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Effects of L-carnitine and iron diet supplementations on growth performance, carcass characteristics and blood metabolites in fattening pigs

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The aim of this study was to evaluate the effect of dietary L-carnitine supplementation either with or without extra Fe supplementation from Fe-amino acid (Fe-AA) complex on body weight gain, feed conversion, carcass characteristics and blood metabolite concentrations in fattening pigs. The study was carried out with 75 fatteners (30–100 kg body weight), divided into three groups, of 25 pigs each. The control group was given a basal diet that contained 85 mg/kg of Fe from premix. A L-carnitine group was given a basal diet supplemented with 100 mg/kg of L-carnitine, and a L-carnitine+Fe group was given a basal diet supplemented with 100 mg/kg of L-carnitine and 60 mg/kg of Fe from a Fe-AA complex. The supplement of L-carnitine to the diets did not have any effects on the growth performance and carcass traits. The L-carnitine supplement decreased the concentration of triglycerides ($p \leq 0.05$), cholesterol ($p \leq 0.05$) and low-density lipoproteins ($p \leq 0.01$) in the blood serum of pigs, while it increased ($p \leq 0.01$) the concentration of high-density lipoproteins. The combination of L-carnitine+Fe increased the growth performance of growing pigs ($p \leq 0.05$) and the lean percentage and fatless ham weight in carcass and also increased ($p \leq 0.05$) the Fe content in the blood serum and the *longissimus dorsi* muscle of pigs. The results suggest the more effective outcomes can be reached when L-carnitine+Fe rather than only L-carnitine is used in diets.

Key-words: L-carnitine, iron, fatteners, growth performance, blood metabolites

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Introduction

L-carnitine is a vitamin-like compound that is necessary for the transportation of long-chain fatty acids across the inner mitochondrial membrane for β-oxidation (Hoppel 2003). It can be synthesized in the body from protein-bound lysine and methionine. In addition, several cofactors are involved such as iron (Fe^{+2}), ascorbate, niacyn and vitamin B_6 (Vaz and Wanders 2002).

The synthesis of L-carnitine in mammal organisms is insufficient, thus its requirement should be supplemented by feed ration. The amount of L-carnitine in plant feeds is small (5–29 mg/kg), while much larger quantities (at about 150 mg/kg) are found in feeds of animal origin (Jacobs 2002). At present, pig diets are based first of all on plant components, thus the demand of pigs for L-carnitine might not be covered, and L-carnitine supplementation could be necessary. Studies have demonstrated the beneficial effects of L-carnitine supplementation on the reproductive performance of breeding sows and weaning of piglets (Eder et al. 2001, Ramanau et al. 2004) and the quality of boar semen (Währner et al. 2004, Jacyno et al. 2007).

In the studies on the effect of L-carnitine on the growth rate, feed conversion and the quality of pig carcasses, no clear results have been found (Owen et al. 2001a, 2001b, Rekiel and Zackiewicz 2004, Han and Thacker 2006). L-carnitine has a role in the metabolism of lipids, carbohydrates and some amino acids and thus can modify the concentration of metabolites in blood (Grela et al. 2005).

One of the most important functions of iron (Fe) is to stimulate the blood-producing system to synthesize hemoglobin and myoglobin, as well as to participate in oxygen transportation by erythrocytes. The effect of iron on the growth rate, feed conversion and pig carcass quality is ambiguous. Dove and Haydon (1991) and Saddoris et al. (2003) found that pig diet supplementation with iron did not have any effect on the fattening results. In other studies, the positive effect of iron was observed on the daily gain in piglets (Rincker et al. 2004) and fatteners (Liao et al. 2005). Some studies also show that the supplementation of fatteners diet with Fe increases its content in meat and blood as well as positively affecting meat sensory quality (O'Sullivan et al. 2003, Liao et al. 2005, Apple et al. 2007).

Iron requirements have not been precisely established for pigs. According to the National Research Council (1998), iron requirements of growing pigs range between 40 and 100 mg/kg. In the European Union, a differential level of iron in the feed for fatteners is used: 80–150 for growing pigs, 65–110 mg/kg for finishing pigs (Lipiński 2007). According to Commission Regulation (No 1334/2003/EC) the maximum content of iron can not exceed 750 (totally) mg/kg of the complete feeding stuff.

The aim of this study was to determine the effect of L-carnitine and L-carnitine and iron supplementation of fattening pig diets on body weight gain, feed conversion, carcass characteristics and concentration of blood metabolites.

Material and methods

Animals and feeding

The study was carried out at production farm with 75 fatteners, hybrids after Polish Large White × Polish Landrace sows and Pietrain × Duroc and Pietrain × Hampshire boars. The same number of pigs with different sex, genotype and body weight were allotted to three treatments. There were 25 pigs in each treatment group. The animals were housed with litter in pens of five pigs. Feed was provided *ad libitum* and water was provided by nipple waterers.

The pigs were given grower base diets during the fattening period of 30–60 kg body weight and finisher types during the fattening period of 60–100 kg body weight. The basal diet met or exceeded NRC (1998) recommendations for nutrients (Table 1).

The basal diets contained a supplement of 85 mg/kg Fe (from premix). The factor distinguishing

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Table1. Composition and nutritive value of basal grower and finisher diets.

	Grower	Finisher
Ingredients (g/kg)		
Barley	350	150
Triticale	226	427.5
Wheat	150	150
Wheat bran	50	100
Soybean meal	120	53.5
Rapeseed meal	60	90
Soybean oil	15	-
Mineral, vitamin and amino acid premix[a]	29	29
Nutrients		
Metabolisable energy (MJ/kg)	12.8	12.6
Crude protein (g/kg)	177	156
Crude fibre (g/kg)	32.0	32.9
Crude fat (g/kg)	32.4	21.4
Crude ash (g/kg)	53.4	38.6
Lysine (g/kg)	9.4	7.7
Methionine + cystine (g/kg)	6.1	5.1
Threonine (g/kg)	6.6	5.4
Ca (g/kg)	7.3	5.3
P (g/kg)	5.9	4.5
Na (g/kg)	1.3	1.1
Fe from premix (mg/kg)	85	85

[a] The premix supplied the following per kg diet: Mn, 60 mg; Zn, 130 mg; Cu, 25 mg; I, 0.5 mg; Se, 0.3 mg; Fe, 85 mg (analyzed); vitamin A, 9000 IU; vitamin D_3, 1000 IU; vitamin E, 87.5 mg; vitamin K, 2 mg; vitamin B_{12}, 25 µg; biotin, 25 µg; niacin, 20 mg; folic acid, 1 mg; choline chloride, 125 mg; pantothenic acid, 20 mg; lysine, 2.4 mg; methionine, 0.6 mg; threonine, 1.1 mg.

respective groups was the content of L-carnitine (Carniking®; Lonza, Ltd, Basel, Switzerland) and Fe (from Fe-AA complex, Polfa Kutno, Ltd, Kutno, Poland) in the diets.

Pig fattening was carried out from 30 to 100 kg body weight. During this period, they were weighed three times: at the beginning of fattening, at a body weight of about 60 kg, and before slaughter (at about 100 kg). Average daily gain (ADG), average daily feed intake (ADFI), feed conversion (feed:gain ratio) were determined for all pigs throughout the experimented period.

Slaughter value

All pigs were slaughtered at 100 kg body weight. Carcasses were weighed immediately following slaughter, then chilled at 4 °C for 24 h, and the right side was dissected. Carcass evaluation was conducted according to the Polish Pig Testing Stations methodology.

Meat content was estimated as follow:

$$y = 1.745x_1 + 0.836x_2 + 0.157x_3 - 1.884$$

where:

y – weight of meat in right carcass side (kg),
x_1 – weight of fatless ham (kg),
x_2 – weight of *longissimus* muscle (kg),
x_3 – double width + height of the *longissimus* muscle (cm).

For determining the content of Fe, samples of the *longissimus dorsi* muscle were collected from the section between lumbar vertebra 2 and 4. Also blood samples were collected from the pigs during slaughter for biochemical analyses.

Chemical analysis

Basic nutrients in feeds were determined by standard methods (AOAC, 1995), while amino acids with a Beckman automatic analyser. Phosphorus (P) was assayed by the vanadium-molybdenum photocalorimetric method, whereas calcium (Ca) and sodium (Na) through an emission spectrometry method on a BUCK Scientific spectrophotometer. The content of Fe in premix, Fe-AA complex and the *longissimus dorsi* muscle was determined by the emission spectrometry method in inductively coupled argon plasma (ICP-OES) on an Optima 2000 DV spectrophotometer (PerkinElmer Instruments INC, Waltham, USA). Metabolites in the blood serum: glucose, total protein, triglycerides, total cholesterol, high-density lipoproteins, low-density lipoproteins, as well as iron were determined by spectrophotometric methods with a PRO-Bio spectrophotometer (Marcel) using Alpha Diagnostics reagents.

Statistical analysis

The obtained data was analysed statistically by means of the STATISTICA 6.0 PL computer software using one-way analysis of variance. The significance of differences between the feeding groups was evaluated with the Duncan test.

Results

In the fattening period 30–60 kg, pigs fed a diet supplemented with L-carnitine and Fe from Fe-AA complex had higher ($p \leq 0.05$) ADG than the fatteners of other two groups, whereas, feed conversion was 0.32 kg less ($p \leq 0.05$) than control group and 0.21 kg less than the group of L-carnitine (Table 2). In the fattening period 60–100 kg, as well as in the whole fattening period (30–100 kg), ADG, ADFI and feed:gain ratio in all feeding groups were similar.

Carcass characteristics of fatteners are presented in Table 3. The pigs obtaining a L-carnitine+Fe (as Fe-AA complex) supplement, when compared to the control group and L-carnitine, were characterised by a better meatiness ($p \leq 0.05$) and a higher weight of fatless ham, respectively at 4.5% ($p \leq 0.05$) and 3.4%. The pigs of L-carnitine+Fe group also had a slightly larger area of *longissimus dorsi* muscle and a slightly thinner backfat. The pigs fed a diet with L-carnitine+Fe had increased Fe concentration in the *longissimus dorsi* muscle of these animals ($p \leq 0.05$). The carcass traits of pigs obtaining 100 mg L-carnitine in 1 kg feed did not differ significantly when compared with the control group.

The effect of the applied supplements on metabolites in the blood serum is presented in Table 4. The supplementation of diet with L-carnitine and L-carnitine+Fe decreased the concentration of triglycerides (by 10.9%, $p \leq 0.05$, and 15.6%, $p \leq 0.05$, respectively), total cholesterol (by 10.3%, $p \leq 0.05$, and 7.0%, respectively), low-density lipoproteins (by 18.8%, $p \leq 0.01$, and 16.3%, $p \leq 0.01$, respectively) and glucose (by 3.9 and 12.3%, respectively; non-significant differences). On the other hand, the concentration of high-density lipoproteins in the blood serum of pigs fed L-carnitine and L-carnitine+Fe diets was higher ($p \leq 0.01$) by 24.7 and 26.0%, respectively when compared to the control group. The combination of L-carnitine+Fe supplementations increased the Fe concentration in the blood serum of these animals ($p \leq 0.05$).

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Table 2. Growth performance of pigs fed diets supplemented L-carnitine or L-carnitine and iron.

Treatment[1]	Control	L-carnitine	L-carnitine+Fe	SEM[c]
N	25	25	25	
Grower phase (30 to 60 kg)				
Body weight (kg)	30.0	30.0	30.0	0.262
ADG (kg)	0.64 [b]	0.66[b]	0.72[a]	0.046
ADFI (kg)	1.96	1.97	1.96	0.186
Feed:gain	3.14[b]	3.03[ab]	2.82[a]	0.025
Finisher phase (60 to100 kg)				
Body weight (kg)	60.0	60.0	60.0	0.311
ADG (kg)	0.76	0.76	0.71	0.062
ADFI (kg)	2.66	2.72	2.53	0.228
Feed:gain	3.54	3.62	3.67	0.023
Overall (30 to 100 kg)				
ADG (kg)	0.70	0.71	0.71	0.053
ADFI (kg)	2.31	2.35	2.24	0.242
Feed:gain	3.34	3.30	3.20	0.028

[1] In each treatment, basal diet contained 85 mg/kg of Fe from mineral premix. L-carnitine supplementation was 100 mg/kg, and Fe supplementation 60 mg/kg from Fe-amino acid complex.

[a,b] means marked with different small letters are significantly different, $p \leq 0.05$

[c] Standard error of the mean

Table 3. Carcass characteristics of pigs fed diets supplemented L-carnitine or L-carnitine and iron.

Treatment	Control	L-carnitine	L-carnitine+Fe	SEM[c]
N	25	25	25	
Slaughter weight (kg)	100	100	100	0.34
Carcass length (cm)	82.8	81.4	85.0	0.85
Dressing percentage	78.3	80.4	78.7	0.37
Meat in right carcass side (kg)	21.12	21.17	21.93	0.193
Fatless ham weight (kg)	8.73[b]	8.92[ab]	9.12[a]	0.094
Longissimus muscle weight (kg)	4.30	4.13	4.00	0.054
Longissimus muscle area (cm^2)	53.2	51.4	54.9	0.99
Backfat thickness (cm)				
- above shoulder blade	3.40	3.33	3.28	0.132
- on the back	2.02	1.87	1.91	0.057
Percentage lean	56.0[b]	56.8[b]	58.5[a]	0.66
Fe in longissimus muscle (mg/kg)	5.72[b]	5.81[b]	6.44[a]	0.112

[a,b] means marked with different small letters are significantly different, $p \leq 0.05$

[c] Standard error of the mean

Table 4. Serum metabolites of pigs fed diets supplemented L-carnitine or L-carnitine and iron.

Treatment	Control	L-carnitine	L-carnitine+Fe	SEM[c]
N	25	25	25	
Glucose (mmol/L)	8.26	7.94	7.24	0.159
Total protein (g/L)	75.6	76.6	78.2	0.49
Triglycerides (mmol/L)	0.64[b]	0.57[a]	0.54[a]	0.014
Total cholesterol (mmol/L)	3.01[b]	2.70[a]	2.80[ab]	0.036
High-density lipoproteins (mmol/L)	0.73[B]	0.91[A]	0.92[A]	0.016
Low-density lipoproteins (mmol/L)	2.02[B]	1.64[A]	1.69[A]	0.016
Fe (μmol/L)	15.7[b]	14.8[b]	21.5[a]	0.79

[A,B]means marked with different big letters are significantly different, $p \leq 0.01$;
[a,b]means marked with different small letters are significantly different, $p \leq 0.05$
[c] Standard error of the mean

Discussion

In piglets and growing pigs, L-carnitine supplementation led to a reduction in body fat and an increase in body protein (Heo et al. 2000, Owen et al. 2001a, 2001b). This effect is due to an enhanced rate of β-oxidation of long-chain fatty acids. On the other hand, Owen et al. (2001a, 2001b) failed to detect an effect of supplementing 50 or 125 ppm L-carnitine on growth performance of growing pigs. In other studies it was shown that pigs fed a diet supplemented with 50 ppm L-carnitine had a higher daily gain, better feed conversion, better carcass meatiness and thinner backfat (Rekiel and Zackiewicz 2004). However, in our study, a supplement of 100 mg/kg L-carnitine to the pigs' diet did not have any effect both on the daily gains and feed conversion and the carcass traits. Similar results were obtained by Han and Thacker (2006) who used a 50 ppm L-carnitine supplement to the diet of finishing pigs. In our study the supplementation of L-carnitine had no effect on the quality of pork carcasses (non-significant statistical differences), however the pig carcasses of fatteners from the L-carnitine group characterised slightly thinner backfat (8%) and slightly higher meatiness in comparison with control groups.

L-carnitine supplementation, by promoting β-oxidation of fatty acids, lowered the synthesis of very low-density lipoproteins and decreased the concentrations of triglycerides and total cholesterol (Maccari et al. 1987). In the presented study, and in those of Grela et al. (2005), it was also shown that L-carnitine decreased the concentration of triglycerides, cholesterol and low-density lipoproteins, while it increased that of high-density lipoproteins in the blood serum. On the other hand, it was found in other studies that L-carnitine did not differentiate the concentration of triglycerides and cholesterol in the blood plasma of piglets and pregnant sows when compared to control animals (Birkenfeld et al. 2006, Doberenz et al. 2006).

Woodworth et al. (2002) and Doberenz et al. (2006) showed that dietary carnitine reduced the concentrations of insulin and glucose in blood plasma, suggesting an enhanced glucose tolerance. In our study only a slight decrease was observed (statistically non-significant) in the concentration of glucose in the blood serum of fatteners obtaining the L-carnitine supplement in their diet.

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The results of the presented study show that a supplement of 85 mg/kg Fe (from premix) to the basal diet (in accordance with NRC, 1998) can be insufficient for growing pigs. An increase of its level by 60 mg/kg Fe in the diet raised daily gains and feed conversion in pigs in the 30–60 kg body weight fattening period, while it did not have any effect on growth performance in the finishing pigs. Rincker et al. (2004) observed a linear increase in ADG as supplemental Fe increased from 0 to 150 ppm in nursery pigs. On the other hand, Dove and Haydon (1991) failed to detect an effect of supplementing 50 to 300 ppm Fe on growth performance of nursery pigs. Daily gains and feed conversion did not depend on 30 to 120 ppm Fe in the pig diet either (Yu et al. 2000, Saddoris et al. 2003). Apple et al. (2007) found that 50 to 150 ppm Fe supplement in the grower and finisher diet increased the daily gains of growing pigs (55–68 kg BW), while not having any effect on growth performance in the finishing pigs. On the other hand, Liao et al. (2005) found a rise of growth performance in 50 to 100 kg BW pigs obtaining the chelated Fe (1 g/kg diet).

Very little information is available concerning the effects of dietary Fe on pork carcass characteristics. Saddoris et al. (2003) observed that supplementing pig diets with 90 ppm Fe did not affect average backfat depth and *longissimus* muscle area, whereas Apple et al. (2007) observed a linear increase in 10^{th}-rib fat depth as supplemental Fe from 50 to 150 ppm in diets. Our study showed a favourable effect of L-carnitine+Fe (as Fe-AA complex) supplement on the quality of pork carcasses. They were characterised by a higher lean percentage, larger fatless ham weight as well as by slightly thinner backfat when compared to control group pigs that obtained 100 mg/kg L-carnitine in their diet.

It was shown that the diet supplement of Fe increased the Fe concentration in the blood serum of nursery pigs (Rincker et al. 2004), while the supplement of chelated iron increased the Fe concentration in the *longissimus dorsi* muscle (Liao et al. 2005). Similar results were also shown in our study.

Conclusions

The results of the presented study show that a supplement of 100 ppm L-carnitine to the diet does not have any effect on the growth performance of growing and finishing pigs and the carcass traits, while it decreases the concentration of lipids in blood. The combination of L-carnitine+Fe supplementations increased the growth performance of growing pigs and had a favourable effect on the carcass meatiness traits.

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