PAPER

Effects of diets with increasing levels of golden flaxseed on carcass characteristics, meat quality and lipid traits of growing rabbits

Pier Giorgio Peiretti,[1] Giorgia Meineri[2]

[1]Istituto di Scienze delle Produzioni Alimentari, Consiglio Nazionale delle Ricerche, Torino, Italy

[2]Dipartimento di Produzioni Animali, Epidemiologia ed Ecologia, Università di Torino, Italy

Abstract

The aim of this study was to determine the effects of three levels (0, 8, or 16%) of the golden variety of flaxseed (GFS; *Linum usitatissimum L.*), included in isonitrogenous and isocaloric diets, on the carcass characteristics, meat composition and fatty acid profile of rabbit meat and perirenal fat. The trial was carried out on 30 weaned crossbred rabbits aged 9 weeks, weighing on average 2074 g. The animals were divided equally into three groups of 10 (five male and five female rabbits each) and kept separate in individual cages. At the end of the experiment, which lasted 5 weeks, there were no significant differences between the groups in the carcass yield or the proportions of various carcass parts and edible organs. Although the chemical composition of the meat was not significantly affected by the dietary treatment, the saturated fatty acid and monounsaturated fatty acid proportion in the *longissimus dorsi* muscle (-22% and -24%, respectively) and perirenal fat (-34% and –29%, respectively) decreased and the polyunsaturated fatty acid (PUFA) increased (+36% in the muscle and 43% in the fat, respectively) with increased GFS inclusion. GFS dietary supplementation has shown to be effective in improving the n-3 PUFA proportion (76% in the muscle and 77% in the fat, respectively), decreasing the n-6/n-3 ratio and reducing the saturation, atherogenic and thrombogenic indexes of the meat, with consequent benefits on the nutritional quality of rabbit meat for consumers.

Introduction

Flaxseed (*Linum usitatissimum L.*) is an excellent source of n-3 polyunsaturated fatty acids (PUFA) and recently there has been increasing interest in enhancing n-3 PUFA in the human diet for heart health and potential chemo-protective purposes (Huang and Milles, 1996; Huang and Ziboh, 2001). Health-conscious consumers have raised the demand for PUFA-enriched meats and numerous studies have been undertaken to increase the PUFA level in meat through dietary supplementation.

The dietary use of flaxseed has been proposed by many authors to obtain meat with raised n-3 PUFA in beef cattle (Scollan *et al*., 2001; Raes *et al*., 2004), in pigs (Enser *et al*., 2000; Riley *et al*., 2000; Matthews *et al*., 2000) and in chickens (Rymer and Givens, 2005; Shen *et al*., 2005). The possibility of improving the n-3 PUFA proportion and decreasing the n-6/n-3 ratio of rabbit meat by dietary supplementation has important implications and the inclusion of flaxseed in diets has successfully been attempted in rabbits (Bernardini *et al*., 1999; Cavani *et al*., 2003; Dal Bosco *et al*., 2004; Colin *et al*., 2005; Bianchi *et al*., 2006, 2009; Kouba *et al*., 2008). Tres *et al*. (2008, 2009) have investigated the effect of various dietary ratios of flaxseed oil and sunflower oil additions on litter growth and health, fattening performance and carcass traits. A commercially available golden variety of flaxseed (GFS) was used in this study. This variety was developed for human consumption and it is extensively consumed by humans that brown flaxseed is generally only considered as an animal feed. GFS can be given to rabbits at levels of up to 16% in the diet without any adverse effects on growth performance and with a better digestibility than the control diet (Peiretti and Meineri, 2008a). Rodríguez *et al*. (2001) have evaluated nutrient digestibility and the metabolisable energy of diets with graded concentrations of GFS fed to growing broiler chickens. Ortiz *et al*. (2001) have evaluated the metabolisable energy and digestibility of crude fat and single fatty acid of GFS in growing broiler chickens. No information is available on the effects of diets with increasing levels of GFS on meat quality and lipid traits of growing rabbits. The present work was designed to study GFS as a dietary source of n-3 PUFA for the production of healthy rabbit meat and its effect on the carcass characteristics, meat composition and fatty acid (FA) profile of the meat and perirenal fat.

Corresponding author: Dr. Giorgia Meineri, Dipartimento di Produzioni Animali, Epidemiologia ed Ecologia, Università di Torino, via Leonardo da Vinci 44, 10095 Grugliasco (TO), Italy.
Tel. +39.011.6709209 - Fax +39.011.6709240.
E-mail: giorgia.meineri@unito.it

Key words: Rabbit, Meat quality, *Linum usitatissimum*, Fatty acid.

Acknowledgments: the authors would like to thank Mr. G. Cerato for the preparation of the pelleted diets.
The research was supported by University funds.

Received for publication: 17 May 2010.
Accepted for publication: 17 July 2010.

Italian Journal of Animal Science 2010; 9:e70
doi:10.4081/ijas.2010.e70

Materials and methods

Animals and diets

The study was carried out at the CISRA experimental rabbitry at the University of Turin according to the guidelines for applied nutrition experiments in rabbits (Fernández-Carmona *et al*., 2005).

Thirtynine litters born the same day were taken at the commercial farm near Turin (north-west of Italy) and given ad libitum access to the weaning diet from 4 weeks until 9 weeks of age and then thirty weaned crossbred rabbits weighing, on average, 2074±145 g were randomly assigned to three groups of ten (five male and five female rabbits each). The animals were housed individually under standard conditions at a temperature of 22°C±2°C in wire cages at a height of 90 cm from the concrete floor. The animals were assigned three isocaloric and isonitrogenous dietary treatments containing 0, 8, or 16% of GFS. The ingredients and chemical composition of the diets are shown in Table 1. The GFS was obtained from the Seed Export Manitoba Inc. (Winnipeg, Canada). All the diets were pelleted fresh and stored in darkness. After 1 week for adaptation to the diets and cages, the animals were fed ad libitum for 5 weeks. The rabbit had free access to clean drinking water. A complete description of the performance and digestibility studies can be found in Peiretti and Meineri (2008a).

Measured traits

At the end of the experimental period, all the rabbits from each group were weighed and slaughtered without fasting. The carcasses were prepared by removing the skin, feet, paws, genital organs, urinary bladder and digestive tract, as recommended by Blasco *et al*. (1993). The carcass was weighed and the weights of the skin and limbs, head, liver, kidneys, heart and lungs were recorded and expressed as a percentage of slaughter weight (SW). The forelegs, hind legs, breast and ribs, loin and abdominal wall were weighed. Their weights were expressed as a percentage of commercial carcass weight (CCW).

The *longissimus dorsi* muscle and perirenal fat samples were collected 24 h post-mortem from the carcass and immediately frozen at -20°C until analysed.

Analytical determinations

The proximate composition of the GFS, diets and meat were determined according to the AOAC procedures (AOAC, 2000). The meat and diet samples were analysed to determine dry matter, total N content, ash by ignition to 550°C and ether extract (EE) using the Soxhlet method. The diet samples were also analysed to determine neutral detergent fibre (NDF) without sodium sulfite or α-amylase, and acid detergent fibre (ADF), as described by Van Soest *et al*. (1991), expressed exclusive of residual ash, acid detergent lignin (ADL) determined by solubilization of cellulose with sulphuric acid, as described by Robertson and Van Soest (1981), and gross energy (GE) by means of an adiabatic bomb calorimeter (IKA C7000, Staufen, Germany). Lipid extraction was performed on the GFS, the diets and the meat and fat samples according to Hara and Radin (1978), while the transesterification of the FAs was carried out according to Christie (1982), with the modifications described by Chouinard *et al*. (1999). The FAs were analysed as their methyl esters. The analysis was carried out by gas chromatography, as reported by Peiretti *et al*. (2007). The saturation (S/P), atherogenic (AI) and thrombogenic (TI) indexes were calculated according to Ulbricht and Southgate (1991) as follows:

$S/P=(C14:0+C16:0+C18:0)/[\Sigma MUFA+\Sigma PUFA]$

$AI=(C12:0+4xC14:0+C16:0)/[\Sigma MUFA+\Sigma(n-6)+\Sigma(n-3)]$

$TI=(C14:0+C16:0+C18:0)/[0.5x\Sigma MUFA+0.5x\Sigma(n-6)+3 x \Sigma(n-3)+\Sigma(n-3)/\Sigma(n-6)]$

where MUFA and PUFA are monounsaturated FAs and polyunsaturated FAs, respectively.

Statistical analyses

The statistical analyses were performed using the SPSS software package (version 11.5.1 for Windows, SPSS Inc., USA). An analysis of variance was used to evaluate the effects of different concentrations of GFS on the performance, carcass characteristics, meat composition and FA profile of the meat and fat of the rabbits. The differences were tested using Duncan's multiple range test. The LNA and LA proportions of the feed and muscles pertaining to the present and other works were also subjected to regression analysis using linear models.

Results and discussion

Productive performances, carcass traits and meat quality

No rabbit died during the trial. The weight gain and food intake did not differ significantly ($P>0.05$) between the dietary treatments (Table 2). These results are in agreement with others authors who have not observed any detrimental effect of whole flaxseed on the productive performance of rabbits (Bernardini *et al*., 1999; Dal Bosco *et al*., 2004; Bianchi *et al*., 2009). No sig-

Table 1. Ingredients and composition of the experimental diets.

	Golden flaxseed, % of diet		
	0	8	16
Ingredients			
Dehydrated alfalfa meal, %	46	44	42
Corn, %	15	17	17
Barley, %	19	15	14.5
Soybean seed meal, %	12	10	6.5
Palm oil, %	4	2	0
Golden flaxseed°, %	0	8	16
Lignosulphite, %	2	2	2
Vitamin-mineral premix#, %	2	2	2
Chemical composition			
Dry matter, %	90.4	91.1	91.7
Organic matter, % DM	92.2	91.8	92.2
Crude protein, % DM	18.9	19.1	18.4
Ether extract, % DM	5.3	7.3	9.7
Ash, % DM	7.8	8.2	7.8
Neutral detergent fibre, % DM	28.5	29.6	28.4
Acid detergent fibre, % DM	17.2	16.8	17.0
Acid detergent lignin, % DM	3.1	3.0	4.4
Gross energy, MJ/kg DM	18.6	19.0	19.7
Digestible energy,§ MJ/kg DM	12.1	12.2	12.2

°Proximate composition: moisture 6.7%, crude protein 23.5%, crude fibre 17.1%, ether extract 36.9%, ash 3.4%, nitrogen free extract 19.1%, gross energy 27.0 MJ/kg DM; #Per kg diet: Vit. A 200 U; α-tocopheryl acetate 16 mg; Niacine 72 mg; Vit. B_6 16 mg; Choline 0.48 mg; DL-methionine 600 mg; Ca 500 mg; P 920 mg; K 500 mg; Na 1 g; Mg 60 mg; Mn 1.7 mg; Cu 0.6 mg; §The digestible energy content of the diets was calculated according to the regression proposed by Fernández-Carmona *et al*. (1996).

Table 2. Carcass yield and proportions (means ± SE) of various carcass parts and organs of rabbits fed three levels of golden flaxseed.

	Golden flaxseed, % of diet		
	0	8	16
Initial weight, g	2091±42	2095±45	2035±52
Slaughter weight (SW), g	2939±80	2947±87	2891±57
Commercial carcass weight (CCW), g	1719±62	1746±56	1733±51
Carcass yield, %	58.4±0.91	59.2±0.38	59.9±0.70
Head, % SW	5.76±0.12	5.87±0.13	5.91±0.11
Liver, % SW	3.56±0.33	3.40±0.19	3.53±0.20
Kidneys, % SW	0.60±0.02	0.59±0.03	0.58±0.01
Heart, lung, etc., % SW	0.75±0.05	0.89±0.02	0.99±0.06
Skin and limbs, % SW	17.6±0.51	17.5±0.43	17.7±0.40
Hind legs, % CCW	27.2±0.54	27.1±0.32	27.0±0.25
Forelegs, % CCW	13.2±0.23	13.1±0.19	12.8±0.36
Breast and ribs, % CCW	20.5±0.36	21.4±0.60	20.4±0.71
Loin and abdominal wall, % CCW	20.8±0.51	20.1±0.50	21.2±0.68

nificant effects of diets with different dietary ratios of flaxseed and sunflower oils were found on the litter or doe performances and the body weight of the fattening rabbits was unaffected up to 77 days (Eiben *et al*., 2010). This finding coincides with that of Maertens *et al*. (2005), who reported beneficial effects of flaxseed on the performance, milk composition and viability of the progeny in rabbit does. Similarly, growth was unaffected when the rabbits were fed a 3% flaxseed oil or a 3% sunflower oil diet from 17 to 44 days of age (Casado *et al*., 2006).

Previous studies pointed out a decrease in the growth rate of rabbits fed diets containing flaxseed oil (Verdelhan *et al*., 2005), extruded flaxseed (Colin *et al*., 2005) or whole flaxseed (Bianchi *et al*., 2006). Some authors associated the poorer growth rate to the presence of toxic substances in raw whole flaxseed, which may depress energy utilization. A correct pelletting procedure may have a good effect on reducing the anti-nutritional factor content, as reported by Shen *et al*. (2005), who found a satisfactory growth performance in broilers fed diets containing 12% of pellet-processed flaxseed.

The inclusion of GFS in the diets did not significantly influence the carcass yield or the proportions of the various carcass parts and organs of the rabbits (Table 2).

The chemical composition of the *longissimus dorsi* muscle was not affected by the diets with increasing levels of GFS (Table 3). This finding coincides with that of Kouba *et al*. (2008), who reported that an n-3 PUFA rich diet with 3% extruded flaxseed did not have any effect on the dry matter, protein or lipids of the rabbit muscles. Similarly, the chemical composition of the *longissimus dorsi* muscle was unaffected when rabbits were fed an 8% flaxseed diet (Dal Bosco *et al*., 2004).

Fatty acid profile of the diet, meat and perirenal fat

The FA profile of the golden variety of flaxseed and the three diets is reported in Table 4. The FA component of the GFS was α-linolenic acid (LNA, C18:3 n-3) (58%) and its value similar to those reported in literature for the brown variety (Ortiz *et al*., 2001; Rodríguez *et al*., 2001; Bean and Leeson, 2002). GFS also presented a good percentage of linoleic acid (LA, C18:2 n-6) and oleic acid (OA, C18:1 n-9). As far as the FA profile of the diets is concerned, there was an increase in LNA and a decrease in palmitic acid (PA, C16:0), OA and LA with increasing GFS supplementation.

The main FA profile of the *longissimus dorsi* muscle and perirenal fat are shown in Tables 5 and 6, respectively. A decrease was found for C14:0, C14:1, C15:0, C16:0, C16:1 and C18:1 n-9 with an increasing GFS inclusion level in both tissues, while a decreasing trend was also found in the perirenal fat for C18:0 and C20:1 n-9. As far the main FA, the increased percentages of LNA in the *longissimus dorsi* muscle and perirenal fat of the rabbits fed diets with increasing levels of GFS is the results of a progressively higher proportion of this FA in the 8 and 16% GFS diets than the control diet. Conversely, the LA proportion of these tissues did not significantly differ between the groups. The significant increase in LNA and the relatively constant trend of LA in the meat of rabbits fed diets rich in LNA and LA is in agreement with the results of Dal Bosco *et al*. (2004), Peiretti *et al*. (2007), Kouba *et al*. (2008) and Peiretti and Meineri (2008a) (Figures 1 and 2, respectively). The relationship between the

Table 3. Chemical composition (on a dry matter basis; means±SE) of the *longissimus dorsi* muscle of rabbits (n=30; age=14 weeks) fed three levels of golden flaxseed after 1 d of storage at 4°C.

	Golden flaxseed, % of diet		
	0	8	16
Dry matter, %	25.4±0.3	25.8±0.3	25.3±0.2
Protein, %	91.8±0.3	90.6±0.5	90.3±0.6
Ash, %	5.2±0.1	5.3±0.1	5.3±0.1
Ether extract, %	2.5±0.2	2.6±0.3	2.9±0.2

Table 4. Fatty acid profile of the golden flaxseed and the diets (% of total FA).

	GFS	Golden flaxseed, % of diet		
		0	8	16
C12:0	0.0	0.1	0.0	0.0
C14:0	0.0	0.5	0.3	0.1
C16:0	4.6	29.1	15.7	8.3
C18:0	3.3	3.9	3.5	3.3
C18:1n-9	15.7	30.0	23.0	18.4
C18:1n-7	0.7	0.6	0.6	0.7
C18:2n-6	15.9	23.5	21.7	20.6
C18:3n-3	58.3	7.6	32.9	46.9
C20:0	0.0	0.3	0.2	0.1
C20:1n-9	0.0	0.2	0.2	0.2
Unidentified	1.4	4.0	1.7	1.4

FA, Fatty acid; GFS, golden flaxseed.

Table 5. Fatty acid (FA) profile (% of total FA; means±SE) of the *longissimus dorsi* muscle of rabbits (n=30; age=14 weeks) fed three levels of golden flaxseed.

	Golden flaxseed, % of diet		
	0	8	16
C14:0	2.16±0.14^{a}	1.85±0.09^{a}	1.52±0.10^{b}
C14:1	0.20±0.05^{a}	0.14±0.03^{ab}	0.06±0.03^{b}
C15:0	0.46±0.02^{a}	0.46±0.01^{a}	0.41±0.01^{b}
C16:0	26.23±0.37^{a}	23.47±0.34^{b}	19.73±0.51^{c}
C16:1	3.51±0.54^{a}	2.67±0.30^{ab}	1.89±0.25^{b}
C17:0	0.25±0.05^{a}	0.45±0.03^{b}	0.45±0.01^{b}
C18:0	5.84±0.21	5.52±0.16	5.22±0.16
C18:1 n-9	27.08±0.53^{a}	23.80±0.33^{b}	21.43±0.28^{c}
C18:1 n-7	1.10±0.05	1.03±0.04	0.97±0.03
C18:2 n-6	20.01±0.70	20.02±0.31	20.24±0.28
C18:3 n-6	0.22±0.02	0.19±0.02	0.15±0.01
C18:3 n-3	4.65±0.21^{a}	12.35±0.66^{b}	20.08±0.91^{c}
C20:1 n-9	0.22±0.01	0.18±0.01	0.18±0.01
C20:3 n-3	0.26±0.03	0.24±0.04	0.18±0.01
C20:4 n-6	2.06±0.24	2.32±0.27	2.05±0.21
Unidentified	5.74±0.48	5.34±0.48	5.44±0.63

^{a,b,c}Means in the same row with different superscripts differ (P<0.05).

LNA proportion of the diet and the LNA proportion in the rabbit meat was evidenced by the linear regressions found in the *longissimus dorsi* muscle (LNA=0.534x feed LNA-0.9994; R^2 =0.84). Viceversa, the LA proportion of this muscle did not change with increasing levels of LA in the diet (Figure 2). This trend is partially confirmed when LNA and LA concentrations on fat basis of feed and muscle were regressed as reported in Figures 3 and 4, respectively, even if the relationship between the LNA concentration of the diet and the LNA concentration in the rabbit meat was less predictive (R^2=0.71). The effectiveness of whole flaxseed in increasing the LNA and n-3 PUFA contents of the meat was previously reported in several studies on rabbits (Bernardini *et al*., 1999; Dal Bosco *et al*., 2004; Bianchi *et al*., 2006; Maertens *et al*., 2008). Bianchi *et al*. (2009) found a close relationship (R^2=0.99) between the LNA content in rabbit meat and the whole flaxseed content in the diet, but the LNA proportion found in this experiment in the *longissimus dorsi* muscle of rabbit fed GFS supplemented diet was lower than that found in the work at the same flaxseed inclusion level. Another close relationship (R^2=0.94) between the n-3 PUFA feed level and the rabbit meat composition was found by Colin *et al*. (2005).

In Tables 7 and 8 are also reported saturated fatty acid (SFA), MUFA and PUFA, n-6 PUFA, n-3 PUFA, n-6/n-3 ratios, saturation (S/P), atherogenic (AI) and thrombogenic (TI) indexes for the *longissimus dorsi* muscle and for perirenal fat, respectively. These parameters are a commonly used criterion to describe the dietetic value of tissues. The PUFA proportion and, in particular, the n-3 PUFA proportion of these tissues increased with increasing levels of GFS inclusion. Conversely, a decrease was found for the SFA and MUFA proportions with an increasing level of GFS inclusion. These results agree with the findings of some authors (Dal Bosco *et al*., 2004; Peiretti *et al*., 2007; Peiretti and Meineri, 2008b) who fed oilseed rich in LNA to rabbits.

The n-6/n-3 PUFA ratio of the rabbit meat decreased from 4.58 and 3.33 in the meat and perirenal fat of rabbits fed the control diet, to 1.13 and 0.79 in the meat and perirenal fat of rabbits fed the 16% GFS diet. However, the n-6/n-3 ratio in the rabbit meat was usually higher than 5, due to the high LNA content of traditional diets, and reached 7 in the loin (Dal Bosco *et al*., 2004) and 11-11.6 in the hin dleg meat (Dalle Zotte, 2002). Similarly, Kouba *et al*. (2008) found that flaxseed, when fed to rabbits, significantly increased the PUFA content and lowered the n-6/n-3 ratios, SFA and MUFA contents of the *longissimus dorsi* muscle and perirenal fat compared to the control diet. Several studies have highlighted that flaxseed enriched diets generally increase the unsaturation of depot lipids (Bianchi *et al*., 2006, 2009) and reduce their n-6/n-3 ratio (Dal Bosco *et al*., 2004; Colin *et al*., 2005; Maertens *et al*., 2008).

The n-6/n-3 ratio found in the rabbit meat and fat of the control group of the present study was higher than GFS-diets, but lower than those found in commercial diets for rabbit and this was mainly due to the high level of incorporation of alfalfa (more than 40%), which increased the amount of LNA in the diet and consequently in the rabbit tissues.

The saturation, atherogenic and thrombogenic indexes showed significant variations, and a decrease with an increasing GFS inclusion level was found for all these indexes

Table 6. Fatty acid (FA) profile (% of total FA; means±SE) of the perirenal fat of rabbits (n=30; age=14 weeks) fed three levels of golden flaxseed.

	Golden flaxseed, % of diet		
	0	8	16
C10:0	0.11±0.03	0.09±0.03	0.11±0.03
C12:0	0.15±0.03	0.14±0.03	0.14±0.03
C14:0	1.94±0.12^{a}	1.54±0.05^{b}	1.33±0.07^{b}
C14:1	0.19±0.05^{a}	0.10±0.03^{ab}	0.04±0.02^{b}
C15:0	0.50±0.03^{a}	0.43±0.02^{b}	0.40±0.01^{b}
C16:0	26.08±0.49^{a}	19.76±0.30^{b}	16.82±0.65^{c}
C16:1	2.99±0.50^{a}	2.02±0.23^{ab}	1.18±0.14^{b}
C17:0	0.55±0.03^{a}	0.56±0.05^{a}	0.44±0.01^{b}
C18:0	6.36±0.22^{a}	5.43±0.13^{b}	5.20±0.11^{b}
C18:1 n-9	29.00±0.42^{a}	24.03±0.24^{b}	20.44±0.26^{c}
C18:1 n-7	0.96±0.10	0.84±0.02	0.82±0.02
C18:2 n-6	21.63±0.58	21.50±0.42	21.69±0.46
C18:3 n-6	0.17±0.01^{a}	0.17±0.01^{a}	0.14±0.01^{b}
C18:3 n-3	6.58±0.18^{a}	19.33±0.33^{b}	28.37±1.22^{c}
C20:0	0.15±0.01^{a}	0.06±0.02^{c}	0.11±0.01^{b}
C20:1n-9	0.25±0.01^{a}	0.25±0.02^{a}	0.17±0.01^{b}
Unidentified	2.48±0.15^{a}	3.77±0.36^{b}	2.59±0.14^{a}

^{a,b,c}Means in the same row with different superscripts differ (P<0.05).

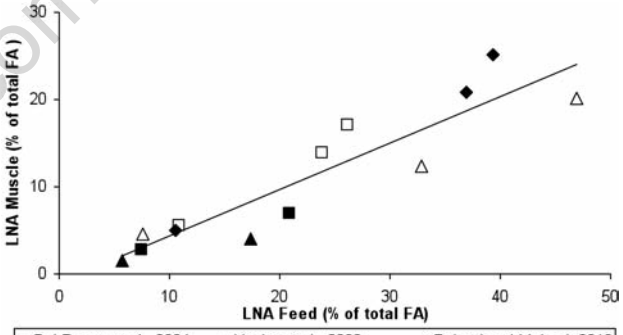

Figure 1. Proportions of α-linolenic acid in feeds plotted against the linolenic acid value of the *longissimus dorsi* muscle of rabbits. Regression line, muscle linolenic acid =0.534 x feed linolenic acid -0.9994 (R^2=0.84).

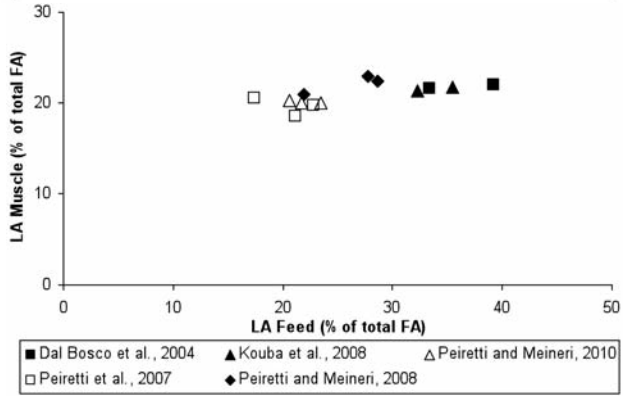

Figure 2. Proportions of linoleic acid in feeds plotted against the linoleic acid value of the *longissimus dorsi* muscle of rabbits.

(Tables 7 and 8). The S/P ratio was higher in the meat and perirenal fat of the rabbits fed the control diet (0.58 and 0.59, respectively) and lower in the meat and perirenal fat of the rabbits fed 16% of GFS (0.39 and 0.33, respectively). A decreasing trend of the atherogenic and thrombogenic indexes of the muscle and perirenal fat was observed in the same experiments there was and their values were similar to those found in the present study.

Conclusions

The dietary use of the golden variety of flaxseed in growing rabbits can be exploited with the aim of producing rabbit meat with a higher LNA proportion. The results of this experiment have demonstrated that the nutritional value of rabbit meat can be improved by increasing its LNA proportion by up to three and four times through the use of diets containing 8% and 16% GFS, while all the indexes related to nutritional quality improve when their values are halved. However, the impact of n-3 PUFA enrichment of rabbit meat on its oxidative stability still needs to be evaluated by feeding animal with supranutritional levels of an antioxidant with the aim of improving meat shelf-life.

In conclusion, there is not much difference between brown flaxseed and GFS, but some specific advantages of using the GFS than brown flaxseed, normally used for animal feed, exist. The demand for organic products grows everyday and GFS is so readily available in certified organic form and it could be used in organic rabbitry; however it is necessary to assess the commercial applicability, considering its greater cost.

References

AOAC, 2000. Official Methods of Analysis of the AOAC. AOAC, Arlington, VA, USA.

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. Poultry Res. 11:209-211.

Bernardini, M., Dal Bosco, A., Castellini, C., 1999. Effect of dietary n3/n6 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.

Bianchi, M., Petracci, M., Cavani, C., 2009. The

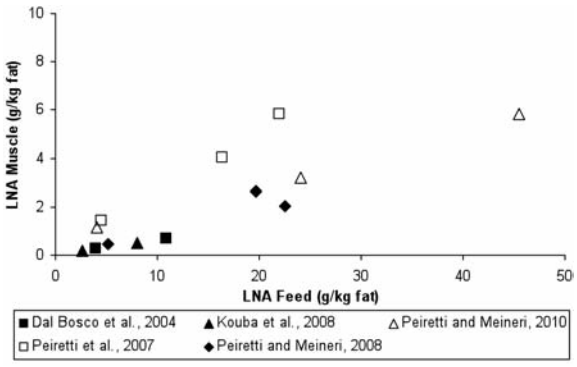

Figure 3. Concentration of α-linolenic acid in feeds plotted against the linolenic acid value of the *longissimus dorsi* muscle of rabbits. Regression line, muscle linolenic acid=0.138 x feed linolenic acid+ 0.169 (R^2=0.71).

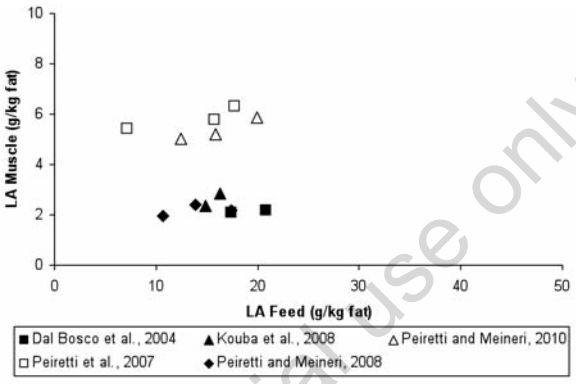

Figure 4. Concentrations of linoleic acid in feeds plotted against the linolenic acid value of the *longissimus dorsi* muscle of rabbits.

Table 7. Fatty acid composition (% of total FA; means±SE) and indexes related to human health in the *longissimus dorsi* muscle of rabbits (n=30; age=14 weeks) fed three levels of golden flaxseed.

	Golden flaxseed, % of diet		
	0	8	16
SFA	34.94±0.36[a]	31.75±0.39[b]	27.33±0.55[c]
MUFA	32.11±1.04[a]	27.81±0.63[b]	24.53±0.51[c]
PUFA	27.20±0.88[a]	35.12±0.45[b]	42.70±0.80[c]
PUFA n-3	4.91±0.19[a]	12.59±0.63[b]	20.25±0.91[c]
PUFA n-6	22.29±0.78	22.53±0.53	22.45±0.36
n-6/n-3	4.58±0.19[a]	1.85±0.15[b]	1.13±0.07[c]
S/P	0.58±0.01[a]	0.49±0.01[b]	0.39±0.01[c]
Atherogenic index	0.59±0.02[a]	0.49±0.01[b]	0.38±0.01[c]
Thrombogenic index	0.81±0.02[a]	0.49±0.02[b]	0.31±0.01[c]

[a,b,c]Means in the same row with different superscripts differ (P<0.05); SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; PUFA n-3, polyunsaturated fatty acid series n-3; PUFA n-6, polyunsaturated fatty acid series n-6; n-6/n-3, PUFA n-6/ PUFA n-3 ratio; S/P, saturated fatty acid/unsaturated fatty acid.

Table 8. Fatty acid composition (% of total FA; means±SE) and indexes related to human health in the perirenal fat of rabbits (n=30; age=14 weeks) fed three levels of golden flaxseed.

	Golden flaxseed, % of diet		
	0	8	16
SFA	34.94±0.36[a]	31.75±0.39[b]	27.33±0.55[c]
MUFA	32.11±1.04[a]	27.81±0.63[b]	24.53±0.51[c]
PUFA	27.20±0.88[a]	35.12±0.45[b]	42.70±0.80[c]
PUFA n-3	4.91±0.19[a]	12.59±0.63[b]	20.25±0.91[c]
PUFA n-6	22.29±0.78	22.53±0.53	22.45±0.36
n-6/n-3	4.58±0.19[a]	1.85±0.15[b]	1.13±0.07[c]
S/P	0.58±0.01[a]	0.49±0.01[b]	0.39±0.01[c]
Atherogenic index	0.59±0.02[a]	0.49±0.01[b]	0.38±0.01[c]
Thrombogenic index	0.81±0.02[a]	0.49±0.02[b]	0.31±0.01[c]

[a,b,c]Means in the same row with different superscripts differ (P<0.05); SFA, saturated fatty acid; MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; PUFA n-3, polyunsaturated fatty acid series n-3; PUFA n-6, polyunsaturated fatty acid series n-6; n-6/n-3, PUFA n-6/ PUFA n-3 ratio; S/P, saturated fatty acid/unsaturated fatty acid.

influence of linseed on rabbit meat quality. World Rabbit Sci. 17:97-107.

Blasco, A., Ouhayoun, J., Masoero, G., 1993. Harmonization of criteria and terminology in rabbit meat research. World Rabbit Res. 1:3-10.

Casado, C., Pascual, J.J., Moya, V.J., Blas, E., Cervera, C., 2006. Effect of type and oxidation level of the dietary fat on the performance of fattening rabbits. pp 1-6 in Proc. 3rd Int. Congr. de Cunicultura de las Américas, Maringá, Brazil.

Cavani, C,. Betti, M., Bianchi, M., Petracci, M., 2003. Effects of the dietary inclusion of vegetable fat and dehydrated alfalfa meal on the technological properties of rabbit meat. Vet. Res. Commun. 27:643-646.

Chouinard, P.Y., Corneau, L., Sæbø, A., Bauman, D.E., 1999. Milk yield and composition during abomasal infusion of conjugated linoleic acids in dairy cows. J. Dairy Sci. 82:2737-2745.

Christie, W.W., 1982. A simple procedure for rapid transmethylation of glycerolipids and cholesteryl esters. J. Lipid Res. 23:1072-1075.

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. pp 163-166 in Proc. 11èmes Journées de la Recherche Cunicole, Paris, France.

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.

Eiben, Cs., Végia, B., Virága, Gy., Gódor-Surmanna, K., Marób, A., Odermattc, M., Zsédelyd, E., Tóthd, T., Schmidt, J., 2010. Effect of different dietary ratios of sunflower and linseed oils on growth and carcass traits of rabbits. Livest. Prod. Sci. 131:15-22.

Enser, M., Richardson, R.I., Wood, J.D., Gill, B.P., Sheard, P.R., 2000. Feeding linseed to increase the n-3 PUFA of pork: fatty acid composition of muscle, adipose tissue, liver and sausages. Meat Sci. 55:201-212.

Fernández-Carmona, J., Blas, E., Pascual, J.J., Maertens, L., Gidenne, T., Xiccato, G., García, J., 2005. Recommendations and guidelines for applied nutrition experiments in rabbits. World Rabbit Sci. 13:209-228.

Fernández-Carmona, J., Cervera, C., Blas, E., 1996. Prediction of the energy value of rabbit feeds varying widely in fibre content. Anim. Feed Sci. Tech. 64:61-75.

Hara, A., Radin, N.S., 1978. Lipid extraction of tissues with a low-toxicity solvent. Anal. Biochem. 90:420-426.

Huang, Y.S., Milles, D.E., 1996. Gamma-linolenic acid: metabolism and its roles in nutrition and medicine. AOCS Press, Champaign, IL, USA.

Huang, Y.S., Ziboh, A., 2001. Gamma-linolenic acid: recent advances in biotechnology and clinical applications. AOCS Press, Champaign, IL, USA.

Kouba, M., Benatmane, F., Blochet, J.E., Mourot, J., 2008. Effect of a linseed diet on lipid oxidation, fatty acid composition of muscle, perirenal fat, and raw and cooked rabbit meat. Meat Sci. 80:829-834.

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. pp 205-208 in Proc. 11èmes Journées de la Recherche Cunicole, Paris, France.

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

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. Brit. J. Nutr. 83:637-643.

Ortiz, L.T., Rebolé, A., Alzueta, C., Rodríguez, M.L., Treviño, J., 2001. Metabolisable energy value and digestibility of fat and fatty acids in linseed determined with growing broiler chickens. Brit. Poultry Sci. 42:57-63.

Peiretti, P.G., Meineri, G., 2008a. Effects of whole golden flaxseed supplementation on performance and feed digestibility of rabbits. J. Anim. Vet. Adv. 7:56-60.

Peiretti, P.G., Meineri, G., 2008b. Effects on growth performance, carcass characteristics, and the fat and meat fatty acid profile of rabbits fed diets with chia (Salvia hispanica L.) seed supplements. Meat Sci. 80:1116-1121.

Peiretti, P.G., Mussa, P.P., Prola, L., Meineri, G., 2007. Use of different levels of false flax (Camelina sativa L.) seed in diets for fattening rabbits. Livest. Sci. 107:192-198.

Raes, K., Haak, L., Balcaen, A., Claeys, E., Demeyer, D., De Smet, S., 2004. Effect of linseed feeding at similar linoleic acid levels on the fatty acid composition of double-muscled Belgian Blue young bulls. Meat Sci. 66:307-315.

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.

Robertson, J.B., Van Soest, P.J., 1981. The detergent system of analysis. In: W.P.T. James and O. Theander (eds.) The Analysis of Dietary Fibre in Food. Marcel Dekker, NY, USA, pp 123-158.

Rodríguez, M.L., Alzueta, C., Rebolé, A., Ortiz, L.T., Centeno, C., Treviño, J., 2001. Effect of inclusion level of linseed on the nutrient utilisation of diets for growing broiler chickens. Brit. Poultry Sci. 42:368-375.

Rymer, C., Givens, D.I., 2005. N-3 fatty acid enrichment of edible tissue of poultry: a review. Lipids 40:121-130.

Scollan, N.D., Choi, N.J., Kurt, E., Fisher, A.V., Enser, M., Wood, J.D., 2001. Manipulating the fatty acid composition of muscle and adipose tissue in beef cattle. Brit. J. Nutr. 85:115-124.

Shen, Y., Feng, D., Fan, M.Z., Chavez, E.R., 2005. Performance, carcass cut-up and fatty acids deposition in broilers fed different levels of pellet-processed flaxseed. J. Sci. Food Agr. 85:2005-2014.

Tres, A., Bou, R., Codony, R., Guardiola, F., 2008. Influence of different dietary doses of n-3- or n-6-rich vegetable fats and alpha-tocopheryl acetate supplementation on raw and cooked rabbit meat composition and oxidative stability. J. Agr. Food Chem. 56:7243-7253.

Tres, A., Bou, R., Codony, R., Guardiola, F., 2009. Dietary n-6 or n-3-rich vegetable fats and α-tocopheryl acetate: effects on fatty acid composition and stability of rabbit plasma, liver and meat. Animal 3:1408-1419.

Ulbricht, T.L., Southgate, D.A.T., 1991. Coronary heart disease: seven dietary factors. Lancet 338:985-992.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74:3583-3591.

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. pp 209-211 in Proc. 11èmes Journées de la Recherche Cunicole, Paris, France.