World Rabbit Science

World Rabbit Sci. 2009, 17: 97 - 107

THE INFLUENCE OF LINSEED ON RABBIT MEAT QUALITY

Bianchi M., Petracci M., Cavani C.

Department of Food Science, Alma Mater Studiorum, University of Bologna, 47023 Cesena. Italy.

Abstract: A research was conducted to study the influence of the dietary use of whole linseed on rabbit meat quality. A total of 288 growing rabbits were fed *ad libitum* (from 55 to 81 d old) with a commercial diet (C) or experimental diets containing 3, 6, or 9% whole linseed (L3, L6 and L9, respectively). After slaughtering, *L. lumborum* muscles and rabbit meat hamburgers were used to determine pH, colour, cooking loss, total lipid content, fatty acid composition and induced TBARS. Hind leg muscles were analyzed for total lipid content, fatty acid composition and induced TBARS. Finally, a sensory test was carried out to establish the level of acceptability of rabbit meat hamburgers prepared with the meat batters stored for 3 or 6 months at −20°C. The use of linseed determined a lower content of total saturated fatty acid and a higher content of PUFA (P<0.01) in all types of meat. The PUFA n-3 content of the meat increased significantly (P<0.01) with the increasing level of whole linseed in the diet, mainly due to the higher content of α-linolenic acid, which also determined a reduction of the n-6/n-3 PUFA ratio. The hamburgers prepared from L6 and L9 groups exhibited higher TBARS values in comparison with L3 and C. Furthermore, the cooking loss of hamburgers was lower in meat from rabbits fed the control diet (C), intermediate in L3 and higher in L6 and L9 (P<0.01). With regard to sensory analysis, the diet did not determine significant differences in the acceptability of the hamburgers produced with frozen meat batters stored for 3 or 6 months. In general, the use of 3% linseed in diets for growing rabbits could be considered suitable for achieving both the enrichment of the meat with α-linolenic acid and maintaining good product quality characteristics.

Key Words: rabbit, diet, whole linseed, raw meat, processed meat, quality traits.

INTRODUCTION

Despite the limited capacity for metabolic conversion of alpha-linolenic acid (ALA; C18:3 n-3) to longer chain PUFA, such as eicosapentaenoic (EPA; 20:5 n-5) and docosapentaenoic (DHA; 22:6 n-3) acids, ALA has many potential roles in human health that could be independent of its conversion to DHA (Plourde and Cunnane, 2008). The major dietary sources of α-linolenic acid are green leaves and some cooking oils such as rapeseed and soybean oil, in which it accounts for up to 10% of total fatty acids (Burdge and Calder, 2006). Linseed (or flaxseed) oil is particularly rich in α-linolenic acid (50-60% of total fatty acids) (Bean and Leeson, 2002) and is commonly used as a dietary supplement in humans (Burdge and Calder, 2006).

The use of linseed in animal feeding has been proposed by many authors as an alternative vegetable source to fish oil or fish meal, to raise the content of n-3 polyunsaturated fatty acids (n-3 PUFA), and mainly α-linolenic acid (C18:3 n-3) in poultry (Ajuyah *et al*., 1993; Rymer and Givens, 2005), pork

Correspondence: C. Cavani, claudio.cavani@unibo.it
Received *December 2008* - Accepted *February 2009*

(Matthews *et al*., 2000; Rey *et al*., 2001; Wood *et al*., 2004) and rabbit meat (Bernardini *et al*., 1999; Dal Bosco *et al*., 2004; Colin *et al*., 2005; Bianchi *et al*., 2006; Maertens *et al*., 2008). Maertens *et al*. (2005) reported beneficial effects of linseed on the performance, milk composition and viability of the progeny in rabbit does. Providing increased amounts of n-3 essential fatty acids in human nutrition through normal meat consumption can contribute to balancing the unbalanced n-6/n-3 PUFA ratio of the consumer's diet, thus helping to prevent certain diseases such as hypercholesterolemia-related heart attack and strokes (Prasad, 1997; Simopoulos, 2000; Wood *et al*., 2004).

Fatty acids are involved in many technological aspects of meat quality. The main problem associated with the modification of the natural fatty acid profile of muscle foods is determined by the ability of unsaturated fatty acids, especially those with more than two double bonds, to oxidise and reduce the shelf-life of meat products (Wood *et al*., 2004). This problem could also be more serious when meat with a high level of PUFA is used for further processing that involves mincing, long term frozen storage, and cooking (Lee *et al*., 2006). It has also been widely reported that lipid oxidation plays a key-role in the development of cooked meat flavour (Enser, 1999). It has been suggested that dietary use of linseed in pig feeds could impair the flavour of cooked pork when the α-linolenic (C18:3 n-3) acid content of the meat is above 3% of total fatty acids (Campo *et al*., 2003; Wood *et al*., 2004).

Bianchi *et al*. (2006) studied the effect of 0 *vs*. 8% whole linseed in diets for rabbits on meat quality traits. However, the dynamic effect of increasing linseed contents in the diet and its influence on meat quality traits was not considered.

The present study was conducted to investigate the effect of different inclusion rates of whole linseed (3, 6, 9%) in diets for growing rabbits on some chemical-physical traits, fatty acid composition, susceptibility to lipid oxidation and sensory quality of the meat.

MATERIALS AND METHODS

Animals and diets

The study was conducted on 288 rabbits weaned at 30 d, caged in pairs and reared under commercial conditions until 55 d. Subsequently, the animals were divided into four groups and fed *ad libitum* with a commercial diet (C) containing 3% of palm oil or the experimental diets without palm oil inclusion but containing 3, 6, or 9% whole linseed (L3, L6, L9, respectively) until slaughtering (81 d). The experimental isoproteic diets were formulated with whole sunflower seeds as the main substituting ingredient for linseed and supplemented with 200 mg α-tocopheryl acetate/kg feed (Table 1).

Productive performances were evaluated by measuring the live weight, daily weight gain (g/d), daily feed intake (g/d) and feed conversion ratio (g/g) through the rearing period (55-81 d).

Slaughtering, and carcass quality evaluation

The rabbits were slaughtered at 81 d old in a commercial slaughtering plant under strict official veterinary control. The animals were removed from transport cages, electrically stunned (70 V, pulsed direct current, 50 Hz for 5 sec), hung on shackles, killed by hand using a conventional unilateral neck cut to sever the carotid artery and jugular vein, bled, skinned, and carcasses prepared as recommended by Blasco and Ouhayoun (1996). Carcass weight, meat to bone ratio of hind leg, perirenal and scapular fat were evaluated after 24 h chilling (0-4°C) on 10 carcasses per group. Furthermore, about 60 carcasses per group were boned and the dissected meat was minced and mixed with a commercial seasoning product to obtain a meat batter used to prepare meat hamburgers.

Table 1: Ingredients and chemical composition of the experimental diets.

	Diet			
	C	L3	L6	L9
Ingredients (%)				
Whole linseed	-	3.0	6.0	9.0
Whole sunflower	-	6.0	3.0	-
Palm oil	3.0	-	-	-
Wheat bran	24.0	24.0	24.0	24.0
Dehydrated lucerne meal	20.0	20.0	20.0	20.0
Sunflower meal, 29%CP	16.0	10.0	10.0	10.0
Alfalfa hay	10.0	10.0	10.0	10.0
Barley grain	9.0	9.0	9.0	9.0
Wheat grain	6.0	6.0	6.0	6.0
Soybean meal, 48%CP	4.6	4.2	4.2	4.2
Cane molasses	2.5	2.5	2.5	2.5
Beet pulp	1.7	1.7	1.7	1.7
Calcium carbonate	1.1	1.4	1.5	1.5
Premix[1]	1.1	1.1	1.1	1.1
Sodium chloride	0.5	0.5	0.5	0.5
Dicalcium phosphate	0.2	0.3	0.2	0.2
α-tocopheryl-acetate	0.02	0.02	0.02	0.02
DL-methionine	0.10	0.11	0.11	0.10
HCL-lysine	0.13	0.11	0.13	0.16
L-threonine	0.03	0.03	0.03	0.04
Chemical composition (%)				
Dry matter	88.9	88.7	88.6	88.5
Ash	8.52	8.79	8.85	8.88
Crude protein (CP)	16.8	16.4	16.7	16.8
Ether extract	5.13	5.77	5.46	5.15
Starch	14.5	14.5	14.6	14.6
Crude fibre	15.4	15.0	14.7	14.5
NDF	31.8	31.4	31.0	30.6
ADF	19.5	19.1	18.8	18.5
ADL	5.71	5.61	5.55	5.5
Lysine	0.75	0.72	0.74	0.75
Threonine	0.61	0.6	0.61	0.62
Methionine	0.35	0.35	0.35	0.34
Sulphur aminoacids	0.61	0.61	0.61	0.61
Digestible energy (MJ/kg)[2]	10.2	10.1	10.2	10.2

[1] included 0.6% of vitamin-mineral premix and 0.5% of pellet binder.
[2] calculated according to the equation reported by Maertens *et al*. (1988)

Meat quality evaluation

L. lumborum muscles (dissected at 24 h *post mortem*; between the 1st and 7th lumbar vertebra) and hamburgers were used to determine pH, colour, cooking loss, total lipid content, fatty acid composition and induced TBARS. Finally, hind leg muscles were analyzed for total lipid content, fatty acid composition and induced TBARS.

The colour parameters L* (lightness), a* (redness), and b* (yellowness) (CIE, 1976) were determined by using a Minolta CR-300 Chroma Meter operating with light source C. The colour of *L. lumborum* was measured on the epymisial surface of the muscle, whereas the colour of hamburgers was determined by averaging three colour measurements taken on the surface of each hamburger.

pH values were measured on *L. lumborum* muscles at 24 h *post mortem* as well as on hamburgers by using the direct probe-method using a portable pH-meter (mod. HI98240, Hanna Inst.) equipped with a glass electrode (mod. FC230, Hanna Inst.).

Cooking loss was determined on a whole dissected *L. lumborum* muscle from each carcass as well as on the hamburgers. The samples were cooked in a convection oven at 180°C until 80°C was reached at the sample core, allowed to equilibrate to room temperature, reweighed, and cooking loss calculated as percentage of weight loss.

Total lipid content was determined by a pressurized solvent extraction method by using an Accelerated Solvent Extraction Automatic System (ASE 200, Dionex, Salt Lake City, Utah, U.S.A.) and a chloroform/methanol (2:1) extracting solution according to the procedure reported by Toschi *et al*. (2003). Fatty acid composition of total lipids was determined by gas-liquid chromatography. The fatty acid methyl esters were prepared by KOH/met-OH transesterification and analysed on a CP-Sil 88 capillary column (50 m×0.25 mm internal diameter) (Chrompack, UK, Ltd, London). Methylated fatty acids were injected on a split-splitless injector at 240°C and helium was used as carrier gas at constant flow of 1 mL/min. Oven programmed temperature profile included two phases from 50 to 100°C at 10°C/min and from 100 to 220°C at 2.7°C/min. A flame ionization detector (FID) was used at 240°C. Peaks were identified using standards (Nu-Check-Prep. Inc., Elysian, MN, USA) and results expressed as percentage by weight of total fatty acids methyl esters.

Susceptibility of muscle tissue homogenates to iron-induced lipid oxidation was determined according to the method proposed by Kornbrust and Mavis (1980). Homogenates were incubated at 37°C and aliquots were removed at fixed time intervals (0, 30, 60, 90, and 150 min) for measurement of 2-thiobarbituric acid-reactive substances (TBARS). Protein content of the meat was determined according to the Lowry procedure (Lowry *et al*., 1951) and TBARS expressed as nmoles malonaldehyde (MDA)/mg protein.

Sensory tests were carried out on rabbit meat hamburgers prepared with the meat batters stored (−20°C, vacuum packaged) for 3 or 6 months. Untrained panellists (n=37 at 3 months; n=32 at 6 months) were used to evaluate the sensory acceptability of the hamburgers. After cooking (conventional oven at 180°C until 80°C at core), the hamburger samples were served warm to the panellists, according to a randomised complete block design. Each judge was presented with four samples (i.e. L9, C, L3, L6) and asked to indicate the level of acceptability according to a five point verbal hedonic scale (very good taste=5; good taste=4; indifferent taste=3; bad taste=2; very bad taste=1) (AMSA, 1995).

Statistical analyses

Productive performances, carcass and meat quality traits data were analyzed by univariate ANOVA (GLM, SAS® software, SAS Institute, 1988), testing the diet (C, L3, L6, L9) as main effect. When significant differences were found among treatments, means were separated by Duncan's multiple-range test. The relationship between the content of whole linseed in the diet and the content of α-linolenic acid in rabbit

meat was evaluated by calculating the regression model (R^2). The data obtained from the panel test were analysed by χ-square 4×5 contingency tables (4 diets and 5 levels of acceptability).

RESULTS AND DISCUSSION

Productive performances and carcass traits

Overall zootechnical performances were satisfactory with all diets and in line with the performances of rabbits under commercial conditions. The diet did not influence either growth rate or feed efficiency (liveweight at 81 d: 2930.5±9.3 g; daily weight gain from 55 to 81 d: 33.10±0.43 g/d; feed conversion ratio from 55 to 81 d: 4.62±0.06; mean±standard error of the mean).

Total mortality at the end of growing phase was very low (2.1%) and not related to the dietary treatment. Previous studies observed a decrease in the growth rate of rabbits fed with diets containing extruded (Colin *et al*., 2005) or whole linseed (Bianchi *et al*., 2006) as well as linseed oil (Verdelhan *et al*., 2005). However, other studies (Bernardini *et al*., 1999; Dal Bosco *et al*., 2004) did not observe any detrimental effect of whole linseed on the productive performance of rabbits. As regards carcass traits, the diet did not influence carcass weight (1639.7±20.4 g), meat to bone ratio (4.06±0.06) or perirenal (3.33±0.16 %) and scapular fat (0.76±0.03 %).

Meat quality traits

The overall chemical-physical traits of *L. lumborum* muscle were not strongly affected by the diet and only meat redness showed a significant change (a*) (Table 2). The most interesting result was the cooking loss of hamburgers, which was lower ($P<0.001$) in meat from rabbits fed the control diet (C) with respect to L3, L6, and L9. These differences revealed a different ability of the meat for retaining juice during cooking and could be related to the high level of unsaturated lipids presented by the linseed-fed meat hamburgers (see after in the Table 5). Finally, hamburgers from the C group were found to have a lower lightness values (L*) ($P<0.001$) -and L6 hamburgers had lower redness values ($P<0.05$).

Table 2: Influence of the diet on ultimate pH, cooking loss and colour parameters of *L. lumborum* muscles and hamburgers.

	Diet					
	C	L3	L6	L9	SEM[3]	*P*-value
L. lumborum[1]						
pHu	5.87	5.92	5.89	5.90	0.02	ns
cooking loss (%)	11.34	12.10	11.84	11.20	0.24	ns
lightness (L*)	55.15	54.38	54.57	54.14	0.51	ns
redness (a*)	4.22[a]	4.23[a]	2.83[b]	2.43[b]	0.26	*
yellowness (b*)	2.43	2.03	1.55	1.61	0.19	ns
Hamburgers[2]						
pHu	5.96	6.02	5.90	5.99	0.02	ns
cooking loss (%)	10.08[c]	10.65[b]	12.74[a]	12.27[a]	0.22	**
lightness (L*)	62.22[b]	64.05[a]	64.58[a]	64.32[a]	0.25	***
redness (a*)	10.56[a]	9.91[ab]	9.80[b]	10.50[a]	0.12	*
yellowness (b*)	9.21	9.18	9.36	9.38	0.08	ns

[1]n=10 per group, [2]n=8 per group, *=$P<0.05$, **=$P<0.01$;***=$P<0.001$, ns=not significant, [a,b, c]=$P<0.05$. [3] Standard error of the mean.

Table 3: Influence of the diet on lipid content and fatty acid composition (% of total methyl esters) of *L. lumborum*.

	Diet					
	C	L3	L6	L9	SEM[4]	*P*-value
No.	8	8	8	8		
Lipid content (%)	1.55	1.32	1.45	1.38	0.06	ns
Fatty acid composition (%)						
C14:0	2.22	1.93	1.85	2.13	0.06	ns
C15:0	0.39	0.38	0.36	0.35	0.01	ns
C16:0	31.60^{A}	26.50^{B}	26.19^{B}	27.14^{B}	0.49	***
C17:0	0.38	0.40	0.37	0.42	0.02	ns
C18:0	7.12	7.07	7.48	7.05	0.15	ns
C20:0	0.07	0.03	0.06	0.03	0.01	ns
Total SFA[1]	41.78^{A}	36.31^{B}	36.32^{B}	37.11^{B}	0.53	***
C14:1	0.05^{b}	0.17^{a}	0.01^{b}	0.03^{b}	0.02	**
C16:1	4.39	3.66	2.93	3.64	0.24	ns
C17:1	0.15	0.14	0.12	0.15	0.01	ns
C18:1	25.32	25.43	24.78	24.24	0.24	ns
C18:1	2.32	2.09	2.20	2.19	0.04	ns
Total MUFA[2]	32.23	31.48	30.04	30.25	0.44	ns
C18:2 n-6	20.21^{B}	23.99^{A}	23.04^{A}	20.60^{B}	0.43	***
C20:2 n-6	0.10	0.10	0.09	0.09	0.01	ns
C20:3 n-6	0.27	0.24	0.25	0.23	0.01	ns
C20:4 n-6	3.20	3.31	3.49	2.87	0.18	ns
Total PUFA n-6	23.78^{B}	27.64^{A}	26.88^{A}	23.79^{B}	0.52	***
C18:3 n-3	1.12^{D}	3.43^{C}	5.39^{B}	7.57^{A}	0.47	***
C20:5 n-3	0.75	0.65	0.62	0.50	0.03	ns
C22:5 n-3	0.21^{B}	0.35^{B}	0.63^{A}	0.61^{A}	0.05	***
C22:6 n-3	0.12	0.14	0.13	0.17	0.01	ns
Total PUFA n-3	2.21^{D}	4.57^{C}	6.77^{B}	8.85^{A}	0.48	***
Total PUFA[3]	25.99^{B}	32.21^{A}	33.64^{A}	32.64^{A}	0.71	***
PUFA/SFA	0.62^{B}	0.89^{A}	0.93^{A}	0.88^{A}	0.03	***
n-6/n-3	10.81^{A}	6.19^{B}	4.14^{C}	2.73^{D}	0.57	***

**=P<0.01, ***=P<0.001, ns=not significant, $^{a-d}$=P<0.05; $^{A-D}$=P<0.01, [1] total saturated fatty acids, [2] total monounsaturated fatty acids, [3] total polyunsaturated fatty acids, [4] Standard error of the mean.

Tables 3, 4, and 5 report the effects of the diet on lipid content and fatty acid composition of *L. lumborum*, leg meat and hamburgers, respectively. As expected, the overall meat fatty acid composition was influenced by linseed in all the types of meat considered. With regard to the main categories of fatty acids, the linseed determined a lower content of total saturated fatty acids (total SFA) and a higher content of polyunsaturated fatty acids (total PUFA) in *L. lumborum*, leg meat and hamburgers. The most important

Table 4: Influence of the diet on lipid content and fatty acid composition (% of total methyl esters) of leg meat.

	Diet					
	C	L3	L6	L9	SEM[4]	*P*-value
No.	8	8	8	8		
Lipid content (%)	4.36	4.94	4.66	4.91	0.15	ns
Fatty acid composition (%)						
C14:0	2.60^{A}	2.25^{B}	2.30^{B}	2.30^{B}	0.04	**
C15:0	0.43	0.39	0.39	0.40	0.01	ns
C16:0	28.93^{A}	23.85^{B}	24.17^{B}	24.22^{B}	0.41	***
C17:0	0.43	0.43	0.42	0.43	0.01	ns
C18:0	6.37	6.28	6.36	6.33	0.10	ns
C20:0	0.06	0.03	0.03	0.05	0.01	ns
Total SFA[1]	38.82^{A}	33.23^{B}	33.66^{B}	33.74^{B}	0.45	***
C14:1	0.07	0.05	0.07	0.10	0.01	ns
C16:1	4.91^{a}	3.48^{b}	4.16^{ab}	3.87^{b}	0.18	*
C17:1	0.20^{a}	0.18^{b}	0.18^{b}	0.19^{ab}	0.00	**
C18:1	27.69^{A}	27.25^{A}	26.07^{B}	25.63^{B}	0.21	***
C18:1	2.17	1.95	2.02	2.01	0.03	ns
Total MUFA[2]	35.03^{A}	32.90^{B}	32.51^{B}	31.80^{B}	0.35	***
C18:2 n-6	22.51^{C}	26.91^{A}	24.41^{B}	22.62^{C}	0.39	***
C20:2 n-6	0.14	0.16	0.12	0.12	0.01	ns
C20:3 n-6	0.10	0.09	0.06	0.07	0.01	ns
C20:4 n-6	1.00	0.76	0.75	0.67	0.05	ns
Total PUFA n-6	23.75^{CD}	27.91^{A}	25.34^{BC}	23.48^{D}	0.41	***
C18:3 n-3	1.96^{D}	5.57^{C}	8.08^{B}	10.55^{A}	0.58	***
C20:5 n-3	0.24^{A}	0.17^{B}	0.14^{B}	0.12^{B}	0.01	***
C22:5 n-3	0.08^{c}	0.11^{bc}	0.16^{ab}	0.17^{a}	0.01	**
C22:6 n-3	0.12	0.12	0.11	0.14	0.01	ns
Total PUFA n-3	2.39^{D}	5.96^{C}	8.48^{B}	10.97^{A}	0.58	***
Total PUFA[3]	26.14^{B}	33.87^{A}	33.83^{A}	34.45^{A}	0.69	***
PUFA/SFA	0.67^{B}	1.02^{A}	1.01^{A}	1.02^{A}	0.03	***
n-6/n-3	9.93^{A}	4.81^{B}	2.99^{C}	2.15^{D}	0.55	***

*= $P<0.05$, **= $P<0.01$, ***= $P<0.001$; ns=not significant; $^{a-d}P<0.05$; $^{A-D}P<0.01$, [1] total saturated fatty acids, [2] total monounsaturated fatty acids, [3] total polyunsaturated fatty acids, [4] Standard error of the mean.

result is represented by the increase of n-3 PUFA ($P<0.001$) observed from C toward L3, L6, and L9. This was mainly due to the higher content of α-linolenic acid (C18:3 n-3), which is the main fatty acid of linseed (50-60% of total fatty acids; Bean and Leeson, 2002).

The close relationship between the content of whole linseed in the diet and the content of α-linolenic acid in rabbit meat was evidenced by the significant linear regressions found in all types of meat (*L. lumborum*: $y = 0.71x + 1.18$, $R^2=0.99$; Leg meat: $y = 0.96x + 2.33$, $R^2 = 0.99$; Hamburgers: $y = 0.81x + 3.64$, $R^2 = 0.96$; where y was the % of α-linolenic acid in the meat and x the % linseed in the diet).

Table 5: Influence of the diet on lipid content and fatty acid composition (% of total methyl esters) of hamburgers.

	Diet					
	C	L3	L6	L9	SEM[4]	*P*-value
No.	4	4	4	4		
Lipid content (%)	6.49	5.66	5.53	5.76	0.14	ns
Fatty acid composition (%)						
C14:0	2.73^{A}	2.10^{B}	2.14^{B}	2.12^{B}	0.06	***
C15:0	0.41^{A}	0.37^{B}	0.38^{B}	0.34^{C}	0.01	***
C16:0	27.43^{A}	21.78^{C}	23.09^{B}	23.49^{B}	0.50	***
C17:0	0.42^{a}	0.42^{a}	0.41^{a}	0.39^{b}	0.00	**
C18:0	5.96	6.20	4.95	7.26	0.47	ns
C20:0	0.01	0.02	0.02	0.01	0.00	ns
Total SFA[1]	36.95^{A}	30.89^{C}	30.99^{C}	33.60^{B}	0.68	***
C14:1	0.06^{A}	0.06^{A}	0.06^{A}	0.05^{B}	0.00	***
C16:1	5.09^{A}	3.32^{B}	3.30^{B}	3.19^{B}	0.18	***
C17:1	0.23^{A}	0.17^{C}	0.18^{BC}	0.18^{B}	0.01	***
C18:1	28.21	27.69	27.66	27.94	0.18	ns
C18:1	2.31	1.93	2.20	2.00	0.06	ns
Total MUFA[2]	35.89^{a}	33.17^{b}	33.40^{b}	33.37^{b}	0.33	*
C18:2 n-6	23.06^{C}	28.56^{A}	25.24^{B}	21.67^{D}	0.76	***
C20:2 n-6	0.15^{b}	0.18^{a}	0.16^{ab}	0.17^{a}	0.00	*
C20:3 n-6	0.06	0.06	0.06	0.05	0.00	ns
C20:4 n-6	0.40^{c}	0.51^{a}	0.46^{ab}	0.44^{bc}	0.01	*
Total PUFA n-6	23.65^{C}	29.31^{A}	25.92^{B}	22.34^{D}	0.78	***
C18:3 n-3	3.24^{D}	6.28^{C}	9.34^{B}	10.36^{A}	0.70	***
C20:5 n-3	0.11^{B}	0.12^{A}	0.10^{B}	0.09^{C}	0.00	***
C22:5 n-3	0.06^{C}	0.09^{B}	0.12^{A}	0.13^{A}	0.01	***
C22:6 n-3	0.10	0.13	0.12	0.12	0.01	ns
Total PUFA n-3	3.50^{D}	6.63^{C}	9.68^{B}	10.69^{A}	0.70	***
Total PUFA[3]	27.16^{C}	35.94^{A}	35.60^{A}	33.03^{B}	0.85	***
PUFA/SFA	0.74^{C}	1.16^{A}	1.16A	0.98^{B}	0.05	***
n-6/n-3	6.80A	4.43^{B}	2.68^{C}	2.09^{D}	0.45	***

*= $P<0.05$, **= $P<0.01$, ***=$P<0.001$, ns=not significant, $^{a\text{-}d}$=$P<0.05$, $^{A\text{-}D}$=$P<0.01$, [1] total saturated fatty acids, [2] total monounsaturated fatty acids, [3] total polyunsaturated fatty acids, [4] Standard error of the mean.

The effectiveness of whole linseed for increasing the PUFA and α-linolenic acid contents of the meat has been previously reported by several studies on both rabbits (Bernardini *et al*., 1999; Dal Bosco *et al*., 2004; Bianchi *et al*., 2006; Maertens *et al*., 2008) and other species (Mattews *et al*., 2000; Riley *et al*., 2000; Rey *et al*., 2001). Colin *et al*. (2005) has recently proposed the use of a commercial feed ingredient (Tradi-Lin®) containing extruded linseed to increase the α-linolenic acid content of rabbit meat.

As regards the lipid susceptibility to oxidation (Figure 1), no differences were observed on *L. lumborum* muscles, whereas the leg meat from L9 exhibited a higher susceptibility compared with the other groups, but only at the end of oxidation induction (120 and 150 min). In hamburgers, the susceptibility to lipid oxidation was higher for L6 and L9 in comparison with L3 and C, which did not differ from each other. On the whole, these results indicate that lipid oxidation of the meat is influenced by both the type of muscle and the processes to which the meat is subjected. These results are consistent with Bianchi *et al*. (2006), who studied the effects of 8% whole linseed in the diet.

The higher susceptibility to lipid oxidation can be attributed to the increased content of α-linolenic acid in the meat. In fact, it is well known that this fatty acid plays a key-role in determining the susceptibility to oxidation of the meat (Enser, 1999; Rey *et al*., 2001; Dalle Zotte, 2002; Hernandez, 2008).

In the sensory analysis, the diet did not determine significant differences in the acceptability of the hamburgers produced with frozen meat batter stored for 3 or 6 months (results not shown). This could also be related to the positive effect exerted by α-tocopheryl-acetate (200 mg/kg feed), as documented in many types of meat and meat products (Jensen *et al*., 1998; Bielanski and Kowalska, 2008; Zsédely *et al*., 2008). In a previous study, Bianchi *et al*. (2006) found no differences in the sensory characteristics of hamburgers produced with meat batters obtained from rabbits fed on diets containing 0 or 8% linseed (coupled with 35% dehydrated lucerne meal) and frozen for 3 months. However, at 6 months, differences in the sensory properties of the meat were detected, even though the diets had been supplemented with the same level of α-tocopheryl-acetate adopted in this study (200 mg/kg feed). Finally, Colin *et al*. (2005) did not observe any alteration of the hedonic characteristics of fresh rabbit meat with a higher content of n-3 PUFA obtained by the use of extruded linseed.

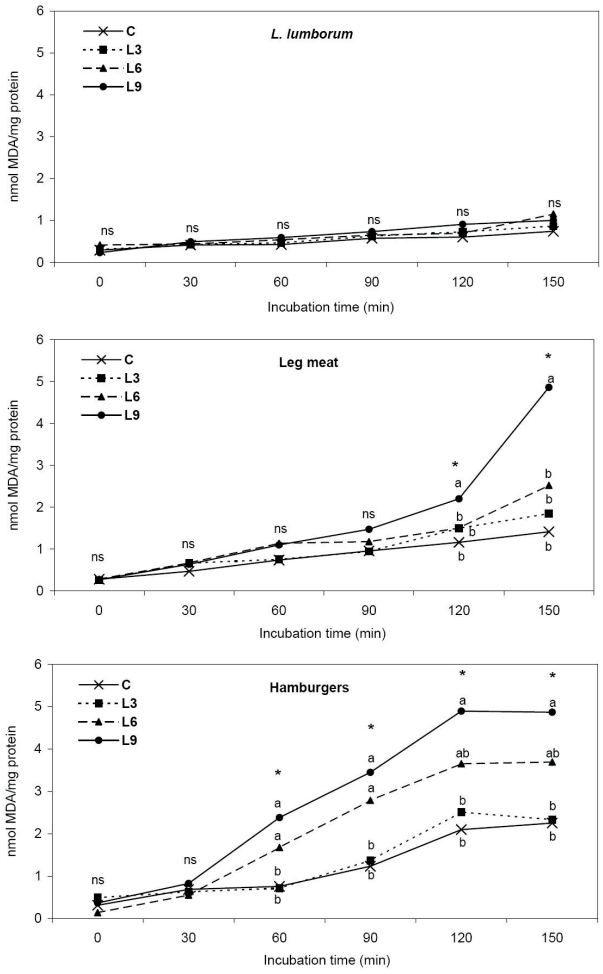

Figure 1: Influence of the diet (C, L3, L6, L9) on susceptibility to lipid oxidation (induced TBARS) of rabbit meat (*L. lumborum,* leg meat and hamburgers). ns=not significant; *=$P<0.05$; a,b=$P<0.05$.

CONCLUSIONS

In conclusion, these results indicate a strict relationship between the content of linseed in the diet and the content of α-linolenic acid in the meat. The dietary use of linseed in growing rabbits can therefore be exploited with the aim of producing rabbit meat with higher α-linolenic acid content. Considering the results as a whole, the product quality can be considered quite good, despite the high level of unsaturation due to the use of linseed. Taking into account the quality traits of both raw and processed meat, a 3% level of linseed in the diet could be considered sufficient to achieve both the enrichment of the meat with α-linolenic acid and to maintain good product quality.

Acknowledgements: The authors are grateful to "F.lli Martini & C. S.p.A." for technical assistance. Research funded by MIUR - PRIN ex 40%.

REFERENCES

Ajuyah A.O., Fenton T.W., Hardin R.T., Sim J.S. 1993. Effect of dietary full flaxseed with and without antioxidant on the fatty acid composition of major lipid classes of chicken meats. *Poult. Sci., 72: 125-136.*

AMSA. 1995. Research guidelines for cookery, sensory evaluation, and tenderness measurements of fresh meat. *Am. Meat Sci. Assoc., Savoy, IL.*

Bean L.D., Leeson S. 2002. Fatty acid profiles of 23 samples of flaxseed collected from commercial feed mills in Ontario in 2001. *J. Appl. Poult. Res. 11: 209-211.*

Bernardini M., Dal Bosco A., Castellini C. 1999. Effect of dietary n-3/n-6 ratio on fatty acid composition of liver, meat and perirenal fat in rabbits. *Anim. Sci., 68: 647-654.*

Bianchi M., Petracci M., Cavani C. 2006. Effects of dietary inclusion of dehydrated lucerne and whole linseed on rabbit meat quality. *World Rabbit Sci., 14: 247-258.*

Bielanski P., Kowalska D. 2008. Use of linseed oil and antioxidant (vitamin E) in rabbit diets to improve dietetic traits of rabbit meat. *In Proc.: 9th World Rabbit Congress, 10-13 June, 2008. Verona, Italy. 1319-1323.*

Blasco A., Ouhayoun J. 1996. Harmonization of criteria and terminology in rabbit meat research. Revised proposal. *World Rabbit Sci., 4: 93-99.*

Burdge G.C., Calder P.C. 2006. Dietary α-linolenic acid and health related outcomes: a metabolic perspective. *Nutr. Res. Rev., 19: 26-52.*

Campo M.M., Nute G.R., Wood J.D., Elmore S.J., Mottram D.S., Enser M. 2003. Modelling the effect of fatty acids in odour development of cooked meat in vitro: part I – sensory perception. *Meat Sci., 3: 367-375.*

CIE. 1976. Recommendations on uniform color spaces, color differences, equations. Psychometric color terms. *Supplement No.2 to CIE Publications n.15. Commission Intenationale de l'Eclairage, Colorimetry. Paris, France.*

Colin M., Raguenes N., Le Berre G., Charrier S., Prigent A.Y., Perrin G. 2005. Influence d'un enrichissement de l'aliment en acides gras oméga 3 provenant de graines de lin extrudées (Tradi-Lin®) sur les lipides et les caractéristiques de la viande de lapin. *In: Proc. 11èmes Journées de la Recherche Cunicole, Paris, 163-166.*

Dal Bosco A., Castellini C., Bianchi L., Mugnai C. 2004. Effect of dietary α-linolenic acid and vitamin E on the fatty acid composition, storage stability and sensory traits of rabbit meat. *Meat Sci., 66: 407-413.*

Dalle Zotte A. 2002. Perception of rabbit meat quality and major factors influencing the rabbit carcass and meat quality. *Livest. Prod. Sci., 75, 11-32.*

Enser M. 1999. Nutritional effects on meat flavour and stability. *In: Richardson R.I., Mead G.C. (ed.). Poultry Meat Science. CABI Publishing, Oxfordshire, UK, 197-215.*

Hernández P. 2008. Enhancement of nutritional quality and safety in rabbit meat. *In Proc.: 9th World Rabbit Congress, 10-13 June, 2008. Verona, Italy. 1287-1299.*

Jensen C., Lauridsen C., Bertelsen G. 1998. Dietary vitamin E: Quality and storage stability of pork and poultry. *Trends Food Sci. Technol., 9: 62-72.*

Kornburst D.J., Mavis R.D. 1980. Relative susceptibility of microsomes from lung, heart, liver kidney, brain, tests to lipid peroxidation. *Lipids, 15: 315-322.*

Lee. S., Faustman C., Djordjevic D., Faraji H., Decker E.A. 2006. Effect of antioxidants on stabilization of meat products fortified with n-3 fatty acids. *Meat Sci., 72: 18-24.*

Lowry O.H., Rosebrough N.J., Farr A.L., Randall R.J. 1951. Protein measurement with the folin phenol reagent. *J. Biol. Chem., 193: 265-275.*

Maertens L., Moermans R., De Groote G. 1988. Prediction of apparent digestible energy content of commercial pelleted feeds for rabbits. *J. Appl. Rabbit Res., 11: 60-67.*

Maertens L., Aerts J.M., De Brabander D.L. 2005. Effet d'un aliment riche en acides gras omega-3 sur les performances et la composition du lait des lapines et la viabilité de leur descendance. *In Proc.: 11èmes Journées de la Recherche Cunicole, Paris, 205-208.*

Maertens L., Huyghebaert G., Delezie E. 2008. Fatty acid composition of rabbit meat when fed a linseed based diet during different periods after weaning. *In Proc.: 9th World Rabbit Congress, 10-13 June, 2008. Verona, Italy., 1381-1386.*

Matthews K.R., Homer D.B., Thies F., Calder P.C. 2000. Effect of whole linseed Linum usitatissimum in the diet of finishing pigs on growth performance and on the quality and fatty acid composition of various tissues. *Br. J. Nutr., 83: 637-643.*

Prasad K. 1997. Dietary flax seed in prevention of hypercolesterolemic atherosclerosis. *Atherosclerosis, 132: 69-76.*

Plourde M., Cunnane S.C. 2008. Extremely limited synthesis of long-chain polyunsaturates in adults: implications for their dietary essentiality and use as supplements. *Appl. Physiol. Nutr. Metab., 33: 228-229.*

Rey A.I., Kerry J.P., Lynch P.B., Lopez-Bote C.J., Buckley D.J., Morrissey P.A. 2001. Effect of dietary oils and alpha-tocopheryl acetate supplementation on lipid TBARS and cholesterol oxidation in cooked pork. *J. Anim. Sci., 79: 1201-1208.*

Riley P.A., Enser M., Nute G.R., Wood J.D. 2000. Effects of dietary linseed on nutritional value and other quality aspects of pig muscle and adipose tissue. *Anim. Sci., 71: 483-500.*

Rymer C., Givens D.I. 2005. N-3 fatty acid enrichment of edible tissue of poultry: a review. *Lipids, 40: 121-30.*

SAS Institute 1988. SAS®/STAT Guide for Personal Computers. *Version 6.03 Edition. SAS Institute Inc., Cary, NC.*

Simopoulos, A.P. 2000. Human requirement for n-3 polyunsaturated fatty acids. *Poult. Sci., 79: 961-970.*

Toschi T.G., Bendini A., Ricci A., Lercker G. 2003. Pressurized solvent extraction of total lipids in poultry meat. *Food Chem., 83: 551-555.*

Verdelhan S., Bourdillon A., Renouf B., Audoin E. 2005. Effet de l'incorporation de 2% d'huile de lin dans l'aliment sur les performances zootechniques et sanitaires de lapins en croissance. *In Proc.: 11èmes Journées de la Recherche Cunicole, Paris, 209-211.*

Wood J.D., Richardson R.I., Nute G.R., Fisher A.V., Campo M.M., Kasapidou E., Sheard P.R., Enser M. 2004. Effects of fatty acids on meat quality: a review. *Meat Sci., 66: 21-32.*

Zsédely E., Tóth T., Eiben Cs., Virág Gy., Fábián J., Schmidt J. 2008. Effect of dietary vegetable oil (sunflower, linseed) and vitamin e supplementation on the fatty acid composition, oxidative stability and quality of rabbit meat. *In Proc.: 9th World Rabbit Congress, 10-13 June, 2008. Verona, Italy., 1473-1477.*