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Flax and hemp
Lin et chanvre

Dossier

Effect of introducing hemp oil into feed on the nutritional quality of pig meat

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Abstract – Research is being carried out to diversify the sources of n-3 fatty acid-rich lipids for animal feed. In this study, 3 batches of 12 pigs with between 50 and 105 kg of live weight, received isolipidic diets containing either palm oil (PO), or rapeseed oil (CO), or hemp oil (HO) (providing respectively 0.6; 1.9 and 3.4 g of C18:3 n-3 (ALA) /kg of feed). The quantity of ALA deposited in the meat is higher ($p < 0.001$) in the HO pigs. Hemp oil may be an interesting source of ALA to improve the nutritional quality of pork.

Keywords: n-3 fatty acids / hemp / pig / meat quality

Résumé – **Effet de l'introduction de l'huile de chanvre dans l'aliment sur la qualité de la viande de porc.** Des recherches en nutrition porcine sont conduites pour trouver des sources de lipides apportant une quantité notable d'acides gras n-3 afin de les retrouver dans la viande. Dans cette étude, l'intérêt de l'huile de chanvre est recherché. Trois lots de 12 porcs ont reçu, entre 50 et 105 kg de poids vif, des régimes contenant soit de l'huile de palme (PO), soit de huile de colza (CO), soit de l'huile de chanvre (HO). Ces huiles apportent respectivement 0,6 ; 1,9 et 3,4 g de C18 :3 n-3 (ALA)/kg d'aliment. La quantité de ALA déposée est plus élevée ($p < 0,001$) chez les porcs HO. L'huile de chanvre peut être une source intéressante d'ALA pour améliorer la qualité nutritionnelle de la viande.

Mots clés : Acides gras n-3 / chanvre / porc / qualité de la viande

1 Introduction

Breeding factors influence the quality of meat. There is a direct relationship between the nature of the fatty acids in feed and those which are deposited in the meat (Mourot and Hermier, 2001). This characteristic is used to modify the nutritional composition of the meat, and into the meat introduce fatty acids that are considered to be good for human health. The nutritional guidelines of the AFSSA recommend increasing the quantity of n-3 fatty acids in human consumption and decreasing the amount of n-6 (ANC, 2001). By providing n-3 fatty acids via the incorporation of linseed into pig feed, it is possible to increase the deposition of these fatty acids in the meat (Corino *et al.* 2014; Guillevic *et al.*, 2009; Wood *et al.*, 2008). The deposition in the meat will be in relation to the quantities ingested (Warnants *et al.*, 1999) and/or the duration of distribution of the n-3 enriched diets (Haak *et al.*, 2008). These products can also be processed and the nutritional advantage is preserved without modification to the sensory properties (Guillevic *et al.*, 2009).

Although linseed is a good vector to provide more n-3 fatty acids, studies are being carried out to seek other plant sources of these fatty acids. Certain varieties of hemp seem to contain an interesting proportion of n-3 fatty acids and an interesting quantity of antioxidant factors (Oomah *et al.*, 2002). What is more, hemp is a plant which has long been part of traditional crops in Europe to supply the fibres used for making ropes for ships and cloth for garments. Cultivation is easy and requires few inputs, which preserves the soil. The cultivation of this plant is developing again in the framework of sustainable agriculture programmes, and the fibres have a new outlet as insulation in building materials. The seeds and oil produced could therefore be used in animal nutrition if they have advantages of interest.

Hemp oil is rich in n-3 fatty acids, but it also contains a high proportion of n-6. Little work has been devoted to the use of this oil in animal feed. The aim of this study will be to

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Table 1. Composition and fatty acid content of two varieties of hemp.

	Percentage of FA		mg FA/100 g of seed	
	Fedora 17	Ferimon	Fedora 17	Ferimon
C14:0	0.12	0.07	28.4	17.5
C16:0	7.27	7.37	1657	1810
C16:1 (n-7)	0.24	0.32	55.7	78.3
C18:0	3.01	2.67	685	656
C18:1 (n-9)	13.14	13.57	2993	3408
C18:2 (n-6)	55.34	55.15	12 609	13 551
C20:0	3.93	4.40	894	1082
C18:3 (n-3)	15.15	14.74	3401	3847
C20:1(n-9)	0.85	0.93	193	228
C20:2	0.08	0.08	18.2	20.3
C20:3(n-3)	0.45	0.40	102.0	97.5
Saturated FA	14.45	14.52	3292	3567
Monounsaturated FA	14.45	15.34	3293	3768
Polyunsaturated FA	71.10	70.15	16 200	17 236
FA n-6	55.36	55.17	12 615	13 557
FA n-3	15.65	14.89	3537	3958
n-6/n-3	3.54	3.71	3.54	3.71

monitor the animals' growth performances and the fatty acid deposition in the meat.

2 Material and methods

2.1 Choice of the hemp oil

A comparison was made of the fatty acid composition of two varieties of hemp seeds (Tab. 1). The lipid contents of these seeds are 25.1 for Fedora 17 and 27.1 for Ferimon. The percentage of C18:3 n-3 is equivalent between the 2 seed varieties. We chose the Ferimon variety for our study, because of the slightly higher C18:3 n-3 content in this seed.

2.2 The animals and the diets:

36 pigs with a Large-White × Landrace dam and a Piétrain sire were divided into 3 batches of 12 pigs, each batch receiving a different diet. The diets were isolipidic and isoenergetic, and the only difference was the source of fat content; either palm oil (PO), or rapeseed oil (CO), or hemp oil (HO). The palm diet contained 0.6 g of C18:3 n-3 (ALA) /kg of feed, the rapeseed diet contained 1.9 g and the hemp diet 3.4 g. The composition of the diets is shown in Table 2. All the diets provided 80 ppm of vitamin E and 0.25 ppm of selenium.

The animals received the diets at between 50 and 105 kg in weight. They were reared in individual housing and their consumption and growth performances were monitored. They were weighed each week.

At slaughter, the carcass muscle rate was determined. Liver, backfat adipose tissue, the *longissimus dorsi* (LD) muscle and blood were sampled to determine the lipid contents and the fatty acid composition.

The meat quality was measured (pH at 24 h, drip loss, losses during cooking).

2.3 The analyses:

The losses in draining and cooking at the level of the ham were analysed according to the Honikel technique (1987).

The total lipids of the lean or fatty tissues were extracted cold according to the method of Folch *et al.*, (1957) in a chloroform-methanol mixture (2/1). For the pork rib, the whole of the meat (lean and fat) was removed from the bone, then mixed to make an homogeneous blend. Aliquot was taken to analyse the lipids. The fatty acid profile was determined by gas chromatography after derivation with Boron trifluoride (BF3) according to the Morrisson and Smith method (1964). The column was a 30 m long capillary tube made of fused silica on an internal diameter of 0.25 mm. The stationary phase was composed of 80% of biscyanopropyl and 20% of cyanopropylphenyl, and the mobile phase was hydrogen. The temperature of the oven was programmed for plates of 2 min, 7 min and twice 2 min at temperatures respectively of 45 °C, 195 °C, 220 °C and 240 °C with rises in temperature between the stages of 20 °C/min, 30 °C/min and 35 °C/min for a total analysis duration of 21.9 min. The temperatures of the injector and the detector were respectively 220 and 280 °C. The fatty acids (FA) were expressed as a percentage of the identified fatty acids and in total quantity calculated using an internal standard (C17:0).

The analysis results were compared by analysis of the variance with the diet as principal effect (SAS, 1999). The two-by-two comparison of the averages was carried out using the Bonferroni test.

2.4 Results

The zootechnical data and the body composition of the animals were identical between the different batches. The introduction of hemp oil into the diet did not modify the growth performances (Tab. 3). The cutting weights of the main pieces expressed in relation to the weight of the carcass were equivalent. There was therefore no modification to the body composition by the introduction of hemp oil into one of the diets.

The quality criteria of the meat were not modified by the diets. The 24 h pH concentrations were identical for the *longissimus dorsi* muscle and the *semi-membranosus* muscle (Tab. 4). The water losses by chilling and after cooking were identical for the *longissimus dorsi* muscle.

The lipid content of the analysed tissues was identical between the diets for the adipose tissue of the back and the liver (Tab. 4). On the other hand, it was higher in the *longissimus dorsi* muscle for the animals receiving the hemp oil ($p < 0.006$).

The circulating fatty acids were the reflection of those ingested (Tab. 5). The C18:2 n-6 and C18:3 n-3 contents were higher in the pigs receiving the diet with the hemp oil ($p < 0.001$). For the long-chain polyunsaturated fatty acids, the derivatives were not in relation to the quantity of precursors. There was a higher quantity of C20:4 n-6 arachidonic acid with the palm diet ($p < 0.02$), whereas for EPA and DHA the quantities were higher for the hemp diet with intermediate values for rapeseed ($p < 0.001$). The value of the DPA was identical between the diets.

Table 2. Composition and fatty acid content of diets (% of identified FA and g FA per kg of feed).

	Percentage of FA			g FA per kg of feed		
Diets	Palm	Rapeseed	Hemp	Palm	Rapeseed	Hemp
Fat matter (g/kg)				43.6	45.5	47.0
C12:0	0.11	0.00	0.00	0.03	0.00	0.00
C14:0	0.66	0.09	0.10	0.19	0.03	0.03
C14:1	0.05	0.04	0.04	0.02	0.01	0.01
C16:0	29.22	10.48	11.56	8.60	3.28	3.60
C16:1 (n-7)	0.29	0.28	0.23	0.09	0.09	0.07
C18:0	3.24	1.96	2.61	0.96	0.61	0.81
C18:1 (n-9)	29.52	40.31	17.36	8.69	12.57	5.42
C18:2 (n-6) LA	34.59	38.77	55.10	10.19	12.12	17.21
C20:0	0.18	0.41	1.85	0.05	0.13	0.58
C18:3 (n-3) ALA	2.08	6.19	10.97	0.61	1.93	3.43
C20:1 (n-9)	0.00	1.27	0.00	0.00	0.40	0.00
C24:0	0.16	0.20	0.19	0.05	0.06	0.06
Σ SFA	33.57	13.14	16.31	9.88	4.11	5.08
Σ MUFA	29.86	41.90	17.63	8.79	13.08	5.50
Σ PUFA	36.67	44.96	66.07	10.81	14.06	20.64
LA/ALA	16.60	6.26	5.02	16.61	6.26	5.02

Table 3. Effect of diets on growth performance and body composition of pigs.

Diets	Palm	Rapeseed	Hemp	Rsd
Initial weight, kg	46.8	46.4	46.8	2.3
Final weight, kg	102	104	106	3.7
Carcass weight, kg	80.2	80.8	80.9	2.7
Carcass yield, %	78.7	77.8	76.2	2.4
Duration in days	63	62	61	5.1
Average daily gain, g	904	943	946	90
Food conversion ratio	2.60	2.67	2.61	0.25
Lean meat content, %	57.3	55.3	56.3	2.9
Loin weight, %	26.9	26.5	26.3	1.33
Back fat weight, %	6.55	7.39	6.40	1.24
Ham weight, %	23.9	23.2	23.4	0.99

N = 12/treatments. No significant effect was observed.

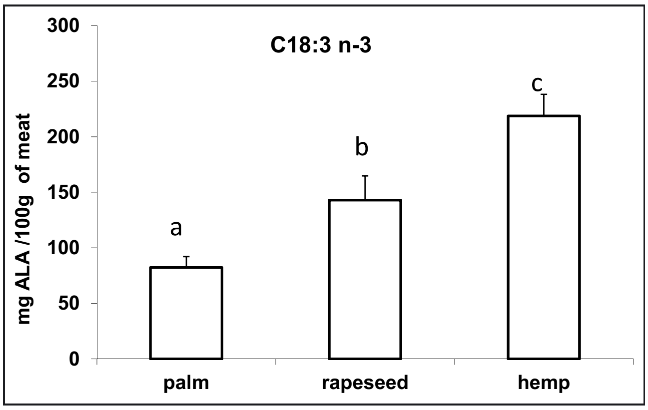

Fig. 1. Effect of diets on α linolenic acid content of the entire pork rib (in mg FA per 100 g of meat) (diet effect: $p < 0.001$).

The backfat adipose tissues of the pigs from the hemp batch (Tab. 6) had less saturated ($p < 0.08$) and monounsaturated ($p < 0.001$) fatty acids than the others, but they had more polyunsaturated AG ($p < 0.001$). The percentage of C18:3 n-3 deposited was in relation to the quantity ingested, these values differing among the 3 diets. The deposition of C18:2 n-6 was higher with the hemp diet ($p < 0.001$) but there was no difference between the palm and rapeseed diets. There was no difference for the long-chain derivatives whose values were identical between all the batches of animals. The LA/ALA ratio was close to 13 for the palm diet and 7 for the n-3 fatty acid-rich diets.

For the muscle, the effects observed were not as marked as at the level of the fat cover tissue (Tab. 7). Only the ALA precursor was increased in the lean part of the meat with the hemp and rapeseed diets compared to the palm diet ($p < 0.001$). But the values were not significantly different between these 2 diets whereas the quantities ingested were higher for hemp. The long chain n-6 and n-3 derivatives were identical between the animals. The LA/ALA ratio was higher than the values observed in the fat tissue. It was lower in animals receiving rapeseed and hemp compared to the palm diet.

The fatty acids present in the whole rib of pork were the reflection of the compositions expressed as a percentage in the fat tissue and the muscle.

The quantity of ALA for 100 g of pork was higher with the animals receiving the hemp diet. It was intermediate for rapeseed and lowest for the hemp diet (Fig. 1). It reached more than 200 mg for the hemp diet. But the long chain fatty acid contents were very low. They varied from 5 to 10 mg for EPA depending on the diets and from 13 to 20 mg for the DPA and they were equivalent for the DHA (5 mg/100 g of meat). The LA content was close to 1.1 g in the pigs of the palm and rapeseed batches and reached 1.6 g in the pigs in the hemp batch. The value of the C18:2/C18:3 ratio was 14 for the animals in the palm batch; 8 for the pigs in the rapeseed batch and 7 for the hemp diet.

The fatty acid composition of the liver was also modified for certain fatty acids depending on the diets (Tab. 8). The percentage of saturated fatty acids was lower in the pigs from the hemp batch ($p < 0.06$) and the percentage of polyunsaturated

Table 4. Effect of diets on meat quality parameters.

	Palm	Rapeseed	Hemp	Rsd	Effect
pH *Longissimus dorsi*, 24h	5.56	5.57	5.56	0.11	NS
pH *Semimembranosus*, 24h	5.61	5.49	5.57	0.15	NS
Drip loss, %	4.96	4.78	3.83	1.72	NS
Cooking loss, %	37.7	38.3	37.6	4.57	NS
Color index L	53.4	55.5	54.4	2.82	NS
a	7.21	7.47	7.47	1.13	NS
b	3.66	4.62	4.29	0.97	NS
Lipid content, %					
Back fat	63.0	66.5	65.2	6.1	NS
Longissimus dorsi	1.42a	1.52a	2.07b	0.44	$p < 0.006$
Liver	3.83	3.83	4.18	0.62	NS

$N = 12$/treatments. The online values assigned to the same letter are not different at the 5%.

Table 5. Effect of diets on fatty acids composition of the plasma (% of identified FA).

Diets	Palm	Rapeseed	Hemp	Rsd	Effect
C12:0	0.21	0.24	0.17	0.12	NS
C14:0	0.88	0.93	0.84	0.17	NS
C14:1	0.40	0.41	0.35	0.18	NS
C16:0	14.22	15.48	14.32	3.12	NS
C16:1 (n-7)	1.64	1.53	1.32	0.61	NS
C18:0	9.95	10.28	9.44	1.71	NS
C18:1 (n-9)	30.09a	29.84a	24.00b	1.79	$p < 0.001$
C18:2 (n-6) LA	31.06a	30.23a	35.64b	3.02	$p < 0.001$
C20:0	0.74a	0.54a	1.24c	0.14	$p < 0.001$
C18:3 (n-3) ALA	0.90a	1.67b	2.52c	0.29	$p < 0.001$
C20:1 (n-9)	0.18	0.31	0.35	0.18	NS
C20:2	0.23	0.27	0.37	0.11	NS
C20:3 (n-6)	0.44	0.36	0.39	0.14	NS
C20:4 (n-6) ARA	6.65a	5.18b	5.52b	1.10	$p < 0.02$
C22:1 (n-9)	0.19	0.26	0.27	0.14	NS
C20:5 (n-3) EPA	0.47a	0.88b	1.28c	0.29	$p < 0.001$
C24:0	0.06	0.08	0.06	0.05	NS
C24:1 (n-9)	0.39a	0.18b	0.31a	0.17	$p < 0.04$
C22:5 (n-3) DPA	1.04	1.09	1.01	0.40	NS
C22:6 (n-3) DHA	0.47	0.48	0.77	0.31	$p < 0.07$
Σ SFA	26.05	27.55	26.07	2.84	NS
Σ MUFA	32.89a	32.54a	26.60b	2.17	$p < 0.001$
Σ PUFA	41.26a	40.15a	47.50b	3.29	$p < 0.001$
n-6	38.15ab	35.79a	41.55b	3.02	$p < 0.001$
n-3	3.28a	4.43b	5.97c	0.83	$p < 0.001$
LA/ALA	34.58a	18.28b	14.46c	2.16	$p < 0.001$

$N = 12$/treatments. The online values assigned to the same letter are not different at the 5%.

Table 6. Effect of diets on fatty acids composition of back fat (% of identified FA).

Diets	Palm	Rapeseed	Hemp	Rsd	Effect
C12:0	0.08	0.07	0.09	0.02	NS
C14:0	1.19	1.13	1.10	0.07	NS
C14:1	0.03	0.03	0.03	0.01	NS
C16:0	24.07a	23.02ab	22.40b	0.99	$p < 0.003$
C16:1 (n-7)	2.21a	1.96b	2.01b	0.15	$p < 0.01$
C18:0	13.38	13.53	12.99	1.1	NS
C18:1 (n-9)	42.49a	42.81a	38.11b	1.14	$p < 0.001$
C18:2 (n-6) LA	12.91a	13.11a	17.54b	1.28	$p < 0.001$
C20:0	0.32a	0.30a	0.50b	0.09	$p < 0.01$
C18:3 (n-3) ALA	0.97a	1.66b	2.44c	0.17	$p < 0.001$
C20:1 (n-9)	0.89	1.02	0.94	0.19	NS
C20:2	0.69a	0.58a	0.89b	0.16	$p < 0.01$
C20:3 (n-6)	0.12a	0.14a	0.31b	0.04	$p < 0.001$
C20:4 (n-6) ARA	0.25	0.22	0.24	0.05	NS
C22:1 (n-9)	0.03	0.04	0.03	0.01	NS
C20:5 (n-3) EPA	0.04	0.05	0.06	0.02	NS
C24:0	0.11	0.12	0.12	0.05	NS
C24:1	0.05	0.05	0.04	0.03	NS
C22:5 (n-3) DPA	0.10a	0.11a	0.15a	0.03	$p < 0.08$
C22:6 (n-3) DHA	0.05	0.04	0.04	0.03	NS
Σ SFA	39.15	38.18	37.19	1.91	$p < 0.08$
Σ MUFA	45.70a	45.90a	41.15b	1.20	$p < 0.001$
Σ PUFA	15.14a	15.92a	21.66b	1.55	$p < 0.001$
n-6	13.28a	13.47a	18.09b	1.32	$p < 0.001$
n-3	1.17a	1.86b	2.68c	0.25	$p < 0.001$
LA/ALA	13.58a	7.92b	7.20b	1.02	$p < 0.001$

$N = 12$/treatments. The online values assigned to the same letter are not different at the 5%.

fatty acids was higher ($p < 0.002$). Overall, the percentage in arachidonic acid was much higher than what was observed in the other tissues, but this value was not affected by the treatment. On the other hand, as for the other tissues, the ALA percentage was in relation to the diets ($p < 0.001$). The long-chain EPA and DPA derivatives were also increased with the diets providing the most n-3 precursor, but the DHA was not modified.

Table 7. Effect of diets on fatty acids composition of the *longissimus dorsi* muscle (% of identified FA).

Diets	Palm	Rapeseed	Hemp	Rsd	Effect
C12:0	0.08	0.08	0.08	0.01	NS
C14:0	0.99	1.05	1.00	0.19	NS
C14:1	0.05a	0.05a	0.0a3	0.01	$p < 0.08$
C16:0	22.51	22.90	22.69	0.98	NS
C16:1 (n-7)	2.96	2.96	2.90	0.46	NS
C18:0	11.50	11.80	12.07	0.69	NS
C18:1 (n-9)	38.25	40.86	39.07	4.89	NS
C18:2 (n-6) LA	15.19	12.94	14.38	3.80	NS
C20:0	0.34	0.34	0.35	0.08	NS
C18:3 (n-3) ALA	0.56a	0.86b	1.03b	0.16	$p < 0.001$
C20:1 (n-9)	0.70	0.76	0.71	0.11	NS
C20:2	0.48	0.44	0.50	0.09	NS
C20:3 (n-6)	0.53	0.41	0.46	0.17	NS
C20:4 (n-6) ARA	4.02	3.00	3.06	1.55	NS
C22:1 (n-9)	0.07a	0.05ab	0.04b	0.01	$p < 0.01$
C20:5 (n-3) EPA	0.21	0.24	0.27	0.11	NS
C24:0	0.69	0.45	0.46	0.22	NS
C24:1	0.15	0.11	0.12	0.07	NS
C22:5 (n-3) DPA	0.54	0.54	0.61	0.28	NS
C22:6 (n-3) DHA	0.19	0.15	0.16	0.09	NS
Σ SFA	36.10	36.62	36.65	1.45	NS
Σ MUFA	42.18	44.80	42.87	5.30	NS
Σ PUFA	21.72	18.58	20.48	6.3	NS
n-6	19.74	16.35	17.90	5.45	NS
n-3	1.50a	1.79a	2.07a	0.56	$p < 0.03$
LA/ALA	27.42a	15.22b	14.13b	4.8	$p < 0.001$

N = 12/treatments. The online values assigned to the same letter are not different at the 5%.

Table 8. Effect of diets on fatty acids composition of liver (% of identified FA).

Diets	Palm	Rapeseed	Hemp	Rsd	Effect
C12:0	0.19	0.12	0.14	0.05	NS
C14:0	0.49	0.47	0.56	0.20	NS
C14:1	0.12	0.08	0.08	0.04	NS
C16:0	15.71	14.41	15.27	1.36	NS
C16:1 (n-7)	1.08	1.11	1.13	0.23	NS
C18:0	27.10	26.17	24.90	3.49	NS
C18:1 (n-9)	17.39	17.85	14.94	2.83	NS
C18:2 (n-6) LA	14.74	15.94a	18.29b	1.09b	$p < 0.001$
C20:0	0.37	0.30	0.43	0.11	NS
C18:3 (n-3) ALA	0.56a	1.10b	1.80c	0.31	$p < 0.001$
C20:1 (n-9)	0.28	0.29	0.26	0.10	NS
C20:2	0.37	0.36	0.56	0.18	NS
C20:3 (n-6)	0.78	0.73	0.72	0.17	NS
C20:4 (n-6) ARA	15.59	14.80	14.44	1.99	NS
C22:1 (n-9)	0.06a	0.24b	0.22b	0.05	$p < 0.001$
C20:5 (n-3) EPA	0.59a	1.42b	1.49b	0.27	$p < 0.001$
C24:0	0.98	0.63	0.66	0.22	NS
C24:1	0.35a	0.17b	0.20b	0.08	$p < 0.01$
C22:5 (n-3) DPA	2.11a	2.91a	2.89a	0.54	$p < 0.03$
C22:6 (n-3) DHA	1.13	0.88	1.05	0.41	NS
Σ SFA	44.85	42.10	41.95	2.22	$p < 0.06$
Σ MUFA	19.29	19.74	16.82	2.99	NS
Σ PUFA	35.86a	38.16ab	41.23b	2.08	$p < 0.002$
n-6	31.11	31.47	33.45	1.57	$p < 0.04$
n-3	4.39a	6.32b	7.23b	0.78	$p < 0.001$
LA/ALA	28.35a	15.05b	10.55b	4.53	$p < 0.001$

N = 12/treatments. The online values assigned to the same letter are not different at the 5%.

3 Discussion

The growth performances were not modified by the introduction of n-3 fatty acids into the animal feed, which confirmed similar studies carried out with the addition of other fats than hemp such as linseed (Corino *et al.*, 2008; Kouba *et al.*, 2003; Matthews *et al.*, 2000).

The pH values and the colour of the meat were not modified, which was in agreement with other studies, as the impact of the lipids seemed to have little effect on these parameters (Haak *et al.*, 2008; Romans, Wulf *et al.*, 1995; Romans, Johnson *et al.*, 1995).

The circulating fatty acids were the reflection of those provided by the feed. Among the n-3 fatty acids, the C18:3 n-3 precursor was in the majority. But the content of long-chain derivatives was also significantly increased as has already been shown in man for EPA and DHA (Weill *et al.*, 2002). This may be explained by the importance of collecting these fatty acids for incorporation into the membranes of the erythrocytes. The increase in the concentration was in relation to the quantity provided by the feed; the pigs with the palm diet were different from those with the rapeseed diet, and they in their turn were different from pigs with the hemp diet for ALA and EPA.

The effect of the nature of the fat content in the diet on the nutritional quality of the animal products was once again demonstrated (Mourot and Hermier, 2001). The n-3 content in the meat was multiplied by 2.6 with the addition of hemp oil and by 1.8 with rapeseed oil compared with animals receiving a diet low in n-3. These results confirmed other studies showing a relationship to the quantity of n-3 ingested (Corino *et al.*, 2014; Warnants *et al.*, 1999). However, with an equivalent quantity of fat content in the diets, the deposits of n-3 fatty acids obtained with hemp oil were lower than those obtained with the introduction of extruded linseed into the diet (Corino *et al.*, 2008), the increase varying from 4 to 7 according to the tissues or products analysed.

The ALA precursor was essentially found in this form in the lean and fat tissues. The long chain n-3 fatty acids were found in a small quantity, which confirms the low conversion of the precursor (Alessandri *et al.*, 2009). In the fat tissue, an increase in C22:5 n-3 was shown ($p < 0.08$) with the hemp diet, which indicated a limiting stage in the transformation into DHA. This accumulation of DPA is not observed in cattle (Geay *et al.*, 2001; Raes *et al.*, 2004). This may be related to the location of lipogenesis synthesis which is preponderant

DOSSIER

in the liver in these animals, compared to the pig where it is essentially located in fat tissue.

The elongase allowing the synthesis of C24:5n-3 was certainly underactive. There is competition between the n-6 and n-3 fatty acids for the synthesis of long-chain derivatives. The transformation of the n-6 fatty acids seems favoured compared to the n-3, which may explain the low transformation observed. Studies adding a larger quantity of n-3 to the diet than this one using linseed (55 g ALA per kg feed *vs.* 34 g at present) have shown a significant increase in DHA (Corino *et al.*, 2008). But the total quantity, even if it was sometimes doubled, still remained very limited, the content passing from 5 to 6 mg of DHA per 100 g of meat to between 10 and 15 mg. This confirmed the low conversion into long-chain polyunsaturated fatty acids from the ALA precursor observed in humans and animals, including fish.

In the muscle, the percentages of long-chain n-3 derivatives were higher than those observed in the fat tissues. This is explained by the fact that lipids in the muscle are half composed of polar lipids coming from membrane structures that are rich in polyunsaturated fatty acids unsaturated long chain to maintain membrane fluidity (Warmants *et al.* 1999). Moreover, Hertzman *et al.*, (1988) suggested that the phospholipidic membranes of the muscle tissue incorporate polyunsaturated fatty acids particularly well, unlike fat tissues which comprise vacuoles of lipids, much less selective as to the incorporation of fatty acids.

As for blood plasma, the nature of fatty acids in food modifies the composition of lipids in the membranes. A larger input of n-3 fatty acids in the diet can therefore have an impact on membrane fluidity.

However, although the fatty acids are expressed in quantity, the low total lipid content in the muscle, approximately 2%, compared to the fat tissue (65 to 70%), means that the muscle will have a limited impact on the input of these long chain fatty acids in the consumer's plate. With the introduction of hemp oil into the diet, the global contents of n-3 fatty acids in the pork rib will be near to 250 to 300 mg for 100 g of meat, whereas with the introduction of linseed selected for its rich n-3 fatty acids, this amount of meat can then provide from 400 to 500 mg (Guillevic *et al.*, 2009).

The effect of the diets was also found in the liver, but a concentration of n-6 fatty acids was highlighted compared to other tissues (Enser *et al.*, 2002). This is probably the particular place for transforming the n-6 family into derivate, since a high increase can be seen in the C20:4 n-6 fatty acid concentration, whatever the nature of the fat content of the feed. The liver will therefore be an important source of arachidonic acid in the human diet in particular through pâtés and prepared meat products rich in lipids (Guillevic *et al.*, 2009).

In the meat, the value of the LA/ALA ratio was close for animals receiving the rapeseed and hemp diets whereas the ALA content was higher in pigs with the hemp diet. This can be explained by the fact that these animals also had a high deposition of LA provided by the hemp oil. The value of this ratio is higher than that of other studies using linseed (7 *vs.* 4 to 5) (Corino *et al.*, 2008; Guillevic *et al.*, 2009) and also higher than the ANSES guidelines which recommend a ratio of 5 (ANC). But these animals receiving rapeseed or hemp oils had a ratio decreased by 2 in comparison with animals receiving standard feed; so this leads to better food balance for human consumption.

4 Conclusion

The use in animal feed of fat content providing a notable quantity of n-3 fatty acids increases the deposition of these fatty acids in the meat and to a lesser degree the deposition of the long-chain derivate, without modifying the growth performances of the animals. The C18:2/C18:3 ratio is better balanced and provides what specialists in human nutrition are looking for. If the ratio is equivalent in the meat of pigs receiving rapeseed or hemp oil, the animals receiving hemp oil will have higher n-3 content than that obtained with the rapeseed diet. Hemp oil can therefore be used favorably in pig feed. Current production of this plant is not as intense as at the beginning of the 20th century. But the new development of cultivation of this plant to supply agro-materials may make hemp oil an interesting co-product for animal nutrition. Research on extruded hemp products would appear to be a worthwhile project.

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Important point. This study concentrates on the effect of hemp oil as a source of n-3 fatty acids in pig feed. This oil comes from sustainable production, and has interesting effects for the increase of n-3 fatty acid content in the meat. Relatively speaking, these effects are higher than those obtained with the incorporation of rapeseed oil into animal feed.

References

Alessandri JM, Extier A, Astorg P, Lavialle M, Simon N, Guesnet P. 2009. Gender-related differences in omega-3 metabolism. *Nutr. Clin. Métabol.* 23: 55–66

ANC. Apports Nutritionnels Conseillés pour la population française. 2001. AFSSA, Ed. Tec & Doc, Paris.

Corino C, Musella M, Mourot J. 2008. Influences of extruded linseed on growth. carcass composition and meat quality of pigs slaughtered at 110 and 160 kg liveweight. *J. Anim. Sci.* 86: 1–11.

Corino C, Rossi R, Cannata S. 2014. Effect of dietary linseed on the nutritional value and quality of pork and pork products: Systematic review and meta-analysis. *Meat Sci.* 98: 679–688.

Enser M, Richardson RI, Wood JD, Gill BP, Sheard PR. 2002. 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.

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

Geay Y, Bauchart D, Hocquette J.F, Culioli J. 2001. Effects of nutritional factors on biochemical, structural and metabolic characteristics of muscles in ruminants: consequences on dietetic value and sensorial qualities of meat. *Reprod. Nutr. Dev.* 41: 1–26.

Guillevic M, Kouba M, Mourot J. 2009. Effect of a linseed diet on lipid composition, lipid peroxidation and consumers evaluation of fresh meat and French cooked pork meats. *Meat Sci.* 81: 612–618.

Haak L, De Smet S, Fremaut D, Van Walleghem K, Raes K. 2008. Fatty acid profile and oxidative stability of pork as influenced by duration and time of dietary linseed or fish oil supplementation. *J. Anim. Sci.* 86: 1418–1425.

Hertzman C, Goransson L, Ruderus H, 1988. Influence of fish-meal, rapeseed and rapeseed meal in fee on the fatty acid composition and storage stability of porcine body fat. *Meat Sci.* 23: 37–53.

Honikel K O. 1987. How to measure the water-holding capacity of meat? Recommendation of standardized methods. In: Tarrant VG. ed. Evaluation and control of meat quality in pigs. Den Haag: Martinus Nijhoff Pub., pp. 129–142.

Kouba M, Enser M, Whittington F M, Nute GR, Wood JD. 2003. Effect of a high-linolenic acid diet on lipogenic enzyme activities, fatty acid composition, and meat quality in the growing pig. *J. Anim. Sci.* 81: 1967–1979.

Matthews KR, Homer DB, Thies F, Calder PC. 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. Nut.* 83: 637–643.

Morrisson WR, Smith LM. 1964. Preparation of fatty acidd methyl ester and dimethyl acetals from lipids with Boron Fluoride-Methanol. *J. Lipid Res.* 5: 600–608.

Mourot J, Hermier D. 2001. Lipids in monogastric animal meat. *Reprod. Nut. Dev*. 41: 109–118.

Oomah BD, Busson M, Godfreya DV, Drovera JCG. 2002. Characteristics of hemp (*Cannabis sativa L.)* seed oil. *Food Chem.* 76: 33–43.

Raes K, De Smet S, Demeyer D. 2004. Effect of dietary fatty acids on incorporation of long chain polyunsaturated fatty acids and conjugated linoleic acid in lamb. beef and pork meat: a review. *Anim. Feed Sci. Technol.* 113: 199–221.

Romans. JR, Wulf DM, Johnson RC, Libal GW, Costello WJ. 1995a. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: I. Dietary level of flaxseed. *J. Anim. Sci.* 73: 1982–1986.

Romans. JR, Johnson RC, Wulf DM, Libal GW, Costello WJ. 1995b. Effects of ground flaxseed in swine diets on pig performance and on physical and sensory characteristics and omega-3 fatty acid content of pork: II. Duration of 15% dietary flaxseed. *J. Anim. Sci.* 73: 1987–1999.

SAS (1999). SAS/STAT® User's Guide (Release 8.1). SAS Inst. Inc, Cary. NC.

Warmants N, Van Oeckel MJ, Boucque CV. 1999. Incorporation of dietary polyunsaturated fatty acids into pork fatty tissues. *J. Anim. Sci.* 77: 2478–2490.

Weill P, Schmitt B, Chesneau G, Daniel N, Safraou F, Legrand P. 2002. Effects of introducing linseed in livestock diet on blood fatty acid composition of consumers of animal products. *Ann. Nutr. Metab.* 46: 182–91.

Wood JD, Enser M, Fisher AV et al. 2008. Fat deposition. Fatty acid composition and meat quality: a review. *Meat Sci.* 78: 343–358.

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