Quality of Italian Istrian Milk lamb meat. Influence of carcass weight and feeding system

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ABSTRACT

The Istrian Milk sheep is an endangered breed of the Pramenka group raised in the North-Adriatic Karst region. Carcass and meat characteristics of 46 suckling, 6- to 14- week-old intact male light lambs from two feeding systems were analysed. Thirty-two lambs were raised in a flock fed only with forage (hay supplied in stall during winter or fresh herbage directly grazed during the other seasons). The lambs had free access to the forage supplied to their dams (feeding system: milk and forage; MF). The other fourteen suckling ovine were grown on a farm with a feeding system incorporating a concentrated supply of the forage base. The lambs were stabled and creep fed on a concentrate (20% CP) at a daily rate of 100 g/head, in addition to the suckled milk (feeding system: milk and concentrate; MC). The carcasses were divided into three categories of weight, following the Community scale of light lambs classification: A (≤7 kg, n=17), B (7.1 - 10 kg, n=15) and C (10.1 - 13 kg, n=14). The frequency of 1st quality carcasses increased with carcass weight, reaching 100% in category C. On average, 72% of the carcasses were scored as 1st quality, without significant differences between feeding systems. The lightness of lamb meat from A carcasses was higher than that from the heaviest ones. Cooking losses showed a pattern opposite to that of pH (mean 5.44; SE 0.058), increasing where pH decreased (categories A and B and concentrate-fed lambs). Shear force values were significantly affected by factors linked to the feeding system; in fact, MC lambs provided more tender meat than MF ones (32.6 vs 46.6 N). As carcass weight increased, moisture concentration decreased steadily (from 77.8% to 75.5%), while lipid content increased progressively (from 1.58% to 3.14%). In agreement with these patterns, the contribution of individual fatty acids (FA) to muscle weight generally increased with carcass weight. A similar trend was observed for the relative concentration of saturated FA and monounsaturated FA, while that of polyunsaturated FA (PUFA) showed an opposite evolution. The feeding system modified the relationship between ω3 and ω6 PUFA series: with respect to MC meat, MF meat presented a higher content of linolenic acid and its long chain ω3 derivatives and a lower content of linoleic acid and its major product, arachidonic acid. As a consequence, MF lambs furnished meat with a ω3/ω6 ratio and an index of thrombogenicity more favourable for human health than those from MC lambs.

Key words: Italian Istrian Milk light lamb, Carcass weight, Carcass quality, Meat quality, Feeding system.

RIASSUNTO

QUALITÀ DELLA CARNE DELL'AGNELLO ISTRIANO. INFLUENZA DEL PESO DELLA CARCASSA E DEL SISTEMA DI ALIMENTAZIONE

La pecora Istriana, chiamata localmente anche Carsolina e conosciuta con il nome internazionale di Istrian Milk o Istrian Pramenka, è una pecora in pericolo d'estinzione caratteristica dell'area carsica nord-adriatica. Viene allevata in Italia, con circa 300 capi iscritti nel "Registro anagrafico delle popolazioni ovine e caprine autoctone a limitata diffusione", Slovenia, dove è attivo da anni un libro genealogico che comprende 630 pecore, e Croazia, con una popolazione intorno al migliaio di capi. La ricerca si propone di contribuire alla caratterizzazione della carne di razza Istriana sotto il profilo della composizione, del valore dietetico e nutrizionale, delle proprietà organolettiche, e della loro variazione in relazione alla categoria commerciale della carcassa e al sistema di alimentazione. I rilievi sperimentali sono stati condotti sulle carcasse di 46 agnelli maschi. Trentadue animali sono stati allevati in un gregge alimentato con solo foraggio (affienato e in stalla durante l'inverno, al pascolo nelle restanti stagioni). Gli agnelli, nati ad inizio inverno e sacrificati fra 6 e 14 settimane, sono rimasti nel gregge delle fattrici, consumando latte materno e quantità progressivamente crescenti di foraggio (regime alimentare: latte e foraggio; LF). Gli altri 14 soggetti provenivano da un'azienda nella quale la base foraggera viene integrata con concentrati. Gli agnelli, sacrificati a inizio primavera all'età di 6-10 settimane, avevano giornalmente a disposizione 100 g/capo di mangime al 20% di PG, oltre al latte delle madri (regime alimentare: latte e concentrato; LC). Le carcasse appartenevano tutte al tipo dell'agnello leggero ed erano distribuite in numero di 17, 15 e 14 rispettivamente nelle categorie di peso A (≤7 kg), B (7,1 - 10 kg) e C (10,1 - 13 kg). La frequenza delle carcasse di qualità 1 è aumentata col peso, raggiungendo il 100% nella categoria C. In media il 72% delle carcasse è stato valutato di qualità 1, senza differenze significative dovute al sistema di alimentazione. La luminosità della carne (rilevata su campioni del muscolo longissimus dorsi) delle carcasse leggere era maggiore di quelle pesanti (L: 47,6 vs 42,3 per la categoria A rispetto alla C). Le perdite di cottura hanno evidenziato un trend opposto a quello del pH - che è comunque rimasto sempre compreso entro valori normali; media 5,44; ES 0,058 - risultando più elevate quando il pH era più basso. Le categorie A e B hanno fornito carni con perdite di cottura maggiori di quelle della carcasse più pesanti (25,8 vs 23,1 %), mentre gli agnelli LC presentavano perdite di cottura maggiori di quelle degli agnelli LF. La resistenza al taglio, misurata con apparecchio Instron dotato di dispositivo Warner-Bratzler, è stata significativamente influenzata dai fattori legati al sistema di alimentazione, risultando più tenera negli agnelli LC (32,6 vs 46,6 N). All'aumentare del peso della carcassa, il tenore di acqua della carne è progressivamente diminuito (dal 77,8% al 75,5%), mentre è cresciuto quello lipidico (dal 1,58% al 3,14%). In accordo con questi andamenti, il contributo dei singoli acidi grassi (AG) al peso del muscolo è in linea generale cresciuto col peso della carcassa. La stessa evoluzione è stata riscontrata per la concentrazione relativa degli AG saturi (cresciuti dal 39,2% della categoria A al 42,8% in peso del contenuto totale di AG della categoria C) e monoinsaturi (passati dal 35,0% al 40,2%), mentre quella dei polinsaturi (AGPI) ha presentato un trend opposto (diminuiti dal 25,8% al 17,0%). Il sistema di alimentazione ha modificato la relazione tra AGPI delle serie ω3 e ω6: la carne LF ha presentato un maggior contenuto di acido linolenico e dei suoi derivati ω3 a catena lunga ($C_{20:5}$ ω3; $C_{22:5}$ ω3 e $C_{22:6}$ ω3) e un minor contenuto di acido linoleico e del suo derivato più importante, l'acido arachidonico, rispetto a quella LC. Per conseguenza, gli agnelli che hanno consumato foraggio, oltre al latte materno, hanno fornito una carne con un rapporto ω3/ω6 (0,687 vs 0,254) e un indice di trombogenicità (0,792 vs 1,082) significativamente più favorevoli per la salute umana di quelli che hanno invece ricevuto del concentrato.*

Parole chiave: *Agnello leggero Istriano, Peso della carcassa, Qualità della carcassa, Qualità della carne, Sistema di alimentazione*

Introduction

The Istrian Milk or Istrian Pramenka (Mason, 1996), called *Istriana* or *Carsolina* in Italy, is an endangered sheep of the Pramenka group, raised in the North-Adriatic Karst region. Likely originated from an indigenous population, infused with Apulian and Syrian ovine blood in Roman times, in the 17^{th} Century the sheep was crossed with strains of Balkan origin.

The Istrian Pramenka is a medium sized ovine; it has a well-proportioned, bare head, placed on a long neck, with a nose crest, protruding medium-short ears and open, well-curved horns, frequently present in females. The legs are long and strong with hard hoofs, mostly slate-grey or black coloured. The tail is rather long and thin. The fleece, not covering legs and belly, is shaggy, with open flocks, typically whitish with spots and patches that are black and dark-brown in colour. Black and brown coats can also be found (Leonarduzzi *et al.*, 2000).

Today the breed is spread over the Karst region of three bordering countries: Italy, Slovenia and Croatia. In Slovenia a conservation program has been run for many years and in the national herd-book 630 breeding ewes have been registered to date. In Croatia the Istrian population amounts to about one thousand heads (Sinkovic, 1999). In Italy, Istrian stock declined dramatically after the Second World War, as a consequence of the collapse of sheep production on the Karst upland. From the 1,000 head presence estimated in the early '60s (Federconsorzi, 1961) a drop to about 250 heads (belonging to only two flocks) was recorded in 1983 (CNR, 1983). In 1997, the Animal Production Service of the Friuli Venezia Giulia Region began a preservation movement, including the Istrian sheep population in the list of breeds benefiting from ECC 2078/92 regulation subsidies. About 300 heads, chiefly reared in the Italian Karst region, are currently listed in the "National official register of sheep and goat autochthonous and rare breeds" (Anonymous, 2001).

Transhumant flocks used to graze nine months a year on natural pastures of both coasts in autumn and spring, and in Alpine pastures in summer. Nowadays, permanent and semi-permanent herds represent the widespread type of farming system, which allows better feeding regimes to be imposed, involving supplementation with some forage and concentrates. The typical products are milk for cheesemaking, and lamb meat, provided by young animals slaughtered from 5-6 weeks of age, weighing 12 to 25 kg. The sheep is also currently raised for meat production only; in this case the production system has extensive connotations.

The conservation of genetic variation, of which the main resources for sheep are local breeds and populations, has economic, scientific, cultural, historical and environmental justifications (Ponzoni, 1997). The preservation of Istrian Milk sheep is characterised by great ecological value (Kompan *et al.*, 1995) and plays a key role in the protection and restoration of dry grasslands, the meadows fenced by dry stone boundary walls and small wood patches, which represented the classic landscape of North-Adriatic uplands for thousands of years. The North-Adriatic Karst open land, created by man's deforestation as far back as Neolithic times and maintained by means of millenary low-intensity agricultural practices and extensive pastoral activities, is endangered by shrub encroachment and reforestation processes, associated with the abandonment of agriculture and a decline in animal husbandry, essentially based on cow and goat milk production. Attractive countryside maintenance, the restoration of habitats and conservation of the genetic resources of endangered animals are performed by multipurpose farms. The livestock enterprises of these farms integrate traditional animal husbandry activities with sustainable landscape and the management of natural resources and become increasingly involved in artisan and farming ventures, promotional activities and marketing initiatives. Typification and differentiation are considered very effective in adding value to livestock products and improving their competitiveness: Istrian Milk lamb has been included in the reference list of Italian traditional agricultural food products (MIPAF, 2001).

The aim of the research, part of a regional project, "Study, characterisation and technological valorisation of Friuli Venezia Giulia typical agri-industrial productions", is to provide objective information on Istrian lamb meat quality and a scientific insight into its variation. Thus the variability of chemical composition, nutritional and dietetic value and organoleptic properties was assessed in relation to feeding system and carcass weight.

The comparison between rearing practices differing in feeding intensities has been judged of interest for an endangered breed, whose conservation and valorisation are closely linked to the preservation and development of ecologically sustainable livestock production systems. Moreover, a feeding strategy based on both the sole or principal utilisation of grasslands is fully consistent with non-conventional farming systems, such as organic ones. The latter are acquiring increasing productive relevance and becoming progressively interesting for Istrian Milk breeders as they seek to attain economic sustainability for their activity.

Grass feeding has been reported to affect several meat quality characteristics, in particular colour and flavour (Geay *et al.*, 2001; Priolo *et al.*, 2001).

Carcass weight is an essential criterion for setting the commercial category of lambs, in particular of light weight lambs (EEC, 1992 and 1993), and is a factor that influences both sheep meat quality (Sañudo *et al.*, 1998) and consumer preferences (Mills *et al.*, 1998).

Material and methods

Animals and experimental design

Data were collected on carcasses from 46 intact male suckling lambs of the Istrian Pramenka breed, aged 6 to 14 weeks and reared on two farms located in the North-Adriatic Karst region. Thirty-two lambs were raised in a flock fed only with forage: hay supplied in the stall during winter or fresh herbage directly grazed during the other seasons. In the farming system the lambs, born in early winter, were suckled until slaughter. During this period, the lambs were always kept with their dams and had free access to the forage supplied to the ewes (feeding system: milk and forage, MF). The lambs were slaughtered in two batches: in the first, thirteen, 6 to 10-week-old animals, sheltered until slaughter, were involved; in the second, the other nineteen lambs were slaughtered after a 4 week-period of grazing, when they were between 10 and 14 weeks of age.

The other fourteen suckling lambs were raised on a farm whose feeding system incorporates a concentrated supply of the forage base. The lambs, slaughtered in early spring at 6 to 10 weeks of age, were stabled and creep fed on a concentrate with a crude protein (CP) content of 20% as feed, supplied at a daily rate of 100 g/head, in addition to the milk suckled from their dams (feeding system: milk and concentrate, MC), which were nourished with hay *ad libitum* and 18% CP-concentrate at a rate of 300 g/head/day.

All the carcasses obtained by using the slaughter procedures of ASPA (1991), as classified following their warm weight (EEC, 1992 and 1993), belonged to the light ovine carcass type and fell into the weight categories, A (≤7 kg), B (7.1 - 10 kg) and C (10.1 - 13 kg), in numbers of 17, 15 and 14, respectively. The distribution of carcasses with respect to the feeding system and weight groups is presented in table 1.

Carcass evaluations

All animals were slaughtered in a commercial EC licensed abattoir, according to standard procedures. After chilling at 4°C for 24 hours, the carcasses were weighed, measured (Fisher and de Boer, 1994) and scored for colour and fatness (EEC, 1992 and 1993).

Meat instrumental measurements

Immediately after the carcass measurements, the loin (6th thoracic vertebrae to 6th lumbar vertebrae) was removed from the left side and cut in the lumbar (muscle *longissimus lumborum*) and thoracic (m. *l. thoracis*) parts to assess meat quality. Then the cutting section of m. *l. thoracis* was examined after a 1-hour blooming period to measure the colour according to L*, a*, b* colour system (CIE, 1986), using a Minolta CR-200 Chroma

Table 1. Experimental design describing the number and weight of carcasses.

Carcass category		A (≤ 7 kg)				B (7.1 - 10 kg)				C (10.1 - 13 kg)			
Feeding		MF		MC		MF		MC		MF		MC	
system		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Lambs	no.	13		4		8		7		11		3	
Live weight	kg	12.8	1.11	14.4	1.03	19.7	1.71	18.2	1.71	23.6	1.41	22.6	2.31
Hot carcass	"	6.08	0.527	6.79	0.433	9.27	0.616	8.56	0.735	10.95	0.545	10.81	0.744
Cold carcass	"	5.93	0.512	6.58	0.430	9.02	0.606	8.29	0.693	10.66	0.528	10.45	0.722

Meter (Minolta Camera, Osaka, Japan), and the pH, utilizing a glass piercing electrode connected to a pH-meter.

Cooking losses and Warner-Bratzler shear force (WBSF) were assessed on the m. *l. lumborum*, after a 7-day ageing period at 4°C. The former was evaluated after immersion of a meat sample (approximately 2x2 cm^2 cross-section x 10 cm long, for an average weight of 40 g) in a 75°C-waterbath for 20 min. This cooked sample was then used to determine WBSF using a Warner-Bratzler cell mounted on an Instron 4301 (Instron Ltd., High Wycombe, United Kingdom) universal testing machine (the measurement was recorded as the peak yield force in N, required to shear, perpendicularly to the direction of the fibres, almost three 1 cm^2-cross-section replicates from each carcass).

Meat chemical analysis

Meat proximate analysis and total lipid (intramuscular fat) fatty acid composition were assessed on two samples of m. *l. thoracis* (between the 6th and the 9th and between the 10^{th} and the 13^{th} ribs) obtained from the complete cross-section of the muscle freed of epimysium and adhering adipose tissue. The samples were vacuum packed and stored at -18°C until chemical analyses were performed.

The first sample was weighed (w1) freeze-dried, air equilibrated, re-weighed (w2) and milled. One weighed sub-sample (w3) was dried to a constant weight (w4) at 105 °C, in order to calculate the total dry matter percentage as: [100 *(w2/w1)*(w4/w3)]. Then, other sub-samples were analysed to determine the amount of ash, by incineration at 550 °C for 16 hours; crude fat, by extraction with petroleum ether in a Soxtec apparatus; and crude protein (Nx 6.25) from Nitrogen analysis by the Kjeldahl method (AOAC, 1990).

On the second sub-sample, total lipids were extracted with a mixture of chloroform and methanol (2:1, v/v; Folch *et al.*, 1957). After transmethylation (ISO, 2000), the fatty acid methyl esters were determined using a flame ionisation detector in a gas chromatography system (Carlo Erba Strumentazioni, Rodano, Italy) equipped with an Omega Wax 320 capillary column (30m x 0.32mm x 0.25 μm film thickness). Nonadecanoic acid ($C_{19:0}$) methyl ester was added as an internal standard (IS). Fatty acids were identified from standards and quantified using the IS. Minor and unresolved fatty acids were not reported.

Statistical analysis

Data were subjected to analysis of variance using a two-way factorial design, in order to examine the effects of feeding system and carcass weight category. Whenever the interaction between factors was significant ($P \leq 0.05$), the cell means were tabulated and discussed, otherwise only the main effect means were examined. Mean comparisons were performed by the Least Square Difference test using the SPSS 7.5.21 package for Windows (SPSS Inc., Chicago, USA).

The comparison between the proportion of carcasses of various quality within each weight category and feeding system was carried out by a chi-square test of independence.

Results and discussion

In order to investigate two real production situations, the lambs belonging to different feeding systems were raised on diverse farms, undergoing the influence of different rearing conditions. In particular, in the feeding system on grass, the lambs maintained at pasture were subjected to higher physical activity and to variable climatic conditions. Thus, together with feeding, all these elements have to be borne in mind when the feeding system effect is examined.

Carcass quality

The commercial characteristics of Istrian light lamb carcass are reported in table 2. The dressing percentage (45.9%, on average) was not significantly influenced by weight category and feeding system. However, the carcasses from MF lambs lost less weight during chilling than those from MC lambs.

The frequency of 1^{st} quality carcasses increased with raising carcass weight, reaching

100% in C category (table 3). Fifty-nine percent of carcasses weighing less than 7 kg were declassed mainly because of the colour, which was not pale enough for the category. In fact, according to the EU standards, the pink colour leads to the exclusion of carcasses from the 1st quality class only if they belong to the lightest category. Twenty percent of carcasses of intermediate weight were declassed owing to their scarce fatness. On average, almost 72% of the carcasses were scored as 1st quality, without significant differences between feeding systems.

Carcass linear measurements (table 4) were positively correlated with carcass weight. However, the percentage increase of dimensions was less than that of weight, thus the compactness index augmented, passing from category A to B and C. The ratio between length of leg and length of carcass, which is an index of the relative importance of bone to muscle mass, was high in the lightest carcasses (38.3% on average). The feeding regime influenced the various linear measurements in a different way and interacted with carcass weight category. Its effect was particularly unfavourable for the width of buttock of the lightest lambs from MF flock, which showed a 129 mm value, equal to 27.7% of carcass length, as a consequence of a slow rate of development.

Meat instrumental quality

Results of instrumentally measured meat quality are presented in table 5. The pH varied within the normal pH range accepted for commercial meats (mean 5.44; SE 0.058) and was slightly higher in the heaviest carcasses and in the carcasses from MF lambs. These differences may be due to a variation in glycogen contents in muscle. A similar trend throughout light lamb carcass weight groups has been reported by Sañudo *et al.* (1996), while Immonen *et al.* (2000) showed that high-energy diets protect against potential glycogen-depleting stressors.

In agreement with the results obtained by other authors (Sañudo *et al.*,1996; Vergara *et al.*, 1999), the lightness (L*) of lamb meat from A carcasses was higher than that from the heaviest ones (47.6 vs 42.3 for category A vs category C respectively). No significant differences were observed between groups B and C. The b* values showed a reverse pattern, but the differences between carcass weight groups did not reach the threshold of significance. The a* values did not vary throughout all groups. The effect of the feeding system on meat colour parameters became noticeable for both a* and b*, which were higher in MF lambs, whose meat has a stronger red and yellow tinge than that of MC animals.

Colour differences between carcass categories may be explained by the different slaughter ages of the lambs and the quantity of milk suckled, since the lambs from the lightest carcass group probably ate proportionally more milk and less forage or concentrate than those from the medium and high weight groups (Sañudo *et al.*, 1996). A direct effect of feeding is difficult to verify, because meat colour may have also been influenced by other factors such as intramuscular fat content, meat ultimate pH and physical activity (Priolo *et al.*, 2001).

Table 2. Commercial characteristics of the carcass of Istrian light lambs.

		Carcass category			Feeding system		SE
		A (≤ 7 kg)	B (7.1 - 10 kg)	C (10.1 - 13 kg)	MF	MC	
Warm dressing percentage	%	47.4	47.1	47.1	47.0	47.4	2.23
Cold dressing percentage	"	46.1	45.8	45.8	45.8	45.9	2.22
Chilling losses	"	2.75	2.92	2.92	2.56[a]	3.16[b]	0.315

[a,b] *differences between means : P ≤ 0.05.*

Table 3. Distribution of light Istrian lamb carcasses in the various classes of fatness and meat colour (absolute values) and percentage frequency of 1st quality carcasses as influenced by carcass category and feeding system ( ).

Carcass		Feeding system														
		MF					MC					ALL CASES				
		Colour (2)			Total	1ST QUALITY	Colour (2)			Total	1ST QUALITY	Colour (2)			Total	1ST QUALITY
Category	Fat class (1)	LP	PP	OC			LP	PP	OC			LP	PP	OC		
A (≤ 7 kg)	1	1			1		1			1		2	0	0	2	
	2	6	5	1	12	6	1	2		3	1	7	7	1	15	7
	3				0					0		0	0	0	0	0
	Total	7	5	1	13	46.2%	2	2	0	4	25.0%	9	7	1	17	41.2%[a]
B (7.1 - 10 kg)	1		1		1		2			2		2	1	0	3	
	2		7		7	7	2	2		4	4	2	9	0	11	11
	3				0			1		1	1	0	1	0	1	1
	Total	0	8	0	8	87.5%	4	3	0	7	71.4%	4	11	0	15	80.0%[b]
C (10.1 - 13 kg)	1				0					0		0	0	0	0	
	2		11		11	11		2		2	2	0	13	0	13	13
	3						1			1	1	1	0	0	1	1
	Total	0	11	0	11	100%	1	2	0	3	100%	1	13	0	14	100%[b]
ALL CASES	1	1	1	0	2		3	0	0	3		4	1	0	5	
	2	6	23	1	30	24	3	6	0	9	7	9	29	1	39	31
	3	0	0	0	0	0	1	1	0	2	2	1	1	0	2	2
	Total	7	24	1	32	75.0%	7	7	0	14	64.3%	14	31	1	46	71.7%

(1) *Fat class:* 1 - *low;* 2 - *slight;* 3 - *average.*
(2) *Meat colour:* LP- *light pink;* PP - *pink;* OC- *other colour.*
a,b *differences between means: P ≤ 0.05.*

Meat cooking losses showed a pattern opposite to that of the pH, increasing where pH decreased. Thus, categories A and B supplied meat with higher cooking losses than that of the heaviest carcasses (25.8 vs 23.1 %), whereas MC lambs provided meat with higher cooking losses than that supplied by MF lambs.

Meat shear force was significantly affected by the feeding system, in particular meat from MC lambs was more tender than that from MF lambs (32.6 vs 46.6 N). Other authors studied the variability of meat shear force and meat tenderness related to the intensity of ruminant production system. Differences between feeding systems, when found, were not considered direct effects of dietary constituents for their intrinsic properties, but associated to differences in animal growth rate and carcass composition. In fact, a carcass with a thin fat cover could be more susceptible to cold shortening (Bowling *et al.*, 1978); moreover, a reduced rate of growth could lower the extent of *post-mortem* tenderisation (Vestergaard *et al.*, 2000). Furthermore, when the experiments investigated real production situations, where animals are free to move, or restricted in feedlots, or tie-stalled, the effect of feeding may be confounded by a different level of physical activity or housing condition (Schroeder

Table 4. Linear measurements of the carcass from Istrian light lambs.

Carcass category		A (≤ 7 kg)				B (7.1 - 10 kg)				C (10.1 - 13 kg)			
Feeding		MF		MC		MF		MC		MF		MC	
system		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Leg length (Ll)	mm	181[a]	5.0	189[b]	6.3	200[cd]	9.2	196[bc]	4.3	210[e]	5.9	206[de]	11.5
Circumference of buttock	"	425[a]	15.2	486[b]	18.0	508[c]	15.4	509[c]	16.2	544[d]	25.1	541[d]	5.3
Width of buttock (wB)	"	129[a]	4.6	176[b]	6.2	180[b]	10.9	185[bc]	6.8	192[c]	11.8	196[c]	3.2
Deep Depth of chest	"	194[a]	7.6	194[a]	6.7	224[c]	9.3	206[b]	3.8	238[d]	7.2	226[c]	11.0
Carcass length (Cl)	cm	46.6[a]	1.74	50.2[b]	2.17	54.2[c]	1.80	52.9[c]	1.06	57.7[d]	1.29	56.8[d]	1.26
Carcass compactness index[(1)]		12.7[a]	0.86	13.1[a]	0.40	16.6[b]	0.70	15.7[b]	1.20	18.5[c]	0.57	18.4[c]	1.09
Ll / Cl	%	38.9[b]	1.27	37.6[a]	1.01	37.0[a]	0.79	37.1[a]	0.61	36.4[a]	0.81	36.3[a]	1.70
wB / Cl	%	27.7[a]	1.04	35.0[c]	0.31	33.1[b]	1.49	35.0[c]	1.51	33.3[b]	1.73	34.4[bc]	0.41

[(1)] *Carcass compactness index = Cold carcass weight (g) / carcass length (mm).*
[a,b,c] *differences between means: P ≤ 0.05.*

et al., 1980). Vestergaard *et al.* (2000) suggested a major influence of physical activity to explain the higher WBSF and the lower tenderness observed in white (*semitendinosus*) and mixed (*l. dorsi*) muscles of bulls raised on pasture compared with bulls tie-stalled and fed a concentrate-based diet.

The results observed in Istrian lamb meat may also be interpreted by considering that texture and ultimate pH are linked by a curvilinear relationship, by which the toughest meat tends to occur in the middle range of pH values, between about 5.8 and 6.2; below pH 5.8 meat becomes more tender (Warriss, 2000).

Table 5. pH and physical properties of *longissimus dorsi* muscle from Istrian light lambs.

		Carcass category			Feeding system		
		A (≤ 7 kg)	B(7.1 - 10 kg)	C(10.1 - 13 kg)	MF	MC	SE
pH at 24h		5.42[a]	5.44[a]	5.48[b]	5.52[b]	5.37[a]	0.058
Colour: L*		47.6[b]	43.8[a]	42.3[a]	44.9	44.2	2.12
a*		18.3	17.7	18.2	18.9[b]	17.3[a]	0.94
b*		0.37	0.74	0.75	1.40[b]	-0.15[a]	0.699
Cooking losses	%	25.4[b]	26.1[b]	23.1[a]	23.4[a]	26.4[b]	2.76
WBSF [(1)]	N	40.3	42.3	36.3	46.6[b]	32.6[a]	7.89

[(1)] *WBSF = Warner-Bratzler shear force.*
[a,b,c] *differences between means: P ≤ 0.05.*

Table 6. Proximate analysis of *longissimus dorsi* muscle from Istrian light lambs (g/100 g meat).

	Carcass category			Feeding system		
	A (≤ 7 kg)	B (7.1 - 10 kg)	C (10.1 - 13 kg)	MF	MC	SE
Dry matter	22.2[a]	23.3[b]	24.5[c]	23.3	23.4	0.90
Ash	1.12	1.11	1.08	1.09	1.11	0.040
Ether extract	1.58[a]	2.24[b]	3.14[c]	2.19	2.45	0.570
Crude protein	19.6	19.7	19.6	19.5	19.8	0.78

a,b,c differences between means: P ≤ 0.05.

Meat chemical quality

Meat proximate composition is shown in table 6; as carcass weight increased, moisture concentrations decreased steadily from 77.8% to 75.5% (P ≤0.05), while lipid content increased progressively from 1.58% to 3.14% (P ≤0.05), in agreement with the evolution of carcass fatness and regular body development (Wood, 1990). Muscle protein concentration, instead, was not influenced by carcass weight.

The nutrient content of lamb meat was not affected by feeding systems (table 6). None of the chemical constitutes reached the threshold of significance, nor did the lipids, which were the most variable ones by far (difference between feeding systems about 11% of the average content).

Fatty acids (FA) content (mg per 100 g muscle) of intramuscular fat of m. *l. thoracis* is given in tables 7a and 7b, which respectively describe the content of FA which were or were not influenced by the interaction between the experimental factors, i.e. "carcass weight" by "feeding system". Table 8 summarises the composition (% by weight of total FA) of main FA series and the relationships between FA, useful in predicting the potential risk for ischaemic heart desease (IHD) associated with the consumption of the various kinds of lamb meat. In an attempt to take into account the two processes which contribute to the development of IHD, i.e. atherosclerosis and thrombosis, the index of atherogenicity (AI) and thrombogenicity (TI) proposed by Ulbricht and Southgate (1991) were calculated and tabulated.

Table 7a. Fatty acid content of *longissimus thoracis* muscle from Istrian light lambs: significative interaction "carcass category" x "feeding system" (P ≤ 0.05; mg /100 g meat).

Carcass category	A (≤ 7 kg)				B (7.1 - 10 kg)				C (10.1 - 13 kg)			
Feeding system	MF		MC		MF		MC		MF		MC	
Fatty acids	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
$C_{10:0}$	1.0[a]	1.69	1.0[a]	0.91	0.0[a]	0.00	3.1[b]	1.75	0.0[a]	0.00	5.6[b]	0.70
$C_{12:0}$	6.5[b]	6.39	4.6[ab]	0.97	0.0[a]	"	7.9[bc]	4.77	0.0[a]	"	12.1[c]	1.73
$C_{18:4}$ ω3	0.0[a]	0.00	0.0[a]	0.00	18.1[b]	5.86	0.0[a]	0.00	28.5[c]	10.02	0.0[a]	0.00

a,b,c differences between means : P ≤ 0.05.

Table 7b. Fatty acid content of *longissimus thoracis* muscle from Istrian light lambs: non significative interaction "carcass category" x "feeding system" (P > 0.05; mg /100 g meat).

Fatty acid	Carcass category			Feeding system		SE
	A (≤ 7 kg)	B (7.1 - 10 kg)	C (10.1 - 13 kg)	MF	MC	
$C_{14:0}$	46.6[a]	67.0[a]	106.3[b]	65.0	81.7	36.11
$C_{16:0}$	232.5[a]	321.8[a]	453.3[b]	322.3	349.4	124.43
$C_{16:1}$ ω7	14.0[a]	22.6[a]	34.1[b]	23.8	23.3	11.46
$C_{18:0}$	148.8[a]	197.9[b]	265.2[c]	188.2	219.7	52.64
$C_{18:1}$ ω9	350.3[a]	475.1[a]	681.2[b]	471.9	532.6	179.30
$C_{18:1}$ ω7	28.5[a]	51.3[b]	68.2[b]	53.7	44.9	21.00
$C_{18:2}$ ω6	116.2[a]	140.4[b]	144.6[b]	106.1[a]	161.3[b]	25.75
$C_{18:3}$ ω3	21.3[a]	25.2[a]	31.6[b]	32.0[b]	20.0[a]	7.79
$C_{20:3}$ ω6	2.8[a]	4.0[b]	3.6[b]	3.5	3.5	0.89
$C_{20:4}$ ω6	56.7	61.9	52.1	52.6[a]	61.3[b]	12.68
$C_{20:5}$ ω3	19.2	18.3	19.2	27.5[b]	10.4[a]	3.99
$C_{22:5}$ ω3	19.4	21.5	21.6	24.2[b]	17.4[a]	2.91
$C_{22:6}$ ω3	9.1	10.3	10.9	12.5[b]	7.7[a]	4.13
SFA	434.4[a]	592.3[a]	833.7[b]	578.0	662.2	209.87
MUFA	392.8[a]	549.0[a]	783.6[b]	549.4	600.8	204.76
PUFA	261.9[a]	303.3[b]	317.5[b]	282.5	305.9	47.55
ω6 PUFA	175.8	207.4	201.3	163.6[a]	226.1[b]	35.81
ω3 PUFA	69.0[a]	84.3[b]	97.5[c]	111.7[b]	55.6[a]	15.00

SFA = *saturated fatty acids;* MUFA = *monounsaturated fatty acids;* PUFA = *polyunsaturated fatty acids.*
[a,b,c] *differences between means: P ≤ 0.05.*

The factorial interaction was significant for FA content found at low levels (table 7a). These FA were merely detected ($C_{18:4}$ ω3) or were completely lacking ($C_{12:0}$) in B and C carcasses from the MF system. The lambs that provided these carcasses were finished at pasture and got an important nutritional contribution from grazed herbage.

In agreement with the pattern of lipid content (table 6), the contribution of individual FA to muscle weight (table 7b) generally increased with carcass weight. In relative terms (table 8), a similar trend was observed for the concentration of saturated FA (SFA) and monounsaturated FA (MUFA), while polyunsaturated FA (PUFA) showed an opposite evolution. This is because at a lower level of lipid content the contribution made by phospholipids is proportionally greater and these are more polyunsaturated than triaglycerols, which themselves increase in proportion as lipid content increases (Enser *et al.*, 1998). The decrease was particularly marked for ω6 PUFA (P ≤ 0.05), thus the ratio ω3/ω6 was enhanced with increasing carcass weight. On the whole, as carcass got heavier both AI and TI got higher, increasing the potential risk for IHD.

The feeding system influenced the meat content and concentration of PUFA, modifying the relationship between ω3 and ω6 series (tables 7a, 7b and 8). In particular, the meat from the MF system presented a higher content of linolenic acid and its long chain ω3 derivatives ($C_{20:5}$ ω3; $C_{22:5}$ ω3 and $C_{22:6}$ ω3) and a lower content of linoleic acid and its major product, arachidonic acid, than that provided by the MC system. As a consequence, the lambs fed on forage furnished meat with a ω3/ω6 ratio and a TI more favourable for human health than those from lambs fed on concentrate.

Table 8. Sums and ratios of fatty acid related to healthy human nutrition in *longissimus thoracis* muscle from Istrian light lambs.

		Carcass category			Feeding system		SE
		A (≤ 7 kg)	B (7.1 - 10 kg)	C (10.1 - 13 kg)	MF	MC	
SFA	%TFA	39.18[a]	40.54[ab]	42.75[b]	40.06	41.59	3.348
MUFA	"	35.00[a]	37.53[ab]	40.23[b]	37.97	37.21	3.999
PUFA	"	25.82[b]	21.93[ab]	17.02[a]	21.97	21.20	6.341
ω6 PUFA	"	17.51[b]	14.97[b]	10.68[a]	12.83[a]	15.94[b]	4.471
ω3 PUFA	"	6.83	6.24	5.49	8.58[b]	3.79[a]	2.322
SFA/PUFA		1.620[a]	1.956[a]	2.627[b]	2.002	2.133	0.5952
SFA/MUFA		0.648[a]	0.687[ab]	0.749[b]	0.675	0.715	0.0937
ω3 PUFA/ω6 PUFA		0.418[a]	0.458[a]	0.536[b]	0.687[b]	0.254[a]	0.0819
AI[(1)]		0.633[a]	0.683[ab]	0.800[b]	0.671	0.740	0.1747
TI[(2)]		0.858[a]	0.917[ab]	1.035[b]	0.792[a]	1.082[b]	0.1600

SFA = *saturated fatty acids;* UFA = *unsaturated fatty acids;* MUFA = *monounsaturated fatty acids;* PUFA = *polyunsaturated fatty acids;*

%TFA = % by weight of total fatty acids.

[(1)] *AI = atherogenicity index = (lauric + 4 x myristic + palmitic) / (ω6 PUFA +ω3 PUFA + MUFA); Ulbricht and Southgate (1991).*

[(2)] *TI = thrombogenicity index =*
= (myristic + palmitic + stearic) / [0.5 x ω6 PUFA + 3 x ω3 PUFA + 0.5 x MUFA + (ω3 PUFA /ω6 PUFA)]; Ulbricht and Southgate (1991).

[a,b,c] *differences between means: P ≤ 0.05.*

The observed differences between levels of PUFA series are in agreement with literature data concerning the effect on meat FA composition of feeding grass or grain diets to ruminants (Enser *et al.*, 1998; Nuernberg *et al.*, 1998; Rowe *et al.*, 1999; Wood *et al.*, 1999; Fisher *et al.*, 2000; Sañudo *et al.*, 2000). In many of these studies, based on weaned ruminants, the ω3 PUFA incorporation paralleled that of $C_{18:0}$ to the detriment of $C_{18:1}$. The consumption of suckled milk possibly decreased the between feeding system variability of FA other than for PUFA series, maintaining low the activity of rumen in lambs from both the examined production systems. In that condition, a high proportion of $C_{18:3}$ ω3, a FA abundant in grass-based diets, and $C_{18:2}$ ω6, a FA important in cereal-based concentrates, probably escaped ruminal hydrogenation and thereby was absorbed and deposited in muscles as both neutral lipids, which mainly incorporate PUFA as $C_{18:2}$ ω6 and $C_{18:3}$ ω3, and phospholipids, which, being less selective, incorporate not only $C_{18:2}$ ω6 and $C_{18:3}$ ω3, but also their derivatives ($C_{20:3}$; $C_{20:4}$; $C_{22:5}$) (Larick *et al.*, 1987).

Conclusions

The combination of feeding system and carcass weight enables the production of various lamb types from Istrian sheep resulting in differing carcass quality, meat appearance, texture, dietetic properties, chemical composition and thus flavour. The knowledge of these characteristics is useful in order to qualify and improve the output of ovine production chains that meet different technical, economic and environmental needs. Production and meat quality data are also important in order to develop marketing strategies, which in turn enable individual farmers, farmer groups, small scale processors and local authorities to promote their products on the basis of objective measurements. Extensive production systems, based on forage diets from semi-natural grasslands and which satisfy ecological and countryside conservative goals, produce a type of Istrian lamb meat that combines the emotional value of "nature" with distinctive intrinsic qualities, due mainly to a favourable ω3/ω6 ratio, which has positive effect on human health. On the other hand, more intensive production systems, oriented towards milk production for cheesemaking, make it possible to obtain - within the space of 8 weeks - Istrian type lambs having 1st quality carcasses with tender meat and a particular fatty acid composition.

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