Effect of type of suckling and polyunsaturated fatty acid use on lamb production. 2. Chemical and fatty acid composition of raw and cooked meat

Arcangelo Vicenti[1], Maria Antonietta Colonna[1], Marco Ragni[1], Francesco Toteda[2]

[1]Dipartimento di Produzione Animale. Università di Bari, Italy
[2]Dipartimento di Progettazione e Gestione dei Sistemi Agro-Zootecnici e Forestali. Università di Bari, Italy

Corresponding author: Prof. Arcangelo Vicenti. Dipartimento di Produzione Animale. Facoltà di Agraria, Università di Bari. Via G. Amendola 165/A, 70126 Bari, Italy - Tel. +39 080 5443106 - Fax: +39 080 5442822 – E-mail: vicenti@agr.uniba.it

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ABSTRACT

This study was carried out in order to examine the chemical and fatty acid composition of raw and cooked meat obtained from lambs raised under mothers or reared by artificial suckling with acidified milk replacers with or without polyunsaturated fatty acid (PUFA) supplementation. Meat samples were taken from twenty Gentile di Puglia male lambs subjected to the following feeding treatments: the control group received only maternal milk (MM, n.=6) while two groups were reared by artificial suckling with an acidified milk replacer (MR, n.=7) or with an acidified milk replacer supplemented with 10 ml/l of a PUFA enriched oil (MR+PUFA, n.=7). Lambs were slaughtered at 45 days of age. After 24 hours of refrigeration at 4 °C, the lumbar region was dissected from each right half-carcass and split into pieces, one of which was used raw while the other was cooked in a ventilated electric oven at 180 °C until an internal temperature of 75 °C was reached. Chemical and fatty acid analysis were performed on raw and cooked meat, while only raw meat was assessed for cholesterol. Cooking losses were also evaluated. Meat obtained from MR+PUFA fed lambs contained more fat ($P<0.01$) and less protein ($P<0.05$) than MM lambs. Nursing under mothers increased the total amount of saturated fatty acids (SFA), compared with both the MR group ($P<0.05$) and to the MR+PUFA one ($P<0.01$). In MM meat samples, fewer PUFAs ($P<0.01$) and omega-6 fatty acids ($P<0.01$) were found in comparison with both MR diets. The highest PUFA/SFA ratio of meat was recorded for the MR+PUFA group (0.27), with statistical differences respect to the MR group (0.21; $P<0.05$) and to the MM one (0.14; $P<0.01$). Lambs raised with maternal milk produced meat containing more cholesterol than the MR+PUFA group (85.89 vs 76.26 mg/100 g; $P<0.05$). The atherogenicity index of meat was higher following natural rearing in comparison with the MR+PUFA treatment (1.34 vs 1.05; $P<0.05$), while the PCL/PCE ratio was significantly higher in MR+PUFA samples than in both MM and MR ones (0.93 vs 0.77 and 0.76, respectively; $P<0.05$). Cooking cancelled the differences between treatments with regard to the all the dietetic parameters evaluated. In conclusion, artificial suckling with acidified milk replacers improves some meat quality features. Supplementation of milk replacers with PUFAs, although in a limited way, may improve the dietetic properties of lamb meat.

Key words: Suckling lambs, PUFA, Meat quality, Fatty acids, Cooking.

RIASSUNTO

EFFETTO DEL TIPO DI ALLATTAMENTO E DELL'IMPIEGO DI ACIDI GRASSI POLINSATURI SULLA PRODUZIONE DELL'AGNELLO. 2. VALUTAZIONE DELLA COMPOSIZIONE CHIMICA E DEL PROFILO ACIDICO DELLE CARNI CRUDE E COTTE.

Con la presente ricerca si è inteso valutare la composizione chimica e acidica di campioni di carne cruda e cotta ottenuti

da agnelli allattati naturalmente o mediante allattamento artificiale con latte acido ricostituito supplementato o no con acidi grassi polinsaturi (PUFA). I campioni di carne sono stati ottenuti da 20 agnelli di razza Gentile di Puglia sottoposti ai seguenti trattamenti alimentari: il gruppo controllo ha ricevuto solo latte materno (MM, n.=6), mentre due gruppi sono stati allattati artificialmente, rispettivamente con latte acido ricostituito (MR, n.=7) o con latte acido ricostituito supplementato con 10 ml/l di una miscela di olio di lino e di pesce ricca in PUFA (MR+PUFA, n.=7). Gli agnelli sono stati macellati all'età di 45 giorni. Due campioni di lombata, isolata dalla mezzena destra dopo 24 h di refrigerazione a 4 °C, sono stati utilizzati per la determinazione della composizione chimica e acidica sul crudo e sul cotto. La cottura, di cui è stata valutata anche la perdita, ha avuto luogo in forno elettrico ventilato preriscaldato a 180 °C fino al raggiungimento della temperatura interna del campione di 75 °C, registrata mediante una sonda munita di termocoppia. Sui campioni di carne cruda, inoltre, è stato valutato il contenuto di colesterolo. I campioni di carne ottenuti dagli agnelli alimentati con MR+PUFA hanno mostrato un contenuto significativamente maggiore (P<0,01) di grasso e minore in proteina (P<0,05) rispetto agli agnelli allevati sotto le madri. L'allattamento naturale ha determinato una maggiore concentrazione di acidi grassi saturi nelle carni, sia in confronto con il gruppo MR (P<0,05) che con il gruppo MR+PUFA (P<0,01). Nei campioni di carne cruda del gruppo in allattamento naturale è stato rilevato un minor (P<0,01) contenuto di PUFA e di acidi grassi della serie ω-6 (P<0,01) rispetto ad entrambi i gruppi sottoposti ad allattamento artificiale. L'allattamento naturale ha determinato un contenuto di colesterolo significativamente superiore nelle carni rispetto al gruppo che ha ricevuto il latte acido ricostituito arricchito con PUFA (85,89 vs 76,26 mg/100 g; P<0,05). Relativamente agli indici dietetici della carne, nei campioni crudi del gruppo MR+PUFA è stato registrato un indice di aterogenicità significativamente più basso rispetto al gruppo naturale (1,05 vs 1,34; P<0.05) e, inoltre, un rapporto PCL/PCE marcatamente più alto in confronto con i campioni MM e MR (0,93 vs 0,77 e 0,76, rispettivamente; P<0,05). Il processo di cottura ha annullato le differenze tra i gruppi per quanto attiene tutti i parametri dietetici considerati. I risultati ottenuti in questa ricerca consentono di affermare che l'allattamento artificiale degli agnelli influenza positivamente alcune caratteristiche qualitative della carne. Inoltre, l'aggiunta di una fonte lipidica ricca in acidi grassi polinsaturi migliora le proprietà dietetiche della carne di agnello.

Parole chiave: Agnelli, Allattamento, PUFA, Acidi grassi, Cottura.

Introduction

The current human health guidelines recommend reducing the dietary intake of fat (FAO/WHO, 1990; Simopoulos *et al.*, 1999) and increasing the consumption of food containing long chain unsaturated and polyunsaturated fatty acids (PUFA) which seem to exert many beneficial effects, such as on the vascular and immune system as well as on the prevention of heart diseases and of some types of cancer (Department of Health, 1994; Noble, 1999; Galli, 1999; Nordoy *et al.*, 2001).

Recently, many attempts have been made with the aim to increase the content of the above-mentioned fatty acids in animal products, among which meat (Noble, 1999; Givens *et al.*, 2000).

In developed countries meat plays an important role in the human diet; however, in recent years, as a consequence of the diffusion of alarms concerning meat consumption, consumers have become increasingly careful and selectively interested in high quality, safe, nutritious and healthy meat products (D'Amicis and Turrini, 2002).

Mediterranean countries are known to be good consumers of lamb and kid meat, particularly appreciated if obtained from suckling animals slaughtered when less than fifty days old (Vergara and Gallego, 1999). These young animals are traditionally raised with their dams and fed only with maternal milk, but breeders are increasingly applying early weaning programmes followed by artificial suckling with milk replacers, which can increase farm productivity and income since the dams' milk may be entirely employed for the cheese industry (Congiu, 1982; Havrevoll, 1988; Morbidini *et al.*, 1998).

A desirable goal may be the manipulation of the animals' diet, with particular regards to the lipid fraction, in order to produce meat which possesses satisfactory organoleptic characteristics and satisfies health requirements.

The effects of nutritional factors on the fatty acid composition of different tissues in ruminants has been widely reviewed by several authors (Banskalieva *et al.*, 2000; Bas and Morand-Fehr, 2000; Antongiovanni *et al.*, 2003). Unfortunately, in ruminants there is only a limited possibility, at least so far, of affecting the tissue fatty acid composition since an extensive hydrogenation of unsaturated fatty acids occurs in the rumen

(Enser *et al.*, 1998; Nürnberg *et al.*, 1998). Therefore, the fatty acids leaving the rumen and hence absorbed by the intestine and incorporated into muscles are quite different from those introduced by the diet.

These problems may be overcome if we turn our attention to suckling animals, since the closure of the esophageal groove allows milk, or a fluid meal as well, to pass directly from the mouth to the abomasum, thus bypassing the rumen (Roy and Stobo, 1975).

It has been documented that the fatty acid composition of the adipose tissue in pre ruminant animals reflects the dietary intake and quality of fat (Zygoyiannis *et al.*, 1992; Bas and Morand-Fehr, 2000). Diets enriched with PUFA have shown to increase, although not proportionally, the relative amount of these fatty acids in the adipose tissue of kids (Potchoiba *et al.*, 1990).

In a previous study we found that kids fed by artificial suckling with a commercial acidified milk replacer containing a mixture of linseed and fish oil rich in PUFA showed a significantly higher content of unsaturated and polyunsaturated fatty acids in the covering fat. Their meat also had better dietetic properties, as documented by the

Table 1. Chemical (% on as it is basis) and fatty acid composition (%) of ewe milk and of acidified milk replacer* diets with or without PUFA supplementation.

		Ewe milk	Acidified milk replacer	Acidified milk replacer + 10 ml/l PUFA
		MM diet	MR diet	MR+PUFA diet
Dry matter		16.34	16.69	16.69
Crude protein		5.53	3.97	3.97
Ether extract		4.90	4.30	4.30
C4:0	(butyric)	5.25	0.10	0.10
C6:0	(caproic)	4.10	0.20	0.10
C8:0	(caprylic)	3.60	2.20	1.10
C10:0	(capric)	7.90	1.80	0.90
C12:0	(lauric)	3.60	14.30	6.80
C14:0	(myristic)	7.80	7.00	3.50
C16:0	(palmitic)	17.60	29.50	29.00
C16:1 ω-7	(palmitoleic)	1.15	0.30	0.40
C18:0	(stearic)	13.45	5.00	4.90
C18:1 ω-9	(oleic)	23.55	29.40	33.30
C18:2 ω-6	(linoleic)	1.75	8.00	12.80
C18:3 ω-3	(linolenic)	1.10	0.20	4.50
C18:2 conj		1.65	0.30	0.40
Total SFA		68.10	60.40	47.20
Total MUFA		27.40	31.10	35.10
Total PUFA		4.50	8.50	17.70

**The milk replacer used was "Starter B", containing on as it is basis: 4.00% moisture, 24% crude protein, 21.00% ether extract, 0.20% crude fibre, 39.90% N-free extract, 8.0% ash, 2.00% lysine and 0.6 % methionine, and integrated with (per kg): vit. A (40,000 U); vit. D3 (5000 U); vit. C (60 mg); vit. E (20 mg); vit. B_1 (3 mg); vit. B_2 (12 mg); vit. B_6 (1 mg); vit. B_{12} (0.04 mg); vit. K_3 (1.5 mg); niacin (50 mg); D panthothenic acid (30 mg); choline (750 mg); iodine (calcium iodine, 2.5 mg); zinc (zinc sulphate, 30 mg); manganese (manganese sulphate, 70 mg); selenium (sodium selenite, 0.1 mg); cobalt (cobalt sulphate, 1.6 mg); iron (iron sulphate, 25 mg).*

satisfactory atherogenicity and thrombogenicity indexes (Vicenti *et al.*, 2001).

Encouraging results have been reported also by Yeom *et al.* (2002), who found a dose dependent linear increase in the contents of α-linolenic and linoleic acids incorporated into the adipose tissue of suckling kids.

In the present study we investigated the effects of the type of suckling and of adding a PUFA enriched oil to a commercial acidified milk replacer for artificial suckling on the chemical and fatty acid composition of raw and cooked lamb meat.

Material and methods

Meat samples

The meat samples used in this study were obtained from twenty male Gentile di Puglia lambs reared and fed according to the techniques described in our previous report (Toteda *et al.*, 2004). Briefly, control lambs (n.=6) underwent natural rearing and received only maternal milk (group MM) throughout the whole experimental period. Two groups of lambs were subjected to artificial suckling with a commercial acidified milk replacer (Starter B). One group (n.=7) was supplemented with 10 ml/l of a mixture of linseed and fish oil containing polyunsaturated fatty acids (group MR+PUFA). In order to make the two milk replacer diets equal in oil content, the other artificial suckling group (n.=7) was supplemented with 10 ml/l of coconut oil (group MR). The chemical and fatty acid composition of maternal milk and of the two artificial suckling diets are shown in Table 1.

Lambs were slaughtered at about 45 days of age following 12 hours fasting. After 24 hours of refrigeration at 4 °C, the entire loin cut of the *Longissimus lumborum* muscle was dissected from the right half carcass.

Representative sub-samples were taken from the *Longissimus lumborum* muscle that was split into two pieces, one of which was used raw while the other was cooked in a common electric ventilated oven at 180 °C until an internal endpoint temperature of 75 °C was reached in the geometric centre of the meat cut, as recorded by a thermocouple (Hanna Instruments) inserted into the meat sample placed on the centre of the wire rack (ASPA, 1996).

Cooking losses were evaluated by weighing the meat samples before and after cooking.

Chemical and fatty acid analysis

Raw and cooked meat samples were homogenized in a grinder in order to perform chemical analysis (ASPA, 1996). For both milk and meat samples, lipids were extracted according to the method suggested by Folch *et al.* (1957) using a

Table 2. Chemical composition of raw and cooked meat in lambs fed with maternal milk or by artificial suckling with milk replacer diets (% on dry matter).

	MM		MR		MR+PUFA		SED	Signif. of main effects	
	Raw	Cooked	Raw	Cooked	Raw	Cooked	(DF=34)	Diet	Cooking
Moisture	77.48 **	68.95	76.92 **	66.76	75.63**	68.66	1.960	ns	**
Protein	83.40a	85.10	80.59	83.71	79.03b**	85.92	3.290	ns	**
Fat	10.03Bb *	5.71	13.62a**	8.41	14.72A**	6.45	3.204	*	**
Ash	4.69	4.23	4.54	4.78	4.39	4.20	0.508	ns	ns
N-free extract	1.88 **	4.96Aa	1.25 **	3.10B	1.86 *	3.43[b]	1.082	*	**
Cooking loss[(1)] (%)	/	29.09	/	30.02	/	28.94	3.435	ns	/

*Differences between diets: A, B: P<0.01; a, b: P<0.05; differences between raw and cooked samples within each diet and significance of main effects: **P<0.01; *P<0.05; ns: not significant.*

[(1)] DF = 17.

chloroform/methanol 2:1 (v/v) solution.

Fatty acids were methylated using a BF_3/methanol solution (12% v/v) and analysed by gas chromatography (Chromopack CP 9000) using a 50 m silicated glass column with a 0.25 mm internal diameter and 0.2 µm film thickness. The cholesterol content was assessed by HPLC using a chromatograph (Beckmann) equipped with a model 163 spectrophotometric detector (Muci *et al.*, 1992).

The atherogenicity and thrombogenicity indexes (Ulbricht and Southgate, 1991) and the PCL (plasma cholesterol lowering)/PCE (plasma cholesterol elevating) ratio (Reiser and Shorland, 1990) were also calculated.

Statistical analysis

Data were processed by analysis of variance using the GLM procedure of SAS (1999/2000). The model utilized was: $y_{ijk} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + \varepsilon_{ijk}$

where: μ is the overall mean; α is the effect of the diet (i = 1-3); β is the effect of the cooking method (j = 1-2: raw vs cooked); $\alpha\beta$ is the interaction and ε is the error. Means were compared by Student's t test (SAS, 1999/2000).

Results

Chemical composition of raw and cooked meat samples

Diet did not affect the moisture content of the different raw or cooked meat samples (Table 2). Cooking significantly reduced (P<0.01) meat samples' moisture regardless of the diet administered.

MM raw meat samples displayed a significantly higher protein content compared to the MR+PUFA group (P<0.05). The cooking process globally increased the protein concentration of meat, which reached a significant level only for the MR+PUFA samples (P<0.01).

MM raw meat samples contained a lower amount of fat than the MR (P<0.05) and MR+PUFA (P<0.01) ones. The fat content was significantly reduced following cooking, in particular at a level of P<0.01 for both the artificial suckling treatments, but at a level of P<0.05 for samples obtained from lambs reared under mothers.

The presence of ashes was similar in all the groups, ranging from 4.20 to 4.78%.

The N-free extract content increased after cooking, but more markedly in MM and MR samples (P<0.01) than in MR+PUFA ones (P<0.05). Furthermore, MM cooked samples showed a higher amount of N-free extract in comparison with both the MR (P<0.01) and MR+PUFA (P<0.05) samples.

The type of diet administered to lambs did not affect meat cooking loss, which ranged from 28.94% to 30.02%.

Fatty acid profile of raw and cooked meat samples

Table 3 shows the fatty acid profile of raw and cooked meat samples. On the whole, the fatty acid profile of raw meat reflects that of the milks administered. In particular, higher concentrations of capric (P<0.01), myristic (P<0.05 vs MR and P<0.01 vs MR+PUFA, respectively) and stearic (P<0.05 vs MR and P<0.01 vs MR+PUFA, respectively) acids were found in MM raw meat samples than in the groups subjected to artificial suckling. A higher amount of palmitic acid was found in the artificial suckling groups, and especially in MR (P<0.05) meat samples than in the MM ones.

Meat obtained from lambs fed the MR+PUFA diet showed a markedly lower amount of saturated fatty acids (SFA) compared to MR feeding (P<0.05) and to nursing under mothers (P<0.01).

Natural rearing determined a significantly (P<0.01) lower amount of PUFAs and ω-6 series fatty acids than both MR treatments.

Moreover, both MR treatments determined a higher ω-6/ω-3 ratio compared to natural rearing, especially when the milk replacer was supplemented with coconut oil (P<0.01). No significant differences arose between groups regarding the total amount of ω-3 fatty acids. Therefore, the higher ω-6/ω-3 ratios found for the MR treatments refelected the greater level of ω-6 fatty acids (P<0.01) in comparison with rearing under mothers, and mainly the higher concentration of linoleic acid ($C_{18:2\ n\text{-}6}$; P<0.01).

The MR+PUFA raw meat samples showed a significantly higher PUFA/SFA ratio than the MR (P<0.05) and the MM treatments (P<0.01).

Rearing under mothers determined a significantly higher content of cholesterol in raw meat samples compared with the MR+PUFA group (P<0.05).

In MR+PUFA cooked meat samples, a higher level of linoleic acid was recorded than MM samples (P<0.05; Table 3). Furthermore, MR+PUFA samples contained more ω-6 fatty acids, especially compared to the MM group (P<0.05).

Cooking changed the fatty acid profile of meat in a different way in relation to the diets administered. In particular, in MM meat samples a reduc-

Table 3. Fatty acid profile of raw and cooked meat (%) and cholesterol content (mg/100 g of meat).

		MM		MR		MR+PUFA		SED	Signif. of main effects	
		Raw	Cooked	Raw	Cooked	Raw	Cooked	(DF=30)	Diet	Cooking
Samples	n.	6	6	6	6	6	6			
$C_{10:0}$	(capric)	0.67A **	0.28	0.18B	0.23	0.17B	0.15	0.224	**	ns
$C_{12:0}$	(lauric)	2.33	3.28	3.17	2.50	2.48	2.65	1.001	ns	ns
$C_{14:0}$	(myristic)	9.25Aa *	7.77a	7.93b	7.80a	6.45B	6.50b	1.117	**	ns
$C_{14:1}$		0.25	0.37	0.27	0.33	0.28	0.33	0.150	ns	ns
$C_{15:0}$		0.97A **	0.37	0.23B	0.33	0.18B	0.20	0.271	**	ns
$C_{15:1}$		0.25A *	0.10	0.05B *	0.22	0.05B	0.05	0.128	ns	ns
$C_{16:0}$	(palmitic)	24.92b	27.40	29.20a	26.57	27.52	28.57	3.017	ns	ns
$C_{16:1}$ ω-7	(palmitoleic)	2.13	2.20	2.48	2.53	2.60	2.52	0.638	ns	ns
$C_{17:0}$		0.80Aa	0.48	0.28B	0.37	0.35b	0.23	0.316	*	ns
$C_{17:1}$		0.73A	0.53	0.25B	0.35	0.25B	0.35	0.311	**	ns
$C_{18:0}$	(stearic)	11.82Aa	9.85	8.62b	9.13	7.85B	8.67	2.611	*	ns
$C_{18:1}$ ω-9	(oleic)	32.62	34.53	33.08	35.80	33.67	35.00	3.417	ns	ns
$C_{18:1}$ ω-7		2.28	2.60	1.62	2.40	2.52	2.73	1.609	ns	ns
$C_{18:2}$ ω-6	(linoleic)	4.33B	5.68b	7.92A *	5.95	8.97A	7.85a	1.761	**	ns
$C_{18:3}$ ω-6		0.30	0.17	0.15	0.23	0.20	0.13	0.172	ns	ns
$C_{18:3}$ ω-3	(linolenic)	0.73	0.50	0.55	0.40	0.93 *	0.43	0.402	ns	*
$C_{20:3}$ ω-6		0.15	0.17a	0.12	0.12	0.05	0.02b	0.119	*	ns
$C_{20:3}$ ω-3		0.23	0.18	0.20	0.15	0.38	0.22	0.209	ns	ns
$C_{20:4}$ ω-6	(arachidonic)	0.20	0.08	0.10	0.17	0.32	0.32	0.272	ns	ns
$C_{20:5}$ ω-3	(EPA)	0.08	0.03b	0.15	0.27a	0.08	0.05b	0.184	ns	ns
$C_{22:5}$ ω-3	(DPA)	0.08	0.12	0.13	0.13	0.08	0.12	0.069	ns	ns
$C_{22:6}$ ω-3	(DHA)	0.05	0.08	0.07	0.10	0.07	0.08	0.063	ns	ns
Other acids		1.82	1.25	1.95	1.72	1.63	1.11	0.961	ns	ns
Total SFA		50.97A	49.63	49.80a	47.38	45.17Bb	47.20	3.769	*	ns
Total MUFA		42.03	42.52	39.73 *	44.33	42.80	42.80	3.750	ns	ns
Total PUFA		6.97B	7.82	10.42A *	8.25	12.00A	9.97	1.921	**	ns
Total UFA		49.00B	50.33	50.15b	52.58	54.80Aa	52.77	3.775	*	ns
ω-6		4.98B	6.10b	8.30A	6.47	9.53A	8.32a	1.709	**	ns
ω-3		1.23	0.92	1.12	1.05	1.55 *	0.90	0.473	ns	ns
ω-6/ω-3		4.26B *	8.11	9.53A	7.75	6.47	9.56	3.359	ns	ns
UFA/SFA		0.9bB	1.02	1.02b	1.12	1.24Aa	1.13	0.169	*	ns
PUFA/SFA		0.14B	0.16	0.21Ab	0.18	0.27Aa *	0.21	0.049	**	ns
Cholesterol(1)		85.89a	/	80.01	/	76.26b	/	8.539	/	/

*Differences between diets: A, B: P<0.01; a, b: P<0.05; differences between raw and cooked samples within each diet and significance of main effects: **P<0.01; *P<0.05; ns: not significant.*
(1) DF = 15.

tion of the concentration of capric (P<0.01), myristic (P<0.05), $C_{15:0}$ (P<0.01) and $C_{15:1}$ (P<0.05) acids was recorded. As for the MR diet, cooking increased the $C_{15:1}$ fatty acid concentration in meat, along with the percentage of MUFAs (P<0.05), whereas linoleic and PUFA fatty acids contents were significantly (P<0.05) lowered. The ω-6/ω-3 ratio of meat was increased following cooking in the MR+PUFA group, but in a marked way only in the MM group (P<0.05).

In relation to the dietetic properties of meat, meaningful difference between treatments emerged only for raw meat samples. In particular, the MR+PUFA group showed significantly (P<0.05) lower values for both the atherogenicity and thromogenicity indexes, but a higher PCL/PCE ratio (P<0.05) in comparison with the other groups (Figure 1). For all the groups tested, the cooking process did not significantly affect any of the dietetic parameters considered.

Discussion

The results obtained in this study evidence that the fatty acid profile of meat obtained from lambs in the pre-ruminant stage reflects that of the milks administered, in accordance with the findings reported by other authors for suckling lambs (Mir *et al.*, 2000; Cañeque *et al.*, 2001; Vicenti *et al.*, 2002) and goats (Manfredini *et al.*, 1988; Potchoiba *et al.*, 1990; Zygoyiannis *et al.*, 1992; Vicenti *et al.*, 2001; Yeom *et al.*, 2002).

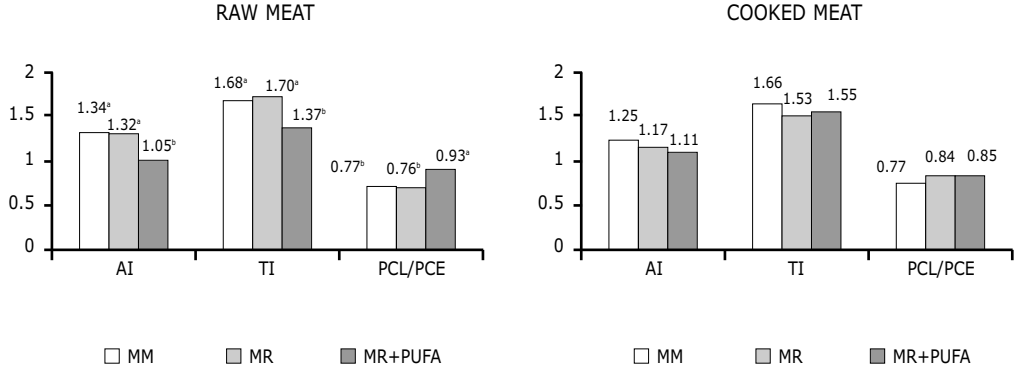
In particular, because capric ($C_{10:0}$), myristic ($C_{14:0}$) and stearic ($C_{18:0}$) acids were present in greater proportions in ewe's milk than in both the artificial suckling diets, higher concentrations of these acids were found in raw meat samples obtained from lambs nursed under mothers in comparison with the artificial suckling treatments.

Coconut oil is known to be rich in lauric acid ($C_{12:0}$), as previously shown in other reports (Manfredini *et al.*, 1988; Piot *et al.*, 2000). As a matter of fact, MR raw meat samples displayed a higher amount of this acid compared to MM and MR+PUFA samples.

Both coconut and fish+linseed oil enriched milk replacers contained a higher amount of palmitic acid ($C_{16:0}$) than maternal milk (about 29% vs 17.60%); therefore, this acid was present in higher concentration in MR and MR+PUFA meat samples than in MM ones.

Meat obtained from lambs fed on maternal milk showed a markedly higher amount of saturated fatty acids (SFA) compared to MR+PUFA feeding, along with fewer PUFAs and ω-6 series fatty acids than both the MR treatments. These

Figure 1. Atherogenicity index (AI), thrombogenicity index (TI) and plasma cholesterol lowering/plasma cholesterol elevating ratio (PCL/PCE) in raw and cooked lamb meat.



Differences between diets: a, b: P<0.05.

results are in substantial agreement with the findings reported by Cañeque *et al.* (2001) in unweaned Talaverana lambs and by Perez *et al.* (2002) in Suffolk Down suckling lambs.

Likewise, Velasco *et al.* (2002) found that lambs remaining with their dams until slaughter presented a higher amount of saturated fatty acids in comparison with early weaned lambs.

In our study, the PUFA/SFA ratio yielded in MM raw meat samples was 0.14, which is a little bit lower than the values recorded in previous reports (0.15: Enser *et al.*, 1996; 0.18: Abbas and Coléou, 1999; 0.19: Cañeque *et al.*, 2001). This result may be due to genotype differences, as documented in comparative studies carried out on different sheep (Sañudo *et al.*, 2000) and goat (Dhanda *et al.*, 1999) breeds, which evidenced that the fatty acid composition of fat tissues deposits may be influenced by genotype but also by diet, sex and slaughter age (Nürnberg *et al.*, 1998).

Regardless of the type of milk replacer used, artificial suckling treatments enhanced the PUFA/SFA ratio to the values of 0.21 for the MR diet and to 0.27 for the MR+PUFA diet, with greater benefits for health; however, these ratios are still below the recommended level of 0.45 (Department of Health, 1994).

Although the PUFA/SFA ratio of meat is an important factor under the human nutrition standpoint, particular attention must be given to the ω-6/ω-3 ratio, which it is suggested should not exceed the value of 4. In this study, however, we found higher ω-6/ω-3 ratios for the artificial feeding regimens.

Since no significant differences emerged between groups regarding to the total amount of ω-3 fatty acids, the high ω-6/ω-3 ratios obtained from the artificial suckling treatments were principally due to the greater level of ω-6 fatty acids compared to rearing under mothers, and especially to the higher concentration of linoleic acid.

Meat obtained from lambs fed only with maternal milk exhibited a higher content of cholesterol, especially in comparison with the MR+PUFA group. Similarly, Potchoiba *et al.* (1990) found a significantly higher meat cholesterol content in kids nursed under mothers in comparison with early weaned kids. Unfortunately, in this trial there was an inadequate amount of cooked meat available, only enough to perform chemical and fatty acid analysis, so that it was not possible to assess the cholesterol content in cooked meat samples, which would have been interesting in order to gain further information on the dietetic properties of meat.

So far, limited research has been carried out on the changes which occur in the fatty acid profile of lamb meat following cooking (Jeremiah *et al.*, 1997; Sheard *et al.*, 1998). Nevertheless, in our opinion, the assessment of the fatty acid profile of cooked meat may provide useful information on meat's effective healthiness, since lamb meat is always consumed cooked in our diet.

The effect of cooking on meat chemical and fatty acid composition seems to be quite controversial. While some researches (Smith *et al.*, 1989; Harris *et al.*, 1992) report that cooking has no significant effect on the fatty acid composition in beef muscle total lipid extracts, Duckett and Wagner (1998) found that cooking reduced the percentages of oleic, linoleic and linolenic acids and increased the concentration of stearic acid in beef intramuscular lipid and that these changes interested especially the polar lipid fraction. It is well known that the neutral lipid fraction has a storage role, whereas the polar fraction represents the membrane component of the cell. There is a substantial difference between the fatty acids located in these two lipid fractions, especially with regard to PUFAs, which are primarily located in membranes (Duckett and Wagner, 1998).

In general, the cooking process, depending on the temperature at which it is carried out, provokes lipid fusion, oxidative degradation and pirolysis, thus affecting the nutritional value of meat and the formation of oxidative products which seem to have harmful biological effects (Rodriguez-Estrada *et al.*, 1997). A translocation of lipids occurs following fusion, determining the production of a greasy film on the surface that prevents meat carbonization. Fat fusion and translocation cause the release of fat in the cooking juice and thus the concentration of flavours developed by lipid oxidation (Jeremiah *et al.*, 1997). Despite cooking, intramuscular fat retention is high, there-

fore lipid concentration increases following cooking due to water evaporation and to the loss of volatile compounds.

In our study, cooking lowered the concentration of saturated fatty acids and of myristic acid, with benefits for human health since these acids are known to have an hypercholesterolemic effect (Ulbricht and Southgate, 1991). In the MR group, cooking determined an increase of the MUFA content of meat in turn of a reduction of the SFA proportion.

Undoubtedly the type of cooking process employed plays an important role in changes to the chemical and fatty acid features of meat (Sheard *et al.*, 1998) and consequently to consumers' health, especially if the hypercholesterolemic fatty acids lost by cooking are served in the cooking juice along with meat, a common practice when cooking lamb in Italy.

Conclusions

Artificial suckling is an interesting strategy for improving animal breeding, both under the economic point of view than in terms of meat quality. Supplementation of milk replacers with a PUFA enriched oil, may, even in a limited way, improve the dietetic properties of cooked meat without substantial additional costs to animal breeding.

Further investigation is needed to assess meat sensory properties and other chemical, physical and rheological features (such as meat pH, tenderness, shelf-life, etc.) following application of artificial suckling programmes, with or without lipid supplementation, in order to evaluate consumers' acceptance of lamb meat products obtained by means of alternative rearing systems.

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