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Nutrient content and retention in selected roasted cuts from 3-month-old ram lambs

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Values for proximate composition, cholesterol, 23 fatty acids, eight inorganic nutrients and six water-soluble vitamins were determined in the separable lean of paired raw and roasted rib-loins and legs from 10 carcasses of 3-month-old ram lambs. Cooking losses (both evaporative and drip) were much lower in rib-loin, which underwent a quicker heating than leg. The percentage apparent retention was calculated for each nutrient. In general, nutrients susceptible to loss through drippings during cooking, i.e. minerals and water-soluble vitamins, were better retained in rib-loin than in leg. The reverse was true for several polyunsaturated fatty acids, whose lower retention in rib-loin than in leg was probably due to the former's higher heating rate. The contribution of roasted lamb to the nutrient requirements of the consumer was noteworthy for oleic and linoleic acids, phosphorus, zinc and iron, vitamin B_{12}, niacin and riboflavin. © 1998 Published by Elsevier Science Ltd. All rights reserved

INTRODUCTION

The consumption of mutton and goat meat in Italy has declined from a peak of 1.8 kg per person per year, reached in 1992, to 1.3 kg in 1994. The self-sufficiency ratio, however, remains rather low, since domestic production covers approximately two-thirds of national consumption (AIA, 1996). This deficit has been present for several years; already in 1987 the Italian Ministry of Agriculture and Forestry had stressed the need to improve efficiency in lamb production, by increasing the number of lambs per ewe through controlled cross-breeding programmes and by marketing lambs at heavier weights (MAF-INN, 1987).

Major obstacles in the endeavour to reach complete self-sufficiency in lamb production are meat purchasing behaviour and attitudes of Italian consumers. A recent survey of both consumers and commercial firms in the sheepmeat sector (ISMEA, 1993) revealed that Italians prefer meat from lightweight lambs, 8–12 kg slaughter weight, which are essentially by-products of the sheep dairy industry. Consumption is still strongly associated with religious festivals, Easter and Christmas in particular, when a high degree of substitution between lamb and kid is also evident. Nevertheless, in several regions there is a trend towards the consumption of heavier and older lambs (30–35 kg slaughter weight, 90–100 days of age). This heavier type of meat is usually broiled or roasted in the oven. Tradition and nutritional misinformation were considered to be the major obstacles to growth in the consumption of meat from heavier animals, because buyers anticipate that larger and older lambs will be of poorer quality due to their age (ISMEA, 1993). This misinformation, in turn, is a reflection of the lack of literature data on nutrient contents of cooked meat from this type of lamb in spite of a considerable number of publications on lamb, from heavier and older animals, or lamb 'in general', as in food composition tables. This study was therefore conducted to: (1) determine the content of nutrients in raw and roasted cuts from 3-month-old ram lambs. Rib-loin and leg were selected, both because they are highly valued and because they represent a high percentage of the carcass; (2) quantify the nutrient retentions after cooking; (3) estimate the contribution that a serving of roasted lamb can provide to meet the nutrient requirements of the consumer.

MATERIALS AND METHODS

Materials

Ten carcasses of average conformation and fatness (EEC, 1992) were obtained from a flock of single born Suffolk rams, 3 months of age, still sucking their dams and having free choice access to creep feed, straw and

sorghum stalks. The carcasses were conditioned in order to avoid cold shortening (15–16°C up to 4 h *post mortem*, 10–11°C up to 24 h *pm*) and then held at 4°C up to 48 h *pm* (cold carcass weight ± s.e. = 17.7 ± 0.5 kg). Upon fabrication (at 48 h *pm*), both legs and rib-loins (6th rib–6th lumbar vertebra) of each carcass were retained for further processing during the following 24 h. The raw cuts from one side of each carcass were prepared for analysis. The anatomically matched cuts from the opposite side of the carcass were roasted, bone-in, and then prepared for analysis (Murphy *et al*., 1975). The cuts to be cooked before analysis came from the left and right side in turn.

Methods

Sample preparation

The leg (oven-ready weight 2.816 ± 0.084 kg) was placed, outside up, on a stainless steel rack in a forced air convection oven (mod. Minimix, Lainox s.r.l., Vittorio Veneto, Italy) pre-warmed to 165°C (AMSA, 1978). In order to reach the same final degree of doneness (Badiani *et al*., 1994), the rib-loin (oven-ready weight 1.215 ± 0.025 kg) was placed, fat to the side, in the oven preheated to 150°C. The cuts were roasted uncovered to a final internal temperature of 75°C. The internal temperature was monitored with a type J (iron-constantan) wire thermocouple inserted into the geometric centre of the cut and attached to a potentiometer (mod. Microtemp2, Eurotron Italiana s.r.l., Milano, Italy). The same type of thermocouple was placed adjacent to the cut to control oven temperature. Total cooking time was recorded and the heating rate (°C min^{-1}) was calculated for each roast. In order to closely follow the time progress of evaporative and drip losses, both the rib-loin and leg were weighed at four different stages: upon removal from the oven (T0); at the end of post-cooking temperature rise (T1), which was about 1°C for rib-loin and 8°C for leg; when the internal temperature dropped to 50°C (T2) and when it finally equalled room temperature (T3). Evaporative loss, drip and total cooking losses were expressed as a percentage of the initial raw mass (AMSA, 1978).

After chilling, both the cooked cuts and the contro-lateral raw pairs were boned and trimmed of external and seam fat, surface browning and heavy epimysial connective tissue. The separable lean dissected from each cut, which was intended as the edible portion, was diced, triple ground through a 0.3 cm plate in a table-top meat grinder and thoroughly mixed between grindings. Each homogenized sample was divided into two parts, which were stored under different conditions depending on the analyses to be performed: one was retained to immediately determine moisture, protein, ash, lipid, fatty acid composition, cholesterol and macro- and microminerals. A second part of the homogenized sample was frozen at −20°C to determine the most important water-soluble vitamins.

Proximate composition, cholesterol content and energy value

Samples were analysed for moisture, total ash and nitrogen using AOAC (1990) methods No. 950.46B, 920.153 and 981.10, respectively. Total protein was calculated from Kjeldahl nitrogen using a 6.25 conversion factor. Lipid was extracted from 10 g of each homogenized sample following the method of Folch *et al.* (1957), as modified by Michaelsen *et al*. (1991), using chloroform/methanol (2:1, v/v) for extraction. Total lipids were measured gravimetrically on an aliquot of this extract. A second aliquot of the fat extract was transferred to a screw-cap test tube, stored in a refrigerator (+ 4°C) and used within 24 h for fatty acid analysis.

Cholesterol content was determined by direct saponification (Adams *et al*., 1986), without derivatization, in accordance with Engeseth and Gray (1989). A known amount of 5-α-cholestane (Sigma Chemical Co., St. Louis, MO, USA) was added during extraction as an internal standard. Analysis of the cholesterol was performed on a Carlo Erba Fractovap 2350 gas chromatograph (Carlo Erba Instruments, Milano, Italy) designed to accommodate a 1.83 m × 3 mm i.d. glass column packed with 3% OV-17 on Gas Chrom Q (100–120 mesh) (Alltech Associated Inc., Deerfield, IL, USA). Nitrogen served as the carrier gas at a flow rate of 20 ml min^{-1}. Temperatures of the injector, oven, and detector were 300, 262 and 300°C, respectively. The injected volume was 4 μl and the run time was 40 min. The output signal from the detector was amplified at an electrometer sensitivity of 10^1. A DP 700 computing integrator (Carlo Erba Instruments) was used to calculate retention times and peak areas. Cholesterol was identified by comparing retention time to that of an authenticated standard (Sigma Chemical Co.). A standard curve was constructed using peak ratios of 5-α-cholestane and cholesterol. The quantities of cholesterol in the tissues were calculated using the standard curve and the peak ratios of 5-α-cholestane and cholesterol in the muscles.

Energy value (kcal) was derived by multiplying the amount of protein and fat by the factors 4 and 9, respectively (EEC, 1990).

Fatty acid content and composition

Lipid extracted from each composite sample was used for fatty acid determination. The lipid sample (about 100 mg, accurately weighed) was saponified using 0.5 N methanolic sodium hydroxide solution. Fatty acids were liberated and esterified in the presence of boron trifluoride catalyst, according to the AOAC (1990) method No. 969.33. The recovered fatty acid methyl esters (FAME) were added with 20 mg methyltridecanoate (C13:0) as an internal standard and analysed on a fused silica capillary column (Omegawax 320; 30 m × 0.32 mm i.d., 0.25 μm coating thickness; Supelco Inc., Bellefonte, PA, USA) in a Fisons Instruments HRGC 8560 Series Mega 2 gas chromatograph (Fisons Instruments,

Milano, Italy) equipped with a flame ionization detector (FID) and operated with a split ratio of 100:1. High purity helium served as the carrier gas at a flow rate of 105 kPa. High purity hydrogen (50 kPa) and chromatographic air (100 kPa) were supplied to the FID. The injector and detector temperatures were 250 and 260°C, respectively. The column oven was programmed from 180°C (2-min hold) to 200°C at 3°C min^{-1}. The injected sample was 1 μl and the run time was 14 min. The output signal from the detector was amplified at an electrometer sensitivity of 10^1. Retention times and peak areas were automatically computed by a DP 700 computing integrator (Carlo Erba Instruments).

Quantitation of methyl esters was based on methyltridecanoate as an internal standard and on relative peak areas of the fatty acids. Identification was accomplished by comparing the retention time of unknown methyl esters with those of known FAME standard mixtures (Supelco Inc.; Alltech Associated Inc.). The identity of peaks with retention times not corresponding to any standards was determined using equivalent chain length values (ECL) (Miwa, 1963). Fatty acid profiles were obtained both as 'normalized' reports (each fatty acid as percentage of total FAME) and as 'gravimetric' reports (mg each fatty acid 100 g^{-1} edible portion).

Mineral content

Ashed samples were dissolved in 3 N HCl and diluted to an appropriate concentration for mineral analysis according to the AOAC method No. 968.08 (AOAC, 1990). Four macroelements (Na, K, Mg and Ca) and three trace elements (Fe, Zn and Cu) were determined using a Pye Unicam SP9 atomic absorption spectrophotometer (Unicam Ltd, Cambridge, UK) equipped with hollow cathode lamps specific for each element and an air–acetylene flame. The instrument settings and other experimental conditions were in accordance with the manufacturer's specifications. The wavelengths (nm) used for each mineral were: Na, 589.0; K, 766.5; Mg, 285.2; Ca, 422.7; Fe, 248.3; Zn, 213.9; Cu, 324.8. Concentrations were determined from calibration curves obtained with standard solutions of NaCl, KCl, $MgCl_2 \cdot 6H_2O$, $CaCl_2 \cdot 6H_2O$, $FeCl_3 \cdot 6H_2O$, $ZnCl_2$ and $CuCl_2 \cdot 2H_2O$ (Carlo Erba Instruments). Samples diluted for calcium analysis contained 0.5% (w/v) lanthanum to overcome potential anionic interference. Phosphorus was assayed photometrically according to the AOAC procedure No. 965.17 (AOAC, 1990), using a Perkin–Elmer Lambda 1 UV/VIS spectrometer (Perkin–Elmer Italia S.p.A., Monza, Italy). Yellow molybdovanadophosphoric acid was measured at 430 nm. A calibration curve obtained with standard solutions of KH_2PO_4 (Merck, Darmstadt, Germany) was used to assess phosphorus concentration.

Mineral contents were expressed on either a wet weight basis, or a moisture-free and fat-free basis, where the latter was determined by difference [100− (moisture + extractable fat)]. The former approach allows comparisons to be made between the present results and those published by others or reported in food composition tables. The latter procedure, by removing the influence of both moisture and fat, reflects the relative amounts of the minerals present in each cut and allows a direct assessment of cooking effects.

Vitamin content

In planning the present research, a choice was made of determining only those water-soluble vitamins most likely to be present in 'significant' quantities, where significant means 'able to provide at least 15% of the Recommended Dietary Allowance (RDA) set by the European Union Council' (EEC, 1990). These vitamins, selected on the grounds of the data reported by Souci *et al.* (1989) for the most important raw red meats, were thiamin, riboflavin, niacin, pantothenic acid, vitamin B_6 and vitamin B_{12}.

Thiamin was assayed by the thiochrome procedure (Ellefson, 1985), whereas riboflavin, niacin, pantothenic acid, vitamin B_6 and vitamin B_{12} were determined by microbiological assay techniques. Riboflavin was determined using *Lactobacillus casei* (ATCC 7469) as the test micro-organism (Shah, 1985). In niacin assay, *Lactobacillus plantarum* (ATCC 8014) was the test micro-organism (Eitenmiller and De Souza, 1985); the vitamin extraction was performed in 0.1 N HCl at 20 pounds pressure for 30 min. Pantothenic acid was determined according to the method reported by Wyse *et al.* (1985); the vitamin content was expressed as calcium pantothenate. Total vitamin B_6 was determined by the method of Toepfer and Polansky (1970), based on the growth response of the yeast *Saccharomyces uvarum* (ATCC 8040). No attempt was made to separate the three forms of vitamin B_6 (pyridoxine, pyridoxal and pyridoxamine) during the determination. Vitamin B_{12} was determined using *Lactobacillus leichmannii* (ATCC 7830) as the test micro-organism. Samples were extracted in a solution containing 1.2 g citric acid, 1.3 g Na_2HPO_4 and 1 g $Na_2S_2O_5$ in 100 ml water by autoclaving at 20 pounds pressure for 30 min (Method No. 952.20; AOAC, 1990). Calibration curves were obtained using USP reference standards (The United States Pharmacopea Inc., Rockville, MD, USA).

As for minerals, vitamin contents were expressed on either a wet weight basis, or a moisture-free and fat-free basis.

Statistical analysis

A Statistica/Mac® software package, release 3.0 (StatSoft, Inc., Tulsa, OK, USA) was used for statistical analysis of the data. All data were analysed using a two way 'between group-within subjects' analysis of variance, with 'cut' (rib-loin, leg) as the between-group factor. The within-subjects (repeated measures) factor was usually 'state' (raw, cooked), except for cooking losses, where 'time of measurement' (T0 to T3) was used. Means were separated at, or below, the 5% level

of significance using the Scheffé *post hoc* test. Apparent retention factors for the various nutrients were calculated as follows: %AR = [nutrient content per g of cooked food (dry basis)]/[nutrient content per g of raw food (dry basis)] * 100, according to Murphy *et al.* (1975). Percent retention data were analysed by Student's *t*-test for independent samples to evaluate the 'cut' effect on the retention of nutrients after cooking. Proximate composition and fatty acid data (as % FAME) were log-transformed before statistical analysis.

RESULTS AND DISCUSSION

Cooking progression and cooking losses

Cooking progression was considerably different for the two cuts despite the fact that their degree of doneness, instrumentally assessed, was comparable (Badiani *et al.*, 1994). The clear differences in shape, size and surface/volume ratio of the two types of cut being heated; the composition of the cuts, i.e. the content and spatial distribution of subcutaneous and intermuscular fat, lean, connective tissue and bones; the spatial orientation of the cuts while cooking: all, as expected, contributed in different ways to affect the cooking losses, cooking times and heating rates presently recorded for rib-loin and leg.

More specifically, in each of the moments selected for weighing the cuts, both evaporative and drip losses (consequently total losses as well) were significantly superior in leg compared to rib-loin (Table 1). In both cuts, evaporative loss considerably exceeded drip loss, being between 78 and 84% of total losses in rib-loin and between 82 and 84.5% of total losses in leg, depending on the moment considered. In the oven (i.e. at time T0) 77% of the total evaporative loss and 57% of the total drip loss occurred for rib-loin, against 90 and 78%, respectively, for leg. Once taken out of the oven, rib-loin lost weight, due to both evaporation and drippings, at a rate that was significantly higher than that of leg. In fact, the evaporative, drip and total losses calculated for rib-loin at time T3 were, respectively, 130, 175 and 137% of those measured upon removal from the oven (T0), against 111, 128 and 114%, respectively, for leg. It should be noted that, between the values calculated at T2 and T3, no significant differences emerged for drip loss of either cut or for evaporative and total losses of leg. On the other hand, with the sole exception of drip loss of leg, the losses recorded at Tl and T2 were significantly different, which is understandable given the considerable time lapse between the two moments and the high temperatures the cuts were still at. On the basis of the results obtained, it therefore seems expedient to continue weighing roasted lamb cuts after the time when maximum post-cooking rise is reached (as recommended by AMSA, 1978) and at least until reaching a core temperature of 50°C.

A comparison between the data given here and those that can be found in literature for cooking tests on lamb is rather difficult due to the fact that thawed rather than fresh cuts are commonly used and that cooked cuts are often weighed only on coming out of the oven. To the best of our knowledge, only Griffin *et al.* (1985) and Jeremiah (1988) reported the weight loss consequent upon cooking fresh lamb cuts. The total cooking losses presently recorded for rib-loin at time T0 were between those reported by Griffin *et al.* (1985) for seven-rib racks either rare (14.42%) or medium-done (19.08%). As regards leg, the total losses recorded here at T0 are fairly close both to those reported by Griffin *et al.* (1985) for well-done whole bone-in legs (29.52%) and to the ones reported by Jeremiah (1988) for Australian bone-in legs (31.09%).

Mean cooking times per unit initial weight were 57.1 and 47.4 min kg^{-1} for rib-loin and leg, respectively, and therefore markedly lower than the values reported both by Griffin *et al.* (1985) for rare and medium-done seven-rib racks (68.13 and 88.23 min kg^{-1}, respectively) and well-done bone-in legs (55.62 min kg^{-1}) and by Jeremiah (1988) for Australian bone-in legs (53.27 min kg^{-1}). However, it should be considered that the former

Table 1. Cooking losses of rib-loin and leg determined at selected times[a]

Trait[b,c,d]	T0	T1	T2	T3
Evaporative loss (%)				
Rib-loin	14.26 ± 0.96C	14.59 ± 0.96C	16.55 ± 0.92B	18.46 ± 0.80A
Leg	26.46 ± 0.24B	26.92 ± 0.24B	28.80 ± 0.28A	29.44 ± 0.29A
Drip loss (%)				
Rib-loin	2.70 ± 0.22C	3.46 ± 0.26B	4.65 ± 0.31A	4.72 ± 0.29A
Leg	4.85 ± 0.24B	5.87 ± 0.26A	6.18 ± 0.29A	6.22 ± 0.29A
Total loss (%)				
Rib-loin	16.96 ± 1.02C	18.05 ± 1.08C	21.20 ± 0.92B	23.18 ± 0.89A
Leg	31.32 ± 0.39C	32.79 ± 0.39B	34.98 ± 0.44A	35.66 ± 0.49A

[a]Values are mean ± standard error of the mean. T0 = upon removal from the oven; T1 = at the end of post-cooking temperature rise; T2 = when the internal temperature dropped to 50°C; T3 = when the internal temperature equalled room temperature.
[b]At any given time and type of loss, the difference between cuts was always statistically significant ($p \leq 0.01$).
[c]Means on the same row followed by different letters differ significantly ($p \leq 0.01$).
[d]Cut×Time interaction was statistically significant for all traits ($p \leq 0.01$).

workers used a non-preheated oven. The mean heating rate was much higher for rib-loin than for leg (1.1 vs. 0.5°C min^{-1}); as a result, the cooking of rib-loin was more similar to oven broiling than to oven roasting (Resurreccion, 1994).

Content and retention of protein, lipids, ash and cholesterol

In the raw state, the two cuts were not significantly different in proximate composition, cholesterol content or energy value (Table 2). With protein and ash contents comparable to literature figures for meat deriving from lambs of various weights and ages (not always stated), the cuts presently analysed had a considerably lower lipid content (Murphy *et al.*, 1966; Ono *et al.*, 1984; Bodwell and Anderson, 1986; Sinclair and O'Dea, 1987; Lin *et al.*, 1988; NLS&MB, 1988; Enser *et al.*, 1996). The cholesterol content, while agreeing with the values found in lamb by Lin *et al.* (1988) and Swize *et al.* (1992), slightly exceeded the contents reported by Ono *et al.* (1984) and by some food composition tables (Greenfield *et al.*, 1987; NLS&MB, 1988). Since a large part of the cholesterol in muscle tissue is linked to the membrane fraction of muscle cells (Hoelscher *et al.*, 1988), its higher content is understood in meat from young animals, such as the ones examined here, characterized by cells of smaller size and therefore by a greater surface/volume ratio compared to those of older animals (Lin *et al.*, 1988).

After cooking, the content of protein, lipids and cholesterol significantly increased in both cuts, upon a decrease in moisture and ash content. The cooked cuts were significantly different in moisture, protein and energy.

The apparent retention of protein fell at the upper end of the spectrum (90–100%) derived from the data by Bodwell and Anderson (1986), Greenfield *et al.* (1987) and NLS&MB (1988) for roasted legs and broiled rib-loins from lamb. Slightly higher values were reported by Ono *et al.* (1984) as true retention factors for lamb cuts (108% for rib-loin, 104% for leg). Overall, in the case of protein, a retention around 100% is expected, deriving from the sheer effect of concentration.

Fat retention turned out to be markedly higher than 100% in both cuts. This phenomenon is common with multiple-muscle cuts, especially if bone-in and with a low content of intramuscular fat, when they are cooked with external fat, thanks to the contribution provided by rendered intermuscular and subcutaneous fat (Jones *et al.*, 1992). In effect, fat retention factors markedly higher than 100%, for bone-in cuts comprised of several muscles and cooked with external fat, have been reported for lamb (Murphy *et al.*, 1966; Ono *et al.*, 1984; Bodwell and Anderson, 1986; Greenfield *et al.*, 1987; NLS&MB, 1988), pork (Moss *et al.*, 1983; Slover *et al.*, 1987*b*), veal (Ono *et al.*, 1986) and beef (Slover *et al.*, 1987*a*; Smith *et al.*, 1989; Jones *et al.*, 1992). The slight superiority of leg compared to rib-loin in fat retention could be due to the greater richness in intermuscular fat of leg compared to rib-loin (Harris *et al.*, 1990), and therefore also to the greater likelihood that small amounts of fat may have been smeared on the lean surface during handling, as well as to the fact that the leg was cooked fat side up, instead of to the side as the rib-loin (Ono *et al.*, 1984; Heymann *et al.*, 1990; Jones *et al.*, 1992).

The coefficients of apparent retention obtained for ash in roasted or broiled lamb cuts from the data by Bodwell and Anderson (1986), Greenfield *et al.* (1987) and NLS&MB (1988) range between 72.11 and 79.62% for rib-loin, and between 60.44 and 71.72% for leg. The retention factors presently found were either at the

Table 2. Proximate composition, cholesterol content and energy value of raw and roasted lamb cuts, with retention values[a]

Trait	Cut[b]	Nutrient values[c] (g 100 g^{-1} lean, except where noted)		Retention values (%)
		Raw	Roasted	
Moisture[d]	RL	76.49 ± 0.19A	X66.54 ± 0.39B	Y142 ± 1.60
	LG	76.89 ± 0.17A	Y63.80 ± 0.37B	X157 ± 1.22
Protein	RL	20.4 ± 0.21B	Y28.7 ± 0.46A	99.1 ± 0.81
	LG	20.0 ± 0.20B	X31.1 ± 0.39A	99.4 ± 0.69
Lipids	RL	2.67 ± 0.13B	4.22 ± 0.26A	111 ± 3.79
	LG	2.53 ± 0.10B	4.53 ± 0.16A	115 ± 1.98
Ash	RL	1.11 ± 0.01	1.09 ± 0.01	X69.2 ± 1.10
	LG	1.13 ± 0.01A	1.08 ± 0.01B	Y61.2 ± 0.87
Cholesterol (mg)	RL	75 ± 3B	104 ± 3A	98.3 ± 3.37
	LG	71 ± 1B	116 ± 5A	104.15 ± 3.53
Energy value (kcal)	RL	105 ± 1B	Y153 ± 3A	102 ± 0.76
	LG	103 ± 1B	X165 ± 2A	103 ± 0.56

[a]Values are mean ± standard error of the mean. RL = rib-loin; LG = leg.
[b]Means within a column and trait preceded by different letters differ significantly ($p \leq 0.01$). Means on the same row (retention values excepted) followed by different letters differ significantly ($p \leq 0.01$).
[c]Cut×State interaction was statistically significant for all traits ($p \leq 0.05$ for lipids, ash and cholesterol; $p \leq 0.01$ for moisture, protein and energy).
[d]For this trait, retention value refers to dry matter.

lower end of the above mentioned spectrum (leg) or below it (rib-loin). In general, rib-loin seemed to retain its ash content better than leg. This phenomenon was also found by Ono *et al.* (1984), though they reported significantly higher true retention factors (87% for rib-loin, 76% for leg). Ash is lost to drippings during cooking, which explains why the retention factors are less than 100% (Murphy *et al.*, 1966, 1975). In this study the rib-loin had suffered less drip loss than the leg. On the other hand, as mentioned earlier, due to the higher heating rate the rib-loin cooking method was somewhere between true roasting and broiling; according to Nanni (1995), this last cooking method would involve slightly higher retentions of minerals than roasting.

The apparent retention of cholesterol was around 100%, which suggests that it had merely been concentrated, that is with no migration from the subcutaneous and intermuscular fat towards the lean and with no loss towards the outside from the separable lean (i.e. muscle tissue + intramuscular fat). On the basis of what was reported for beef by Rhee *et al.* (1982), Hoelscher *et al.* (1988) and Sweeten *et al.* (1990), one is more likely to believe that cholesterol retention, in the lean portion of a cut containing intermuscular fat and cooked with external fat, depends on the proportion of the various tissues in the cut and on the partitioning, in those tissues, of cholesterol into cytoplasmic and membrane fractions. With beef, this distribution is increasingly shifted in favour of the cytoplasmic fraction (more likely to migrate), when we pass from considering muscle tissue to intramuscular fat and then subcutaneous fat. These dynamics could explain the considerable variability in the cholesterol retention factors found in literature for lamb and other meats: from values even lower than 90% up to over 120% (Murphy *et al.*, 1975; Moss *et al.*, 1983; Ono *et al.*, 1984, 1986; Slover *et al.*, 1987*a*,*b*; NLS&MB, 1988). On the other hand, one cannot neglect the possibility that part of the cholesterol has been oxidized, as conditions present during cooking may be conducive to cholesterol oxidation in muscle foods (Pie *et al.*, 1991). In conclusion, the contribution of subcutaneous and intermuscular fat to cholesterol retention (probably higher in leg) could have been attenuated by oxidative decomposition of the cholesterol (probably greater in rib-loin, due to the higher heating rate).

Fatty acid content and retention

The fatty acid profile of rib-loin and leg, both raw and cooked, is reported quantitatively (mg 100 g^{-1} lean) and qualitatively (% total FAME) in Tables 3 and 4. As % total FAME, the fatty acid composition of the two raw cuts was significantly different only for C15:0 *ante-iso* (*ai*) and C17:1. In descending order of concentration, the main fatty acids were oleic (C18:1), palmitic (C16:0), stearic (C18:0), linoleic (C18:2), myristic (C14:0) and arachidonic (C20:4), totalling 86.1% of FAME in rib-loin, and 85.1% in leg. Branched-chain acids plus odd-numbered n-fatty acids were 6.50 and 7.05% of total FAME in rib-loin and leg, respectively. In quantitative terms (mg 100 g^{-1} lean), only the content of C16:0 *ai* differed significantly in the two raw cuts. A comparison with some published data, which can be used provided they are expressed qualitatively (Greenfield *et al.*, 1987; Sinclair and O'Dea, 1987; Solomon *et al.*, 1990; Enser *et al.*, 1996), illustrates how the lean of the cuts presently analysed had lower levels of palmitic, stearic and oleic acids, against decidedly higher percentages of linoleic and arachidonic acids. Consequently, the ratio between polyunsaturated fatty acids (PUFA) and saturated fatty acids (SFA) was especially high. The sex of the animals examined could have contributed to what was observed, as ram lambs are known to have intramuscular lipids richer in PUFA and poorer in SFA compared to ewes and wethers (Solomon *et al.*, 1990). In addition, with such a modest lipid content, a good level of PUFA was expected, since: (1) the leaner the meat, the higher the percentage of phospholipids relative to the total fat content, and (2) phospholipids are known to be richer in PUFA than triglycerides (Lazarus *et al.*, 1977; Sinclair *et al.*, 1982; Bodwell and Anderson, 1986; Sinclair and O'Dea, 1987; Gandemer, 1992). Branched-chain acids and odd-numbered n-fatty acids corresponding to the ones normally present in the tissue lipids of ruminants (Garton *et al.*, 1972) were found in both cuts at levels considered normal in ovine tissue lipids (Christie and Moore, 1971).

An examination of the fatty acid composition of the lean separated from the two cuts after cooking (as % total FAME) shows that the sum of the SFA remained statistically unchanged; that of monounsaturated fatty acids (MUFA) increased only for leg, while that of PUFA decreased. In quantitative terms, in both cuts cooking involved a virtually generalized increase in the concentration of fatty acids; this increase was distinctly higher for the sum of SFA than for that of PUFA, to the point that the PUFA/SFA ratio significantly decreased.

On the basis of the coefficients of retention, three groups of fatty acids could be distinguished: fatty acids with a retention around 100% (C18:2 and C18:3 in rib-loin, C20:3), fatty acids with a retention much lower than 100% (C16:0 *ai*, C18:0 *ai*, C20:2, C20:4), fatty acids with a retention markedly higher than 100% (the remaining fatty acids, i.e. all SFA with most branched-chain fatty acids, all MUFA, C18:2 and C18:3 in leg, C18:2 conjugated). With the sole exception of C15:0 *ai*, fatty acids were better retained in leg than in rib-loin, although the difference between the two cuts was statistically significant only for C18:3, C18:2 conjugated, C20:2 and C20:4. The above agrees with the data derived from NLS&MB (1988) for roasted lamb leg and broiled lamb rib-loin; however, in the present study linoleic and linolenic acids were retained much more in both cuts.

Table 3. Saturated fatty acid composition of raw and roasted lamb cuts, with retention values[a]

Trait[b]	Cut[c]	F.a. content (mg 100 g^{-1} lean)[d]		Retention value (%)	F.a. content (% total FAME)[e]	
		Raw	Roasted		Raw	Roasted
C10:0	RL	6 ± 0.4B	10 ± 0.8A	120 ± 6.77	0.27 ± 0.01	0.28 ± 0.02
	LG	5 ± 0.4B	11 ± 0.7A	128 ± 3.48	0.26 ± 0.01	0.26 ± 0.01
C12:0	RL	8 ± 0.8B	16 ± 1.9A	145 ± 9.30	0.34 ± 0.03B	0.42 ± 0.05A
	LG	8 ± 0.8B	18 ± 1.7A	146 ± 4.44	0.36 ± 0.03B	0.42 ± 0.03A
C14:0	RL	81 ± 9.2B	163 ± 20A	143 ± 9.14	3.60 ± 0.27B	4.24 ± 0.33A
	LG	79 ± 8.7B	179 ± 17A	148 ± 6.11	3.61 ± 0.30B	4.21 ± 0.28A
C15:0 *ai*	RL	4 ± 0.4B	8 ± 0.8A	155 ± 12.12	Y0.16 ± 0.01B	0.21 ± 0.01A
	LG	4 ± 0.3B	8 ± 0.6A	144 ± 4.50	X0.18 ± 0.01b	0.20 ± 0.01a
C15:0	RL	9 ± 0.9B	18 ± 1.6A	149 ± 8.85	0.38 ± 0.02B	0.47 ± 0.02A
	LG	9 ± 0.7B	20 ± 1.3A	149 ± 5.06	0.41 ± 0.02B	0.48 ± 0.01A
C16:0 *i*	RL	3 ± 0.3B	7 ± 0.6A	139 ± 6.82	0.16 ± 0.01B	0.18 ± 0.01A
	LG	3 ± 0.2B	7 ± 0.4A	145 ± 5.68	0.16 ± 0.01B	0.18 ± 0.01A
C16:0 *ai*	RL	y44 ± 2.2	Y48 ± 2.6	76 ± 2.43	2.05 ± 0.10A	1.43 ± 0.12B
	LG	x50 ± 1.3B	X64 ± 3.1A	81 ± 2.78	2.41 ± 0.11A	1.55 ± 0.06B
C16:0	RL	477 ± 37B	855 ± 65A	127 ± 5.62	21.6 ± 0.43b	22.7 ± 0.30a
	LG	449 ± 28B	917 ± 51A	132 ± 3.87	20.9 ± 0.54b	21.8 ± 0.36a
C17:0 *i*	RL	10 ± 0.8B	19 ± 1.4A	129 ± 5.79	0.46 ± 0.02B	0.49 ± 0.02A
	LG	10 ± 0.5B	21 ± 1.3A	139 ± 5.14	0.46 ± 0.02B	0.51 ± 0.02A
C17:0 *ai*	RL	15 ± 1.3B	27 ± 1.8A	125 ± 5.94	0.70 ± 0.02	0.71 ± 0.01
	LG	15 ± 0.6B	30 ± 1.4A	131 ± 4.15	0.69 ± 0.02b	0.72 ± 0.01a
C17:0	RL	22 ± 1.5B	39 ± 2.5A	128 ± 6.30	0.96 ± 0.03B	1.04 ± 0.03A
	LG	20 ± 1.1B	43 ± 2.1A	138 ± 4.70	0.95 ± 0.03B	1.03 ± 0.03A
C18:0 *ai*	RL	22 ± 1.1	Y24 ± 1.7	77.6 ± 5.05	1.01 ± 0.09A	0.66 ± 0.05B
	LG	23 ± 1.0B	X30 ± 1.1A	81.5 ± 3.32	1.13 ± 0.08A	0.72 ± 0.05B
C18:0	RL	275 ± 11B	472 ± 25A	121 ± 4.75	12.8 ± 0.35	X12.8 ± 0.45
	LG	255 ± 8B	499 ± 13A	125 ± 3.99	12.2 ± 0.34	y12.1 ± 0.46
$\sum$ SFA	RL	975 ± 63B	1703 ± 116A	123 ± 5.23	44.5 ± 0.66	x45.6 ± 0.70
	LG	930 ± 45B	1848 ± 85A	128 ± 3.44	43.6 ± 0.71	y44.2 ± 0.71

[a]Values are mean ± standard error of the mean. RL = rib-loin; LG = leg; F.a. = fatty acid.
[b]F.a. are represented in the following manner: the first number indicates the number of carbons, while the second represents the number of double bonds; *i* is an *iso*-isomer and *ai* an *ante-iso*-isomer. SFA = saturated f.a.
[c]Means within a column and trait preceded by different letters differ significantly (x, y: $p \leq 0.05$; X, Y: $p \leq 0.01$). Means on the same row under each calculation unit heading (retention values excepted) followed by different letters differ significantly (a, b: $p \leq 0.05$; A, B: $p \leq 0.01$).
[d]Cut×State interaction was statistically significant for C17:0 *ai* and C17:0 ($p \leq 0.05$) and for C16:0 *ai* ($p \leq 0.01$).
[e]FAME = fatty acid methyl ester. Cut×State interaction was statistically significant only for C15:0 *ai* ($p \leq 0.05$).

As mentioned earlier, the high lipid retention, for both cuts, suggests a certain contribution of fat to the lean from rendered subcutaneous and intermuscular fat. Since these tissues are notoriously more endowed with neutral lipids, and therefore with SFA and MUFA, compared to the lean (Sinclair *et al.*, 1982; Enser *et al.*, 1996), it is reasonable to hypothesize that this migration led to the high coefficients of retention presently found for SFA and MUFA. Judging by the coefficients of retention found above all in leg, C18:2, C18:3 and C18:2 conjugated might have been provided to the lean following the same route. On the other hand, according to Gandemer (1992), linoleic and linolenic acids would be barely susceptible to oxidation. It is a very different matter for C20 PUFA, which have virtually only been isolated from the phospholipid fraction (Lazarus *et al.*, 1977; Enser *et al.*, 1996) and therefore should not undergo migration (Armstrong and Bergan, 1992; Gandemer, 1992). On the basis of the coefficients of retention, C20:2 and C20:4 seem, to a greater or lesser extent, to have undergone oxidative decomposition, a phenomenon moreover already highlighted for C20:4 in meats from other species (Keller and Kinsella, 1973; Igene and Pearson, 1979; NLS&MB, 1988; Gandemer, 1992). Coefficients of retention very close to those of C20:4 were obtained also for C16:0 *ai* and C18:0 *ai*, a finding for which we have no ready explanation. The differences observed between rib-loin and leg in the coefficients of retention, which were significant only for some fatty acids, could have different possible joint causes, namely the different content and spatial orientation of subcutaneous and intermuscular fat and the different heating rate. Neither, on the basis of the observations made on beef by Sweeten *et al.* (1990), can it be excluded that, in the various lamb muscles, there is a different distribution of fatty acids in the cytoplasmic and membrane fractions, with a consequently different propensity for migration during cooking.

Content and retention of minerals and vitamins

When expressed on a wet weight basis (WWB), the raw lean separated from rib-loin was significantly richer in calcium than that separated from leg; the latter was

Table 4. Unsaturated fatty acid composition of raw and roasted lamb cuts, with retention values[a]

Trait[b]	Cut[c]	F.a. content (mg 100 g^{-1} lean)[d]		Retention value (%)	F.a. content (% total FAME)[e]	
		Raw	Roasted		Raw	Roasted
C14:1	RL	4 ± 0.6B	8 ± 1.1A	147 ± 10.63	0.17 ± 0.02b	0.20 ± 0.02a
	LG	4 ± 0.5B	10 ± 1.2A	150 ± 7.00	0.20 ± 0.02	0.23 ± 0.02
C16:1	RL	41 ± 4.8B	75 ± 8.1A	132 ± 7.57	1.81 ± 0.11B	1.97 ± 0.09A
	LG	39 ± 3.9B	79 ± 8.5A	135 ± 6.57	1.82 ± 0.10b	1.92 ± 0.11a
C17:1	RL	14 ± 1.5B	26 ± 2.4A	136 ± 5.95	Y0.62 ± 0.03B	y0.69 ± 0.03A
	LG	14 ± 1.2B	31 ± 2.4A	139 ± 5.55	X0.66 ± 0.04B	x0.73 ± 0.04A
C18:1	RL	790 ± 65B	1365 ± 93A	123 ± 5.53	35.7 ± 0.92	36.8 ± 0.87
	LG	748 ± 44B	1544 ± 80A	133 ± 5.04	34.8 ± 0.76	36.8 ± 0.70
C18:2	RL	202 ± 11B	Y284 ± 17A	99.8 ± 5.66	9.15 ± 0.46A	7.94 ± 0.35B
	LG	208 ± 8B	X356 ± 17A	109 ± 3.67	9.83 ± 0.56A	8.57 ± 0.34B
C18:3	RL	6 ± 0.4B	Y9 ± 0.7A	y103 ± 6.22	0.28 ± 0.01a	0.24 ± 0.01b
	LG	6 ± 0.3B	X11 ± 1.0A	x126 ± 6.26	0.27 ± 0.01	0.27 ± 0.02
C18:2	RL	10 ± 1.0B	16 ± 1.7A	y113 ± 3.29	0.43 ± 0.02	0.42 ± 0.02
conj.	LG	9 ± 0.6B	19 ± 1.7A	x139 ± 9.56	0.43 ± 0.02	0.45 ± 0.02
C20:2	RL	7 ± 0.7	Y7 ± 0.8	y73.1 ± 4.50	0.29 ± 0.02A	0.19 ± 0.02B
	LG	7 ± 0.5B	X9 ± 1.0A	x89.7 ± 5.96	0.31 ± 0.02A	0.22 ± 0.02B
C20:3	RL	5 ± 0.3	7 ± 0.9	91.9 ± 11.41	0.24 ± 0.02A	0.17 ± 0.01B
	LG	6 ± 0.3b	9 ± 1.1a	102 ± 14.72	0.28 ± 0.02	0.22 ± 0.02
C20:4	RL	70 ± 3.3	Y68 ± 6.8	y66.9 ± 4.59	3.24 ± 0.15A	1.99 ± 0.20B
	LG	79 ± 5.2B	X102 ± 10A	x82.0 ± 4.20	3.80 ± 0.23A	2.43 ± 0.16B
$\sum$ MUFA	RL	848 ± 71B	1475 ± 104A	124 ± 5.60	38.3 ± 1.01	39.6 ± 0.87
	LG	801 ± 48B	1640 ± 85A	132 ± 4.79	37.3 ± 0.92b	39.1 ± 0.79a
$\sum$ PUFA	RL	301 ± 15B	Y391 ± 26A	91.5 ± 4.86	13.6 ± 0.59A	11.0 ± 0.52B
	LG	315 ± 13B	X507 ± 29A	103 ± 3.61	14.9 ± 0.76A	12.2 ± 0.43B
PUFA/SFA	RL	0.316 ± 0.02A	0.232 ± 0.01B	—	—	—
	LG	0.345 ± 0.02A	0.276 ± 0.01B	—	—	—

[a]Values are mean ± standard error of the mean. RL = rib-loin; LG = leg; F.a. = fatty acid.
[b]F.a. are represented in the following manner: the first number indicates the number of carbons, while the second represents the number of double bonds; conj. stands for conjugated isomer. SFA = saturated f.a.; MUFA = monounsaturated f.a.; PUFA = polyunsaturated f.a.
[c]Means within a column and trait preceded by different letters differ significantly (x, y: $p \leq 0.05$; X, Y: $p \leq 0.01$). Means on the same row under each calculation unit heading (retention values excepted) followed by different letters differ significantly (a, b: $p \leq 0.05$; A, B: $p \leq 0.01$).
[d]Cut×State interaction was statistically significant for C18:2 conj. and $\sum$ MUFA ($p \leq 0.05$) and for C18:2, C18:3, C20:2 and C20:4 ($p \leq 0.01$).
[e]FAME = fatty acid methyl ester. Cut×State interaction was statistically significant only for C18:3 ($p \leq 0.05$).

significantly richer in potassium, iron and zinc (Table 5). When expressed on a moisture-free, fat-free basis (MFFB), the differences between the raw cuts remained significant for potassium, iron and zinc, to which was added phosphorus, equally more plentiful in leg. The content of magnesium, iron and zinc of both rib-loin and leg presently analysed fell within the ranges derived from literature (Hazell, 1982; Ono *et al*., 1984; Bodwell and Anderson, 1986; Greenfield *et al*., 1987; NLS&MB, 1988; Lin *et al*., 1989). Compared to these ranges, moreover, rib-loin was better endowed with potassium, whereas leg turned out richer in sodium and above all in calcium. The differences found between these two cuts as regards the content of macrominerals and trace elements should not be surprising. Finding a different elemental composition according to the anatomical location of the muscle tissue examined is a common event, both in sheep (Ono *et al*., 1984; Lin *et al*., 1989) and in other species (Moss *et al*., 1983; Ono *et al*., 1986; Bodwell and Anderson, 1986; NLS&MB, 1988), since it appears to be affected by genetic, physiological and environmental factors. On a WWB, only the content of potassium significantly decreased in both cuts after cooking, whereas the phosphorus, iron and zinc contents increased significantly. Apart from the content of moisture and lipids (i.e. on an MFFB), however, it was clear that, with the sole exception of zinc and iron (for leg only), the content of mineral elements significantly decreased, as they were lost through drippings (Murphy *et al*., 1975). As a consequence of the different progression of drip losses, and again on a MFFB, the two cuts differed in their content of most of the minerals considered, with the sole exceptions of calcium and copper. Leg was superior to rib-loin only for iron and zinc contents, which can be traced back to the greater presence of dark muscles in the former than in the latter (Lin *et al*., 1989).

In general, the coefficients of retention for minerals were markedly lower than 100%; only iron and zinc were exceptions to this, which is predictable as they are largely bound to high-molecular-weight ligands. Considering the true retentions reported for roasted lamb cuts by Ono *et al*. (1984) and the apparent ones derived from the data by Bodwell and Anderson (1986), Greenfield

et al. (1987) and NLS&MB (1988) for roasted legs and broiled rib-loins, the coefficients of apparent retention calculated here were comparable for iron and zinc of both cuts and for sodium, magnesium and phosphorus restricted to rib-loin. Excluding these cases, the coefficients of apparent retention presently calculated were lower than the ones reported in the above mentioned papers. It is thought that the better retention of sodium, potassium, magnesium and phosphorus recorded for rib-loin compared to leg, likewise its worse iron retention, may be due to the higher heating rate undergone by the former compared to the latter. Similar observations have been made by Nanni (1995), when reviewing the effects of different cooking methods on nutrient retentions in several meats.

As regards vitamins, both on an WWB and on an MFFB, the two cuts in their raw state were significantly different only in pantothenate and vitamin B_6 contents (Table 6). Compared to the reference ranges found in literature for raw lamb (Ono *et al.*, 1984; Bodwell and Anderson, 1986; Greenfield *et al.*, 1987; Lin *et al.*, 1988; NLS&MB, 1988), the values presently found were higher for vitamin B_6 and B_{12}, and lower for riboflavin (in leg) and pantothenate. The expression of the vitamin contents on an MFFB makes it possible to appreciate how, after cooking, major and, for the most part, significant losses of the vitamins considered had occurred. These losses left the rib-loin richer in vitamins than the leg, although the difference was significant only for niacin and vitamin B_6.

The coefficients of retention were systematically higher in rib-loin than in leg, the difference between cuts being significant for niacin, pantothenate, vitamin B_6 and vitamin B_{12}. With reference to the coefficients of retention derived from literature data on lamb (Ono *et al.*, 1984; Bodwell and Anderson, 1986; Greenfield *et al.*, 1987; NLS&MB, 1988), the rib-loin examined here showed comparable retentions for riboflavin, niacin, pantothenate and vitamin B_{12}, while showing significantly lower retentions for thiamin and vitamin B_6. Retentions in leg were comparable to literature figures only for riboflavin and thiamin, all the others being lower. Finally, with the sole exception of riboflavin that was well retained in both cuts, the retentions given in Table 6 were medium-low (rib-loin), when they were not decidedly low (leg), which, on the basis of what Guilland *et al.* (1991) reported for beef, could be linked to the low fat content of both cuts. The better retentions recorded for rib-loin could be ascribed both to the higher heating rate and to the shorter time this cut spent in the oven (Nanni, 1995).

Contribution of roasted lamb to the diet

The results allow the contribution to nutrient requirements obtainable from roasted rib-loins and legs from young ram lambs to be evaluated. In the discussions to follow, the two cuts will be kept distinct only for the nutrients which differ significantly. A value of 100 g of cooked lean will be taken to be an average serving. The content of water-soluble vitamins and of most of the minerals determined here will be discussed on the basis of the RDAs suggested by the EEC (1990). Only for sodium, potassium and copper, will the RDAs set by the US National Academy of Sciences (NAS–NRC, 1989) for males, age 25–50, be used.

A serving of roasted lamb was able to supply between 57 and 62% (for rib-loin and leg, respectively) of the

Table 5. Mineral content of raw and roasted lamb cuts, with retention values[a]

Trait	Cut[b]	Wet weight basis[c] (mg 100 g^{-1})		Retention value (%)	Moisture-free, fat-free basis (MFF)[d] (mg 100 g^{-1})		MFF retention value (%)
		Raw	Roasted		Raw	Roasted	
Sodium	RL	69.9 ± 1.8	x70.6 ± 1.3	X71.3 ± 1.60	336 ± 11A	X242 ± 6B	X72.3 ± 1.59
	LG	67.9 ± 1.5	y64.8 ± 1.9	Y61.1 ± 2.01	331 ± 10A	Y205 ± 8B	Y62.2 ± 2.02
Potassium	RL	y325 ± 4a	309 ± 7b	X67.1 ± 1.78	Y1558 ± 21A	X1060 ± 32B	X68.0 ± 1.56
	LG	x338 ± 5A	302 ± 5B	Y57.2 ± 0.80	X1642 ± 28A	Y956 ± 23B	Y58.2 ± 0.77
Magnesium	RL	19.6 ± 0.6	19.5 ± 0.7	X69.9 ± 1.66	94.1 ± 2.6A	x66.8 ± 2.5B	X70.9 ± 1.42
	LG	19.9 ± 0.6	19.9 ± 0.6	Y64.1 ± 0.53	96.5 ± 2.6A	y63.0 ± 1.9B	Y65.2 ± 0.47
Calcium	RL	x12.6 ± 0.9	12.3 ± 0.4	70.9 ± 4.69	61.0 ± 5.1A	42.2 ± 1.7B	71.9 ± 4.68
	LG	y10.3 ± 0.8	10.8 ± 0.3	68.4 ± 2.46	50.3 ± 4.2A	34.1 ± 1.3B	69.6 ± 2.53
Phosphorus	RL	209 ± 2B	Y223 ± 3A	X75.0 ± 1.34	y1005 ± 10A	X764 ± 13B	X76.0 ± 1.10
	LG	213 ± 2B	X230 ± 2A	Y68.8 ± 0.51	x1036 ± 9A	Y726 ± 8B	Y70.0 ± 0.38
Iron	RL	Y1.70 ± 0.08B	Y2.20 ± 0.04A	y91.9 ± 1.56	Y8.15 ± 0.38a	Y7.54 ± 0.19b	y93.3 ± 1.73
	LG	X1.99 ± 0.05B	X2.99 ± 0.06A	x96.1 ± 1.02	X9.67 ± 0.21	X9.45 ± 0.14	x97.8 ± 1.00
Zinc	RL	Y2.75 ± 0.12B	Y3.59 ± 0.08A	92.1 ± 1.58	Y13.2 ± 0.6	Y12.3 ± 0.3	93.5 ± 1.78
	LG	X3.31 ± 0.12B	X4.86 ± 0.13A	94.3 ± 2.01	X16.1 ± 0.6	X15.3 ± 0.3	96.0 ± 2.14
Copper	RL	0.17 ± 0.02	0.18 ± 0.01	77.7 ± 5.14	0.83 ± 0.09a	0.63 ± 0.06b	78.7 ± 5.12
	LG	0.19 ± 0.01	0.20 ± 0.01	69.1 ± 5.27	0.92 ± 0.08A	0.63 ± 0.04B	70.3 ± 5.44

[a]Values are mean ± standard error of the mean. RL = rib-loin; LG = leg.
[b]Means within a column and trait preceded by different letters differ significantly (x, y: $p \leq 0.05$; X, Y: $p \leq 0.01$). Means on the same row under each calculation unit heading (retention values excepted) followed by different letters differ significantly (a, b: $p \leq 0.05$; A, B: $p \leq 0.01$).
[c]Cut×State interaction was statistically significant for potassium, iron and zinc ($p \leq 0.01$).
[d]Cut×State interaction was statistically significant for sodium ($p \leq 0.05$) and for potassium, magnesium and phosphorus ($p \leq 0.01$).

Table 6. Vitamin content of raw and roasted lamb cuts, with retention values[a]

Trait	Cut[b]	Wet weight basis[c] (mg $100\,g^{-1}$ except where noted)		Retention value (%)	Moisture-free, fat-free basis (MFF)[d] (mg $100\,g^{-1}$ except where noted)		MFF retention value (%)
		Raw	Roasted		Raw	Roasted	
Thiamin	RL	0.175 ± 0.027	0.135 ± 0.021	54.9 ± 5.15	0.854 ± 0.128a	0.465 ± 0.070b	56.0 ± 5.27
	LG	0.155 ± 0.027	0.096 ± 0.011	41.3 ± 4.43	0.763 ± 0.123a	0.310 ± 0.037b	42.0 ± 4.54
Riboflavin	RL	0.193 ± 0.004B	0.258 ± 0.006A	94.9 ± 4.02	0.938 ± 0.014	0.907 ± 0.031	96.7 ± 3.61
	LG	0.198 ± 0.005B	0.280 ± 0.002A	92.3 ± 2.51	0.973 ± 0.011	0.909 ± 0.020	93.5 ± 2.64
Niacin	RL	5.756 ± 0.315	x5.186 ± 0.305	x64.3 ± 3.33	27.8 ± 1.187A	x18.1 ± 1.257B	X65.2 ± 3.05
	LG	5.412 ± 0.376A	y4.282 ± 0.148B	y52.0 ± 1.93	26.5 ± 1.856A	y 13.8 ± 0.459B	Y52.7 ± 2.06
Pantothenate	RL	y0.311 ± 0.029	0.325 ± 0.040	x74.2 ± 5.19	y1.50 ± 0.123a	1.12 ± 0.116b	x75.4 ± 5.36
	LG	x0.391 ± 0.037	0.355 ± 0.031	y59.3 ± 0.98	x1.91 ± 0.160A	1.14 ± 0.090B	y60.1 ± 0.94
B_6	RL	x0.343 ± 0.017A	X0.259 ± 0.019B	X53.3 ± 3.33	x1.65 ± 0.081A	X0.892 ± 0.072B	X54.1 ± 3.50
	LG	y0.295 ± 0.014A	Y0.182 ± 0.013B	Y39.5 ± 2.16	y1.44 ± 0.074A	Y0.579 ± 0.046B	Y40.2 ± 2.15
B_{12} (μg)	RL	3.075 ± 0.225	3.600 ± 0.050	x83.7 ± 2.08	15.4 ± 0.792	13.1 ± 0.038	x85.5 ± 4.15
	LG	3.550 ± 0.150	3.575 ± 0.075	y65.4 ± 1.92	18.0 ± 1.051a	11.9 ± 0.465b	y66.2 ± 1.29

[a]Values are mean ± standard error of the mean. RL = rib-loin; LG = leg.
[b]Means within a column and trait preceded by different letters differ significantly (x, y: $p \leq 0.05$; X, Y: $p \leq 0.01$). Means on the same row under each calculation unit heading (retention values excepted) followed by different letters differ significantly (a, b: $p \leq 0.05$; A, B: $p \leq 0.01$).
[c]Cut×State interaction was not statistically significant for all traits ($p \leq 0.05$).
[d]Cut×State interaction was statistically significant for pantothenate and vitamin B_{12} ($p \leq 0.05$).

daily protein requirements for adults of both sexes on a mixed diet (Bodwell and Anderson, 1986), whilst providing, on average, 5.5% of the recommended daily energy intake for men and 7.2% for women engaged in moderate activity (2900 and 2200 kcal per day, respectively, according to SINU, 1989 and NAS–NRC, 1989). Therefore, like other meats with a low fat content, lamb was found to have a high nutrient density for protein. The average protein contribution of a serving of roasted lamb to total energy value (Pcal%) was found to be about 75%, as opposed to the 25% contributed by lipids, which is in line with what has been suggested for adults by SINU (1989). A 100 g serving of lamb would supply around 36% of the safe daily intake of cholesterol for adults of both sexes, which should not exceed 300 mg per day (SINU, 1989; NAS–NRC, 1989).

The saturated fatty acids contained in a serving of lamb provided approximately 10% of total calories, which corresponds to the maximum amount suggested by SINU (1989) and NAS–NRC (1989). However, this percentage decreases if stearic acid is excluded from the sum of saturated fatty acids, in that C18:0 does not elevate plasma levels of low density lipoprotein cholesterol in humans (Bonanome and Grundy, 1988). The contribution of monounsaturated fatty acids was very interesting, especially that of oleic acid, which has been reported to be hypolipidemic (Mattson and Grundy, 1985). Moreover, a serving of lamb would cover between 4.7 and 9.5% for rib-loin and between 5.9 and 11.9% for leg of the adequate daily intake of linoleic acid, which is estimated to be 3 to 6 g per day for the average adult consuming a diet moderate in fat (Ensminger *et al.*, 1994).

Lamb turned out to be a valuable source of phosphorus, zinc and iron. A serving of roasted rib-loin supplied 27.9, 23.9 and 15.7% of the RDAs for phosphorus, zinc and iron, respectively, against 28.8, 32.4 and 21.4% of the RDAs for these same minerals supplied by 100 g of roasted leg.

As regards the water-soluble vitamins, rib-loin generally turned out to be a richer source than leg. The vitamins provided by the two cuts in a more significant measure were vitamin B_{12}, niacin and riboflavin. In both cuts, the content of vitamin B_{12} far exceeded its RDA. Rib-loin supplied 28.8 and 16.1% of the RDAs for niacin and riboflavin, respectively, against 23.8 and 17.5% of the RDAs supplied for the same vitamins by leg. Rib-loin was a non-negligible source of vitamin B_6 and thiamin (12.9 and 9.6% RDA, respectively), whereas leg was a less interesting source of these vitamins (9.1 and 6.9% RDA, respectively).

Finally, fat-on roasting of rib-loin and leg of lamb did not bring about undue enrichment of lipids and cholesterol in the lean. This was an interesting source of protein, oleic and linoleic acids, phosphorus, zinc and iron, vitamin B_{12}, niacin and riboflavin. The higher heating rate the rib-loin was exposed to, on the one hand seemed to induce oxidation of some polyunsaturated fatty acids, while on the other it allowed higher retention of minerals (iron excepted) and water-soluble vitamins. Fat-on roasting of cuts of moderate weight (1.0–1.2 kg), if carried out in such a way that rather high heating rates are obtained, seems to better preserve the content of nutrients in lamb.

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