

PAPER

Effects of dietary level of pantothenic acid and sex on carcass, meat quality traits and fatty acid composition of thigh subcutaneous adipose tissue in Italian heavy pigs

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Abstract

Two trials were carried out to evaluate the effects of i) supranutritional doses of pantothenic acid (PA) and ii) sex on carcass, meat quality and fatty acid (FA) composition of subcutaneous adipose tissue in Italian heavy pig. In trial 1, 59 Duroc x (LxLW) pigs were fed the same diet containing either 10 [in the control (C) group] or 110 ppm [in the treatment (T) group] PA, from 107 to 168 kg live weight. At slaughtering, forty carcasses were sampled randomly. The T carcasses had lower backfat thickness ($P < 0.05$), lower incidence of adipose cuts ($P < 0.05$), higher lean cuts percentage (63.09 vs 60.64%; $P < 0.01$) and lean meat yield ($P < 0.07$). In trial 2, 42 pigs [Dumeco Cofok x (LxLW)], evenly divided into three groups, were fed the same feed containing respectively 10 (C), 60 (T1) and 110 ppm (T2) PA, from 95 to 165 kg live weight. The treatment lowered total adipose cuts yield ($P < 0.05$) and increased lean/adipose cuts ratio ($P < 0.07$). In the outer layer of thighs subcutaneous adipose tissue, the treatment raised polyunsaturated FA content ($P < 0.01$), unsaturation coefficient ($P < 0.01$) and polyunsaturated/saturated (P/S) FA ratio ($P < 0.05$). In the inner layer, the treatment led to a lower saturated FA ($P < 0.05$) and

higher polyunsaturated FA content ($P < 0.01$). In both trials, females generally provided leaner carcasses. In neither trials, vitamin level affected meat quality. Thus, feeding high levels of PA to heavy pigs can yield more valuable carcasses without affecting meat quality. However, effects on FA composition suggest caution in adopting this practice in the Italian heavy pig production.

Introduction

Pantothenic acid (PA) (vitamin B5) is a water-soluble vitamin of the B-complex which is present in all living cells, usually in the form of coenzyme A (CoA) (EVM, 2001). The importance of this vitamin in pig feeding has been known for some time (Hughes, 1942; Luecke *et al.*, 1952). This vitamin, indeed, plays a considerable variety of roles in cell metabolism and the synthesis of many molecules such as FAs, amino acids, neurotransmitters, etc. Appropriate dietary intake of vitamin B5 is therefore essential in maximizing the performance of farm animals. The US National Research Council (NRC, 1998) thus recommends a 7 to 12 ppm concentration of PA in swine diets. This recommendation is based on studies carried out several decades ago on subjects that were genetically very different from those bred today, especially as regards their ability in lean tissue accretion (Lutz *et al.*, 2004). Studies performed in the last decade seem to show almost invariably that the administration of diets with concentrations of PA much higher (45-120 ppm) than those recommended would make carcass lean content significantly increase (Autrey *et al.*, 2002; Radcliffe *et al.*, 2003) and backfat thickness significantly reduce (Stahly and Lutz, 2001; Autrey *et al.*, 2002) – without affecting meat quality (Stahly and Lutz, 2001) – in pigs fed from 10-30 and up to 115-120 kg of live weight. In the heavy pig production, the commercial exploitation of the carcass depends also on the amount of the lean cuts it provides. Still, the variations described, albeit reportedly advantageous for the qualitative characteristics of the carcass (Santoro *et al.*, 2006; Lo Fiego *et al.*, 2009), could negatively affect lipid characteristics and add unfavourable features to the final product. This is even more so in protected designation of origin (PDO) circuits, where prescribed limits for the degree of lipid unsaturation exist (Consorzio del Prosciutto di Parma, 1992). Indeed, it is a well-known fact that not only is the FA composition of lipids influenced

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Carcass traits, Meat quality, Fatty acid composition.

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by numerous factors – including diet (Bosi *et al.*, 2000; Rossi and Corino, 2002; Lo Fiego *et al.*, 2005a) and genetic type (Bout *et al.*, 1988; Lo Fiego *et al.*, 2005b) – but is also strictly correlated to carcass fatness (Geri *et al.*, 1988; Geri *et al.*, 1990; Lebret and Mourot, 1998; Lo Fiego *et al.*, 2005b). A reduction in carcass fatness would cause an increase in the degree of lipid unsaturation (Lo Fiego, 1996; Piedrafita *et al.*, 2001; Lo Fiego *et al.*, 2010). Thus, this study was carried out to verify the effect of i) supranutritional doses of PA in the diet of fattening-finishing heavy pigs and ii) sex on the qualitative characteristics of carcass and meat, and on the FA composition of the subcutaneous adipose tissue of fresh thigh.

Materials and methods

Trial 1

In trial 1, 59 Duroc x (LxLW) pigs (30 females and 29 castrated males) were divided into two groups of 30 [control (C) group] and 29 [treatment (T) group] subjects, respectively (Santoro *et al.*, 2006). Each group was collectively weighed at the beginning of the trial and the average live weight was approximately 107 kg. The two groups were housed in two adjacent pens. For the entire duration of the experiment (85 days), a cereal-soybean meal-based commercial feed [crude protein (CP) 15.5%; lysine (Lys) 0.80%] was administered at a rate of 9% of metabolic weight [live weight (lw)^{0.75}] and up to a maximum amount of 3.5 kg/head/day. The feed of the two groups differed only as for the level of supplementation with PA, such as calcium pantothenate: C group was supplemented with 10 ppm, while T with 110 ppm. Water was available *ad libitum*. The PA content in the diet was determined by using the *Lactobacillus plantarum* (*arabinosus*) bacterial strain with a spectrophotometric reading at 675 nm (AOAC, 1995). After carcass grading, a sub-sample of 20 carcasses per group, evenly balanced for sex, was randomly chosen, and the weight of the individual lean and adipose cuts was assessed in each left half-carcass. Within 1 h *post-mortem*, the values of pH (pH_i) and the colour were measured on the *biceps femoris* (BF) and *semimembranosus* (SM) muscles of each left thigh. pH was measured using a portable Crison pH-meter equipped with a Xerolite electrode (Crison Instruments, Alella, Spain), while the colour was assessed using a portable Minolta Chromameter CR-300 colorimeter (Minolta, Osaka, Japan) [International Commission on Illumination (CIE) L*a*b*, 1976 co-ordinates, light source D65, 8-mm diameter]. The same measurements were taken after 24 h of chilling, at a temperature of 0-4°C, when the weight of the left thigh was also determined. Samples of subcutaneous adipose tissue and BF were also taken from each thigh, vacuum packed and stored at -20°C until the subsequent determinations of the iodine value in adipose tissue according to the Wijs method (AOAC, 1984), and of the lipid and protein content in BF (AOAC, 1995). The results were submitted to ANOVA, using a linear model which considered PA dietary supplement and sex as fixed effects (SAS, 1996). The interaction between dietary treatment and sex was also tested; this was statistically significant for none of the examined parameters (P>0.05)

and was thus removed from the model. Warm carcass weight was used as covariate to analyse carcass traits.

Trial 2

In trial 2, 42 Dumeco-Cofok x (LxLW) pigs (21 females and 21 castrated males) were used. The pigs were individually weighed and then divided into three groups of 14 subjects each, balanced for weight and sex (Lo Fiego *et al.*, 2009). The average lw was 94.5±5.4 kg. The three groups were given the same commercial feed (CP 15%, Lys 0.67%) based on cereals and soybean meal solvent extracted. Each group received a different supplement of PA, such as calcium pantothenate, at doses of 10 (C), 60 [treatment 1 (T1)] and 110 ppm [treatment 2 (T2)]. The PA content in the diets was determined according to the AOAC method (1995) already described in trial 1. The three groups were housed in three adjacent pens. For the entire duration of the experiment (97 days) the animals received the diet at a rate of 9% of metabolic weight up to a maximum amount of 3.2 kg/head/day. Drinking water was always available.

After carcass grading, the weight of the lean and adipose cuts of the left half-carcasses was individually assessed. One h after slaughtering and 24 h *post-mortem*, pH and colour were measured in the BF, SM and *longissimus dorsi* (LD) muscles, using the same equipment and methods described in the first trial. Furthermore, 1 h *post-mortem*, a sample of LD was withdrawn, vacuum packed and stored at -20°C, until subsequent determinations of the lipid and protein content (AOAC, 1995). On trimming, the trimmed weight of each left thigh was recorded, and from each thigh a sample of subcutaneous adipose tissue was taken, vacuum packed and stored at -20°C until subsequent determinations. Each trimmed thigh was sent to the seasoning plant for production of Parma ham and after 12 months the weight of the seasoned ham was recorded. After extracting total lipids (IUPAC, 1979) from the sample of subcutaneous adipose tissue taken from the fresh thigh, the iodine value was separately determined for outer and inner layer, according to the Wijs method (AOAC, 1984). Also, 50 mg of extracted lipids were subjected to methylation by means of a methanolic solution of potassium hydroxide (KOH 2N) according to Ficarra *et al.* (2010), and adding 100 µL of methyl nonadecanoate (C19:0) (Larodan Fine Chemicals, Malmö, Sweden) as an internal standard. The fatty acid methyl esters (FAME) were separated by capillary gaschromatography using a TRACE™ GC Ultra apparatus (Thermo Electron

Corporation, Rodano, Italy), equipped with an ultra fast module (UFM), a fast flame ionization detector (FFID), a programmed temperature vaporization (PTV) injector and an UFM-Carbowax column, 5 m long, with an internal diameter of 0.1 mm, and a stationary phase thickness of 0.2 µm. The injection of the FAME sample (1 µL) was performed with the split mode technique (splitting degree equal to 1:150) operating at a constant flow of 0.5 mL/min and using helium as the gas carrier. The temperature of the injector and the detector was kept at 240°C. The temperature programme used for the analysis started from 150°C, was maintained for 10 sec, then increased to 240°C, at a rate of 102°C/min, and kept at this temperature for 2.5 min. The peaks of the FAs were recorded and integrated using Chrom-Card software (vers. 2.3.3; Thermo Electron Corporation) and identified by comparison with the retention times of a standard solution with known quantities of various methyl esters (Supelco® 37 Component FAME mix and PUFA standard n. 2 animal source; Sigma Aldrich, St. Louis, MO, USA). Quantification was based on the internal standard technique and the areas of the peaks corresponding to each FA were corrected by means of a response factor calculated on the basis of the above-mentioned standard. The quantity of each fatty acid is expressed as a percentage of the total FAs detected. The results obtained were processed by means of ANOVA, using a linear model which considered PA dietary supplement and sex as fixed effects (SAS, 1996). Warm carcass weight was included in the statistical model as covariate to analyse carcass traits. The interaction between dietary treatment and sex was also tested; this was statistically significant for none of the examined parameters (P>0.05) and was thus removed from the model. The differences between means were tested by using the Tukey-Kramer multiple comparison test (SAS, 1996).

Results and discussion

Carcass characteristics

Data reported in Table 1 show that, in trial 1, the T group yielded carcasses with generally higher lean meat content, a reduced backfat thickness at the level of the third/fourth last lumbar vertebra, a greater incidence of lean cuts, in particular loin, neck and shoulder, a lower percentage of adipose cuts (namely backfat), and a higher lean/adipose cut ratio.

No significant treatment-related difference was observed relative to the carcass weight, which tended to be lower in females than in barrows. The carcasses of the females were also characterised by a greater incidence of lean meat, a higher percentage of lean cuts and a higher lean/adipose cut ratio. The iodine value of the subcutaneous adipose tissue was on average 71.56 in T and 69.94 in C, although the difference was not statistically significant, and was significantly higher in females.

Data relative to the qualitative characteristics of the carcass and the incidence of commercial cuts (Table 2) show how T1 and T2 groups in trial 2 have a slightly higher percentage of lean meat and cuts compared to C group, without reaching statistical significance. With respect to the C group, the T2 group showed lower percentage of adipose cuts, particularly the backfat, and a generally higher lean/adipose cut ratio. No significant difference was found between the two treatment levels. As far as the effect of sex is concerned, the same trend observed in trial 1 was detected. In particular, the females showed significantly higher values in the percentage of lean cuts, especially of thigh. On the contrary, the carcasses of barrows showed a greater incidence of the total of adipose cuts, particularly of belly, backfat and flare fat. The thickness of subcutaneous adipose tissue of thigh (Table 2) tended

to be greater in castrated males than in females. Thus, the effect of sex on the characteristics of the carcass broadly confirms what reported in the literature (Wood *et al.*, 1986; Lo Fiego *et al.*, 2000; Latorre *et al.*, 2003, 2008; Maiorano *et al.*, 2007; Lo Fiego *et al.*, 2010; Peinado *et al.*, 2012).

The results of these experiments show that the use of high doses of vitamin B5 can modify some carcass traits also in heavy pigs bred for PDO products. As for the carcass content of lean meat, the dietary treatment led to an increase of around 3% points in trial 1. A similar trend, with non-statistically significant differences between the groups, was recorded in trial 2.

These data confirm what was observed in light pigs by Groesbeck *et al.* (2007), while other authors (Stahly and Lutz, 2000, 2001; Autrey *et al.*, 2002; Radcliffe *et al.*, 2003) reported significant increases in carcass lean meat due to the administration of supranutritional doses of PA.

The thickness of subcutaneous adipose tissue was lower in the treated subjects, especially in the first experiment, in agreement with Stahly and Lutz (2001) and Autrey *et al.* (2002). The repartitioning effect of the vitamin treatment was of considerable interest, given its commercial implications: the incidence of adipose cuts significantly dropped in

both trials and the percentage of lean cuts considerably increased, especially in the first trial. In the available literature, only Groesbeck *et al.* (2007) did not observe any repartitioning action of the vitamin. This idiosyncrasy could have been caused by the use of genetic types with different ability in lean accretion. In fact, according to Baldwin and Stahly (2005), the action of PA is more evident at high rates of *de novo* lipogenesis (modulating the expression of RNAm for the synthesis of liposynthetic enzymes). In addition, by administering high levels of vitamin B5 to subjects of genetic strains with high or moderate lean deposition, Stahly and Lutz (2000) found an interaction ($P < 0.07$) between PA and genetic type. In particular, the effect of the high dose was more marked in the genetic strain with moderate lean deposition compared to the strain with a high degree of lean deposition. The subjects studied by Groesbeck *et al.* (2007) produced carcasses with 60% of lean meat, while in the other studies examined this value was equal to or less than 56%. The vitamin, thus, would act in limiting *de novo* lipogenesis; when this is anyhow operating at relatively low rates, either due to the characteristics of the diet (Baldwin and Stahly, 2005) or to the genetic characteristics of the subjects, no significant effects of supplementary doses of PA added to the diet are observed. This could partly explain the

Table 1. Effect of pantothenic acid dietary level and sex on various carcass traits in trial 1.

	PA dietary level, ppm		S		R-MSE	Significance	
	10, C	110, T	Barrows	Females		PA	S
Subjects, n	20	20	20	20			
Warm carcass weight, kg	139.11	138.86	144.00	133.96	15.43	ns	***
Lean meat ^o , %	47.37	50.38	47.15	50.60	5.06	***	***
Backfat thickness $\frac{3}{4}$ LLV, mm	35.13	29.08	34.12	30.09	9.54	*	ns
Backfat thickness $\frac{3}{4}$ last rib, mm	33.30	29.07	33.88	28.49	9.16	ns	ns
Cuts weight [†] , %							
Fresh thigh	25.96	25.88	25.54	26.30	0.84	ns	**
Chilled thigh	25.66	25.63	25.28	26.01	0.75	ns	**
Shoulder	13.31	14.04	13.56	13.79	1.09	*	ns
Loin	14.94	16.21	15.14	16.01	1.02	**	*
Neck	6.44	6.95	6.50	6.89	0.48	**	*
L	60.64	63.09	60.75	62.99	2.62	**	**
Belly	11.52	11.22	11.49	11.25	1.13	ns	ns
Jowl	6.35	6.04	6.39	6.00	0.53	***	*
Backfat	8.08	7.03	7.84	7.27	1.21	**	ns
A	25.95	24.29	25.71	24.53	2.17	*	ns
L/A ratio	2.38	2.63	2.40	2.61	0.29	**	*
Thigh chilling loss, %	1.10	0.92	0.87	1.16	1.49	ns	ns
Iodine value [§]	69.94	71.56	69.12	72.39	3.13	ns	**

PA, pantothenic acid; S, sex; R-MSE, root mean square errors; C, control group; T, treatment group; LLV, last lumbar vertebra; L, total lean cuts; A, total adipose cuts; L/A ratio, ratio of total lean cuts to total adipose cuts. Results are expressed as least squares means. ^oEstimated by fat-o-meater; [†]weights measured on left-half carcass; [§]value measured in thigh subcutaneous adipose tissue; ns, not significant; *** $P < 0.07$; ** $P < 0.05$; * $P < 0.01$.

more marked effect of the treatment on the carcass characteristics in trial 1 compared to trial 2, where the paternal line was represented by a commercial hybrid strain which, with respect to subjects belonging to breeds like Duroc, Landrace, Large White and their crosses, generally yields more meaty carcasses (Nanni Costa *et al.*, 1993; Lo Fiego *et al.*, 2000).

Meat quality traits

Meat quality parameters, such as pH and colour, as well as the protein and lipid contents of BF (trial 1) and LD (trial 2) did not change depending on the diet (Tables 3 and 4), in agreement with Stahly and Lutz (2001). In these tables, the values of a* and b* colour parameters are not shown since they never attained significance.

As far as sex is concerned, females showed pH₁ values significantly higher in BF in trial 1 (Table 3), and in SM and BF muscles in trial 2 (Table 4). No sex-related difference was found in pH values in the muscles considered after 24 h chilling (pH₂). Other authors (Cisneros *et al.*, 1996; Latorre *et al.*, 2003) did not find any sex-related differences for the pH values detected in SM and LD muscles at 45 min and

Table 2. Effect of pantothenic acid dietary level and sex on various carcass traits in trial 2.

	PA dietary level, ppm			S		R-MSE	Significance	
	10, C	60, T1	110, T2	Barrows	Females		PA	S
Subjects, n	14	14	14	21	21			
Warm carcass weight, kg	142.80	138.66	140.35	142.79	138.42	8.47	ns	ns
Lean meat ^o , %	48.10	49.48	48.83	48.00	49.61	3.02	ns	ns
Backfat thickness ³ / ₄ last rib, mm	31.26	27.03	28.22	30.63	27.34	6.23	ns	ns
Thigh fat thickness, mm	32.63	33.41	30.85	33.96	30.63	7.19	ns	ns
Cuts weight [#] , %								
Fresh thigh	24.64	24.90	24.99	24.30	25.39	0.92	ns	**
Chilled thigh	24.29	24.50	24.59	23.91	25.02	0.92	ns	**
Trimmed thigh	20.78	20.96	21.20	20.61	21.55	1.06	ns	*
Shoulder	15.75	16.29	15.93	15.88	16.10	0.66	ns	ns
Loin	17.17	17.22	17.47	17.06	17.52	1.14	ns	ns
Neck	7.23	7.18	7.43	7.34	7.23	0.55	ns	ns
L	64.80	65.59	65.82	64.57	66.24	2.23	ns	*
Belly	12.07	11.75	11.61	11.95	11.67	1.00	ns	**
Jowl	5.51	5.24	5.21	5.36	5.28	0.40	ns	ns
Flare fat	7.77	7.36	6.98	7.93	6.81	1.23	ns	**
Backfat	8.01 ^A	7.24 ^B	6.83 ^B	7.85	6.87	1.01	**	**
A	33.37 ^a	31.52 ^{ab}	30.63 ^b	33.10	30.63	2.77	*	**
L/A ratio	1.95 ^d	2.11 ^{cd}	2.16 ^c	1.98	2.18	0.23	***	**
Technological traits of ham								
Chilling loss, %	1.41	1.63	1.61	1.62	1.48	0.49	ns	ns
Trimming loss, %	17.21	16.81	16.38	16.57	17.02	3.23	ns	ns
Seasoning loss, %	27.99	27.70	28.19	27.81	28.11	2.98	ns	ns

PA, pantothenic acid; S, sex; R-MSE, root mean square errors; C, control group; T1, treatment group 1; T2, treatment group 2; L, total lean cuts; A, total adipose cuts; L/A ratio, ratio of total lean cuts to total adipose cuts. Results are expressed as least squares means. ^aEstimated by fat-o-meater; [#]weights measured on the left-half carcass (whitout head); ns, not significant; **, ^{A,B}P<0.01; ^{a,b}P<0.05; ^{c,d}***P<0.07.

Table 3. Effect of pantothenic acid dietary level and sex on some meat quality characteristics in trial 1.

	PA dietary level, ppm		S		R-MSE	Significance	
	10, C	110, T	Barrows	Females		PA	S
Subjects, n	20	20	20	20			
Values at 1 h <i>post-mortem</i>							
pH BF	6.19	6.17	6.07	6.29	0.30	ns	*
pH SM	6.01	5.84	5.88	5.96	0.31	ns	ns
L* BF	39.13	39.31	39.80	38.64	2.73	ns	ns
L* SM	44.41	45.67	44.76	45.32	3.16	ns	ns
Values at 24 h <i>post-mortem</i>							
pH BF	5.68	5.61	5.62	5.67	0.12	ns	ns
pH SM	5.61	5.58	5.58	5.62	0.10	ns	ns
L* BF	43.20	44.99	45.40	42.80	3.19	ns	*
L* SM	49.18	48.86	50.52	47.53	4.08	ns	*
Protein BF, %	24.73	24.65	24.48	24.90	0.76	ns	ns
Lipid BF, %	1.73	1.64	1.99	1.39	0.75	ns	*

PA, pantothenic acid; S, sex; R-MSE, root mean square errors; C, control group; T, treatment group; BF, *biceps femoris*; ns, not significant; SM, *semimembranosus*; L*, L* value of the colour detected. Results are expressed as least squares means. ns, not significant; *P<0.05.

24 h *post-mortem*, while Alonso *et al.* (2009) reported a significantly higher pH value in the BF muscle and a lower value in the LD muscle of the females with respect to the castrated males at 24 h *post-mortem*.

In trial 1 (Table 3), castrated males showed a significantly higher content of intramuscular lipids of BF compared to the females. The same trend was found in trial 2 (Table 4) in LD muscle. These data also confirm previous literature findings (Franci *et al.*, 1995; Lo Fiego *et al.*, 2000; Latorre *et al.*, 2003).

No sex-related difference was detected for the L* value of the colour of the muscles at 1 hour *post-mortem*, while at 24 h this parameter was significantly higher in BF and SM of castrated males in trial 1 (Table 3). The same trend, without reaching statistical significance, was observed in trial 2 as well (Table 4).

Many authors (Ellis *et al.*, 1996; Weatherup *et al.*, 1998; Lindahl *et al.*, 2001) stated that meat colour is not affected by sex. Lloveras *et al.* (2008), on the other hand, reported significantly higher L* values in LD muscle of castrated males with respect to females. In our studies reporting the L* value, *i.e.* a parameter measuring luminosity, the differences could be partly due to higher content of lipids. The L* value was, in fact, higher in castrated males which also had a higher quantity of intramuscular lipids.

Fatty acid composition

Tables 5 and 6 show data relative to FA composition of the two layers of subcutaneous adi-

pose tissue of the fresh thigh. In the outer layer (Table 5), an increase of polyunsaturated FAs was observed in the treated groups, though significantly only in T1, basically owing to a greater amount of linoleic acid (C18:2). On the other hand, no significant variation was observed in the content of each saturated FA and in the total content of both saturated and monounsaturated FAs. The control group showed a higher content of palmitoleic (C16:1) and eptadecenoic (C17:1) FAs in comparison with T2 group, and of eicosenoic (C20:1) and linolenic (C18:3) FAs as compared with T1 group. This last one, when set against T2, showed a tendentially lower content of C20:1 and a higher content of C18:3. No other significant difference was found between the two treatment levels. Overall, the treatment increased the unsaturation coefficient [Σ of each unsaturated FA (%) x number of its double bonds/total unsaturated FAs (%)] and the polyunsaturated/saturated (P/S) FAs ratio, both statistically significant only for T1. As regards the effect of sex on FA composition, a significantly lower content of saturated FAs – particularly of miristic (C14:0) and palmitic acid (C16:0) – was found in females, and a significantly higher percentage of polyunsaturated FAs was also detected due to higher levels of linoleic, linolenic and eicosadienoic acids (C20:2). In females, these trends led to a significant increase both in the unsaturation coefficient and the P/S FA ratio. Sex, on the other hand, did not significantly influence the iodine value, which tended, however, to be

higher in females.

In the inner layer of the subcutaneous adipose tissue (Table 6), the vitamin supplement led to a drop in the percentage of saturated FAs, which was significant only for T2 and mainly ascribable to the reduced content of C16:0. This trend was not observed in the outer layer. According to Mersmann and Leymaster (1984), the outer layer plays an important thermoinsulatory role; the inner layer, on the other hand, seems to be more active in the deposition and mobilisation of energy reserves (Abadía *et al.*, 2008). Therefore, *de novo* lipogenesis, which brings about a preferential deposition of saturated FAs and its main component, *i.e.* palmitic acid, is thought to be more relevant in the inner layer. If, as mentioned above, the vitamin reduces *de novo* lipogenesis by modulating the expression of RNAm for the synthesis of liposynthetic enzymes (Baldwin and Stahly, 2005), a decreased synthesis of palmitic acid, and saturated FAs in general, should take place. As regards the percentage of total monounsaturated FAs, a slight reduction was observed in the treated groups, statistically significant only for eicosenoic acid in T1 group and C16:1 in both T1 and T2. The treatment caused a statistically significant increase in the content of total polyunsaturated FAs. In particular, when compared to the C group, T1 group showed higher content of C18:2, C18:3 and C20:2 FAs, whereas T2 differed significantly from C group for linoleic acid content only. The P/S ratio increased significantly in both treated groups. Accordingly, the unsatura-

Table 4. Effect of pantothenic acid dietary level and sex on some meat quality characteristics in trial 2.

	PA dietary level, ppm			S	R-MSE	Significance	
	10, C	60, T1	110, T2			PA	S
Subjects, n	14	14	14	21	21		
Values at 1 h <i>post-mortem</i>							
pH BF	6.13	5.99	6.28	6.02	6.25	0.39	ns
pH SM	6.18	6.02	6.12	5.99	6.22	0.32	ns
pH LD	5.74	5.64	5.88	5.76	5.74	0.32	ns
L* BF	36.15	37.08	35.18	36.90	35.37	3.52	ns
L* SM	39.22	38.77	40.38	39.45	39.47	2.28	ns
L* D	51.20	51.50	52.41	52.76	50.65	5.71	ns
Values at 24 h <i>post-mortem</i>							
pH BF	5.59	5.56	5.59	5.57	5.59	0.09	ns
pH SM	5.56	5.55	5.58	5.54	5.58	0.08	ns
pH LD	5.48	5.52	5.50	5.50	5.50	0.08	ns
L* BF	42.01	42.98	41.10	42.43	41.64	4.30	ns
L* SM	42.61	43.23	43.50	43.70	42.54	2.63	ns
L* LD	52.84	52.52	53.78	54.39	51.71	4.73	ns
Protein LD, %	23.56	23.52	23.64	23.34	23.81	0.97	ns
Lipid LD, %	3.82	3.35	3.25	4.45	2.50	1.33	ns

PA, pantothenic acid; S, sex; R-MSE, root mean square errors; C, control group; T1, treatment group 1; T2, treatment group 2; BF, *biceps femoris*; SM, *semimembranosus*; LD, *longissimus dorsi*; L*, L* value of the colour detected. Results are expressed as least squares means. ns, not significant; ***P<0.07; *P<0.05; **P<0.01.

Table 5. Effect of pantothenic acid dietary level and sex on fatty acid composition (% of total fatty acids) of the outer layer of fresh thigh subcutaneous adipose tissue in trial 1.

	PA dietary level, ppm			S		R-MSE	Significance	
	10, C	60, T1	110, T2	Barrows	Females		PA	S
Subjects, n	14	14	14	21	21			
C14:0	1.14	1.10	1.12	1.15	1.09	0.09	ns	*
C16:0	21.78	21.13	21.50	21.79	21.15	0.84	ns	*
C17:0	0.28	0.28	0.27	0.27	0.28	0.04	ns	ns
C18:0	12.00	11.92	12.60	12.41	11.94	1.07	ns	ns
C20:0	0.16	0.17	0.21	0.16	0.20	0.08	ns	ns
Total saturated	35.36	34.61	35.70	35.78	34.68	1.63	ns	*
C16:1	1.96 ^A	1.84 ^{AB}	1.72 ^B	1.86	1.82	0.20	**	ns
C17:1	0.26 ^a	0.25 ^{ab}	0.21 ^b	0.25	0.24	0.06	*	ns
C18:1	40.86	40.25	40.19	40.83	40.04	1.34	ns	***
C20:1	1.05 ^c	0.84 ^d	1.05 ^c	0.97	1.00	0.24	***	ns
Total monounsaturated	44.14	43.20	43.17	43.90	43.10	1.45	ns	ns
C18:2	18.37 ^B	19.81 ^A	18.93 ^{AB}	18.21	19.87	1.26	**	**
C18:3	1.00 ^b	1.14 ^a	0.98 ^b	0.99	1.09	0.14	*	*
C20:2	0.80	0.89	0.83	0.79	0.89	0.12	ns	**
C20:3	0.13	0.16	0.17	0.15	0.16	0.05	ns	ns
C20:4	0.20	0.20	0.22	0.19	0.22	0.06	ns	ns
Total polyunsaturated	20.50 ^B	22.21 ^A	21.13 ^{AB}	20.33	22.23	1.42	**	**
Iodine value	72.83	75.27	74.62	73.61	74.87	2.90	ns	ns
Unsaturation coeff.	1.341 ^B	1.366 ^A	1.353 ^{AB}	1.341	1.366	0.21	**	**
Polyunsat/sat. ratio	0.582 ^b	0.643 ^a	0.595 ^{ab}	0.570	0.643	0.06	*	**

PA, pantothenic acid; S, sex; R-MSE, root mean square errors; C, control group; T1, treatment group 1; T2, treatment group 2; unsaturation coeff., unsaturation coefficient= Σ (% of each unsaturated fatty acids x number of its double bonds)/% unsaturated; polyunsat/sat. ratio, ratio of polyunsaturated to saturated fatty acids. Results are expressed as least squares means. ns, not significant; ^{A,B},**P<0.01; ^{a,b},*P<0.05; ^{c,d},***P<0.07.

Table 6. Effect of pantothenic acid dietary level and sex on fatty acid composition (% of total fatty acids) of the inner layer of fresh thigh subcutaneous adipose tissue in trial 2.

	PA dietary level, ppm			S		R-MSE	Significance	
	10, C	60, T1	110, T2	Barrows	Females		PA	S
Subjects, n	14	14	14	21	21			
C14:0	1.15 ^c	1.07 ^d	1.09 ^{cd}	1.10	1.11	0.09	***	ns
C16:0	23.53 ^A	22.55 ^B	22.30 ^B	22.80	22.78	0.90	**	ns
C17:0	0.26	0.27	0.25	0.25	0.26	0.05	ns	ns
C18:0	14.82	14.91	14.53	14.87	14.64	1.04	ns	ns
C20:0	0.17	0.18	0.17	0.18	0.17	0.04	ns	ns
Total saturated	39.94 ^a	38.89 ^{ab}	38.34 ^b	39.21	38.90	1.53	*	ns
C16:1	1.67 ^c	1.52 ^d	1.52 ^d	1.57	1.56	0.16	***	ns
C17:1	0.19	0.19	0.17	0.19	0.18	0.04	ns	ns
C18:1	39.28	38.42	39.22	39.20	38.74	1.51	ns	ns
C20:1	1.17 ^A	0.89 ^B	1.11 ^{AB}	1.11	1.01	0.24	**	ns
Total monounsaturated	42.32	41.03	42.02	42.08	41.49	1.59	ns	ns
C18:2	15.95 ^{Bb}	17.79 ^A	17.67 ^a	16.69	17.58	1.58	**	ns
C18:3	0.80 ^B	0.98 ^A	0.87 ^{AB}	0.88	0.89	0.13	**	ns
C20:2	0.72 ^B	0.83 ^A	0.80 ^{AB}	0.76	0.81	0.09	**	ns
C20:3	0.13	0.20	0.16	0.20	0.13	0.14	ns	ns
C20:4	0.16	0.22	0.16	0.21	0.15	0.12	ns	ns
Total polyunsaturated	17.69 ^{Bb}	19.84 ^A	19.48 ^a	18.54	19.46	1.75	**	ns
Iodine value	67.79	69.25	69.17	68.03	69.44	2.67	ns	ns
Unsaturation coeff.	1.315 ^B	1.351 ^A	1.337 ^{AB}	1.328	1.340	0.03	**	ns
Polyunsat/sat. ratio	0.445 ^b	0.511 ^a	0.513 ^a	0.476	0.503	0.06	*	ns

PA, pantothenic acid; S, sex; R-MSE, root mean square errors; C, control group; T1, treatment group 1; T2, treatment group 2; unsaturation coeff., unsaturation coefficient= Σ (% of each unsaturated fatty acids x number of its double bonds)/% unsaturated; polyunsat/sat. ratio, ratio of polyunsaturated to saturated fatty acids. Results are expressed as least squares means. ns, not significant; ^{A,B},**P<0.01; ^{a,b},*P<0.05; ^{c,d},***P<0.07.

tion coefficient increased in the treated groups, but significantly only in T1. No significant difference was found in this layer between the two treatment levels as regards iodine value and FA composition. Unlike what was observed in the outer layer, sex had no statistically significant effect on FA composition or iodine value in the inner layer.

The FA composition of lipids plays an important role both from a nutritional and a technological point of view. From the point of view of human nutrition, it is well known that guidelines suggest an increase in the consumption of polyunsaturated FAs in order to reduce the onset of cardiovascular diseases (WHO, 2003). Conversely, the excessive increase of polyunsaturated FAs, especially of linoleic acid, is negatively considered in a technological perspective as it worsens the firmness and oxidative stability of the lipids. Leuret and Mourot (1998) indicate a linoleic acid content of 15% as the maximum amount. Another important parameter for evaluating the suitability of adipose tissue for transformation into PDO products, such as Parma ham, is the iodine value. The cut-off fixed by the protection Consortium is equal to 70 (Consorzio Prosciutto di Parma, 1992). The above-mentioned results indicate that the subjects studied, especially those in trial 2, presented fat with no completely satisfactory characteristics for the processing into PDO products, regardless of the vitamin oversupplementation which, in general, increased the degree of lipid unsaturation. In these subjects, in fact, the mean content of linoleic acid was always above 15% in both layers of subcutaneous adipose tissue. Considering the mean iodine value of the two layers, this was always over 70 in all three groups and markedly higher in the treated groups. The maximum threshold (data not shown) was exceeded by a total of 75.0 and 71.4% of the treated subjects *vs* 50.0 and 64.3% of the control groups, in trial 1 and 2, respectively. Overall, iodine values above the threshold of 70 were found in 62.5% of the subjects in the first trial and in 69.0% of those in the second one (data not shown).

As regards sex, the threshold was exceeded by a higher percentage of females than of castrated males. The data relative to the effect of sex on FA composition is in line with other findings (Barton-Gade, 1987; Sturaro *et al.*, 2003; Lo Fiego *et al.*, 2010); compared to the castrated males, females presented a lower overall content of saturated and monounsaturated FAs and a higher quantity of polyunsaturated FAs, above all of linoleic acid and, accordingly, a higher unsaturation coefficient and a higher P/S FA ratio. These differences between the sexes were more pronounced in the outer

layer of subcutaneous adipose tissue. A higher iodine value was also recorded in females with respect to castrated males, although the difference was statistically significant only in the first experiment. The sex-related effects could be due to a lower lipogenic potential of the adipose tissue in females (Mersmann, 1984), which could imply a lower *de novo* FA synthesis, thus reducing the deposition of saturated FAs. In our study, females showed lower carcass fatness, and in heavy pigs at high slaughter weights, there are notoriously very close correlations between fatness and FA composition of subcutaneous adipose tissue (Lo Fiego *et al.*, 2005b).

Conclusions

The administration of supranutritional doses of PA in finishing heavy pigs makes it possible to produce carcasses with a greater incidence of lean cuts and a lower percentage of adipose cuts, without affecting meat quality. Vitamin concentrations of 60 ppm seem to be sufficient for the repartitioning action of vitamin B5 causing an increase in the degree of unsaturation of the lipids in the subcutaneous adipose tissue, along with increases in the level of linoleic acid and iodine value. The effects detected, though favourable for the quality of the carcass and the characteristics of the lipids from a human nutritional point of view, advise against a generalised oversupplementation to the diets fed to pigs reared for long seasoned (*i.e.* PDO) products. This is even more so in high lean strains and in females, whose adipose depots are already richer in polyunsaturated FAs. Indeed, an excessive increase in the degree of unsaturation of the lipids could lead to a considerable rise in non-conformities and an increased risk of oxidation of the products during the long seasoning periods.

References

- Abadía, S., Mendizabal, J., Alfonso, L., 2008. Relationship between depth of individual backfat layers and size of their constituent adipocytes in sows. *Acta Agr. Scand. A-An.* 58:161-163.
- Alonso, V., Campo, M.M. Español, S., Roncalés, P., Beltrán, J.A., 2009. Effect of crossbreeding and gender on meat quality and fatty acid composition in pork. *Meat Sci.* 81:209-217.
- AOAC, 1984. Official methods of analysis. 14th ed., Association of Official Analytical Chemists, Washington, DC, USA.
- AOAC, 1995. Official methods of analysis, 16th ed., Association of Official Analytical Chemists, Washington, DC, USA.
- Autrey, B.A., Stahly, T.S., Lutz, T.R., 2002. Efficacy of dietary pantothenic acid as an economic modifier of body composition in pigs. *J. Anim. Sci.* 80(Suppl.1):163(abstr.).
- Baldwin, C.A., Stahly, T.S., 2005. Efficacy of pantothenic acid as a modifier of body composition in a porcine model of obesity development. Iowa State University ed., Ames, IA, USA.
- Barton-Gade, P.A., 1987. Meat and fat quality in boars, castrates and gilts. *Livest. Prod. Sci.* 16:187-196.
- Bosi, P., Cacciavillani, J.A., Casini, L., Lo Fiego D.P., Marchetti, M., Mattuzzi, S., 2000. Effects of dietary high-oleic acid sunflower oil, copper and vitamin E levels on the fatty acid composition and the quality of dry cured Parma ham. *Meat Sci.* 54:119-126.
- Bout, J., Girard, J.P., Sellier, O., Runavot, J.P., Salort, D., 1988. Résultats préliminaires d'une comparaison entre quatre races porcines pour la composition chimique du tissu gras et le taux de gras intramusculaire. *Journées Rech. Porcine* 20:279-284.
- Cisneros, F., Ellis, M., McKeith, F.K., McCaw, J., Fernando, R.L., 1996. Influence of slaughter weight on growth and carcass characteristics, commercial cutting and curing yields, and meat quality of barrows and gilts from two genotypes. *J. Anim. Sci.* 74:925-933.
- Consorzio del Prosciutto di Parma, 1992. Prosciutto di Parma Denominazione di Origine Protetta - disciplinare generale e dossier di cui all'articolo 4 del regolamento (CEE) no. 2081/92 del consiglio del 14 luglio 1992. Consorzio del Prosciutto di Parma ed., Parma, Italy.
- Ellis, M., Webb, A.J., Avery, P.J., Brown, I., 1996. The influence of terminal sire genotype, sex, slaughter weight, feeding regime and slaughter-house on growth performance and carcass and meat quality in pigs and on the organoleptic properties of fresh pork. *Anim. Sci.* 62:521-530.
- EVM, 2001. Covering note for EVM/01/01/P. Review of pantothenic acid. Proc. 10th Meet. Expert Group on Vitamins and Minerals, London, UK.
- Ficarra, A., Lo Fiego, D.P., Minelli, G., Antonelli, A., 2010. Ultra fast analysis of subcutaneous pork fat. *Food Chem.* 121:809-814.
- Franci, O., Bozzi, R., Pugliese, C., Poli, B.M., Parisi, G., Balò, F., Geri, G., 1995.

- Confronto fra progenie di verri Large White, Landrace Italiana, Landrace Belga, Duroc, Cinta Senese e scrofe Large White a 130 e 160 kg di peso vivo. 3. Caratteristiche fisico-chimiche del magro e del grasso della coscia. *Zootec. Nutr. Anim.* 21:237-247.
- Geri, G., Poli, B.M., Zappa, A., Campodoni, G., Franci, O., 1990. Relationships between adipose tissue characteristics of newborn pigs and subsequent performance: III. Histological and chemical characteristics of backfat. *J. Anim. Sci.* 68:1936-1943.
- Geri, G., Poli, B.M., Zappa, A., Franci, O., 1988. Influenza dello sviluppo corporeo, della localizzazione e del sesso sulla composizione acidica del tessuto adiposo suino. *Zootec. Nutr. Anim.* 14:123-135.
- Groesbeck, C.N., Goodband, R.D., Tokach, M.D., Dritz, S.S., Nelssen, J.L., DeRouchey, J.M., 2007. Effects of pantothenic acid on growth performance and carcass characteristics of growing-finishing pigs fed diets with or without ractopamine hydrochloride. *J. Anim. Sci.* 85:2492-2497.
- Hughes, E.H., 1942. Pantothenic acid in the nutrition of the pig. *J. Agric. Res.* 64:185-187.
- IUPAC, 1979. Standard methods for the analysis of oils, fats and derivatives. 6th ed. International Union of Pure and Applied Chemistry, Pergamon Press, New York, NY, USA.
- Latorre, M.A., García-Belenguer, E., Ariño, L., 2008. The effects of sex and slaughter weight on growth performance and carcass traits of pigs intended for dry-cured ham from Teruel (Spain). *J. Anim. Sci.* 86:1933-1942.
- Latorre, M.A., Lázaro, R., Gracia, M.I., Nieto, M., Mateos, G.G., 2003. Effect of sex and terminal sire genotype on performance, carcass characteristics, and meat quality of pigs slaughtered at 117 kg body weight. *Meat Sci.* 65:1369-1377.
- Lebret, B., Mourot, J., 1998. Caractéristiques et qualité des tissus adipeux chez le porc. Facteurs de variation non génétiques. *Prod. Anim.* 11:131-143.
- Lindahl, G., Lundström, K., Tornberg, E., 2001. Contribution of pigment content, myoglobin forms and internal reflectance to the colour of pork loin and ham from pure breed pigs. *Meat Sci.* 59:141-151.
- Loveras, M.R., Goenaga, P.R., Irurueta, M., Carduza, F., Grigioni, G., García, P.T., Améndola, A., 2008. Meat quality traits of commercial hybrid pigs in Argentina. *Meat Sci.* 79:458-462.
- Lo Fiego, D.P., 1996. Carcass fatness and lipid quality in the heavy pig. *Meat Focus Int.* 5:261-263.
- Lo Fiego, D.P., Macchioni, P., Minelli, G., Ielo, M.C., Santoro, P., 2009. Effect of pantothenic acid level in the diet of the finishing heavy pig on carcass and meat quality traits. *Ital. J. Anim. Sci.* 8(Suppl.2):504-506.
- Lo Fiego, D.P., Macchioni, P., Minelli G., Santoro, P., 2010. Lipid composition of covering and intramuscular fat in pigs at different slaughter age. *Ital. J. Anim. Sci.* 9:200-205.
- Lo Fiego, D.P., Macchioni, P., Santoro, P., Pastorelli, G., Corino, C., 2005a. Effect of dietary conjugated linoleic acid (CLA) supplementation on CLA isomers content and fatty acid composition of dry-cured Parma ham. *Meat Sci.* 70:285-291.
- Lo Fiego, D.P., Santoro, P., Macchioni, P., De Leonibus, E., 2005b. Influence of genetic type, live weight at slaughter and carcass fatness on fatty acid composition of subcutaneous adipose tissue of raw ham in the heavy pig. *Meat Sci.* 69:107-114.
- Lo Fiego, D.P., Virgili, R., Bellatti, M., Tassone, F., Pecoraro, M., Reverberi, M., Russo, V., 2000. Caratteristiche delle carcasse e dei tagli di differenti tipologie di suino pesante attualmente presenti sul mercato. *Riv. Suinicolt.* 41:143-148.
- Luecke, R.W., Hofer, J.A., Thorp, F.Jr., 1952. The relationship of protein to pantothenic acid and vitamin B12 in the growing pig. *J. Anim. Sci.* 11:238-243.
- Lutz, T.R., Autrey, B.A., Stahly, T.S., 2004. Efficacy of pantothenic acid as a modifier of body composition in pigs. Iowa State University ed., Ames, IA, USA.
- Maiorano, G., Cavone, C., Paolone, K., Pilla, F., Gambacorta, M., Manchisi, A., 2007. Effects of slaughter weight and sex on carcass traits and meat quality of Casertana pigs reared outdoors. *Ital. J. Anim. Sci.* 6(Suppl.1):698-700.
- Mersmann, H.J., 1984. Effect of sex on lipogenic activity in swine adipose tissue. *J. Anim. Sci.* 58:600-604.
- Mersmann, H.J., Leymaster, K.A., 1984. Differential deposition and utilization of backfat layers in swine. *Growth* 48:321-330.
- Nanni Costa, L., Lo Fiego, D.P., De Grossi, A., Russo, V., 1993. Relazioni tra attitudine alla stagionatura del prosciutto di Parma e contenuto di carne magra della carcassa in suini ibridi. *Riv. Suinicolt.* 34:79-84.
- NRC, 1998. Nutrient requirements of swine. 10th ed. National Research Council, National Academy Press, Washington, DC, USA.
- Peinado, J., Serrano, M.O., Nieto, M., Sánchez, J., Medel, P., Mateos, G.G., 2012. The effects of gender and castration of females on performance and carcass and meat quality of heavy pigs destined to the dry-cured industry. *Meat Sci.* 90:715-720.
- Piedrafita, J., Christian, L.L., Lonergan, S.M., 2001. Fatty acid profiles in three stress genotypes of swine and relationships with performance, carcass and meat quality traits. *Meat Sci.* 57:71-77.
- Radcliffe, J.S., Richert, B.T., Peddireddi, L., Trapp, S.A., 2003. Effects of supplemental pantothenic acid during all or part of the growing-finishing period on growth performance and carcass composition. *J. Anim. Sci.* 20:353-359.
- Rossi, R., Corino, C., 2002. Influence of long-term nutrition with different dietary fats on fatty acid composition of heavy pigs backfat. *Ital. J. Anim. Sci.* 1:7-16.
- Santoro, P., Macchioni, P., Franchi, L., Tassone, F., Ielo, M.C., Lo Fiego, D.P., 2006. Effect of dietary pantothenic acid supplementation on meat and carcass traits in the heavy pig. *Vet. Res. Commun.* 30(Suppl.1):383-385.
- SAS, 1996. SAS/STAT user's guide: statistics. SAS Inst. Inc., Cary, NC, USA.
- Stahly, T.S., Lutz, T.R., 2000. Biological role of pantothenic acid in the pig. *J. Anim. Sci.* 78(Suppl.2):78(abstr.).
- Stahly, T.S., Lutz, T.R., 2001. Role of pantothenic acid as a modifier of body composition in pigs. *J. Anim. Sci.* 79(Suppl.1):68(abstr.).
- Sturaro, E., Romani, C., Noventa, M., Gallo, L., Carnier, P., 2003. Sources of variation of iodine number and fatty acids profile in raw hams for dry curing. *Ital. J. Anim. Sci.* 2(Suppl.1):373-375.
- Weatherup, R.N., Beattie, V.E., Moss, B.W., Kilpatrick, D.J., Walker, N., 1998. The effect of increasing slaughter weight on the production performance and meat quality of finishing pigs. *Anim. Sci.* 67:591-600.
- WHO, 2003. Diet, nutrition and the prevention of chronic diseases. Report of a joint WHO/FAO expert consultation. World Health Organisation ed., Geneva, Switzerland.
- Wood, J.D., Buxton, P.J., Whittington, F.M., Enser, M., 1986. The chemical composition of fat tissues in the pig: effects of castration and feeding treatment. *Livest. Prod. Sci.* 15:73-82.