70% in chevon that is lower than the present results. The effect of muscle type on moisture is in agreement with the found of Badiani et al. [48] for *Infraspinatus* and *Semitendinosus* in beef.

Oliveira et al. [27] found a linear decrease in goat meat ash content by replacing corn by cactus meal, which is in agreement with the found for *L. dorsi.* Turner et al. [36] reported 4.3 – 4.4% of ash in the meat of goat kids on pasture that is higher than the current results. However, the present results remained in the range cited by Webb et al. [3] (0.95 – 3.4%) for goat meat.

Meat protein results remained in the range reported by Webb et al. [3] (17 – 29.2%) for goat meat. Mioč et al. [13] found that 30% of OC decreases protein in lamb leg meat that agrees with the results observed in *L. dorsi* protein content. Atti et al. [26] reported, by contrast, lack of CC effect on protein. Protein content was similar by muscle. However, the interaction muscle/diet effect could be attributed to the dietary effect on meat protein content in *L. dorsi*.

Goat meat is considered as lean [3]. The intramuscular fat influences meat quality parameters such as juicy, yellowness, and tenderness [49]. Chevon is thus less juicy because of its lower content in intramuscular fat [3]. Fat content was lower than the range cited by Webb et al. [3] (4.4 – 21.2%). Mahouachi et al. [20] found a decrease of fat in *L. dorsi* by introducing CC in goat kids diet in agreement with the current found for the same muscle. The CC is considered as a forage and Hocquette et al. [50] reported that cattle fed on grass had a high lipidic than glucidic blood profile traduced by a low lipogenesis in adipose tissue. By contrast, Kotsampasi et al. [12] reported a lack of OC effect on moisture, ash, and fat what is in agreement with the current results.

Meat texture is affected by many factors as pre-slaughter temperature, slaughtering management, carcass post-mortem, rigor mortis speed, post-mortem pH, glucose concentration in the muscle, sampled muscle and sample preparation method [3, 51]. Tenderness depends on collagen content, connective tissue reticulation degree, and muscular fibers size [52]. This author reported that females' meat is tenderer than males'. The parameter also is correlated positively with carcass fatness [53] and depends on sampled muscle, species, and breed [54]. These authors reported that *Longissimus thoracic* and *lumborum* muscles are tenderer than *Semimembranosus* and tenderness differs according to goat species. Meat tenderness beyond 11 kgf is considered as tough for lamb meat. A value beyond 10 kgf is unacceptable and less than 7 kgf, moderately acceptable in beef meat [3]. So, goat *Semimembranosus*

did not reach an acceptable tenderness degree [3]. Tenderness of raw and cooked *Semimembranosus* was not affected by diet. Costa et al. [19] found that the inclusion of cactus pear has no-effect on ram meat tenderness. The current result of tenderness is near to that found by Swan et al. [54] (9.1 kgf) and lower than reported by Sheridan et al. [55] (11.1 kgf) for *Semimembranosus* of Boer goat. Chevon is more hardness than sheep meat because it is characterized by a high collagen content with a low solubility, high fibrous residues, and larger and ticker myofibrils [3].

Fatty acid profile

The FA profile of meat influences meat quality (flavor, consumer acceptance, hardness, and palatability), shelf life and human health [3, 12, 23]. Chevon FA profile is healthy because of its high rate of oleic acid (C18:1) and low concentrations of lauric (C12:0) and myristic (C14:0) acids compared to other meats [56]. Generally, the main FA in goat fat are C18:1, palmitic (C16:0), stearic (C18:0) and linoleic (C18:2) acids [23].

The FA concentration results are within the range of C18:0 (6 – 17 g/100g fat) and C18:2 (4 – 15 g/100g fat) and lower than of C18:1 (28 – 50 g/100g fat) and C16:0 (15 – 31 g/100g fat) reported by Banskalieva et al. [23]. The major FA in chevon that was cis form of oleic acid (C18:1n9c) is known by reducing low-density lipoprotein cholesterol (LDL), maintaining high-density lipoprotein cholesterol (HDL) and preventing cardiac diseases [56].

Sampled muscles had a significant effect on FA profile, groups, ratios and indexes what is in agreement with observations reported by Badiani et al. [48], Cho et al. [57] and Raes et al. [58] for beef. Also, Enser et al. [59] reported FA profile differences when comparing a more white and a more red muscles (*Longissimus vs Gluteobicepts*), which concurs with the observed results.

No effect of C14:0 and C18:0 because these FA are related to weight increase [40] and the body weight was similar for all groups in this study. The low content of C16:1 in T_{OC} and T_{CC} groups compared to control might be explained by its low content in CC and OC compared to control diet. Mele et al. [7] found that 35% of OC decreases C16:1 in lamb meat, which is in agreement with the current work. The C20:3n3 that is a metabolic product of the oleic acids (C18:1n9) [35], is a ω-3 acid that is increased by fresh forage [60], which could explain its high rate in T_{CC} group with the incorporation of CC that is considered as a green forage.

The high concentration of C15:1 in *Semimembranosus* for the control group could be explained by the dietary carbohydrates that produce high quantities of propionate that are used to synthesize odd-chain FA in fat [61]. The high content of C6 and C8 acids in *Semimembranosus* for T_{OC} group could be caused by the high content of oil in OC that could alter ruminal bacteria and inhibit long-chain FA synthesis [39].

The diet effect on C18:3n3 level in *Semimembranosus* is in agreement with Kotsampasi et al. [12] that found an increment of C18:3n3 by OC diet and with Vasta et al. [42] feeding OC and CC silage in lamb meat. This increase could be explained by its escape from ruminal biohydrogenation because of the

presence of tannins that depressed the biohydrogenation process in the rumen, which results in a high concentration of α-linolenic acid in intramuscular fat [12]. Also, Δ5 and Δ6 desaturase enzymes in association with elongase permit the formation of long-chain PUFA (C20-C22) from C18:3n3 and C18:3n6 [60], which explains the high content of C20:2 and C22:2 in intramuscular fat of OC chevon.

Luciano et al. [6], Abidi et al. [17], Mahouachi et al. [20] and Atti et al. [26] reported a lack of CC effect on SFA, MUFA, and PUFA in lambs and goat kids meat that is in agreement with the current results. Generally, SFA are positively correlated to meat palatability and hardness [23]. The fiber in the diet stimulates the ruminal activity and the biohydrogenation that provokes an increment in SFA [51]. However, a diet containing rapidly degradable carbohydrates has a short stay in rumen, which perturbs the biohydrogenation process and conducts implicitly to a high content of unsaturated FA [51]. The DFA in goat meat is higher than in cattle and sheep. In the present work, the DFA is in the range of chevon DFA (61–80%) [23].

Generally, long-chain FA (PUFA and ω3) are more susceptible to escape the biohydrogenation, and comparatively to be absorbed and deposited as ω3 and ω6 in animal tissues [51]. Berthelot [52] reported that in a lean muscle, PUFA n-6 are high because these acids are from membrane cell origin. The high content of ω-6 is undesirable because it generates eicosanoids with more thrombotic tendency compared to ω-3 that could cause coronary diseases to human [3].

The ω-6/ω-3 ratio that associated with the risk of cancers and heart diseases [62], is lower than 4, which is considered as benefic in human nutrition [56].

The lack of diet effect on PUFA : SFA and MUFA : PUFA ratios, atherogenicity (AI) and thrombogenic index (TI), and (C18:0 + C18:1) / C16:0 in *L. dorsi* and *Semimembranosus*, agrees with Kotsampasi et al. [12] who found a lack of OC effect on SFA, MUFA, PUFA, PUFA / SFA, the AI and the (C18:0 + C18:1) / C16:0 ratio of lamb meat. The PUFA : SFA ratio that presents the risk of a diet to provoke coronary heart disease [35], should have a high value to be beneficial in human nutrition, and a value of 0.45 is recommended [59]. The current result PUFA : SFA ratio was below 0.4 and 0.3 in *L. dorsi* and *Semimembranosus* respectively and lower than the recommendation that is normal in ruminants' meat because of unsaturated FA biohydrogenation in rumen [23]. Mahouachi et al. [20] reported the absence of CC effect on PUFA : SFA ratio in chevon as observed presently in this experiment. This parameter is lower for ruminant than monogastric because of the hydrogenation by microflora in rumen. Ulbricht and Southgate [35] consider that AI and TI are indicators of cardiovascular disease risks because they take into consideration other factors and permit a comparison between diets. The AI and TI obtained in *L. dorsi* and *Semimembranosus* are close to stewed ox liver that is considered as an antithrombogenic food (AI = 0.41 and TI = 0.82) [35]. The (C16:0 + C18:1) / C18:0 ratio, which describes the health effects of different lipid types [23], is mainly influenced by diet and breed. It ranged from 3.2 to 4 that is in the range and slightly higher than values reported by Banskalieva et al. [23] (1.37–3.64).

Conclusions

The incorporation of olive cake and cactus cladodes in the diet of Beni Arouss goat kids had no negative effect on carcass and meat quality, and fatty acids profile. Meat quality and fatty acids profile differed according to muscle type. Thus, olive cake and cactus cladodes are two alternatives feed resources that could be introduced in diet of goat kids to reduce feeding cost. Further studies are recommended to evaluate the incorporation of olive cake and cactus cladodes on ruminal microbiota and goat milk quality.

Abbreviations

a*: redness; AI: atherogenicity index; b*: yellowness; C*: chroma; CC: cactus cladodes; Co: control; DFA: desirable fatty acid; DM: dry matter; FA: fatty acid; FAME: fatty acid methyl ester; GC: gas chromatograph; H°: Hue angle; L*: lightness index; MUFA: monounsaturated fatty acid; OC: olive cake; PUFA: polyunsaturated fatty acid; SFA: saturated fatty acid; TI: thrombogenic index.

Declarations

Ethics approval

All study procedures and Guidelines for Experimental Animals were approved by the Regional Center of Agricultural Research of Tangier (permit number: 01/CRRAT/2017). All efforts were made to minimize the suffering of the animals.

Consent for publication

Not applicable.

Availability of data and materials

All data generated or analyzed during this study are included in the article.

Competing interests

The authors declare no competing financial interest

Authors' contributions

SEO conceived of the study, carried out the experiments, collected the sample, analyzed data and drafted the manuscript. YC assisted with data analysis and manuscript drafting. MC, JLH and JFC participated in the study's design and coordination. All authors read and approved the final manuscript.

Acknowledgments

The authors are sincerely ARES-CCD (Academy of Research and Higher Education) for providing funds and facilities for the study.

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Tables

Table 1 Ingredients, chemical and nutritive composition of goat kids diets.

	Co	T_{OC}	T_{CC}	T_{OC+CC}
Diet ingredients (on DM basis)				
Oat hay (% TD)	51	43	47	46
Barley (% CD)	39	0	0	0
Olive cake (% CD)	0	35	0	15
Cactus cladodes (% CD)	0	0	30	15
Faba beans (% CD)	59	63	68	68
Vitamin-Mineral Supplement (% CD)	2	2	2	2
Chemical composition of diet				
Dry matter (% CM)	89	89	29	44
Ash (g/kg DM)	47	47	77	62
Crude protein (g/kg DM)	875	874	880	892
Ether extract (g/kg DM)	35	60	33	44
Neutral detergent fiber (NDF) (g/ kg DM)	446	480	456	467
Acid detergent fiber (ADF) (g/kg DM)	273	328	276	300
Lignin (ADL) (g/ kg DM)	51	41	51	47
Metabolizable energy (MJ/ kg DM)	12	10	11	11
Forage unit for meat (FUMeat/ kg DM)	0.8	0.7	0.7	0.7
Digestible proteins in the intestines (g/ kg DM)	75	63	69	67

Co: control diet; T_{OC}: diet with 35% of olive cake; T_{CC}: diet with 30% of cactus cladodes; T_{OC+CC}: diet with 15% of olive cake and 15% of cactus cladodes; *DM*: dry matter; *TD*: total diet; *CD*: concentrate diet; *CM*: crude matter.

Table 2 The effect of olive cake and cactus cladodes on bodyweight, and carcass characteristics of goat kids.

		Co	T_{OC}	T_{CC}	T_{OC+CC}	*P*	*SEM*
Initial body weight (kg)		10.4	10.6	10.5	10.4	NS	0.311
Final body weight (kg)		14.9	13.9	14.0	14.7	NS	0.373
Hot carcass weight (kg)		6.43	6.24	6.02	6.56	NS	0.167
Carcass yield (%)		40.7	41.5	40.1	42.3	NS	0.504
Cold carcass weight (kg)		6.07	5.80	5.60	6.10	NS	0.156
Full digestive tract (kg)		4.91	4.44	4.14	4.69	NS	0.159
Empty digestive tract (kg)		1.39	1.19	1.14	1.29	NS	0.046
Skin							
Weight (g)		699	674	685	742	NS	0.823
Rate (%)		4.69	4.85	4.88	5.04	NS	0.122
Pluck							
Weight (g)		717	663	663	734	NS	21.4
Rate (%)		4.81	4.77	4.73	4.99	NS	0.103
Paws							
Weight (g)		415	398	389	409	NS	10.3
Rate (%)		2.78	2.87	2.77	2.78	NS	0.073
Head							
Weight (g)		945	921	926	1000	NS	24.1
Rate (%)		6.34	6.64	6.60	6.79	NS	0.121
Perirenal fat (g)		20.3	15.0	13.4	14.6	NS	1.77
Mesenteric fat (g)		40.2	43.0	41.3	40.1	NS	3.28
Carcass length (cm)		44.9	47.0	46.4	47.4	NS	0.492
Thigh length (cm)		19.2	19.4	19.1	19.9	NS	0.344
Thigh thickness (cm)		5.60	5.49	5.09	5.45	NS	0.153
Compactness index (%)		11.1	10.2	9.93	10.6	NS	0.211
Compliance index (%)		40.5	33.9	36.3	37.0	NS	0.773
Muscle index (%)		29.4	23.7†	26.4	26.4	0.033	0.612
Back							
	L*	59.0	60.5	59.3	60.7	NS	0.691
	a*	8.28	8.10	8.11	8.14	NS	0.302
	b*	-4.07	-4.06	-4.24	-4.24	NS	0.414
Saddle							
	L*	54.9	54.3	55.1	55.0	NS	1.04
	a*	14.8	14.9	14.5	14.1	NS	0.364
	b*	2.88	3.06	2.79	3.07	NS	0.336
Tail outline							
	L*	49.2	48.9	49.7	49.9	NS	0.492
	a*	17.8	19.5	14.7†	14.8†	0.004	0.483
	b*	3.63	7.88†	4.93	4.60	0.021	0.484
Belly							
	L*	54.8	54.4	54.4	55.5	NS	0.651
	a*	12.7	10.1†	9.66†	9.86†	0.029	0.385
	b*	4.32	3.30	1.09†	3.21	0.006	0.369

Co: control diet; T_{OC}: diet with 35% of olive cake; T_{CC}: diet with 30% of cactus cladodes; T_{OC+CC}: diet with 15% of olive cake and 15% of cactus cladodes;

Pluck: liver, lung, pancreas, heart, spleen, and trachea;

*L**: lightness index; *a**: redness index; *b**: yellowness index;

NS: No-significant $P \geq 0.05$;

†: Values followed by † are significantly different from the control group at $P < 0.05$.

Table 3 The effect of olive cake and cactus cladodes on pH, color, composition and tenderness of *Longissimus dorsi* and *Semimembranosus* muscles of goat kids

	Longissimus Dorsi						*Semimembranosus*						*P*	
	Co	T_{OC}	T_{CC}	T_{OC+CC}	*P*	SEM	Co	T_{OC}	T_{CC}	T_{OC+CC}	*P*	SEM	Muscle	Muscle*diet
pH0	6.98	7.16	7.08	6.99	NS	0.043	6.85	7.17†	6.98	6.91	0.031	0.031	0.006	NS
pH24	6.12	6.01	6.05	6.06	NS	0.035	6.08	6.05	6.01	6.05	NS	0.044	NS	NS
Meat color														
L*	53.3	54.7	54.8	53.4	NS	0.501	51.1	52.6	52.0	51.0	NS	0.560	0.008	NS
a*	17.7	17.2	17.2	17.5	NS	0.343	21.1	20.7	20.1	20.6	NS	0.413	<0.001	NS
b*	5.17	5.38	5.19	5.44	NS	0.185	6.69	6.62	6.79	6.64	NS	0.200	<0.001	NS
Hue angle	16.0	18.3	16.0	16.8	NS	0.622	17.4	18.8	19.0	18.0	NS	0.561	0.004	NS
Chroma	18.4	18.2	17.0	18.9	NS	0.441	22.0	20.6	21.3	21.6	NS	0.442	<0.001	NS
Moisture (%)	82.5	82.4	82.8	82.1	NS	0.010	79.2	79.5	80.2	80.2	NS	0.251	<0.001	NS
Ash (%)	2.10	2.12	1.96†	2.02†	0.019	0.021	2.15	2.19	2.13	2.12	NS	0.096	NS	NS
WRC (%)	23.2	23.5	22.4	23.1	NS	0.560	14.6	17.2	21.9†	22.9†	<0.001	0.764	0.026	0.003
Protein (%)	19.8	19.0†	21.5†	18.3†	<0.001	0.224	19.9	19.8	19.7	19.6	NS	0.213	NS	<0.001
Fat (%)	1.80	1.94	1.43†	1.82	0.028	0.067	1.39	1.37	1.39	1.31	NS	0.059	NS	NS
Raw Tenderness (kgf/cm²)	-	-	-	-	-	-	15.0	14.3	14.3	14.1	NS	0.930	-	-
Cooked tenderness (kgf/cm²)	-	-	-	-	-	-	9.39	9.60	9.31	9.83	NS	0.293	-	-

Co: control diet; T_{OC}: diet with 35% of olive cake; T_{CC}: diet with 30% of cactus cladodes; T_{OC+CC}: diet with 15% of olive cake and 15% of cactus cladodes;

*L**: lightness index; *a**: redness index; *b**: yellowness index;

WRC: water retention capacity;

NS: No-significant $P \geq 0.05$;

† : Values followed by † are significantly different from the control group at $P < 0.05$.

Table 4 The effect of olive cake and cactus cladodes on fatty acid profile (g/100g fat), groups (g/100g fat), ratios and indexes of *Longissimus dorsi* and *Semimembranosus* of goat kids

	Longissimus Dorsi						*Semimembranosus*						*P*	
	Co	T_{OC}	T_{CC}	T_{OC+CC}	*P*	SEM	Co	T_{OC}	T_{CC}	T_{OC+CC}	*P*	SEM	M	M*D
C4	0.35	0.35	0.33	0.35	NS	0.066	0.65	0.64	0.53	0.563	NS	0.070	0.001	NS
C6	0.29	0.30	0.26	0.28	NS	0.039	0.24	0.43†	0.16	0.128	0.025	0.041	0.009	0.003
C8	0.25	0.25	0.27	0.26	NS	0.041	0.15	0.43†	0.09†	0.23	0.005	0.041	NS	0.022
C10	0.16	0.14	0.16	0.17	NS	0.023	0.12	0.11	0.05†	0.05†	0.046	0.012	<0.001	NS
C11	0.07	0.08	0.09	0.10	NS	0.016	0.65	0.65	0.63	0.662	NS	0.126	<0.001	NS
C12	0.13	0.10	0.12	0.13	NS	0.014	0.25	0.20	0.20	0.217	NS	0.032	<0.001	0.001
C13	0.13	0.18	0.18	0.15	NS	0.023	0.31	0.31	0.31	0.287	NS	0.033	NS	<0.001
C14	0.79	0.75	0.89	0.85	NS	0.054	1.24	1.22	1.22	1.245	NS	0.062	<0.001	<0.001
C14:1	0.35	0.37	0.39	0.39	NS	0.022	0.58	0.59	0.56	0.573	NS	0.037	<0.001	0.014
C15	5.07	5.06	4.66	4.62	NS	0.544	6.41	6.45	6.20	6.303	NS	0.485	0.010	0.046
C15:1	0.81	0.73	0.78	0.73	NS	0.101	0.73	0.35	0.32†	0.445	0.042	0.057	0.005	NS
C16	11.2	11.3	12.2	11.9	NS	0.759	13.1	13.4	14.0	13.7	NS	0.585	0.026	NS
C16:1	2.12	0.88†	1.29†	1.79	0.044	0.158	2.19	3.05	2.22	2.18	NS	0.246	<0.001	<0.001
C17	3.94	4.21	4.09	3.91	NS	0.368	3.76	4.07	3.85	4.08	NS	0.314	<0.001	0.004
C17:1	1.11	1.07	1.05	1.09	NS	0.111	1.34	1.25	1.33	1.29	NS	0.081	<0.001	0.015
C18	17.7	18.1	17.9	17.5	NS	0.812	17.1	16.6	16.9	16.8	NS	0.730	NS	NS
C18:1n9t	0.71	0.76	0.76	0.74	NS	0.110	1.41	1.25	1.45	1.22	NS	0.176	<0.001	0.007
C18:1n9c	25.5	25.8	25.6	25.4	NS	1.211	26.3	25.3	26.8	26.1	NS	1.162	NS	NS
C18:2n6t	0.41	0.45	0.41	0.40	NS	0.058	0.36	0.36	0.32	0.31	NS	0.030	NS	NS
C18:2n6c	5.93	5.56	5.41	5.62	NS	0.328	6.41	6.10	6.38	6.57	NS	0.404	NS	NS
C20	1.21	1.15	1.23	1.07	NS	0.067	0.30	0.30	0.30	0.29	NS	0.024	0.003	NS
C18:3n6	0.54	0.52	0.57	0.51	NS	0.076	0.35	0.30	0.31	0.31	NS	0.066	<0.001	NS
C20:1	0.64	0.63	0.61	0.63	NS	0.129	0.40	0.39	0.40	0.38	NS	0.049	NS	NS
C18:3n3	0.80	0.76	0.74	0.75	NS	0.124	0.39	0.56†	0.40	0.39	0.023	0.029	0.006	NS
C21	0.65	0.67	0.63	0.61	NS	0.123	1.11	1.27	1.00	1.16	NS	0.086	0.007	NS
C20:2	0.42	0.41	0.46	0.47	NS	0.082	0.13	0.26†	0.11	0.20	0.029	0.021	0.004	NS
C22	1.45	1.49	1.61	1.41	NS	0.118	1.26	1.13	1.19	1.34	NS	0.024	<0.001	<0.001
C20:3n6	0.63	0.65	0.63	0.62	NS	0.064	0.51	0.51	0.51	0.50	NS	0.044	0.003	0.002
C22:1n9	0.52	0.53	0.60	0.58	NS	0.076	0.27	0.30	0.28	0.28	NS	0.036	<0.001	NS
C20:3n3	0.16	0.18	0.53†	0.48†	0.043	0.058	0.20	0.19	0.20	0.20	NS	0.033	0.002	0.002
C20:4n6	0.56	0.64	0.57	0.52	NS	0.114	0.84	0.83	0.86	0.83	NS	0.102	NS	NS
C23	6.19	6.93	6.42	6.68	NS	0.481	4.58	4.21	4.79	4.80	NS	0.316	<0.001	<0.001
C22:2	1.04	1.09	1.05	1.00	NS	0.204	0.54	1.41†	0.52	0.64	0.035	0.131	NS	NS
C24	2.24	2.05	2.07	2.06	NS	0.191	0.51	0.57	0.51	0.52	NS	0.083	<0.001	NS
C20:5n3	1.37	1.41	1.43	1.40	NS	0.210	1.24	1.21	1.30	1.26	NS	0.103	NS	0.025
C24:1	1.88	1.81	1.79	1.93	NS	0.241	1.75	1.81	1.71	1.83	NS	0.240	NS	NS
C22:6n3	2.62	2.61	2.29	2.96	NS	0.212	2.27	2.10	2.17	2.14	NS	0.155	0.013	NS
Summary														
SFA	52.5	52.1	52.7	51.8	NS	1.201	51.6	52.0	52.0	52.7	NS	0.914	NS	0.003
MUFA	28.6	28.9	29.0	29.1	NS	0.945	35.2	34.1	34.7	34.0	NS	1.073	<0.001	NS
PUFA	18.9	18.9	18.3	19.1	NS	1.683	13.2	13.9	13.3	13.3	NS	0.710	NS	NS
DFA	65.2	66.0	65.2	65.7	NS	1.001	65.5	64.6	64.8	64.1	NS	0.961	<0.001	NS
ω - 3	4.95	4.97	5.00	5.58	NS	0.420	4.10	4.06	4.06	3.98	NS	0.276	NS	NS
ω - 6	8.06	7.82	7.58	7.66	NS	0.379	8.50	8.10	8.39	8.51	NS	0.564	NS	0.016
ω - 9	26.7	27.1	26.9	26.7	NS	1.263	27.9	26.8	28.5	27.6	NS	1.342	<0.001	NS
Ratio														
ω6/ ω 3	1.63	1.57	1.52	1.37	NS	0.113	2.07	2.00	2.06	2.14	NS	0.182	NS	0.018
PUFA:SFA	0.36	0.36	0.35	0.37	NS	0.040	0.26	0.27	0.26	0.25	NS	0.019	NS	NS
MUFA:PUFA	1.51	1.53	1.59	1.53	NS	0.141	2.66	2.45	2.61	2.55	NS	0.268	0.003	NS

Index														
AI	0.31	0.30	0.34	0.32	NS	0.020	0.38	0.38	0.40	0.40	NS	0.013	0.025	NS
TI	0.88	0.89	0.91	0.84	NS	0.064	0.91	0.92	0.94	0.94	NS	0.030	<0.001	NS
(C18:0+C18:1)/C16:0	3.91	4.0	3.62	3.68	NS	0.247	3.41	3.23	3.23	3.21	NS	0.086	<0.001	NS

Co: control diet; T_{OC}: diet with 35% of olive cake; T_{CC}: diet with 30% of cactus cladodes; T_{OC+CC}: diet with 15% of olive cake and 15% of cactus cladodes; M: muscle; D: diet.

AI: Atherogenicity index; *TI*: Thrombogenic index; *DFA*: Desirable fatty acids; *MUFA*: monounsaturated fatty acids; *PUFA*: polyunsaturated fatty acids; *SFA*: saturated fatty acids; *NS*: No-significant $P \geq 0.05$; *†*: Values followed by † are significantly different from the control group at $F < 0.05$.