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Institute of Genetics and Animal Biotechnology
of the Polish Academy of Sciences, Jastrzębiec, Poland

Is it possible to increase goat meat production under Mediterranean forest conditions using small amounts of concentrate without deterioration of its quality?*

Olfa Slimeni[1], Hadhami Hajji[2], Ilyes Mekki[1], Samir Smeti[1], Mokhtar Mahouachi[3], Faïcel Saidani[4], Naziha Atti[1]*

[1] University of Carthage, National Institute of Agronomic Research of Tunisia, Animal and Forage Productions Laboratory- rue Hédi Karray 2049 Ariana Tunisia

[2] University of Gabes, Livestock and Wildlife Laboratory, Arid Regions Institute (IRA), 4119 Médenine, Tunisia

[3] University of Jendouba, ESA Kef, Le Kef Tunisia

[4] ODESYPANO Béja, Tunisia

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Meat is considered a highly nutritious and valued food, although red meat contains high amounts of fat, while goat meat has been established as lean meat. The main objective of this study was to investigate the nutritional quality of meat from Mediterranean kids raised on two forest pastures in the extensive production system (EPS) where goats grazed on a natural forest pasture without concentrate and in the semi-intensive production system (SIPS) where goat received concentrate in addition to pasture grazing. The meat analysis involved 10 kids from each system. The physicochemical characteristics of meat were similar for both management variants of forest raised goats. The meat of the EPS variant contained more ($p<0.01$) saturated fatty acids (SFA) while that of SIPS more ($p<0.01$) monounsaturated FA. Contents of polyunsaturated FA (PUFA), PUFA

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**Corresponding author: naziha.belhaj@iresa.agrinet.tn; naziha.atti@gmail.com

n-3 and n-6 as well as ratios of PUFA/SFA and n-6/n-3 were similar for all meat samples of forest raised goats. The n-6/n-3 ratio was below 4, indicating high nutritional quality of meat from forest raised goats. After 9 days of storage meat lipid oxidation in all the samples was below the threshold concentration. Meat of Mediterranean goats grazing in forest pastures may be considered as food of high nutritional quality, which was improved at a small concentrate supply given to goats.

KEY WORDS: fatty acids / food / forest pasture / goat meat / lipid stability

Red meat is a highly nutritious food thanks to its abundance of proteins, vitamins (A, B6, B12, D and E) and micronutrients (iron, zinc and selenium). Nevertheless, it has been given a negative image in relationship with its content of fat, especially saturated fatty acids (SFA). However, goat meat is widely regarded as lean and thus healthy meat, which leads to an increase in the demand for this meat [Webb 2014], especially when produced in natural ecological conditions, where quality is considered to be the fundamental concept of agricultural and food policies. Furthermore, meat produced on grassland, natural pasture and forest is generally perceived as being of superior quality [Smeti *et al.* 2014, Mekki *et al.* 2016]. In terms of the relationship of food and human health special attention is increasingly given to the fatty acid (FA) profile, particularly some biologically-active substances [Aranceta *et al.* 2012]. Besides a lower total fat intake, human nutritionists are recommending a higher intake of polyunsaturated fatty acids (PUFA), especially n-3 PUFA rather than n-6 [Liu *et al.* 2017]. For meat production the animal feeding regime is considered one of the most important factors affecting meat quality, the FA composition in particular [Atti *et al.* 2013, Poławska *et al.* 2013, Bhatt *et al.* 2020]. Animal nutritional treatments can be used to manipulate the FA content of this human food; it could improve the nutritional balance in ruminants with the challenge being to increase the PUFA/SFA and reduce the n-6/n-3 PUFA ratio in the meat. In addition, lipid oxidation is an important criterion considerably affecting the quality of both raw meat and meat products. As a consequence, consumers prefer meat produced based on natural resources, free range and grassland, or formulated with natural antioxidants [Ben Abdelmalek *et al.* 2018]. Likewise, it was shown that meat produced in the natural pasture system has a stronger antioxidant power than that produced using concentrate in the feedlot system [Hajji *et al.* 2016], although the growth rate and meat production were lower in the pasture-based system. While forest pasture grazing is one of the most common goat production systems in the Mediterranean area, limited data on the resulting meat quality is available. To our knowledge, no previous report has established the fatty acid profile or antioxidant activity of meat produced in the forest goat raising system in the southern Mediterranean region. Therefore, this comparative study focused on the nutritional quality of meat from goat kids allocated to two production sub-systems based on Mediterranean forest pasture alone or pasture grazing supplemented with concentrate. It was decided to verify the hypothesis that the concentrate supply, which increases meat production, negatively alters the FA profile and reduces lipid stability of goat meat in the forest production systems.

Material and methods

Animals

The study was conducted in summer (the hot season); it took place in northwestern Tunisia. Goats were selected in two mountainous sites, representing the extensive and semi-intensive production systems, respectively. Feeding goats in the extensive production system (EPS) is based on grazing of natural vegetation dominated by trees and shrubs and characterized by the scarcity or absence of herbaceous plants at this time of year (summer). In the semi-intensive production system (SIPS) farmers used concentrate and hay in addition to pastures. For both sites goat parturition occurs mainly in spring. The kids were reared with their dams until they reached the usual age of sale around of 150 days corresponding to an average live weight of 18 and 22 kg for EPS and SIPS, respectively. From each site ten male kids of the local breed were provided for meat quality analyses.

Slaughtering and meat sampling

The kids were slaughtered after an overnight fasting period with free access to water. The carcasses were weighed and the region containing ribs with the spine and the *longissimus thoracis et lumborum* (LTL) muscle samples of both sides was immediately detached and transported to the laboratory. After measuring initial pH using an Orion 9106 pH-meter, they were refrigerated at 4°C. After 24 h of refrigeration both LTL muscle parts of LTL were separated and the ultimate pH and color parameters were measured. Then each muscle was divided into 7 samples, of which one was immediately used for cooking loss determination and 4 were placed in polystyrene packaging and stored at +4°C for color stability and lipid oxidation measurements; the last two samples were frozen at -20°C for chemical and sensory analyses.

Meat physical and chemical analyses

Meat color coordinates were assessed 24 h post-mortem using a Minolta Chroma Meter CR-400. Color coordinates were calculated in the CIE *L*a*b** space [CIE; 1978]. The lightness (*L**), redness (*a**) and yellowness parameters (*b**) were directly recorded. From these measured parameters, hue angle (H) and Chroma (C*) were calculated as:

$$H = \text{arctg}\ (b^*/a^*)$$

$$C^* = (a^2 + b^2)^{0.5}$$

For cooking loss analyses meat samples were weighed (*Wi*) and held in plastic bags and then immersed in a water bath at 75°C and heated for 30 min until the internal temperature reached 75°C, which was monitored with a thermocouple. Then the bags were cooled under running tap water and blotted dry with paper towels. The cooked meat was weighed again (*Wf*). Cooking loss was calculated as the difference between the loin portion weight before packaging and its weight after cooking and it was expressed as a percentage (*100 * (Wi – Wf) / Wi*).

For chemical composition analyses samples of meat were dried by lyophilization, with samples of dry matter (DM) used for subsequent analyses. Mineral content was determined by ashing meat DM samples at 600°C for 8 h. Crude protein (CP) was determined by the Kjeldahl method and then CP content was calculated as CP = N*6.25. The total lipid content was determined by the Soxhlet method based on extraction using a Solvent Extractor unit SER 148.

Fatty acid profile

The FAs were extracted from intramuscular fat according to the method of Lee *et al.* (2012]. Samples of lyophilized and minced meat (0.4-0.8 g) were mixed with 1 ml of the internal standard (C23:0) and 2 ml of heptanes. Then, 4 ml of $NaOH/CH_3OH$ 0.5M were added. The mixture was homogenized with a vortex mixer and heated for 20 min at 50°C, followed by cooling for 6-7 min. Then 4 ml of acetyl chloride/CH_3OH (1/10v/v) were added. The mixture was shaken and reheated for 60 min at 50°C. After cooling at ambient temperature 2 ml of milli-Q water were added. Then the mixture was shaken, homogenized and centrifuged for 5 min at 3500 rpm and 10°C. The upper layer (heptanes) was collected and transferred to a 5ml test tube and then dehydration was performed with anhydrous Na_2SO_4. The mixture was shaken using a vortex mixer for 30 seconds and then centrifuged for 5 min at 1000 rpm at 10°C. The volume of 1 ml of the supernatant was carefully transferred into a screw cap glass vial for gas chromatography so as not to include any Na_2SO_4. The fatty acid composition of the intramuscular (i.m.) fat was analyzed after extraction and methylation with K-OH for methyl esters. The methyl esters were injected (0.2 µl) in a gas chromatograph equipped with a flame ionization detector (Thermo Finnigan, Les Ulis, France). Its function is to eliminate the aqueous solution which crosses it in a flame of hydrogen, the effluent brought by nitrogen (carrier gas), and of an injector in the split mode, making it possible to introduce a liquid which must be vaporized instantaneously before being transferred onto the column. The methyl ester samples were separated on a fused silica capillary column (CP-Sil 88, Chrompack, Middelburg, Netherlands) of 100 m*0.25 mm in diameter. The injector temperature was maintained at 250°C and the detector temperature at 255°C. The carrier gas was hydrogen. The fatty acid identification was based on retention times as compared with those of the standard FAME mixture of the two commercial fatty acids: GLC-463 and GLC-538. Fatty acid values were expressed as g/100g total fatty acids. The desirable fatty acids (DFA) were calculated as DFA = MUFA + PUFA + C18:0.

Color stability and lipid oxidation measurements

Samples of LTL muscles were placed on semi-rigid trays, wrapped with a film (Cryovac Lid2050) with oxygen permeability rate of 15 cm^3 m^2 24 hr-1 at 1 bar and 23 °C and stored in darkness at 4°C for 9 days. Samples from each tray were randomly taken at days 1, 3, 6 and 9 for instrumental color analysis. A Minolta CM-400 was used to measure color directly on the muscle surface 1 hour after pack opening; the

measured area diameter was 8 mm. Each sample was measured twice and then the results were averaged.

After color analysis the same meat samples were used for lipid oxidation determination by measuring 2-thiobarbituric acid reactive substances (TBARS) according to the procedure proposed by Botsoglou [1994]. For this purpose 10 g of minced meat were homogenized with 20 mL of 10% trichloroacetic acid using an Ultra-Turrax T25 (IKA-Labortechnik, Staufen, Germany) at 13500 rpm for 10 s. After homogenization and centrifugation at 4000 rpm and 4°C for 30 min, the supernatant was decanted through a paper filter. The volume of 2 ml of the filtrate was mixed with 2 ml of aqueous thiobarbituric acid and heated in a water bath for 20 min at 97°C. The mixture was cooled to ambient temperature. The absorbance values of the final solutions and the blank were recorded at 532 nm in a Shimadzu spectrophotometer. TBARS values were calculated from a standard curve and expressed as mg malondialdehyde (MDA) per kg of meat (mg MDA/kg of meat).

Sensory evaluation

For sensory analysis the LTL muscle samples were roasted in aluminum paper in a pre-heated oven at 180°C for 30 min without salt. Each sample was cut into 8 pieces, which were coded and served in a random order for testing by 8 panelists. The panelists evaluated tenderness (scale 1-10; 1 – extremely tough, 10 – extremely tender), juiciness (scale 1-10; 1 – extremely dry, 10 – extremely juicy) and flavor (scale 1-10; 1 – very poor, 10 – very good). Bread and water were provided for each panelist to freshen their mouth between each two samples.

Statistical analysis

A one-way analysis of variance was used to test the effect of the goat diet (with or without concentrate) on meat pH, color parameters measured after blooming, as well as cooking loss, chemical composition, the FA profile and sensory properties. A linear model was used for TBARS and meat color stability parameters. It included the fixed effect of goat diet (GD), time of storage (days; 1, 3, 6 and 9) and their interaction (GD × Time). The Duncan test was used to compare the diet mean and storage time effects. Statistical analyses were performed using SAS software [2004].

Results and discussion

Kid growth and meat production

The body weight (BW) at slaughter was higher for SIPS (21.8±3.2 kg) than EPS kids (17.7±1.3 kg). The weight difference is the consequence of the feeding management difference with feed supply for SIPS resulting in higher growth rate between birth and slaughter, which was 129 vs. 101 g/day for SIPS and EPS kids, respectively. The same trend was observed for carcass and non-carcass component weight (Tab. 1), showing an increase in goat meat production for SIPS compared to

Table 1. Means and standard deviations (in parentheses) of weight of carcass and non-carcass components for kids from forest extensive (EPS) and semi-intensive production systems (SIPS)

Item	EPS	SIPS	P-value
Carcass (kg)	6 (1.1)	9 (1.5)	0.001
Skin (g)	1013 (190)	1551 (331)	0.001
Head (g)	1014 (376)	1425 (207)	0.007
Liver (g)	319 (52)	427 (88)	0.003
Omental fat (g)	55 (11)	78 (47)	0.143

EPS (9.2 vs. 6.1 kg, respectively). For SIPS the growth rate could be further improved using some equilibrated concentrate rich in protein, as farmers fed goats only cereals, especially barley. However, for EPS the growth rate was low due to the rarity of herbaceous plants and the low nutritive value of shrubs and trees. However, a great number of these fodder trees are used for distillation and production of essential oils providing considerable amounts of distillation residues, which could be used in animal nutrition [Yagoubi *et al.* 2018a]. In addition, the use of unconventional feeds such as nutrient blocks made from urea and other by-products of the region could improve the potential production of forest grazing animals [Wyngaarden *et al.* 2020].

Meat chemical composition

Meat chemical components were similar for all forest grazing goats (Tab. 2), which meat has high protein (88.2% DM) and low fat contents (9.4% DM). These values are improved compared to those obtained for kids of the same breed, but reared in the stall system, which contained less than 84% protein and more than 11% fat [Atti *et al.* 2004]. This confirms the fact that animals grazing on the pasture had leaner meat than feedlot ones [Hajji *et al.* 2016]. It was shown that herb addition in the quail diet had a positive effect on the chemical composition of its meat [Jakubowska and Karamucki 2021].

Meat physical characteristics

pH. The initial and final pH values (pH1 and pH2) are shown in Table 2. The meat from EPS has significantly higher initial and final pH compared to SIPS meat; this difference can be explained by the stress experienced by the animals before slaughter. The breeding conditions were more comfortable for the SIPS animals reared on medium altitude pastures, while EPS animals grazed in high altitude pastures. Furthermore, lower pH was recorded for meat obtained from animals receiving high-energy diets, which could protect animals against potentially glycogen-depleting stressors [Hajji *et al.* 2016]. Our results confirmed this explanation given the higher energy level of SIPS compared to the EPS group. The recorded values were close to those previously found for Spanish or Tunisian kids [Ayeb *et al. 2019*], but they were higher than others reported in the literature [Kadim *et al.* 2004]. At such a pH the meat is considered appropriate for consumption within a short period. The pH decrease within 24-48 hours post mortem is very important, as it could drop from 7 to 5.7-5.5

Table 2. Means and standard deviations (in parentheses) of chemical composition and physical characteristics of kid meat from forest extensive (EPS) and semi-intensive production system (SIPS)

Item	EPS	SIPS	P-value
Dry matter (DM)	26.3 (1.63)	27.1 (1.35)	0.230
Ash(% DM)	3.2 (0.52)	3.6 (0.28)	0.050
Proteins (% DM)	88.0 (9.77)	88.5 (6.76)	0.650
Lipids (% DM)	9.3 (0.87)	9.6 (4.28)	0.860
pH1	6.8 (0.11)	6.3 (0.08)	<0.001
pH2	6.3 (0.2)	5.9 (0.05)	0.001
dpH[1]	0.5 (0.1)	0.4 (0.1)	0.100
Cooking loss	15.1 (7.02)	20.6 (6.21)	0.071
Color parameters			
*L**	47.1 (4.12)	48.5 (5.52)	0.490
*a**	12.1 (1.38)	16.5 (3.1)	0.001
*b**	6.2 (0.92)	9.0 (1.82)	0.005
*c**	13.6 (1.37)	19.1 (3.36)	0.001
*h**	27.4 (3.89)	27.2 (4.35)	0.906

[1]dpH – pH dropper.

[Monin 1988], while in the current study meat pH drop was similar (0.4-0.5) for both groups.

Cooking loss. Meat of the SIPS group showed a greater cooking loss than that of EPS (Tab. 2); the difference between the production systems tended to be significant (P=0.07). These results confirm those of other researchers [Cañeque *et al.* 2003], who found that the cooking loss percentage was significantly higher for meat of goats fed concentrate than those fed exclusively on grass. This difference may also be assigned to the final pH, with cooking loss values being dependent to final pH [Monin 1988]. In fact, the considerable decrease of cooking loss in the first 24 hours after slaughter is due to a decrease in pH.

Meat color after blooming. The index L*, which reflects the degree of brightness was similar for meat of both types of forest grazing goat production systems (Tab. 2). However, it was shown that the type of diet affected the luminance of meat [Cañeque *et al.* 2003]; it is lower for grass-fed lambs than those fed concentrate. In fact, for the current study all kids providing meat were reared on the pasture, so they had a similar diet type. The similarity of fat content could also explain the absence of the effect of the diet on meat brightness [Manso *et al.* 2016]. In addition, the lack of the diet effect on pH drop could explain the unaffected lightness. This color index of meat from all forest grazed goats was above 44 (47-48). This L* value is within the range of most meat acceptability; it has been shown that meat with the L* value above or equal to 34 is averagely accepted, and when it exceeds 44 the meat is considered acceptable by 95 % of consumers [Khliji *et al.* 2010].

The redness (a*), yellowness (b*) and chroma (C*) values were higher for meat of the SIPS group than in the EPS group, while hue angle (H*) was similar for meat

of both forest raising systems (Tab. 2). However, it was shown that meat from animals finished on the pasture is darker than meat from animals finished on concentrate [Rodrigues et al., 2011]. In this study higher values for a* and b* were recorded for meat with lower pH, while Priolo et al. [2002] had shown an opposite trend.

For b* indices, depending mainly on carotenoid pigment intake, the difference is related to the nature of ingested diet. Animals of the SIPS group might consume greater amounts of grass thus more carotenoids, given the higher availability of herbaceous plants in this production system. For the redness index (a*) it was shown that the differences could be linked to differences in weight and/or age at slaughter [Sheridan *et al.* 2003]. In this study the difference in slaughter weight (> for SIPS) could explain the difference in redness. Moreover, our results (a* = 16.5) for the SIPS group were comparable to those found for other breeds [Cañeque *et al.* 2003] with an average value of 16.8.

The fatty acid profile

For all meat samples of forest grazing goats the major FAs were C16:0, C18:0 and C18:1. They accounted jointly for over 70 % of total detected FAs (Tab. 3). The prevalence of the palmitic, stearic and oleic FAs is in line with the first results on the meat FA profile of the Tunisian local goat [Ayeb *et al.* 2019; Smeti *et al.* 2021], while also being consistent with the commonly accepted FA values for goat meat [Banskalieva *et al.* 2000]. Meat from the EPS goats contained significantly more C14:0; the same trend was recorded for C16:0 and C18:0, although the difference was not significant. However, C18:1 was significantly higher in meat of the SIPS kids (Tab. 3). Also, the C18:2 content tended to be higher ($p<0.08$) in the SIPS group, this increase is related with the concentrate consumed by kids from this system. The conjugated linoleic acid (CLA) was similar for meat of all forest grazing goats (Tab. 3), which reflected the similarity between the diet types. Meat of ruminants is one of the richest natural dietary source of CLA. The CLA content recorded in the current study is relatively high, indicating the health-promoting value of this meat produced by forest raised goats. Several health benefits of CLA have been recognized in relation to atherosclerosis, immunodeficiency, diabetes and carcinogenesis [Aranceta *et al.* 2012, den Hartigh 2019]. In addition, some studies have indicated that CLA could improve body composition by reducing body fat and increasing muscle mass [Blankson *et al.* 2000].

The SFA level was significantly higher in meat of the EPS goats compared to the SIPS kids (50.3 vs. 44.58). In contrast, the proportion of MUFA was significantly higher in the SIPS meat (Tab. 3). It is known that MUFA percentage contents in meat from animals receiving concentrate are higher than in meat from those reared exclusively on pasture [Alfaia *et al.* 2009, Hajji *et al.* 2016]. This difference is mainly due to oleic acid, the major MUFA in meat of forest raised goats, which accounted for 90-91% of total MUFA content. The same trend was recorded for the PUFA content in meat, but here the difference was non-significant, while the proportion of all UFAs was significantly higher for meat of the SIPS group compared to the EPS group (Tab.

Table 3. Means and standard deviations (in parentheses) of fatty acid (FA) composition (% of total FA), index and ratios in meat from kids from forest extensive (EPS) and semi intensive production systems (SIPS)

Item	EPS	SIPS	P-value
C14 :0	5.86 (1.23)	3.41 (3.01)	0.006
C14 :1n-5	0.17 (0.10)	0.19 (0.08)	0.53
C15 :0	1.32 (0.11)	0.96 (0.28)	0.009
C16 :0	24.3 (1.17)	22.6 (3.91)	0.13
C16 :1n-7	2.55 (0.52)	2.51 (0.62)	0.43
C17 :0	1.83 (0.28)	1.74 (0.12)	0.43
C17 :1n-7	0.53 (0.26)	0.68 (0.11)	0.11
C18 :0	16.5 (2.11)	15.6 (2.42)	0.33
C18 :1	31.2 (0.85)	36.3 (0.62)	0.003
C18 :2n-6	4.8 (1.81)	6.12 (1.8)	0.091
C18 :3n-6	0.12 (0.12)	0.13 (0.05)	0.84
C18 :3n-4	0.14 (0.05)	0.15 (0.05)	0.7
C18 :3n-3	1.24 (0.34)	1.03 (0.2)	0.082
CLA	0.47 (0.15)	0.44 (0.12)	0.58
C20 :0	0.30 (0.08)	0.21 (0.13)	0.12
C20 :1n-9	0.14 (0.06)	0.17 (0.06)	0.44
C20 :2n-6	0.45 (0.11)	0.34 (0.22)	0.19
C20 :3n-6	0.4 (0.14)	0.34 (0.22)	0.46
C20 :4n-6	2.38 (1.3)	2.44 (1.45)	0.93
C20 :5n-3	0.79 (0.4)	0.74 (0.65)	0.87
C22 :0	0.11 (0.05)	0.07 (0.07)	0.25
C22 :5n-6	0.13 (0.19)	0.18 (0.15)	0.57
C22 :5n-3	1.13 (0.45)	1.18 (1.13)	0.74
C22 :6n-3	0.23 (0.14)	0.22 (0.10)	0.95
SFA	50.3 (3.35)	44.6 (6.81)	0.001
MUFA	34.7 (4.02)	39.9 (4.05)	0.003
PUFA	12.3 (1.26)	13.4 (4.91)	0.59
PUFA:SFA	0.25 (0.11)	0.3 (0.13)	0.28
n-6 FA	8.25 (3.24)	9.6 (3.26)	0.39
n-3 FA	3.4 (1.26)	3.13 (1.91)	0.66
n-6:n-3	2.53 (0.38)	3.09 (0.78)	0.03
DFA	63.5 (4.35)	67.8 (5.81)	0.12

SFA – total saturated fatty acids; MUFA – total monounsaturated fatty acids; PUFA – total polyunsaturated fatty acids; n-6 – total PUFA omega-6 fatty acids; n-3 – total PUFA omega-3 fatty acids; DFA – desirable fatty acid content (DFA = MUFA + PUFA + C18:0).

3). The proportion of SFAs recorded in meat of forest raised goats remained lower than values recorded for meat of other breeds (54%), whereas the PUFA level was higher (12-13 vs. 3-4%) than in the South African breeds [Tshabalala *et al.* 2003]. Similarly, PUFA levels in meat of the forest raised goats were much higher than those previously recorded in meat from goats of the same breed fed hay and concentrate (Mahouachi *et al.* 2012]. However, Saturno *et al.* [2020] recorded lower SFA and PUFA levels and higher MUFA contents in meat of goats fed diverse diets. In this study all meat samples were obtained from forest raised goats fed based on pasture,

while several other studies compared meat of pasture raised goats to that of goats raised in the feedlot system, showing higher PUFA proportions, especially n-3 PUFA, in grazing animals [Hajji *et al.* 2016].

The PUFA/SFA and n-6/n-3 ratios in meat, as indicators widely used to assess the nutritional value of fat for human consumption, are given in Table 3. The PUFA/SFA ratio with an average value of 0.27 was similar for meat of goats from both forest based management systems; however, the nutritional recommendations indicate values over 0.45 [Alfaia *et al.* 2009]. Nevertheless, this value is considered high compared to other results concerning goat meat [Banskalieva *et al.* 2000; Tüfekci and Mustafa 2021]. The high proportions of PUFA and PUFA/SFA ratios recorded in the current study were favorable for meat of forest raised goats. The average n-3 and n-6 PUFA contents in meat were 3.25 and 8.85, respectively, for meat of all forest raised goats, as the n-6/n-3 ratio in goat meat was below 4.0, which is within the nutritional recommendations for the human diet, promising a balance between the two PUFA groups [Alfaia *et al.* 2009]. Thus, the small amount of concentrate added to the diet of grazing animals did not compromise their FA profile, particularly the n-6/n-3 ratio, which remained advantageous for human nutrition and health.

Lipid oxidation and color stability

TBARS values reflecting lipid oxidation were similar in meat of all forest raised goats. The diet in the two production systems was based on forest pasture rich in natural antioxidants, which resulted in a high antioxidant power of the meat. However, storage time significantly affected ($P<0.01$) this parameter (Fig. 1). TBARS values increased considerably with storage time, with the first surge recorded on day 3 and a rebound on the 9th day. However, it is noteworthy that until the 9th day of storage TBARS values of kid meat from both systems remained below the threshold of refusal at 1 mg MDA/kg meat [Ripoll *et al.* 2011]. These values are remarkably lower than those

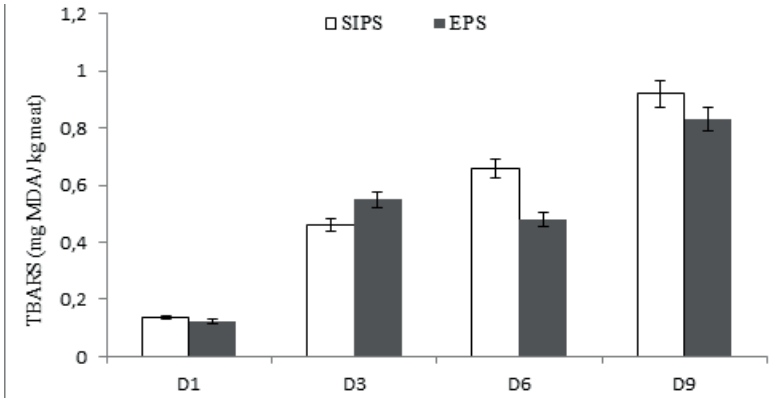

Fig. 1. Evolution of lipid oxidation (TBARS, mg MDA/kg meat) of meat from kids from forest extensive (EPS) and semi intensive production systems (SIPS) during time (Days).

suggested as a threshold (2 mg MDA/kg of meat) for the sensory detection of rancid flavours [Campo *et al.* 2006]. Thus meat produced in forest pastures rich in shrubs did not require antioxidants to be preserved for a long time; although it is known that a high percentage of PUFAs, which are very sensitive to oxidation processes, may reduce the shelf life of retail meat [Morán *et al.* 2013]. A positive relationship has been reported between PUFA and lipid oxidation in muscles, leading to a negative aroma. However, when the diet is rich in vitamin E or natural antioxidants, the high PUFA, n-3 and n-6 contents did not influence lipid oxidation [Ponnampalam *et al.* 2014], which could be the case in the current study. Many investigations showed that lipid oxidation of meat can be controlled or minimized by the addition of commercial synthetic or natural antioxidants [Pokorný 2007]. The diet for all forest raised goats in this study is mainly based on forest plants rich in natural substances (e.g. terpenes, phenols) considered to be natural antioxidants, which can limit the formation of MDA (malondialdehyde) and explain resistance of the meat to oxidation for up to 9 days; this phenomenon was more pronounced for the extensive rearing system.

The goat diet, storage time and their interaction significantly affected different color parameters (Tab. 4). Brightness (*L**) decreased with time of storage with no significant effect of the production system. For both systems even at the 9th day the (*L**) values fluctuated within the range of meat acceptability [Khliji *et al.* 2010].

Table 4. Effects of production system (PS) and storage time on color parameters in kids from forest extensive (EPS) and semi-intensive production systems (SIPS)

Item	PS	D1	*p*-PS	D3	*p*-PS	D6	*p*-PS	D9	*p*-PS	*p*-Time
L*	EPS	43.5	0.040	44.9	0.010	43.4	0.010	43.3	0.010	0. 210
	SIPS	42.7^{b}		47.7^{a}		47.6^{a}		47.7^{a}		0.020
a*	EPS	11.0^{a}	0.520	8.5^{b}	0.035	9.2^{ab}	0.610	10.5^{b}	0.720	0.030
	SIPS	12.5^{a}		10.4^{ab}		9.7^{b}		10.5^{ab}		0.020
b*	EPS	7.4^{b}	0.001	10.4^{a}	0.080	5.9^{bc}	0.001	4.8^{c}	0.001	0.050
	SIPS	10.2^{a}		11.5^{a}		11.1^{a}		7.8^{b}		0.001
c*	EPS	13.4^{a}	0.001	13.5^{a}	0.310	11.1^{b}	0.010	11.5^{ab}	0.010	0.010
	SIPS	16.2^{a}		15.6^{ab}		15.1^{ab}		14.1^{b}		0.010
h*	EPS	32.8^{b}	0.070	51.4^{a}	0.090	32.9^{b}	0.001	24.4^{b}	0.010	0.001
	SIPS	39.4^{b}		47.6^{a}		48.8^{a}		34.4^{b}		0.001

^{abc}Within the same line means bearing different superscripts differ significantly at P<0.05 depending on time (different storage days).
p-PS – probability values for PS at D_i (1, 3, 6 and 9); *p*-Time – probability values for Time within each PS (EPS and SIPS).

The *a** and *b** indices showed greater variations than *L**, with higher values for SIPS compared to EPS. Similar results were found by Balentine *et al.* [2006], who when working on the addition of rosemary to minced beef recorded higher (*a**) and lower (*b**) values after 9 days of storage.

For all forest raised goats the intensity of meat redness (*a**) significantly dropped during the first three days of storage, while it remained high (>9) and increased during

the 6th day of storage. It was shown that meat of lambs receiving rosemary residues rich in antioxidants maintained the same redness during storage [Yagoubi *et al.* 2018b], given the close relationship between redness and the level of antioxidants in the muscle tissues. Moreover, Camo *et al.* [2008] reported beneficial effects of the use of some natural antioxidants on delaying meat color loss by enhancing the red color (a^*) and delaying metmyoglobin formation.

The (b^*) value was lower on the 9th day of storage in the extensive system compared to that of the semi-intensive system (4.76 vs. 7.82). For meat from the EPS group the (b^*) value decreased significantly along the storage period while for SIPS the value recorded on the 9th day was significantly higher than the values recorded at other time points. Similar results were found by Balentine *et al.* [2006], who when working on rosemary addition to minced beef recorded higher (a^*) and lower (b^*) values after 9 days of storage. Storage time, production system and their interaction have a significant effect on yellowness.

The values of chroma (c^*) decreased continuously during the storage period for both production systems. However, it is known that chroma is related to the amount of pigments, with higher values representing a brighter and more vivid color of meat [Normand *et al.* 2005]. In this study the highest values were recorded for meat from the SIPS system.

For the chroma (c^*) parameter the diet and storage time showed significant effects, but the interaction between both factors was non-significant. The chroma value of goat meat from the two systems decreased significantly throughout the storage period, thus confirming previous results which showed that c^* decreased as storage progressed, resulting in pigment oxidation of lamb meat [Yagoubi *et al.* 2018b].

Storage time, diet and their interaction had significant effects on the hue (H^*). For meat derived from the extensive system the value of (h^*) registered on the 3rd day of storage (51.4) differs significantly from those recorded at other time points, while for the extensive system the H^* values of meat vary significantly throughout the storage period.

Sensory analysis

The results of sensory analysis are summarized in Table 5. The meat was considered tender with 6.4 and 7 as tenderness scores for the extensive and semi-intensive systems, respectively, without significant differences between both systems where basal diet was of the same nature (forest pasture). Priolo *et al*. [2002] found that meat of lambs

Table 5. Meat sensory characteristics of meat from kids from the forest extensive (EPS) and semi-intensive production systems (SIPS)

Item	EPS	SIPS	P-value
Tenderness	6.4 (1.66)	7.0 (1.95)	0.18
Juiciness	5.9 (1.71)	6.1 (1.81)	0.54
Flavor	6.6 (1.52)	5.8 (1.86)	0.07

raised on the pasture is less tender than those kept in the stall management system, while Lowe *et al.* [2002] and Hajji *et al*. [2016] found no differences in tenderness between these two types of production system. The juiciness score was similar for both systems, averaging 6 and thus meat was considered to be moderately juicy. Meat produced in both systems was assessed as free from undesirable off-flavor. The flavor notes were superior for SIPS compared to EPS, with the difference tending to be significant ($p<0.07$).

Conclusion

The FA composition of goat meat resulting from the adoption of these forest animal rearing systems generates favorable food for human health, considering the low SFA content and the low n-6/n-3 ratio largely considered as health-promoting. Meat obtained from both forest-based production systems of goats had a higher antioxidant capacity; this rearing method resulted in a high antioxidant capacity of well-preserved meat as food without undesirable health effects. For this reason meat of Mediterranean goats grazing in forest pastures may be considered as food with high nutritional quality, additionally improved with a small concentrate supply to goats. Secondly, carcass weight, of major importance in meat production, was improved by concentrate supply in the SIPS group without any negative effect on meat quality. Hence, farmers using the forest pasture system should consider supplementation to improve meat quantity without compromising meat health-promoting quality.

In addition, kid meat produced under the Mediterranean forest conditions has a unique fat composition and high natural antioxidant capacity, which result in added health benefits and increased consumer appeal. These qualities, the FA profile in particular, could be used in order to distinguish these production sub-systems [Dias *et al.* 2008], as providing specialty meat given the increasing consumer interest in this category of products. However, further studies are needed in order to make this proposal feasible.

Conflict of interest

The authors declare that there are no conflicts of interest.

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Ethics Approval

All the procedures employed in this study (transport and slaughtering) meet ethical guidelines and adhere to Tunisian legal requirements in accordance with Law no. 2005-95 (18 October 2005).

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