Mediterranean Journal of Nutrition and Metabolism 11 (2018) 175–185
DOI:10.3233/MNM-17195
IOS Press


# Physicochemical and nutritional characteristics of Béni Guil lamb meat raised in eastern Morocco

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Received 28 November 2017
Accepted 12 March 2018

**Abstract**.
**BACKGROUND:** The Béni Guil sheep is the main ovine breed that dominates livestock farming in the semi-arid region of eastern Morocco. No previous data is available on the quality of Béni Guil PGI (Protected Geographical Indication) lamb meat raised on the natural pasture of this area.
**OBJECTIVE:** This study aims to provide the physicochemical and nutritional characteristics of Béni Guil PGI lamb meat.
**METHODS:** Béni Guil PGI lamb meat was analysed for its quality parameters, fatty acid composition and amino acid profile.
**RESULTS:** Results show that the Béni Guil PGI lamb meat has a significant juiciness (high water holding capacity), a marked tenderness (low collagen content) and a bright red colour. *Longissimus lumborum* muscle from Béni Guil PGI lambs contains 25.72% dry matter, including 19.43% protein, 5.14% fat, and 0.94% minerals. Gas chromatography-flame ionisation detection, for fatty acid analysis, revealed 49.45% saturated fatty acids (SFA), 38.48% monounsaturated fatty acids (MUFA) and 12.4% polyunsaturated fatty acids (PUFA). The UFA:SFA and n-6:n-3 PUFA ratios were 1.04 and 3.78, respectively, and were comparable to those recommended for a balanced diet. The amino acid analysis, allowed the identification of eight essential amino acids. The chemical index and the protein digestibility-corrected amino acid score values were 132 and 124, respectively.
**CONCLUSION:** The results of this study indicate that the Beni Guil PGI meat has nutritional values in accordance with the nutritional recommendations and specific to the feeding system based mainly on grazing.

Keywords: Béni guil PGI, lamb meat, fatty acids, amino acids, nutritional quality

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ISSN 1973-798X/18/$35.00 

## 1. Introduction

Red meat is valuable in our diet, due to its high biological protein value and important micronutrients (vitamins and essential minerals), necessary for good health [1]. Also, red meat is considered to be a notable source of fat in our diet, particularly saturated fatty acids [2]. These fatty acids (FA) are implicated and associated with diseases, such as coronary disease [2]. Hence, considerable attention is granted to the FA profile and its partition into SFA, monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA), particularly, the n-3 PUFA, at the expense of n-6. The FA composition is largely affected by various factors, such as the age, gender, breed and weight of the animal, as well as the production system [2–6].

In Morocco, the livestock sector is a principal component of agriculture, accounting for 19% of the country's gross domestic product. Currently, 98% of the red meat consumed in Morocco, is produced locally by cattle, sheep and goats [7]. Livestock production is one of the primordial sectors in the national economy, playing an important socio-economic role. The total workforce exceeds 25 million head, with sheep accounting for 17.5 million head.

The predominance of ovine breeding through the Moroccan territory is due mostly to the biodiversity of this species and its adaptation to most agroecosystems. Most of the sheep population is located in pastoral areas and more than 95% is represented by the six main local breeds Timahdite, Sardi, Béni Guil, Boujaâd, D'man, and Béni Hsen. According to the recent statistics from the "Haut commissariat au Plan – Région Orientale" eastern Morocco represents 14% of the national livestock, and the region is well known for its quality of sheep, which largely populate the highlands, but are capable of acclimatising elsewhere in Morocco. The Béni Guil breed is particularly prevalent, with a population approximately estimated to 2 million head. This breed is the result of a genetic selection, via cross-breeding for more than 30 years, in the national program of genetic improvement and the preservation of pure breeds lead by the Ministry of Agriculture and the National Association for Sheep and Goat Breeders (Association Nationale Ovine et Caprine = ANOC). The sheep meat of Béni Guil breed is a protected Geographical Indication (PGI) and is one of the main Moroccan local meats that is highly appreciated by the consumer because of its tasty and sensorial properties, which seem to be linked to an extensive breeding in natural rangelands, rich in aromatic plants. However, its excellent reputation is still only limited to the hedonic quality, being linked to individual assessments and consumer feedback. There is no prior published scientific data and little is known about the physicochemical characteristics and nutritional quality of Béni Guil PGI lamb meat. This study aims to determine the physicochemical quality parameters of the *longissimus lumborum* (LL) muscle of Béni Guil PGI lamb and to evaluate its nutritive value. Chemical analyses focus on the intramuscular fat (IMF) content, FA profile, protein content and amino acid composition.

## 2. Material and methods

### *2.1. Animals*

Data were obtained from twelve 6−7 month old female lambs, weaned at 3 to 4 months of age, and belonging to the L category, according to the regulation of the European Commission N° 823/98 [8]. The animals were slaughtered at 33−37 kg live weight, with a strong fattening condition, corresponding to notation 4 (scale 1−5), according to the community scale for the classification of carcasses of ovine animals, regulation of the European Commission N° 2137/92 [8]. Lamb selection was done with the assistance of an official of ANOC – Oujda, Morocco. These lambs belong to herds associated with the Béni-Guil PGI consortium and raised in the rural commune of Ain Beni Mathar, north-eastern Morocco (–2.0247 longitude, 34.0081 latitude and 921 m altitude). The sheep farmer was a member of the ANOC, adopted an annual rhythm of lambing and practiced a semi-extensive breeding system (70−80% natural pasture and 20−30% supplementation with barley bran and alfalfa hay, depending on the season and forage resource). Ain Beni Mathar is considered among the major places of Béni

Guil breeding, where the main forage resource is rangeland grazing. The semi-arid climate of this geographic site and human practices, favour the dominance of vegetal specimens, such as alfa (*Stipa tenacissima*), white wormwood (*Artemisia herba-alba*) and Chenopodiaceae.

### 2.2. Slaughtering and sampling

The animals were slaughtered according to a halal ritual in a slaughterhouse belonging to the urban commune of Oujda, Morocco. After chilling at 4°C for 24 h, samples of the LL muscle were excised, wrapped in aluminium foil, and stored at –20°C.

### 2.3. Meat quality measurement

The Ultimate pH (pHu) of the LL muscle was measured in all carcasses at 24 h post-mortem, using a portable pH meter (pH/Cond 340i WTW, Weilheim, Germany), fitted with a penetration electrode. The electrode was inserted into a small incision in the right loin (L2–L3 vertebrae), with triplicate direct probing. The pH meter was initially calibrated, using standard buffer solutions at pH 4 and 7.

Meat colour was estimated in the LL muscle, using the L*a*b* system, with a MiniScan XE chromameter (Hunterlab, Reston, VA). The colour measurements were made on freshly cut surfaces and assessed according to the Commission Internationale de l'Eclairage, where the coordinates L*a*b* represent, respectively, lightness, redness and yellowness. The hue angle (arctan $(b^*/a^*)$) and the saturation index $\left(\sqrt{a^{*2}+b^{*2}}\right)$ were calculated respectively, according to McGuire [9] and Calnan et al. [10].

Meat water holding capacity (WHC), was calculated by weight difference of a sample before and after juice extraction, by centrifugation (Beckman Coulter centrifuge Avanti$^{R}$ J-E) at 17000 rpm for 30 min. Meat cooking loss, was calculated by weight difference of a sample before and after cooking in a water bath at 75°C for 1 h.

### 2.4. Preparation of freeze-dried meat

The samples of LL muscle were trimmed and then, lyophilised at –60°C for 72 h. The lyophilised meat samples were crushed with a rotary blade mill to generate a homogenous meat powder that was stored under vacuum in sachets sterilised at –18°C, until further analyses.

### 2.5. Chemical analysis

#### 2.5.1. Protein, moisture and ash analyses

The moisture was determined by drying at 100°C for 24 h according to the official Method of the Association of Official Analytical Chemists [11]. The nitrogen content of the freeze-dried meat powder, was determined by the Kjeldahl procedure [11] using a conversion factor of 6.25 to calculate the protein content. The ash percentage was quantified by incineration in compliance with AOAC official method [11].

#### 2.5.2. Total IMF and FA analysis

The intramuscular fat (IMF) was extracted according to the Bligh and Dyer [12] method, using a chloroform/methanol/water mixture (2/1/1; v/v/v). The lipid extract was methylated before analysis. The FA were converted to fatty acid methyl esters (FAME) according to the method described by Ben Moumen et al. [13] using $BF_3$ at 14% weight in methanol. Separation of the FAME, was performed on an Agilent gas chromatograph (GC) (HP6890 series, Agilent Technologies, USA), equipped with an Omegawax capillary column (30 m × 0.25 mm, 0.25 μm film thickness) from Supelco (Bellefonte, PA, USA) and a flame ionisation detector (FID). Helium (99.999%, Air Liquide, Liège, Belgium) was used as the carrier gas, at a flow rate of 1.7 ml min$^{-1}$. The

temperature of the injector and detector were set at 150 and 250°C, respectively, and the oven temperature was set at 210°C. The injection volume was 1 µl, in splitless mode. A FAME standard, containing 37 components (Supelco, Bellefonte, PA, USA), was used to identify the individual peaks.

*2.5.3. Amino acid composition*

A 300 mg of the lyophilised meat powder sample was dissolved in 10 ml of 6 N HCl, containing 0.1% phenol, followed by hydrolysation under nitrogen at 110°C for 24 h. Afterwards, the pH was adjusted between 0.5 and 1 with 7.5 N of NaOH and pH 2.2 with a 1 N of NaOH. The sample was diluted to 100 ml with citrate buffer (pH 2.2) after adding 0.5 ml of a 50 µM norleucine (Sigma-Aldrich, St. Louis, MO, USA) solution, as the internal standard. Finally, the solution was filtered through a 0.2 µm filter. A 20-µL aliquot of the filtrate was analysed using a high-performance liquid chromatography (Biochrom 20 Plus amino acid analyser, Pharmacia, Cambridge, UK), equipped with sodium oxidised column, cation-exchange resin, followed by post-column derivatisation of the amino acids to ninhydrin and spectrophotometric detection at 570 nm, except for proline, which was detected at 440 nm.

The chemical index (CI) was calculated based on the literature [14]. The CI corresponds to the minimum ratio between the percentage of each amino acid in the Béni Guil meat protein, compared to each of the corresponding amino acids present in the reference protein. Protein digestibility-corrected amino acid score (PDCAAS) was determined, according to Schaafsma [14], where PDCAAS = CI × true digestibility of the meat.

*2.5.4. Collagen content*

The collagen concentration was calculated as L(-)hydroxyproline (a collagen specific amino acid), according to the standard AFNOR [15] NF V04-415.

## 3. Results and discussion

### *3.1. Quality parameters of Béni Guil PGI lamb meat*

The quality parameters (pH, colour, juiciness and collagen content) of the Béni Guil LL muscle are shown in Table 1. Meat pH is closely associated with biochemical processes involved during the post-mortem ageing of meat and the pH values depend more on pre- and post-slaughter conditions than on genotype [16, 17]. Thus, for the inspected carcasses of Béni Guil lambs, the initial (pHo) and pHu values recorded in the LL muscle were within the normal meat pH values found in the literature [5, 17]. As shown in Table 1, the average pH values of LL muscle before ($pH_0$) and 24 h after slaughter (pHu), were 6.7 and 5.79, respectively. These results demonstrate that the animals were slaughtered under stress-free conditions, that rigor mortis occurred accurately and that the slaughtering procedures were compatible with the standards. Consequently, the mean pHu value, fell within the pH range of commercially acceptable meat quality.

The pH of meat is a determining factor that has consequences on colour, juiciness, and tenderness [18, 19]. Meat colour, which is considered an indicator of product freshness and wholesomeness [20], is mostly influenced by pH, myoglobin content and oxidation state [21]. The Béni Guil LL muscle colour measurement (Table 1), showed that it is a luminous (L* = 41.04), bright red (a* = 16.68) and orange (b* = 17.12) meat. A high pHu affects the colour stability of fresh meat because it influences the activities of the enzymes and the oxygenation rate. In our study, the pHu values, generally, were close to the isoelectric pH of the meat proteins, thus, allowing the neutralisation of the charges and reduction in the spacing of the muscle fibres. These changes affect how light is reflected and absorbed, and reduce light penetration into the muscle, giving the meat a bright red appearance. The average values of the hue angle and the chromaticity of Béni Guil PGI lamb meat, were 46.47° and 23.97 respectively, corresponding to a bright red meat, rich in oxygenated oxymyoglobin [10]. This typical fresh meat colour is also due to the low concentration of myoglobin in the meat due to the halal slaughtering method,

Table 1
Béni Guil lamb meat quality characteristics

| Analytical parameters | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|
| $pH_0$ (45 min) | 6.70 | 0.13 | 6.5 | 6.89 |
| pHu (24 h) | 5.79 | 0.14 | 5.62 | 6.09 |
| L* (lightness) | 41.04 | 4.67 | 36.29 | 51.78 |
| a* (redness) | 16.68 | 5.94 | 7.8 | 23.54 |
| b* (yellowness) | 17.12 | 4.91 | 9.44 | 23.94 |
| a*:b* | 0.96 | 0.16 | 0.74 | 1.24 |
| Chromaticity | 23.97 | 7.48 | 12.99 | 32.98 |
| Hue angle | 46.47 | 4.59 | 38.93 | 53.33 |
| WHC (%)[a] | 22.73 | 2.31 | 20.00 | 27.26 |
| Cooking loss (%)[a] | 35.87 | 1.53 | 33.54 | 38.84 |
| Collagen (%)[a] | 0.06 | 0.05 | 0.02 | 0.29 |

[a]Results expressed in % fresh weight. Scales of a*, b*, L*: a* and b*: –60 to 60, L*: 0 to 100. Scales of chroma and hue: chroma: 0–60, hue: 0–360°. WHC: Water Holding Capacity.



which favours the evacuation of the blood and, consequently, decreases the pigment concentration. Calnan et al. [10] showed that an increase in myoglobin concentration, results in a darker meat colour. In addition, the high chromaticity value reflects the optimum freshness and colour of the meat. Moreover, the a*:b* ratio was 0.96, a value that characterises the red predominance.

Meat tenderness and juiciness are important in terms of eating quality. Hence, they have a direct influence on the consumer decision to repurchase. Many factors have been shown to affect meat tenderness, among them, animal age, slaughtering stress and post-mortem factors, particularly, the muscle collagen content, sarcomere length and proteolysis, which affect the conversion of muscle to meat, appear most important. Collagen contributes to meat tenderness and its post-mortem degradation plays an important role in the meat tenderising process [22, 23]. The low collagen content of the analysed lamb meat (0.06%), the young age of the slaughtered lambs and the slaughtering of the animals under stress-free conditions, explain and guarantee the tenderness of the studied Béni Guil lamb meat. Dragomir [24] reported that the meat of young lambs is physiologically tender because the contribution of connective tissue is less important than in older lambs.

The meat juiciness is predominantly influenced by the meat pH and the IMF content [21, 25]. This attribute can be assessed by a trained sensory evaluation panel or by measurement of WHC and cooking loss [21]. In this context, the assessment of juiciness of Béni Guil lamb meat was estimated, by measuring the WHC and juice loss during cooking. As shown in Table 1, the recorded average values for WHC and cooking loss were 22.73 and 35.87%, respectively, suggesting that Béni Guil PGI lamb meat is juicy and loses its fluids easily. Therefore, from an organoleptic perspective and in terms of eating quality, the juiciness is a good qualitative aspect, particularly during the time of chewing. However, if good packaging practices are not respected, the ready loss of juice can lead to a decrease in nutritional quality and a reduced shelf life [26].

### *3.2. Chemical composition of the LL muscle of Béni Guil PGI lamb*

The samples used in the present study consisted exclusively of the LL muscle, without visible fat or connective tissue. The nutritional composition of the LL muscle of Béni Guil breed samples (Table 2) showed that 100 g of the fresh meat material contained 25.72 g of dry matter, including 5.13 g fat, 19.42 g protein and 0.93 g mineral

Table 2
Chemical composition of Béni-Guil lamb meat

| Parameters | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|
| Dry matter (%) | 25.72 | 1.10 | 23.16 | 27.89 |
| Intramuscular fat (%) | 5.13 | 0.65 | 3.83 | 5.93 |
| Protein (%) | 19.43 | 1.01 | 17.88 | 21.64 |
| Ash (%) | 0.94 | 0.10 | 0.73 | 1.12 |

Results expressed in % fresh weight.

matter. These values are similar to several previous reports [27–30], in which the reported values ranged from 69−76% moisture, 0.98−1.2% ash, 3.0−5.5% lipid, and 18−22% protein.

*3.2.1. FA composition of the LL muscle of Béni Guil PGI lamb*

Nowadays, public health institutes and various authorities pay close attention to dietary fatty acids intake. They recommend a balanced proportion of SFA, MUFA and PUFA, for a proper diet and a healthy lifestyle. This led us to study the FA composition of Béni Guil PGI meat and to evaluate certain parameters that have a direct effect on human health.

The chromatograms obtained from FAME analysis by GC-FID revealed the presence of twenty-five FA compounds in the LL muscle's intramuscular fat (Table 3). The analysed samples are characterised by an interesting UFA:SFA ratio (1.04); this is due to the relatively low proportion of saturated fatty acids (49.45%) compared with unsaturated fatty acids (50.88%). SFA fraction is often considered detrimental to our health. However, recent studies have reported the gap between scientific literature and commonly accepted dietary recommendations [31]. Among the identified SFA in the analysed samples, those with a long chain (12C or more) constitute the majority, with a dominance of C16:0 (24.73%) followed by C18:0 (17.02%) and C14:0 (4.24%). This group of SFA such as C16:0 is often considered an undesirable cholesterol factor. However, C18:0 and short-chain SFA are considered FA with a neutral effect on undesirable cholesterol and are capable of increasing good cholesterol content [32, 33]. Short-chain SFA, exclusively represented by C10:0 in the analysed samples, accounted for a low percentage of 0.2 of total FA content. The quantitative importance of SFA is similar to the results reported in the literature [34–36].

Regarding the unsaturated fatty acids, our results (Table 3) showed that quantitatively, MUFA (38.48%) dominated over the PUFA (12.40%). C18:1 (*cis*+*trans*) dominates the MUFA fraction with an average percentage of 35.33. The latter possibly possesses hypocholesterolemic properties [32, 37]. Its presence plays an important role in determining meat's firmness and oxidative stability as well as its colour, juiciness and taste [38]. The other MUFA represent 3.15% of total FA content.

Table 3 also shows an interesting PUFA proportion (12.4%) compared to results on other lamb meats reported in the literature [34–36], which is probably because these animals are mainly pasture-raised. In fact, Demeyer and Doreau [39] have shown that pastured meats contain more PUFA than animals receiving high concentrate rations. The PUFA fraction of the analysed samples consists mainly of n-3 PUFA and n-6 PUFA. This fraction is dominated by C18:2n6 (*cis*+*trans*) with 6.97%, followed by C18:2n3 (2.54%) and C20:4n6 (1.54%). The richness of meat in PUFA may have beneficial or negative health effects [40, 41]. In fact, the most significant epidemiological studies on the cardioprotective activity of PUFA were revised by examining the clinical role of the n-6:n-3 ratio as an increasing factor in cardiovascular disease [42–44]. This ratio is also considered as a benchmark for the nutritional imbalance of meat. Table 3 shows that the IMF of the Béni Guil LL muscle has a n-6:n-3 ratio of 3.78. This ratio seems ideal according to French Agency for the Safety of Food [45], which estimates that this ratio must not exceed 5. The low ratio that was found in the analysed samples could be explained by the feeding method of the animals (70% pasture and 30% supplementation). In fact, Velasco et al.

Table 3
Fatty acid composition (% of total fatty acids) of intramuscular fat of Béni Guil lamb meat

| Fatty acids | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|
| C10:0 | 0.20 | 0.08 | 0.05 | 0.33 |
| C12:0 | 0.34 | 0.18 | 0.13 | 0.61 |
| C13:0 | 0.03 | 0.01 | 0.01 | 0.05 |
| C14:0 | 4.24 | 1.66 | 2.26 | 7.04 |
| C15:0 | 0.57 | 0.08 | 0.44 | 0.71 |
| C16:0 | 24.73 | 1.45 | 22.05 | 27.59 |
| C17:0 | 1.34 | 0.10 | 1.09 | 1.46 |
| C18:0 | 17.02 | 3.36 | 13.94 | 24.26 |
| C20:0 | 0.10 | 0.06 | 0.06 | 0.26 |
| C21:0 | 0.65 | 0.28 | 0.09 | 1.14 |
| C24:0 | 0.23 | 0.08 | 0.05 | 0.43 |
| SFA | 49.45 | 2.89 | 45.03 | 53.91 |
| C14:1 | 0.14 | 0.06 | 0.06 | 0.26 |
| C15:1 | 0.12 | 0.08 | 0.01 | 0.45 |
| C16:1n7 | 0.37 | 0.05 | 0.28 | 0.44 |
| C16:1n9 | 1.63 | 0.31 | 1.06 | 2.13 |
| C17:1 | 0.81 | 0.12 | 0.64 | 1.04 |
| *cis*/*trans*-C18:1n9 | 35.33 | 3.36 | 31.22 | 42.12 |
| C20:1n9 | 0.07 | 0.01 | 0.06 | 0.09 |
| MUFA | 38.48 | 3.44 | 34.23 | 45.61 |
| *cis*/*trans*-C18:2n6 | 6.97 | 0.82 | 5.37 | 8.74 |
| C18:3n6 | 0.89 | 0.34 | 1.86 | 3.36 |
| C18:3n3 | 2.54 | 0.34 | 0.27 | 1.63 |
| C20:2 | 0.20 | 0.14 | 0.07 | 0.73 |
| C20:3n6 | 0.22 | 0.26 | 0.11 | 1.34 |
| C20:4n6 | 1.54 | 0.29 | 1.17 | 2.28 |
| C20:5n3 | 0.04 | 0.01 | 0.02 | 0.07 |
| PUFA | 12.40 | 1.52 | 10.02 | 16.98 |
| UFA | 50.88 | 3.30 | 46.09 | 57.01 |
| PUFA:SFA | 0.25 | 0.04 | 0.19 | 0.36 |
| UFA:SFA | 1.04 | 0.13 | 0.85 | 1.27 |
| n-6 PUFA | 9.62 | 1.29 | 7.49 | 12.88 |
| n-3 PUFA | 2.58 | 0.34 | 1.89 | 3.37 |
| n-6:n-3 | 3.78 | 0.61 | 2.91 | 5.06 |
| IT | 1.44 | 0.16 | 1.18 | 1.74 |
| IA | 0.83 | 0.18 | 0.58 | 1.16 |
| OFA | 3.52 | 0.42 | 2.84 | 4.68 |
| DFA | 67.90 | 3.32 | 61.86 | 71.79 |

SFA: Saturated fatty acid; MUFA: Monounsaturated fatty acid; PUFA: Polyunsaturated fatty acid; UFA: Unsaturated fatty acids; OFA: Odd Fatty Acids; DFA: Desirable fatty acids = C18:0+UFA. IT = Thrombogenic Index [C14:0+C16:0+C18:0]/[(0.5*MUFA)+(0.5*Σn-6)+(3*Σn-3)+(n–3/n-6)]. IA = Atherogenic Index [(4*C14:0)+C16:0]/[(PUFA)+(MUFA)].

Table 4
Amino acid composition (% of dry matter) of Béni Guil lamb meat

| Parameters | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|
| Aspartic acid | 4.29 | 0.33 | 3.39 | 4.78 |
| Threonine | 2.52 | 0.16 | 2.25 | 2.91 |
| Serine | 2.18 | 0.30 | 1.23 | 2.68 |
| Glutamic acid | 6.69 | 0.49 | 6.03 | 7.96 |
| Proline | 2.45 | 0.16 | 2.05 | 2.77 |
| Glycine | 2.61 | 0.25 | 2.36 | 3.17 |
| Alanine | 2.83 | 0.30 | 2.01 | 3.52 |
| Cysteine-Cysteine | 0.10 | 0.04 | 0.03 | 0.16 |
| Valine | 2.32 | 0.17 | 2.07 | 2.74 |
| Methionine | 1.63 | 0.09 | 1.41 | 1.76 |
| Isoleucine | 2.38 | 0.17 | 2.03 | 2.89 |
| Leucine | 3.86 | 0.34 | 3.23 | 4.71 |
| Tyrosine | 2.00 | 0.30 | 1.15 | 2.61 |
| Phenylalanine | 2.40 | 0.19 | 2.09 | 2.98 |
| Histidine | 1.87 | 0.15 | 1.68 | 2.24 |
| Lysine | 3.48 | 0.16 | 3.14 | 3.97 |
| Arginine | 3.49 | 0.15 | 3.14 | 3.81 |
| Total Amino Acids | 47.06 | 2.65 | 42.55 | 52.30 |
| CI | 132.42 | 5.50 | 122.58 | 143.99 |
| PDCAAS | 124.47 | 5.17 | 115.22 | 135.36 |

CI: Chemical Index; PDCAAS: Protein Digestibility Corrected Amino Acid Score.



[46] reported that pasture-raised lambs have a higher PUFA content and a lower n-6:n-3 ratio than lambs on a concentrate-rich diet.

PUFA:SFA ratio was found to be 0.25, which is relatively lower than current recommendations. This ratio is often used to determine whether or not a diet causes coronary heart disease. In fact, Oh et al. [47] have demonstrated an inverse association between PUFA:SFA ratio and cardiovascular disease suggesting the replacement of SFA with PUFA for a balanced diet that could decrease the risk of these diseases. However, other studies suggest that some SFA are hypercholesterolemic. Therefore, Ulbricht and Southgate [48] defined atherogenicity (AI) and thrombogenicity (TI) indices to measure the propensity of a food to influence the incidence of coronary heart disease [49, 50]. The first index evaluates the risk of atherosclerosis, while the second is used as a sign of potential platelet aggregation [49]. AI and TI mean values of IMF of the analysed samples are 0.83 and 1.44, respectively (Table 3). On the other hand, odd-chain fatty acids had a considerable content level (3.52%). These FA are very beneficial in regards to preventing ischemic heart disease [51].

### *3.2.2. Amino acid composition of the LL muscle of Béni Guil PGI lamb*

The amino acid composition plays important roles in flavour development because they include numerous compounds that are capable of developing into important flavour precursors when heated [52]. Heating also develops flavour via the Maillard reaction. A sweet flavour could be related mainly to glycine, alanine, lysine, cysteine, methionine and glutamic acid, while a bitter flavour could be associated with arginine and leucine, and a sour flavour with aspartic acid and histidine. The amino acid content of a muscle depends on its collagen content and varies according to the animal (breed, gender), muscle type, and the treatments to which it has been subjected [21]. Table 4 represents Béni Guil's LL muscle amino acid composition analysis, which allowed the

identification of 17 components, including eight essential amino acids (histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine and valine). It should be noted that basic hydrolysis was not performed to determine the presence and quantification of tryptophan. The amino acid composition of the Béni Guil LL muscle is characterised by comparable levels among the amino acids, with a slight dominance of the amino acids Glu (6.69%) and Asp (4.29%). The high contents of aspartic and glutamic acids recorded in PGI Béni Guil lamb meat could be related to the experimental conditions that could cause the transformation of glutamine and asparagine into aspartic and glutamic acids, respectively [53]. The Béni Guil PGI meat protein quality was evaluated by the calculation of the CI and the PDCAAS (Table 4). The CI reflects the content of essential amino acids in the meat, whereas the PDCAAS allows evaluating the protein digestibility [14]. From a nutritional perspective, the Béni Guil lamb meat has a high biological protein value, with a CI of 132.42 and a PDCAAS of 124.47. Consequently, the consumption of this meat will satisfy the human nutritional needs for essential amino acids, considering that foods with a PDCAAS greater than 100 are nutritionally valuable, whereas those below 100 are deficient in essential amino acids [54].

## 4. Conclusion

Sheep breeding is a long tradition and a crucial component in agricultural systems of the steppe zones of highlands in eastern Morocco. This region is characterised by the specificity of its breeding system of sheep, principally, pasture-based, in areas rich in aromatic plants. Due to the quality of meat of the Béni Guil breed, the Béni Guil lamb has been recently labelled as a protected geographical indication. This lamb meat constitutes an important protein source for the population and it is highly appreciated by consumers. This study confirms the organoleptic and nutritional qualities of this meat. Béni Guil is a pasture lamb, and the IMF of its meat is characterised by more UFAs than SFAs and, particularly, by the quality of its FA profile. Chemical analysis showed that Béni Guil PGI lamb meat has high nutritional and biological values due to its richness in PUFAs and essential amino acids. Consequently, the consumption of this meat meets human nutritional needs.

Béni Guil PGI lamb meat, which is sought and appreciated by consumers, showed a significant juiciness and a marked tenderness. These sensory parameters, seem, partially, due to the young age of the slaughtered animals, the IMF quality, and the low collagen content of the muscles but also to the "semi-extensive" sheep production system and the grazing in areas rich in aromatic plants. However, a decrease in rainfall in eastern Morocco, has led breeders to introduce various types of supplements. Thus, to follow up the qualitative changes in this lamb meat that could be generated by the effect of supplementation, it will be important to continue this study over the next few years.



## Acknowledgments

We are grateful to the Moroccan-Belgian bilateral cooperation program for the financial support of this research through a "WBI-Project 1-6, "2015-2017". Our thanks are also due to the "Association Nationale Ovine et Caprine" for its collaboration, particularly to Mr A. Mejdoubi.

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