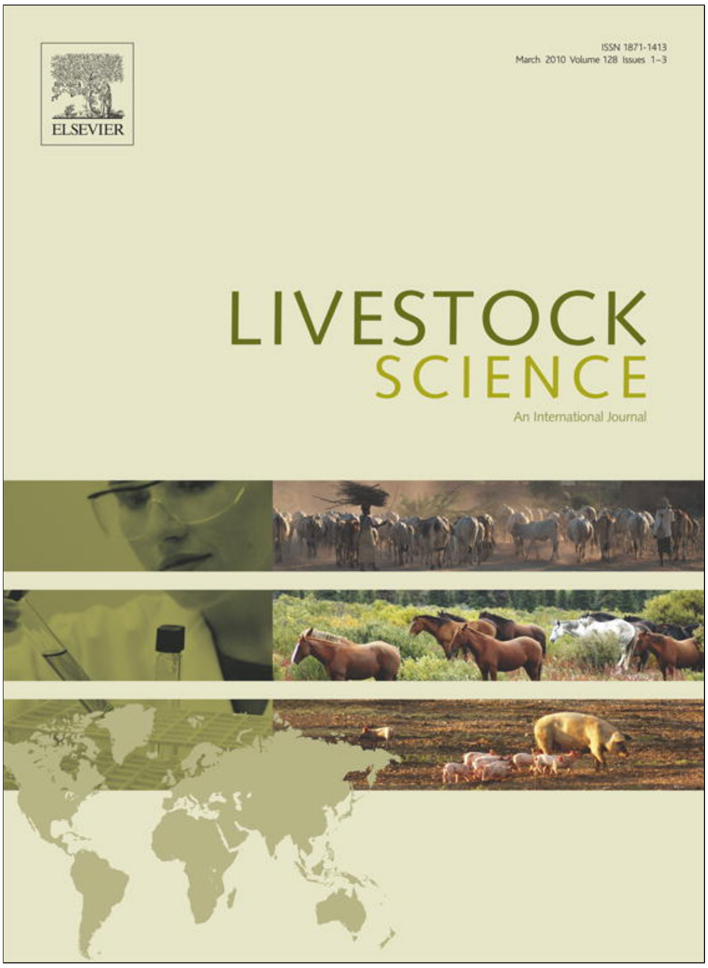
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Influence of marine algae (*Schizochytrium spp.*) dietary supplementation on doe performance and progeny meat quality

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ABSTRACT

A study was conducted on a total of 240 primiparous does and their 1184 kits. Does were divided into two experimental groups of 120 each and their kits into four groups. Does were all submitted to artificial insemination on the same day; both groups were fed commercial diets supplemented respectively with coconut oil (2 g/kg) and dehydrated alfalfa (2 g/kg) (Group D−) or cultivated single-cell marine algae (4 g/kg) characterized by a high content of long-chain polyunsaturated fatty acids (LCPUFA) (primarily docosahexaenoic acid, DHA) (Group D+). Kits born from the 200 does that became pregnant (100 in the first group and 100 in the second) were assigned to 4 experimental groups (2 treated and 2 controls) and received, like their mothers, commercial diets with or without LCPUFA supplementation. Results showed a substantial similarity in the reproductive efficiency of does and zootechnical and slaughtering performances of growing–fattening rabbits. The quality of loin and thigh lipids also were influenced not only by the presence of algae in the feeds administered to weaned and finishing rabbits, but also by n-3 LCPUFA supplementation in the mothers' diet.

1. Introduction

Among herbivorous animals of zootechnical interest, the rabbit lends itself well to the production of meat rich in long-chain polyunsaturated fatty acids (LCPUFA). In intensive breeding conditions, supplementing the diet with 25–40% of dehydrated alfalfa meal is sufficient to induce a significant increase in the n-3 fatty acid content of meat and reduce the n-6/n-3 ratio of muscle lipids (Castellini et al., 1999; Cavani et al., 2004; Dal Bosco et al., 2004). In such conditions, the n-6/n-3 ratio is near to 4, deemed satisfactory for human nutrition (Wood et al., 2003).

When diets are supplemented with fish meal the effect on lipid composition is evident (Castellini and Dal Bosco, 1996; Castellini et al., 1999). Supplementation of the diet with linseeds and linseed oil, well known to be rich in α-linolenic acid, has likewise shown to be effective in enriching rabbit meat with n-3 LCPUFA (Bernardini et al., 1999; Cavani et al., 2003; Dal Bosco et al., 2004; Cavani et al., 2004). Such a circumstance, besides confirming the capacity of rabbit to elongate and desaturate linolenic acid to LCPUFA n-3 (≥C 20), offers concrete possibilities of improving the nutritional properties of rabbit meat for human health. To obtain this result there must be a good balance between n-6 and n-3, since excessive quantities of dietary n-6 would have a negative impact in rabbits (Bernardini et al., 1999). Moreover, epidemiologic studies suggest that unbalances in the n-6/n-3 ratio may increase the incidence of breast and prostate cancer in humans (Terry et al., 2004).

While it may be relatively easy to increase the LCPUFA content in rabbit meat by raising the level of α-linolenic acid in the diet, an even more effective approach is to add PUFA n-3 from fish derivatives or cultivated algae, known to be extremely rich in eicosapentaenoic acid (EPA) and/or docosapentaenoic acid (DPA) and/or DHA (Tassinari et al., 2002).

Literature findings leave some doubts about the concrete possibilities for enriching the lipid fraction of rabbit meat through dietary manipulation. There are few data about the rate of LCPUFA transfer, as well as the stability and shelf life of enriched meat, though research into the latter aspect has

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already given some interesting insights (Castellini et al., 1998; Bianchi et al., 2006; Dal Bosco et al., 2004).

The use of LCPUFA n-3 supplements in animal diets is not limited to enriching tissues to produce functional foods for human consumption; such supplements are also employed in the preparation of pet foods (Biagi et al., 2004) and possibly of livestock feeds as well, with the aim, however, of improving the reproductive performance and health of mothers and offspring (Mordenti et al., 2005).

At this point a question arises. "Can the use of LCPUFA n-3 enriched feeds in the diets of rabbit does during gestation and lactation in any way influence the reproductive efficiency and zootechnical performances of mothers or the nutritional properties of the meat obtained from their kits?" Studies have been conducted in sows where the addition of linseed oil to the diet increased the linoleic acid and docosahexaenoic acid (DHA) content both in milk and in the piglets' tissues (Bazinet et al., 2003).

The aim of this study was to evaluate whether the use of LCPUFA n-3 enriched feeds in the diets of rabbit does during gestation and lactation can influence the reproductive efficiency and zootechnical performances of mothers or the nutritional properties of the meat obtained from their kits.

2. Materials and methods

The institutional ethical committee on care and use of laboratory animals of the University of Bologna reviewed and approved the experimental protocol.

2.1. Diets

Does (D) received a commercial single formula feed (gestation and lactation); growing rabbits (K) received two different commercial feeds: growing (first 28 days after weaning) and finishing. Water and feed were available *ad libitum* to the animals. Does and growing rabbits were divided into two experimental groups that differed in the lipid source used: groups D− and K− received commercial feed supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa: groups D+ and K+ received the same commercial feed supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold — Omega Tech. Inc. Boulder Colorado, USA), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents. Both supplements were included in the feed before pelleting. All the diets were pelleted fresh and stored in darkness to avoid auto-oxidation of the lipid source.

The composition of the algae used and fatty acid pattern of its lipid fraction are shown in Table 1. Analytical composition of all the diets are shown in Table 2.

2.2. Does and kits up to weaning

Two hundred forty nulliparous does of the commercial Hycole hybrid were used. Does were randomly assigned to two experimental groups (D−, Control and D+, Treated) of 120 does each and all does were submitted to artificial insemination on the same day.

Ten days after mating, does were palpated to detect pregnancy: non pregnant does were discarded from the trial. Does belonging to the two groups continued to receive experimental diets throughout the period of gestation and lactation until weaning, which took place 35 days after parturition.

Table 1
Composition of the algae (*Schizochytrium spp.*) used and its lipid fraction.

Chemical composition (% of DM)	
Dry matter (wet basis)	96.5
Crude protein (CP)	14.5
Ether extract (EE)	49.5
Crude fiber	0.2
Ash	8.6
Fatty acid composition (% of total fatty acids)	
C 14:0	10.0
C 16:0	23.0
C 16:1	1.8
C 18:0	0.5
C 18:1 n-9	6.2
C 18:3 n-3	2.7
C 20:3 n-6	2.2
C 20:4 n-6	0.1
C 20:5 n-3 (EPA)	2.6
C 22:5 n-6 (DPA)	13.4
C 22:6 n-3 (DHA)	37.6
n-6/n-3 ratio	0.36

During the study, data were collected regarding the reproductive performance of does (weight at insemination, mean born/delivery, mean live born/delivery, kits' born average weight, kits weaned/doe, and kits' weaned average weight) and the state of health of kits from birth to weaning and mortality were recorded weekly. Kits were weighed at birth and at weaning. Feed intake was measured weekly for feeder that serves 2 cages containing totally 4 pregnant does (25 experimental units for each treatment).

2.3. Growing–fattening rabbits

Two hundred does (D− and D+) kindled 1184 kits that were allocated into four experimental groups identified as D−K−, D−K+, D+K+ and D+K−. Growing rabbits were weighed individually at weaning, after 28 d (change of diet) and after 56 d (end of the trial); slaughtering took place when rabbits reached a weight of approximately 2.8 kg. Mortality was recorded weekly. There was no replacement of growing rabbits that died. The mortality data along with weekly feed intake and growth rate were used to calculate feed conversion ratios. Feed intake was determined weekly for each feeder that served four cages containing a total eight rabbits of both gender (38 experimental units for group D−K− and D−K+; 36 experimental units for group D+K+ and D+K−).

Rabbit carcasses were individually weighed 24 h after slaughtering according to the method suggested by Blasco and Ouhayoun (1996) which enabled calculation of chilled carcass weights and dressing percentages. Subsequently, carcasses of 12 rabbits per group (6 males and 6 females) were used to analyse the quality of meat and muscle lipids.

2.4. Chemical analysis

All feeds were analyzed according to AOAC (2000) except for fiber analysis which was carried out according to the method of Van Soest et al. (1991).

Table 2
Chemical composition (% as fed) of experimental diets fed to does and growing–fattening rabbits during the trial.

Item	Does [a]		Growing–fattening rabbits [b]			
	Gestation–lactation		First four weeks after weaning		Finishing phase	
	D+	D−	K+	K−	K+	K−
Dry matter (wet basis)	92.4	92.3	91.8	91.9	91.1	91.1
Crude protein (CP)	17.5	17.1	16.7	16.5	15.7	16.0
Ether extract (EE)	3.8	3.5	4.1	4.2	3.4	3.3
Crude fibre	15.7	15.7	15.6	15.0	14.2	14.0
Ash	8.1	9.2	8.8	9.0	7.3	7.6
Neutral detergent fiber (NDF)	34.5	34.1	34.9	33.8	33.2	33.2
Acid detergent fiber (ADF)	20.8	20.6	20.9	20.4	20.8	19.7
Acid detergent lignine (ADL)	3.0	3.6	4.8	4.7	4.1	3.8
Ca	1.7	1.8	1.7	2.0	1.1	1.2
P	0.7	0.7	0.7	0.7	0.7	0.8

[a] D− = does receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; D+ = does receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.
[b] K− = growing–fattening rabbits receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; K+ = growing–fattening rabbits receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.

Thigh and loin muscles, removed *in toto*, were submitted to gas chromatography to determine the fatty acid profile. Total lipid extraction was performed according to the method of Folch et al. (1957) and fatty acid methyl esters were prepared according to the method of Christie (1989). Analysis was carried out with an HRGC Mega 2 series gas chromatograph (Fisons Instruments) with a Supelco SP 2330 30 m × 0.25 mm 0.2 µm column, using helium 70 kPa as carrier with a 1.1 ml/min flow rate. The split ratio was 40:1 with a flame ionization detector. Identification of the methyl esters present in the mixture was achieved by comparing retention times with known standards.

2.5. Statistical analysis

For does and kits, data were analyzed with one-way ANOVA. Dietary treatment of does and kits was the source of variation to determine whether any significant differences existed ($P<0.05$).

For growing rabbits, data were analyzed in a 2 × 2 factorial arrangement using a two-way ANOVA to test: i) the effect of mother's feeding (together with pre-weaning solid feeding of the kits), D− vs. D+; ii) the effect of post-weaning feeding of growing-fattening rabbits, K− vs. K+; and iii) its interaction. Mortality data were subjected to statistical analysis using the χ^2 test.

Individual data were used as the experimental unit for reproductive performance of does, growth performance, slaughtering parameters and meat quality of growing rabbits. For feed intake and feed conversion rate the experimental unit was the feeder. Doe feeders served four cages each containing one doe. Growing rabbit feeders served four cages each containing two rabbits of both genders.

3. Results

3.1. Effects on does and kits up to weaning

The trial results are summarised in Table 3.

The kindling rate in both groups was approximately 83% and was considered as a normal reproductive result.

No differences were observed between the two groups for number born or number born alive per kindling.

Mean kit weights at birth and at weaning were significantly lower in group D+ than in group D− (52 vs. 55 g and 705 vs. 769 g, respectively).

There was no difference in mortality between D+ and D−. The numerically high levels were associated with multiple outbreaks of diarrhea.

Table 3
Reproductive performance and average daily feed intake of does and kits until weaning.[1,2]

Item		Experimental groups[3]	
		D+	D−
Reproductive performance			
Does	n	101	99
Mean weight of does at insemination	g	3367 ± 17	3412 ± 34
Mean born/kindling	n	8.5 ± 0.2	8.5 ± 0.3
Mean born live/kindling	n	7.6 ± 0.2	7.8 ± 0.3
Mean kit birth weight	g	52 ± 2^a	55 ± 1^b
Kits weaned per doe	n	5.7 ± 0.1	6.1 ± 0.2
Mean kit weaning weight	g	705 ± 4^a	769 ± 4^b
Litter mortality	%	25.1	21.2
Feed intake			
Feeder[4]	n	25	25
Gestation	g/d	163 ± 3	171 ± 3
Lactation	g/d	429.7 ± 5	437.5 ± 4

[1]Values are shown as means ± SE.
[2]Values in the same row with different superscripts are different (a and b, $P<0.05$).
[3]D− = does receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; D+ = does receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents. K− = growing–fattening rabbits receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; K+ = growing–fattening rabbits receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.
[4]One feeder served two cages containing a total of four pregnant does.

Table 4
Growth rate, mortality, mean daily feed intake and feed efficiency in weaned rabbits up to slaughter.

Item		Experimental groups [a]				SEM	*P* value		
		D+	D−	K+	K−		D	K	D×K
Growth and mortality									
Observations	*n*	563	553	557	559				
Average daily gain	g/d	35.1	34.4	34.7	34.8	0.13	<0.05	n.s.	n.s.
Mortality	%	10.1	19.6	12.5	17.4	–	n.s.	n.s.	–
Feed intake									
Observations	*n*	72	76	74	74	–	–		
Feed intake [b]	g/d	138.9	139.5	135.3	140.1	1.56	n.s.	n.s.	n.s.
Feed conversion rate		3.9	4.2	4.0	4.1	0.05	<0.01	n.s.	n.s.

[a] D− = does receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; D+ = does receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents. K− = growing-fattening rabbits receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; K+ = growing–fattening rabbits receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.
[b] One feeder served four cages containing a total of eight growing rabbits of both genders.

3.2. Effects on growing–fattening rabbits

Data reported in Table 4 refer to growing rabbit performance and reveal that ADG was higher ($P<0.05$) in rabbits whose mothers had received 750 mg/kg of DHA-enriched feed during pregnancy and lactation. There was no significant effect on mortality, but it was numerically higher in the progeny of does that had not received algal n-3 enriched diets (D−).

The addition of single-cell marine algae (*Schizochytrium spp.*) to the diets of weaned kits did not affect feed intake to an appreciable degree over the entire productive period. Feed conversion rates showed differences among the various groups. Growing rabbits whose mothers had received 750 mg/kg of DHA-enriched feed during pregnancy and lactation had lower feed conversion rates ($P<0.01$).

Slaughter studies (Table 5) performed on 1007 rabbits revealed no significant differences in live weight or dressing out percentage.

3.3. Fatty acid profile of the meat

The fatty acid compositions of lipids from loin and thigh muscles of fattening rabbits are shown in Tables 6 and 7, respectively.

The values for loin (Table 6) show that diets containing *Schizochytrium spp.*, fed to growing–fattening rabbits significantly increased the content of some saturated (myristic, palmitic and stearic) and unsaturated (linoleic and linolenic) fatty acids. Diet supplementation with algae directly to growing–fattening rabbits significantly increased the content of EPA and DHA fatty acids ($P<0.001$), but did not influence the content of DPA.

Thus, diet supplementation with algae induced in growing–fattening rabbits significantly reduced n-6/n-3 ratio ($P<0.001$), thus improving the nutritional quality of muscle lipids.

Algae administered to mothers during gestation–lactation did not modify the concentration of saturated fatty acids, but induced an increase of DHA ($P<0.05$) and reduced ($P<0.01$) the n-6/n-3 ratio of fatty acids in the lipid fraction.

The composition of thigh lipids is shown in Table 7. Saturated fatty acids were not affected by different diets administered to does and/or to growing–fattening rabbits.

By contrast, the amount of LCPUFA in thigh muscles was positively influenced by the presence of marine algae in fattening diets. Administration of DHA-rich feeds to the mothers did not affect the LCPUFA in rabbit thighs, except in the case of DHA, which was significantly increased ($P<0.001$).

As in the case of loin, the n-6/n-3 ratio of the thigh muscle was associated with an improvement in nutritional quality of

Table 5
Slaughtering parameters.

Item		Experimental groups [a]				SEM	*P* value		
		D+	D−	K+	K−		D	K	D×K
Observations	*n*	517	487	516	488				
Live weight	g	2787.2	2805.8	2803.8	2788.1	6.99	n.s.	n.s.	n.s.
Chilled carcass weight	g	1635.1	1639.6	1638.8	1635.7	4.26	n.s.	n.s.	<0.05
Dressing out percentage	%	58.8	58.5	58.5	58.8	0.12	n.s.	n.s.	n.s.

[a] D− = does receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; D+ = does receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents. K− = growing–fattening rabbits receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; K+ = growing–fattening rabbits receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.

Table 6
Fatty acid content of loin muscles in fattening rabbits at slaughter.

Fatty acids (mg/100 g edible part)		Experimental groups [a]				SEM	P value		
		D+	D−	K+	K−		D	K	D×K
Observations	*n*	23	25	23	25	–			
C 14:0		106.3	114.7	130.6	92.3	5.7	n.s.	< 0.001	n.s.
C 16:0		1208.2	1267.5	1385.5	1104.4	45.8	n.s.	< 0.01	n.s.
C 16:1 n-7		228.0	236.0	268.9	198.4	15.5	n.s.	< 0.05	n.s.
C 18:0		290.9	309.2	333.4	270.1	11.4	n.s.	< 0.01	n.s.
C 18:1 n-9		1017.6	1097.6	1139.5	985.4	45.1	n.s.	n.s.	n.s.
C 18:2 n-6		1086.8	1207.2	1274.6	1034.4	47.0	n.s.	< 0.01	n.s.
C 20:0		3.4	3.6	4.0	3.1	0.1	n.s.	< 0.01	n.s.
C 18:3 n-3		112.8	128.9	144.0	100.2	7.0	n.s.	< 0.01	n.s.
C 20:1 n-9		9.4	11.3	10.4	10.3	0.6	n.s.	n.s.	n.s.
C 20:4 n-6		137.0	139.8	135.3	141.3	3.3	n.s.	n.s.	n.s.
C 20:5 n-3 (EPA)		5.2	5.2	6.1	4.4	0.2	n.s.	< 0.001	n.s.
C 22:4 n-6		34.7	41.3	31.5	44.3	1.4	< 0.01	< 0.001	n.s.
C 22:5 n-6		29.4	28.3	38.7	19.8	1.6	n.s.	< 0.001	n.s.
C 22:5 n-3 (DPA)		20.9	22.0	22.1	21.0	0.5	n.s.	n.s.	n.s.
C 22:6 n-3 (DHA)		49.5	37.4	73.6	15.2	5.0	< 0.05	< 0.001	n.s.
n-6/n-3 ratio		7.2	7.9	6.0	9.0	0.2	< 0.01	<0.001	n.s.

[a] D− = does receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; D+ = does receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents. K− = growing–fattening rabbits receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; K+ = growing–fattening rabbits receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.

Table 7
Fatty acid content of thigh muscles in fattening rabbits at slaugther.

Fatty acids (mg/100 g edible part)		Experimental groups [a]				SEM	P value		
		D+	D−	K+	K−		D	K	D×K
Observations	*n*	25	24	24	25	–			
C 14:0		434.6	422.4	428.8	428.5	13.1	n.s.	n.s.	n.s.
C 16:0		4492.3	4360.4	4470.6	4386.5	121.1	n.s.	n.s.	n.s.
C 16:1 n-7		848.9	831.1	813.9	865.4	47.9	n.s.	n.s.	n.s.
C 18:0		1086.0	1106.8	1153.1	1041.6	36.4	n.s.	n.s.	n.s.
C 18:1 n-9		3813.6	3889.5	3661.9	4032.0	122.8	n.s.	n.s.	n.s.
C 18:2 n-6		4533.4	4638.5	4640.6	4531.3	111.6	n.s.	n.s.	n.s.
C 20:0		15.3	15.3	16.1	14.5	0.6	n.s.	n.s.	n.s.
C 18:3 n-3		555.3	568.7	581.1	543.4	15.7	n.s.	n.s.	n.s.
C 20:1 n-9		43.0	47.4	40.2	49.9	1.6	n.s.	< 0.01	n.s.
C 20:4 n-6		156.1	160.2	169.8	147.0	5.8	n.s.	n.s.	n.s.
C 20:5 n-3 (EPA)		8.1	7.1	10.6	4.7	0.5	n.s.	< 0.001	n.s.
C 22:4 n-6		45.1	54.2	44.1	54.9	1.6	< 0.001	< 0.001	n.s.
C 22:5 n-6		59.8	47.9	79.4	29.6	4.3	< 0.01	< 0.001	n.s.
C 22:5 n-3 (DPA)		30.6	31.0	33.9	27.8	0.9	n.s.	< 0.001	n.s.
C 22:6 n-3 (DHA)		111.2	71.2	158.2	27.6	10.8	< 0.001	< 0.001	n.s.
n-6/n-3 ratio		7.0	7.3	6.3	7.9	0.1	< 0.001	< 0.001	< 0.05

[a] D− = does receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; D+ = does receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents. K- = growing–fattening rabbits receiving commercial diet supplemented with 2 g/kg of coconut oil and an additional 2 g/kg of dehydrated alfalfa meal; K+ = growing–fattening rabbits receiving commercial diet supplemented with 4 g/kg of marine algae (*Schizochytrium spp.*, DHA Gold), which contributed 2 g of oil containing 750 mg of DHA and 2 g of non-lipidic algal constituents.

muscle lipids composition, whether from growing rabbits or from mothers, fed LCPUFA-enriched diets ($P<0.001$).

4. Discussion

The presence of algae in primiparous doe diets appears to negatively impact zootechnical performance, as shown by the number and weight of kits. These data are partially in contrast with Kowalska (2008) who obtained higher body weight of kits and lower mortality, using fish oil. The presence of algae in the diet may have reduced its palatability, as it has been observed in studies on beef cattle (Mordenti et al., 2005). In growing does (primiparous) this may have negatively influenced the reproductive performance as well as kits vitality.

Positive responses in average daily gain and feed efficiency of growing–fattening rabbits deriving from D+ group (Table 4) may be attributed to the presence of algae in gestating and lactating doe feeds. One possible reason may be that the presence of algae in diet of gestating and lactating does could help to strengthen the rabbit defence mechanisms as it has been hypothesized for other animal species including humans (Calder et al., 2006).

According to Dalle Zotte (2002), the composition of lipid fraction of meat was influenced by diet: DHA significantly increased when the diet of growing rabbits included LCPUFA, as it has also been observed with heavy pigs (Sardi et al., 2006).

This dietary enrichment of the meat of three months old growing rabbits was evident not only when the diets were administered directly to growing rabbits, but also when the mothers received supplemented feed during gestation and lactation (only for DHA and n-6/n-3 ratio).

Depending on the fat source added to the basal diet (Dal Bosco et al., 2004; Peiretti et al., 2007, Peiretti and Meineri, 2008) rabbits are able to incorporate dietary fatty acids directly into muscle tissue lipids, making it possible to modify the fatty acid profile by the strategic use of an unsaturated dietary fat source.

5. Conclusions

The effects of supplementing commercial rabbit diets with algae rich in long-chain polyunsaturated fatty acids, DHA in particular, were investigated both in gestating and lactating does and in their weaned progeny during the growing–fattening stage.

In the case of primiparous does, which are still growing, the presence of algae in the diet appears to impact negatively zootechnical performances, in particular as measured by weight of weaned kits, though this may be due to a reduction, albeit slight, in feed intake.

In lactating and growing–fattening rabbits the dietary supplementation did not affect the dressing percentage, but it did have a noteworthy influence on the quality of muscle lipids (loin and thigh), making them better suited to the nutritional needs of humans, whose diets normally include excessive quantities of linoleic acid.

The administration of algae supplemented diets to does during gestation and lactation also served to increase the DHA content of the thighs and loins of their progeny at slaughter, even when the latter did not receive DHA-enriched diets during the growing and fattening stage.

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References

AOAC, 2000. Official Methods of Analysis, Assoc. Offic. Anal. Chem., Gaithersburg, MD, USA, 17th ed.

Bazinet, R.P., Mc Millan, E.G., Cunnane, S.C., 2003. Dietary α-linolenic acid increase the n-3 PUFA content of sow's milk and the tissue of suckling piglet. Lipids 38 (10), 1045–1049.

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. J. Anim. Sci. 68, 647–654.

Biagi, M., Mordenti, A.L., Cocchi, M., 2004. Il ruolo degli acidi grassi essenziali omega-3 e omega-6 nell'alimentazione del cane e del gatto: una rassegna. Progress in Nutrition 6 (2), 97–107.

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

Blasco, A., Ouhayoun, J., 1996. Harmonization of criteria and terminology in rabbit meat research. Revised proposal. World Rabbit Science 4 (2), 93–99.

Calder, P.C., Krauss-Etschmann, S., de Jong, E.C., Dupont, C., Frick, J.S., Frokiaer, H., Heinrich, J., Garn, H., Koletzko, S., Lack, G., Mattelio, G., Renz, H., Sangild, P.T., Schrezenmeir, J., Stulnig, T.M., Thymann, T., Wold, A.E., Koletzko, B., 2006. Early nutrition and immunity — progress and perspectives. Br. J. Nutr. 96, 774–790.

Castellini, C., Dal Bosco, A., 1996. Effect of dietary herring meal on the omega-3 fatty acid content in rabbit meat. Proc. 31st Intern. Symp. Soc. It. Progr. Zoot. "Food and Health: role of animal products". Elsevier, Paris, France, pp. 67–71.

Castellini, C., Dal Bosco, A., Bernardini, M., Cyril, H.W., 1998. Effect of dietary vitamin E on oxidative stability of raw and cooked rabbit meat. Meat Sci. 50 (2), 153–161.

Castellini, C., Dal Bosco, A., Bernardini Battaglini, M., 1999. Effetti dell'integrazione alimentare di acidi grassi n-3 sulla composizione lipidica e sulla stabilità ossidativa della carne di coniglio. Zootecnia e Nutrizione Animale 25, 63–70.

Cavani, C., Betti, M., Bianchi, M., Petracci, M., 2003. Effects of dietary inclusion of vegetable fat and dehydrated alfalfa meal on the technological properties of rabbit meat. Vet. Res. Commun. 27 (suppl. 1), 643–646.

Cavani, C., Betti, M., Bianchi, M., Petracci, M., 2004. Sistemi di alimentazione e di allevamento del coniglio per il miglioramento della qualità della carne. Rivista di Coniglicoltura XLI (2), 37–42.

Christie, W.W., 1989. In: Gas Chromatography and Lipids: a Practical Guide. The Oil Press Ltd, Ayrshire, Scotland.

Dal Bosco, A., Castellini, C., Bianchi, M., 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.

Folch, J., Lees, M., Stanley, G.H., 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226, 497–509.

Kowalska, D., 2008. Effect of essential unsaturated fatty acids in fish oil on litters and composition of milk of rabbit does. 9th World Rabbit Congress, Verona, pp. 705–709.

Mordenti, A.L., Lambertini, L., Gatta, P.P., Tassinari, M., 2005. Effetti della somministrazione con l'alimento di LCPUFA sui lipidi muscolari e di riserva in bovine da carne. Progress in Nutrition 7 (3), 201–210.

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.

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

Sardi, L., Martelli, G., Lambertini, L., Parisini, P., Mordenti, A., 2006. Effects of dietary supplement of DHA-rich marine algae on Italian heavy pig production parameters. Livest. Sci. 103, 95–103.

Tassinari, M., Mordenti, A.L., Testi, S., Zotti, A., 2002. Esperienze sulla possibilità di arricchire con la dieta la carne di coniglio di LCPUFA n-3. Progress in Nutrition 4 (2), 119–124.

Terry, P.D., Terry, J.B., Rohan, T.E., 2004. Long-chain (n-3) fatty acid intake and risk of cancers of the breast and the prostate: recent epidemiological studies, biological mechanisms, and direction for future research. J. Nutr. 134, 3412S–3420S.

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, 3583–3597.

Wood, J.D., Richardson, R.L., Nute, G.R., Fisher, A.V., Campo, M.M., Kasapidou, E., Sherad, P.R., Enser, M., 2003. Effect of fatty acid on meat quality. Meat Sci. 66 (1), 21–32.