Animal (2020), **14:2**, pp 277–284 © The Animal Consortium 2019
doi:10.1017/S1751731119001708

animal

Effect of ractopamine and conjugated linoleic acid on performance of late finishing pigs

J. C. Panisson[1], A. Maiorka[1], S.G. Oliveira[1], A. Saraiva[2], M. S. Duarte[2], K. F. Silva[1], E. V. Santos[3], R. L. S. Tolentino[3], I. M. G. Lopes[3], L. L. M. Guedes[3] and B. A. N. Silva[3†]

[1]Animal Science Department, Universidade Federal do Paraná (UFPR), R. dos Funcionários 1540, Juvevê Curitiba, 80035-050 PR, Brazil; [2]Animal Science Department, Universidade Federal de Viçosa (UFV), Av. P H Rolfs sn, Viçosa, 36570-900 MG, Brazil; [3]Institute of Agricultural Sciences/ICA, Universidade Federal de Minas Gerais (UFMG), Av. Universitária 1.000, Montes Claros, 39404-547 MG, Brazil

(Received 23 October 2018; Accepted 2 July 2019; First published online 30 July 2019)

*The dietary inclusion of feed additives to improve the carcass characteristics of the final product is of great importance for the pork production chain. The aim of our study was to evaluate the effects of the association of ractopamine (**RAC**) and conjugated linoleic acid (**CLA**) on the performance traits of finishing pigs during the last 26 days prior to slaughter. In total, 810 commercial hybrid barrows were used. Animals were distributed among treatments according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels (0, 5 or 10 ppm) and three CLA levels (0, 0.3 or 0.6%). Pigs fed the diet with 5 ppm RAC had higher average daily feed intake (**ADFI**) (2.83 kg;* $P < 0.05$*) when compared with those fed 10 ppm RAC and the control diet (2.75 and 2.74 kg, respectively). Lower ADFI values (*$P < 0.01$*) were observed with the diets containing CLA compared with the control diet with no CLA (2.73 and 2.75* v. *2.85 kg/day, respectively). The average daily weight gain of pigs fed 5 and 10 ppm RAC was +148 and +173 g/dayhigher (*$P < 0.001$*), respectively, than those fed the control diet. Dietary RAC levels influenced (*$P < 0.001$*) feed conversion ratio (**FCR**), which was reduced as RAC levels increased, with the pigs fed 10, 5 and 0 ppm RAC presenting FCR values of 2.57, 2.71 and 3.05, respectively. FCR also improved (*$P < 0.05$*) with the inclusion of 0.6% CLA relative to the control diet (2.70* v. *2.84, respectively). There was a significant interaction between CLA × RAC levels (*$P < 0.01$*) for final BW, loin eye area (**LEA**) (*$P < 0.05$*) and backfat thickness (**BT**) (*$P < 0.05$*). The treatments containing 10 ppm RAC + 0.6% or 0.3% CLA increased LEA and reduced BT. In conclusion, the level of 10 ppm inclusion of RAC increased the overall performance parameters of pigs and therefore improved production efficiency. The combined use of RAC and CLA promoted a lower feed conversion ratio as well as better quantitative carcass traits, as demonstrated by the higher LEA and lower BT. The dietary inclusion of CLA at 0.3% improved feed efficiency, however, without affecting LEA or BT yields.*

Keywords: carcass traits, β-adrenergic, feed conversion ratio, lean meat deposition, backfat thickness

Implications

Pig producers target an efficient lean production to compete with other animal products. Ractopamine is a feed additive that has the potential to improve the rate and efficiency of lean muscle growth. However, due to world market trends, several nations have banned or are restricting the use of this feed additive during pig production. Therefore, there is an urge from pig producers to search for an alternative replacement for ractopamine because the dietary inclusion of conjugated linoleic acid improves feed efficiency in finishing pigs. This feed additive could help pig nutritionists to formulate finishing pig diets without the use of ractopamine and still maintain performance.

† E-mail: brunosilva@ufmg.br

Introduction

Feed additives that improve feed efficiency and change carcass composition, especially by reducing fat deposition and increasing meat yield, have been studied in the past years (Fernández-Fígarez *et al.*, 2007). Ractopamine (**RAC**) and conjugated linoleic acid (**CLA**) have been among the feed additives studied for this purpose (Weber *et al.*, 2006; Rickard *et al.*, 2011; Pompeu *et al.*, 2013; Marcolla *et al.*, 2017). RAC is a β-adrenergic agonist, which has proven efficiency in pork production. In addition to genetics, lysine and protein levels, the RAC inclusion level and the supplementation period may influence the efficiency of the additive (Schinckel *et al.*, 2003). RAC changes protein, lipid and carbohydrate metabolism, redirecting dietary nutrients from adipose tissue deposition towards protein accretion in the carcass, improving performance and carcass traits (Armstrong *et al.*, 2004). However, due to world market trends, about 160 nations have restricted the use of RAC, including all European countries, Russia and China. Therefore, there is an increasing demand from pig producers to search for an alternative for RAC. CLA is used to describe a mixture of geometric and positional isomers of linoleic acid (C18:2), which contains two conjugated double bonds (Donovan *et al.*, 2000). It inhibits the activity of enzymes linked to lipid synthesis, such as stearoyl-CoA desaturase or delta 9-desaturase or acetyl-CoA oxidase, reduces leptin levels and activates peroxisome proliferation receptors (Khosla and Fungwe, 2001; Kamphuis *et al.*, 2003). The inclusion of CLA in pig diets promotes better live performance, reducing the activation of the immune system, and additionally, can improve carcass traits (Pariza *et al.*, 2001).

However, there are few studies evaluating the combined inclusion of CLA with RAC in diets based on corn and soybean fed to pigs (Weber *et al.*, 2006; Rickard *et al.*, 2011; Pompeu *et al.*, 2013; Marcolla *et al.*, 2017). Therefore, the aim of our study was to evaluate the effects of the dietary inclusion of RAC and CLA, individually or combined, on the performance and carcass traits of pigs genetically selected for high lean tissue yield meat in the last 26 days of the finishing phase.

Materials and methods

The experiment was approved by the Committee of Ethics on Animal Use of the sector of Agricultural Sciences of the Federal University of Paraná (CEUA-SCA/UFPR), Brazil, under protocol number 060/2014. The experiment was conducted between August and September 2015 at the post-weaning facilities of the Penalva Farm, Juiz de Fora, Minas Gerais, Brazil (21°45′50″S and 43°20′59″W). The climate of the region is classified as hot, temperate and rainy, with a dry winter and hot and humid summer (CWA - humid subtropical climate), according to the Köppen (1948) classification.

Animals and experimental design

In total, 810 commercial hybrid barrows (Pietran × Large White / Landrace), with 80 ± 5 kg BW and 123 ± 5 days of age, were used. Animals were distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels (0, 5 or 10 ppm) and three CLA levels (0%, 0.3% or 0.6%), totalling nine treatments with six replicates (pens) of 15 pigs each. Body weight (light: 75 ± 1.08 kg, medium: 80 ± 1.32 kg and heavy: 84 ± 1.42 kg) was used as the blocking criterion, and the experimental unit consisted of the pen. The experiment was carried out for 26 days and on day 27 the pigs were slaughtered.

Measurements and collected parameters

The pigs were housed in pens with concrete floors and masonry walls in a building covered with fibre cement tiles and equipped with semi-automatic feeders and nipple drinkers. Environmental conditions were monitored daily using a data logger (Model Log Tag HAXO-8, Auckland, New Zealand) placed in the centre of the barn at the middle of body height.

The treatments (Table 1) consisted of nine diets with three RAC inclusion levels (RacTop®; HERTAPE CALIER, Juatuba, Minas Gerais, Brazil) and three CLA inclusion levels (LUTALIN®; BASF, Germany), which were added to the diets in replacement of starch. The RAC product contains 10% RAC hydrochloride. The CLA product is composed of 56% CLA methyl ester, with 1:1 isomer ratio (*cis*-9, *trans*-11; *trans*-10, *cis*-12). Experimental dietary nutrient levels were determined based on treatments (i.e. RAC inclusion or not) and pig's daily needs. Daily requirements were calculated based on a literature survey (Schinckel *et al.*, 2003; Webster *et al.*, 2007; National Research Council, 2012; Pompeu *et al.*, 2013; Rikard-Bell *et al.*, 2013) to guarantee a minimum ingestion of 24 or 26 g standardised ileal digestibility lysine/day and 8.5 Mcal metabolisable energy/day, considering the use of 5 or 10 ppm of RAC. The dietary amino acid and lysine ratio, according to the ideal protein concept, followed the recommendations of Rostagno *et al.* (2011) for finishing barrows.

Pigs were weighed individually per pen in the beginning (123 days of age) and end (149 days of age) of the experimental period. A maximum feed allowance of 3 kg of feed/pig per day was offered, whereas water was supplied *ad libitum* during the entire experimental period (26 days). Feed allowance and feed refusals were weighed daily to determine the average daily feed intake (**ADFI**).

Carcass traits

After pigs were weighed at the end of the trial, 15 pigs per treatment were selected for the evaluation of loin eye area (**LEA**) and backfat thickness (**BT**) using an ultrasound apparatus (Aloka SSD 500, Tokyo, Japan). The images were collected between the 10th and 11th ribs by a trained technician, as recommended by the Bates and Christians (2004). Based on the images obtained, LEA and BT values were calculated using the software program BiosoftSwine (Biotronics Inc. 1609 Golden Aspen Dr 105, Ames, IA 50010, USA).

Calculations and statistical analyses

Maximum and minimum daily ambient temperatures were averaged and analysed for the entire experimental period. Average daily weight gain (**ADWG**) was calculated as the initial weight minus final weight divided by the number of experimental days. Feed conversion ratio (**FCR**) was calculated as ADFI divided by ADWG. The experimental unit considered for the analysis of performance parameters (ADFI, ADWG and FCR) was the pen and 15 pigs per treatment for the analysis of quantitative carcass traits (LEA and BT). Data were analysed using the mixed procedure SAS 9.4 (SAS Institute Inc., Cary, NC, USA) following a completely randomised design according to a 3 × 3 factorial arrangement (three levels of RAC and three levels of CLA) with the pen as the experimental unit. The statistical model included the fixed effects of the RAC levels, CLA levels and their interaction and the

Table 1 *Ingredients and nutritional composition of the experimental diets fed to pigs*

	Experimental diets[1]								
	0 ppm RAC[1]			5 ppm RAC			10 ppm RAC		
	Conjugated linoleic acid			Conjugated linoleic acid			Conjugated linoleic acid		
Ingredients	0%	0.3%	0.6%	0%	0.3%	0.6%	0%	0.3%	0.6%
Corn	70.69	71.05	71.42	70.20	70.62	70.98	68.28	68.62	69.08
Soybean meal 46%	21.88	21.88	21.88	21.84	21.85	21.84	23.67	23.67	23.67
Soybean hulls	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Palm oil	0.90	0.53	0.16	0.77	0.37	0.00	0.80	0.45	0.00
Starch	1.00	0.50	0.00	1.00	0.50	0.00	1.00	0.50	0.00
Lutalin®[2]	0.00	0.50	1.00	0.00	0.50	1.00	0.00	0.50	1.00
Ractopamine (RAC)[3]	0.00	0.00	0.00	0.025	0.025	0.025	0.05	0.05	0.05
Salt	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
Limestone	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56	0.56
Dicalcium phosphate	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
L-lysine HCl	0.00	0.00	0.00	0.33	0.33	0.33	0.34	0.34	0.34
DL-methionine	0.00	0.00	0.00	0.10	0.10	0.10	0.12	0.12	0.12
L-threonine	0.00	0.00	0.00	0.15	0.15	0.15	0.16	0.16	0.16
L-tryptophan	0.00	0.00	0.00	0.03	0.03	0.03	0.036	0.036	0.036
Trace mineral premix[4]	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Vitamin premix[5]	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Antibiotics[6]	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Calculated nutritional composition[7]									
Metabolisable energy (Mcal/kg)	3220	3220	3220	3220	3220	3220	3220	3220	3220
Crude protein (%)	15.71	15.74	15.77	16.17	16.20	16.23	16.84	16.87	16.90
Digestible lysine (%)	0.68	0.68	0.68	0.93	0.93	0.93	0.98	0.98	0.98
SID methionine + cystine (%)	0.49	0.49	0.49	0.59	0.59	0.59	0.63	0.63	0.63
SID threonine (%)	0.51	0.51	0.51	0.65	0.65	0.66	0.68	0.69	0.69
SID tryptophan (%)	0.14	0.14	0.14	0.17	0.17	0.17	0.19	0.19	0.19
SID valine (%)	0.66	0.66	0.67	0.66	0.66	0.66	0.69	0.69	0.69
Sodium (%)	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
Calcium (%)	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Digestible phosphorus (%)	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Phytase (FTU[8]/kg)	500	500	500	500	500	500	500	500	500
Ractopamine (ppm)	0	0	0	5	5	5	10	10	10
Conjugated linoleic acid (%)	0.00	0.30	0.60	0.00	0.30	0.60	0.00	0.30	0.60

SID = stardardised ileal digestibility.
[1] Eight hundred and ten commercial hybrid barrows were used and distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three ractopamine (RAC) levels and three conjugated linoleic acid levels
[2] Content/kg of product: 60% conjugated linoleic acid, vehicle qsp 1000 g.
[3] Content/kg of product: 20 g ractopamine hydrochloride (RacTop®; Hertape Calier, Juatuba, Minas Gerais, Brazil), vehicle qsp 1000 g.
[4] Content/kg of product: iron (45 000 mg), copper (37 000 mg), manganese (25 000 mg), zinc (35 000 mg), cobalt (300 mg), iodine (800 mg), selenium (120 mg) and vehicle qsp 1000 g.
[5] Content/kg product: vitamin A (3 000 000 IU), vitamin D3 (1 200 000 IU), vitamin E (7500 mg), vitamin K (1250 mg), vitamin B12 (7000 mcg), vitamin B2 (20 000 mg), biotin (50 mg), Ca pantothenate (6000 mg), niacin (10 000 mg), choline (125 g), antioxidant (5000 mg), vitamin B1 (500 g), vitamin B6 (1000 mg), folic acid (150 mg), and vehicle qsp 1000 g.
[6] Tylan 40®Premix – content/kg product: tylosin activity (as phosphate) 88 g, vehicle qsp 1000 g.
[7] Nutritional composition calculated based on the Brazilian Tables Poultry and Pigs (Rostagno *et al.*, 2011).
[8] FTU: Phytase unit.

random effect of the experiment. Statistical analysis of the data was performed following two methodologies. The main effects of RAC and CLA were analysed with all significant interactions ($P < 0.05$) included in the model and the random effects within the model included block, block × RAC, block × CLA and block × CLA × RAC. The α level of 0.05 was considered statistically significant.

Results

The temperatures measured during the experimental period were 14.3°C and 25.3°C, respectively, for average minimum and maximum. The interaction between CLA × RAC for ADFI was not significant (Table 2, $P > 0.10$). Pigs fed the diet with 5 ppm RAC had greater ADFI (2.83 kg; $P < 0.05$) when compared with those fed 10 ppm RAC and the control diet (2.75

Table 2 *Live performance of barrows fed diets with different ractopamine (RAC) and conjugated linoleic acid (CLA) for the last 26 days of the finishing phase (least square means)*

	Treatments[1]																		
	CLA			RAC			0 ppm Ractopamine			5 ppm Ractopamine			10 ppm Ractopamine						
	0	0.3	0.6	0 ppm	5 ppm	10 ppm	0 CLA	0.3 CLA	0.6 CLA	0 CLA	0.3 CLA	0.6 CLA	0 CLA	0.3 CLA	0.6 CLA	RSD	P CLA	P RAC	P C × R
BW initial (kg)	80.11	79.77	79.82	80.19	79.74	80.01	80.88	79.30	79.70	79.65	79.71	79.84	79.80	80.31	79.91				
ADFI (kg/day)	2.85^{B}	2.75^{A}	2.73^{A}	2.74^{a}	2.83^{b}	2.75^{a}	2.86	2.72	2.66	2.83	2.84	2.83	2.86	2.70	2.70	0.10	**	*	ns
ADWG (kg/day)	1.009	0.991	1.020	0.900^{b}	1.048^{a}	1.073^{a}	0.928	0.896	0.877	1.053	1.019	1.070	1.046	1.057	1.115	0.05	ns	***	ns
FCR	2.84^{B}	2.79^{AB}	2.70^{A}	3.05^{c}	2.71^{b}	2.57^{a}	3.09	3.03	3.03	2.69	2.78	2.65	2.74	2.56	2.42	0.15	*	***	ns
BW final (kg)	106.15	105.66	106.10	102.98	107.14	107.80	104.07	103.19	101.68	107.29	106.40	107.73	107.10	107.41	108.89	1.46	ns	***	**

P CLA = effect of conjugated linoleic acid; P RAC = effect of ractopamine; P C × R-interaction between CLA and RAC; RSD = residual standard deviation; ADFI = average daily feed intake; ADWG = average daily weight gain; FCR = feed conversion ratio.

^{a,c}Values within a row with different superscripts differ significantly at $P < 0.05$ for RAC.

^{A,B}Values within a row with different superscripts differ significantly at $P < 0.05$ for CLA.

[1] Eight hundred and ten commercial hybrid barrows were used and distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels and three CLA levels.

$***P < 0.001$; $**P < 0.01$; $*P < 0.05$; $^{ns}P > 0.05$.

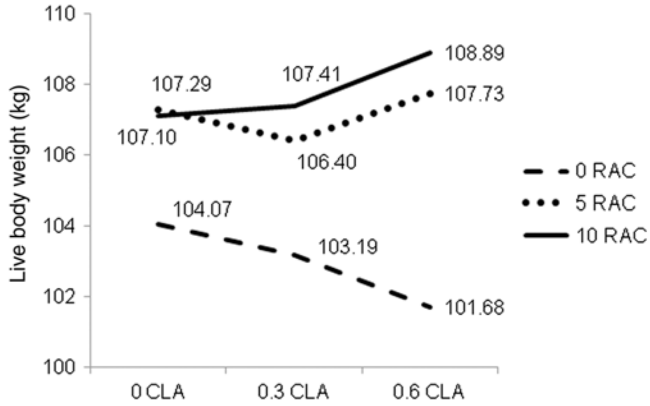

Figure 1 Final body weight of barrows fed diets with different ractopamine (RAC) and conjugated linoleic acid (CLA) for the last 26 days of the finishing phase (810 commercial hybrid barrows were used and distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels and three CLA levels).

and 2.74 kg, respectively; Table 2). Lower ADFI values ($P < 0.01$) were observed with the diets containing CLA (0.6% and 0.3%) compared with the control diet with no CLA (2.73 and 2.75 *v.* 2.85 kg/day, respectively; Table 2).

There was no interaction between CLA × RAC for ADWG ($P > 0.10$). The ADWG of pigs fed 5 and 10 ppm RAC was +148and +173 g/daygreater ($P < 0.001$), respectively, than those fed the control diet. There was no effect ($P > 0.05$) of dietary CLA inclusion on the ADWG.

There was no significant interaction between CLA × RAC for FCR ($P > 0.05$). Dietary RAC levels influenced ($P < 0.001$) FCR, which was reduced as RAC levels increased, with the pigs fed 10, 5 and 0 ppm RAC presenting FCR values of 2.57, 2.71 and 3.05, respectively. FCR also improved ($P < 0.05$) with the inclusion of 0.6% CLA relative to the control diet (2.70 *v.* 2.84, respectively), while the FCR obtained with 0.3% CLA was not different compared with the other treatments. There was a significant interaction between CLA × RAC levels ($P < 0.01$) for final BW. The heaviest pigs at the end of the trial were those fed 10 ppm RAC and 0.6% or 0.3% CLA (Figure 1).

The effects of dietary RAC and CLA inclusion on carcass traits are presented in Table 3. A significant interaction was observed between CLA and RAC for carcass traits. The addition of RAC and CLA to the experimental diets increased ($P < 0.05$) LEA (Figure 2) and reduced ($P < 0.05$) BT values (Figure 3). The pigs fed 10 ppm RAC presented larger LEA when the diets included 0.3% and 0.6% CLA compared with the control treatment. However, when the pigs were fed 0.6 CLA + 10 ppm RAC, they reduced BT when compared with the 0 CLA + 10 RAC, 0.3 CLA + 0 RAC, 0.6 + 0 RAC and 0.6 + 5 RAC. In addition, the pigs fed 0 CLA + 5 RAC had a lower BT when compared with 0.6 CLA + 5 RAC and 0 CLA + 10 RAC. The treatments containing 10 ppm RAC + 0.6% or 0.3 % CLA increased by 8% LEA and reduced 4% BT compared with the previous cited treatments, indicating higher protein accretion and lower fat deposition.

Table 3 *Loin eye area (LEA) and backfat thickness (BT) measurements of barrows fed diets with different ractopamine (RAC) and conjugated linoleic acid (CLA) for the last 26 days of the finishing phase (least square means)*

	Treatments[1]																		
	Conjugated linoleic acid			Ractopamine			0 ppm Ractopamine			5 ppm Ractopamine			10 ppm Ractopamine						
	0	0.3	0.6	0 ppm	5 ppm	10 ppm	0 CLA	0.3 CLA	0.6 CLA	0 CLA	0.3 CLA	0.6 CLA	0 CLA	0.3 CLA	0.6 CLA	RSD	P CLA	P RAC	P C × R
BW	106.4	103.7	106.7	105.3	104.3	107.2	106.7	104.7	104.5	106.1	101.3	105.4	106.3	105.1	110.3				
LEA	45.23	46.80	45.29	46.54	46.17	44.35	44.63	44.48	43.02	46.54	46.17	44.35	44.5	49.74	48.48	4.51	ns	***	*
BT	17.80	17.27	18.16	18.02	17.51	17.71	17.44	18.27	18.34	16.73	16.37	19.42	19.23	17.17	16.71	3.61	ns	ns	*

RSD=residual standard deviation; P CLA=effect of conjugated linoleic acid; P RAC=effect of ractopamine; P C × R=interaction between CLA and RAC; LEA= Loin eye area (cm^2); BT=backfat thickness (mm); ns=not significant.
[1] Eight hundred and ten commercial hybrid barrows were used and distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels and three CLA levels.
***$P<0.001$; *$P<0.05$; $^{ns}P>0.05$.

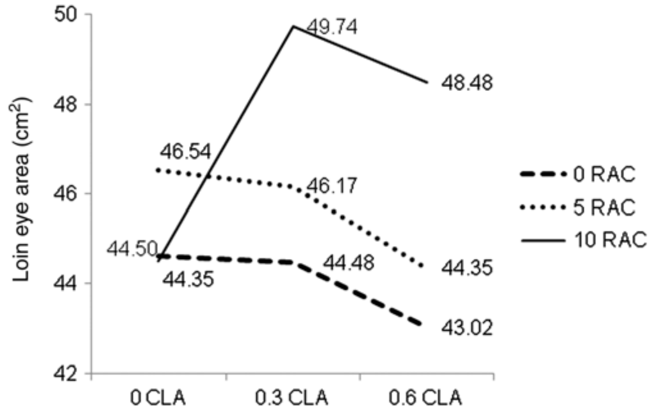

Figure 2 Loin eye area (LEA) of barrows fed diets with different ractopamine (RAC) and conjugated linoleic acid (CLA) for the last 26 days of the finishing phase (810 commercial hybrid barrows were used and distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels and three CLA levels).

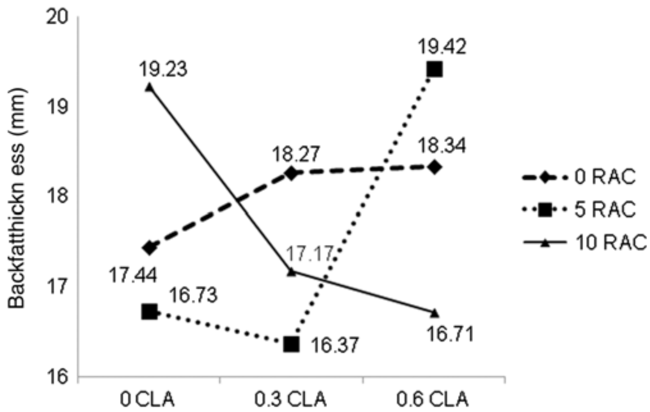

Figure 3 Backfat thickness (BT) of barrows fed diets with different ractopamine (RAC) and conjugated linoleic acid (CLA) for the last 26 days of the finishing phase (810 commercial hybrid barrows were used and distributed according to a randomised block design in a 3 × 3 factorial arrangement, with three RAC levels and three CLA levels).

Discussion

Effects of dietary ractopamine levels

In our study, ADFI reduced by 5% with 5 ppm RAC when compared to control and 10 ppm RAC. Similarly, Crome *et al.* (1996) and See *et al.* (2004) also reported reductions of 15% and 8% in the ADFI of pigs fed RAC levels of 10 and 20 ppm, respectively, mainly in the last 2 weeks prior to slaughter in relation to the control treatments. Watkins *et al.* (1990) feeding RAC levels of 0, 5, 10, 15 and 20 ppm to finishing pigs observed a reduction of 6% in ADFI between 5 and 10 ppm. Still, in contrast to our findings, Trapp *et al.* (2002), Marinho *et al.* (2007) and Sanches *et al.* (2010), evaluating increasing dietary RAC levels (0, 5, 10, 15 and 20 ppm) in diets for finishing pigs, did not find any differences in ADFI. The observed differences in ADFI between our study and the previously cited studies may be explained by the effects of pig genetics, composition of the experimental diets (i.e. lysine and protein levels) and particularly the RAC levels and duration of the supplementation period.

In the present study, RAC levels influenced ADWG. In agreement with our findings, Ferreira *et al.* (2011), evaluating increasing RAC levels (5, 10, 15 and 20 ppm) in diets for finishing pigs, observed an ADWG increase of 200 g/day, as for Marinho *et al.* (2007), an increase of 163 g/day ADWG was found in pigs fed RAC 5 ppm. In the present study, FCR improved as dietary RAC levels increased, corroborating the results of Ferreira *et al.* (2011) who evaluated the inclusion of increasing RAC levels (5, 10, 15 and 20 ppm) in the diet of finishing pigs and observed a 15% reduction in the FCR.

The improvement of performance traits obtained with the addition of RAC in the diet can be explained by the greater protein deposition promoted by RAC. Ractopamine induces metabolic changes, increasing muscle protein accretion relative to fat deposition (Schinckel *et al.*, 2003). In addition, muscle protein synthesis requires less energy and deposits until it reaches 2.5 times more water molecules compared with the adipose tissue (Pereira et al, 2008); therefore, improving daily growth rates.

Conjugated linoleic acid levels

In the present study, the ADFI of pigs fed 0.6% CLA was 5% lower compared to those fed the control diet. Dugan *et al.* (1997) also reported a similar 5% reduction in the ADFI intake of pigs (60 to 105 kg LW) fed 2% CLA compared to those fed sunflower oil. Cook *et al.* (1998) observed reduced feed intake of growing pigs with 26 kg initial BW supplemented with CLA for the first 49 days of the trial. On the other hand, Weber *et al.* (2006), Surek *et al.* (2011) and Pompeu *et al.* (2013) did not observe any ADFI differences between finishing pigs fed diets without or with CLA inclusion (0% or 0.6%, 0% or 0.3% and 0% or 0.6%, respectively).

The reduction of the ADFI observed in our study with the different dietary CLA levels may be due to the influence of CLA on blood leptin levels (Santos-Zago *et al.*, 2008). Leptin plays an important role in feed intake regulation. According to Pelleymounter *et al.* (1995) who studied the effects of CLA supplementation to rats, increased blood leptin concentrations reduced the appetite of the rats. The amount of leptin secreted in blood is proportional to the adipose tissue mass; the larger the adipocyte, the higher the blood concentration of leptin. Still in agreement with the previous authors, Parra *et al.* (2010), also feeding CLA to rats, observed that the higher dose of CLA reduced both plasma leptin and adiponectin concentrations. These findings could be related to the reduction in fat depots, the main synthesising organs, together with the reduction in its gene expression. Therefore, the body fat-lowering effect of CLA (Santos-Zago *et al.*, 2008) would result in lower leptin plasma concentrations, reducing the sense of satiety of the animals and consequently reducing the ADFI of the animals. Therefore, based on our findings, we can hypothesise that CLA induced a dystrophy of the fatty acid depots (lypolytic effect) and affected insulin levels by causing a hyperinsulinic effect (Santos-Zago *et al.*, 2008), which could have led to a reduction in leptin secretion, via reduced fatty acid depots, and caused the observed reduction in pig voluntary feed intake.

The FCR results obtained with CLA in the present study are consistent with those of Thiel-Cooper *et al.* (2001) who fed pigs CLA-supplemented diets (0%, 0.12%, 0.25%, 0.5% or 1%) and observed a linear improvement in feed efficiency as CLA levels increased. However, Pompeu *et al.* (2013) and Barnes *et al.* (2012) both evaluating the inclusion of CLA (0%, 1% and 0.6%, respectively) in finishing-pig diets did not detect any effect on FCR. According to Pariza *et al.* (2000) and Thiel-Cooper *et al.* (2001), the differences obtained in ADFI, ADWG and FCR results across studies may be attributed to variations in sex, season, CLA inclusion period and genetics.

Ractopamine and conjugated linoleic acid interaction

In our study, the combined inclusion of RAC and CLA in the diet increased final BW (+3%). Differently from our findings, Pompeu *et al.* (2013) did not observe any interaction between dietary RAC (0 and 7.4 ppm) and CLA (0% and 0.6%) levels in the final BW of finishing pigs. The LEA increase and BT reduction observed when both RAC and CLA were included in the diet are possibly due to their additive effect. Both CLA and RAC modulate body fat deposition as fat portioning agents by reducing lipogenesis and increasing lipolysis in the adipose tissue. Both RAC and CLA change protein metabolism, increasing muscle growth accretion and decreasing fat deposition (Schinckel *et al.*, 2003; Amaral *et al.*, 2009), enhancing fat oxidation and fat degradation rates in adipocytes, resulting in higher energy availability for protein deposition (Santos-Zago *et al.*, 2008; Silva *et al.*, 2008; Parra *et al.*, 2010). Therefore, protein and energy metabolism and utilisation are improved (Amaral *et al.*, 2009), increasing BW and LEA and reducing BT of finishing pigs.

In conclusion, the level of 10 ppm inclusion of RAC increased the overall performance parameters of pigs and therefore improved production efficiency. The combined use of RAC and CLA promoted a lower FCR as well as better quantitative carcass traits, as demonstrated by the higher LEA and lower BT. However, as there is a global tendency to ban the use of RAC, nutritionists should refer to the local and international legislation before considering its inclusion in pig diets. In this sense, the observed results of the use of only CLA in our study may help pig nutritionists to formulate finishing pig diets without the use of RAC and still maintain performance. The dietary inclusion of CLA at 0.3% improved the feed efficiency of finishing pigs, however, without affecting LEA or BT yields. Still further studies are needed to understand the mechanisms of how CLA can influence pig metabolism.

Acknowledgements

The authors gratefully acknowledge the farm owner (Mr Manuel Teixeira, Fazenda Penalva, Juiz de Fora, MG, Brazil) for the opportunity to perform the study in their pig facilities.

Declaration of interest

The authors declare to have no conflicts of interest.

Ethics statement

All animals used in this study were kept according to the Brazilian legislations for pig production. All procedures described were in compliance with Brazilian and European Union regulations for animal care and slaughter.

Software and data repository resources

Data may be available upon request by contacting the corresponding author.

References

Amaral NO, Fialho ET, Cantarelli VS, Zangeronimo MG, Rodrigues PB and Girão LVC 2009. Ractopamine hydrochloride in formulated ratios for barrows or gilts from 94 to 130 kg. Revista Brasileira de Zootecnia 38, 1494–1501.

Armstrong TA, Ivers DJ, Wagner JR, Anderson DB, Weldon WC and Berg EP 2004. The effect of dietary ractopamine concentration and duration of feeding on growth performance, carcass characteristics, and meat quality of finishing pigs. Journal of Animal Science 82, 3245–3253.

Barnes KM, Winslow NR, Shelton AG, Hlusko KC and Azain MJ 2012. Effect of dietary conjugated linoleic acid on marbling and intramuscular adipocytes in pork. Journal of Animal Science 90, 1142–1149.

Bates RO and Christians LL 2004. National swine improvement federation guidelines. Retrieved on 20 October 2016, from https://www.extension.purdue.edu/extmedia/NSIF/NSIF-FS16.html

Cook ME, Jerome DL, Crenshaw TD, Buege DR, Pariza MW, Albright SP, Scimeca JA, Lofgren PA and Hentges EJ 1998. Feeding conjugated linoleic acid improves feed efficiency and reduces carcass fat in pigs. FASEB Journal 11, 3347.

Crome PK, Mckeith FK, Carr TR, Jones DJ, Mowrey DH and Cannon JE 1996. Effect of ractopamine on growth performance, carcass composition, and cutting yields of pigs slaughtered at 107 and 125 kilograms. Journal of Animal Science 74, 709–716.

Donovan DC, Schingoethe DJ, Baer RJ, Ryali J, Hippen AR and Franklin ST 2000. Influence of dietary fish oil on conjugated linoleic acid and other fatty acids in milk fat from lactating dairy cows. Journal of Dairy Science 83, 2620–2628.

Dugan MER, Aalhus JL, Schaefer AL and Kramer JKG 1997. The effect of conjugated linoleic acid on fat to lean repartitioning and feed conversion in pigs. Canadian Journal of Animal Science 77, 723–725.

Fernández-Fígarez FI, Conde-Aguilera JA, Lachica M and Aquilera JF 2007. Synergistic effects of betaine and conjugated linoleic acid on growth and carcass composition of growing Iberian pigs. Journal of Animal Science 86, 102–11.

Ferreira MSS, Sousa RV, Silva VO, Zangerônimo MG and Amaral NO 2011. Cloridrato de ractopamina em dietas para suínos em terminação. Acta Scientiarum Animal Science 33, 25–32.

Kamphuis MMJW, Legeune MPGM, Saris WHM and Westerterpplantenga MS 2003. The effect of conjugated linoleic acid supplementation after weight loss on body weight regain, body composition, and resting metabolic rate in overweight subjects. Internationl Journal of Obesity 27, 840–847.

Khosla P and Fungwe TV 2001. Conjugated linoleic acid: effects on plasma lipids and cardiovascular function. Current Opinion Lipidology 12, 31–34.

Köppen W 1948. Climatología: Con un estudio de los climas de la Tierra, 1st edición. Fondo de Cultura Econômica, Buenos Aires, DF, MEX.

Marcolla CS, Holanda DM, Ferreira SV, Rocha GC, Serão NVL, Duarte MS, Abreu A and Saraiva MLT 2017. Chromium, CLA, and ractopamine for finishing pigs. Journal of Animal Science 95, 4472–4480. doi: 10.2527/jas2017.1753.

Marinho PC, Fontes DO, Silva FCO, Silva MA, Pereira FA and Arouca CLC 2007. Efeito da ractopamina e de métodos de formulação de dietas sobre o desempenho e as características de carcaça de suínos machos castrados em terminação. Revista Brasileira de Zootecnia 36, 1061–1068.

National Research Council (NRC) 2012. Nutrient requirements of swine, 11th revised edition. National Academy Press, Washington, DC, USA.

Pariza MW, Park Y and Cook ME 2000. Mechanisms of action of conjugated linoleic acid: evidence and speculation. Proceedings of Society for Experimental Biology and Medicine 225, 9–13.

Pariza MW, Park Y and Cook ME 2001. The biologically active isomers of conjugated linoleic acid. Progress in Lipid Research 40, 283–298.

Parra P, Palou A and Serra F 2010. Moderate doses of conjugated linoleic acid reduce fat gain, maintain insulin sensitivity without impairing inflammatory adipose tissue status in mice fed a high-fat diet. Nutrition and Metabolism 7, 5. doi: 10.1186/1743-7075-7-5. Published online by PubMed 20 January 2010.

Pelleymounter MA, Cullen MJ, Baker MB, Hecht R, Winters D, Boone T and Collins F 1995. Effects of the obese gene product on body weight regulation in ob/ob mice. Science 269, 540–543.

Pereira FA, Fontes DO, Silva FCO, Ferreira WM, Lanna AMQ, Corrêa GSS, Silva MA, Marinho PC, Arouca CLC and Salum GM 2008. Efeitos da ractopamina e de dois níveis de lisina digestível na dieta sobre o desempenho e características de carcaça de leitoas em terminação. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 60, 943–952.

Pompeu D, Weigand BR, Evans HL, Rickard JW, Gerlemann GD, Hinson RB, Carr SN, Ritter MJ, Boyd RD and Allee GL 2013. Effect of corn distiller's grains with solubles, conjugated linoleic acid, and ractopamine (paylean) on growth performance and fat characteristics of late finishing pigs. Journal of Animal Science 91, 793–803.

Rickard JW, Wiegand BR, Pompeu D, Hinson RB, Gerlemann GD, Disselhorst R, Briscoe ME, Evans HL and Allee GL 2011. The effect of corn distiller's dried grains with solubles, ractopamine, and conjugated linoleic acid on the carcass performance, meat quality, and shelf-life characteristics of fresh pork following three different storage methods. Meat Science 90, 643–652.

Rikard-bell CV, Pluske JR, Van Barneveld RJ, Mullan BP, Edwards AC, Gannon NJ, Henman DJ and Dunshea FR 2013. Dietary ractopamine promotes growth, feed efficiency and carcass responses over a wide range of available lysine levels in finisher boars and gilts. Animal Production Science 53, 8–17.

Rostagno HS, Albino LFT, Donzele JL, Gomes PC, Oliveira RFM, Lopes DC, Ferreira AS and Barreto SLT 2011. Brazilian tables for poutlry and swine: nutritional requirements and feed compositions, 3rd edition. Universidade Federal de Viçosa, Viçosa, MG, Brazil.

Sanches JF, Kiefer C, Moura MS, Silva CM, Luz MF and Carrijo AS 2010. Níveis de ractopamina para suínos machos castrados em terminação e mantidos sob conforto térmico. Ciência Rural 40, 403–408.

Santos-Zago LF, Botelho AP and Oliveira AC 2008. Os efeitos do ácido linoléico conjugado no metabolismo animal: avanço das pesquisas e perspectivas para o futuro. Revista de Nutrição 21, 195–221.

Schinckel AP, Li N, Richert BT, Preckel PV and Einstein ME 2003. Development of a model to describe growth and dietary lysine requirements of pigs fed ractopamine. Journal of Animal Science 81, 1106–1119.

See MT, Armstrong TA and Weldon WC 2004. Effect of a ractopamine feeding program on growth performance and carcass composition in finishing pigs. Journal of Animal Science 82, 2474–2480.

Silva MLF, Wolp RC, Amaral NO, Carvalho Júnior FM, Pereira LM, Rodrigues VV and Fialho ET 2008. Efeito da ractopamina em rações com diferentes níveis de lisina sobre as características de carcaça de suínos machos castrados e fêmeas. In PorkExpo & IV Fórum Internacional de Suinocultura, 30–2nd September 2008, Curitiba, Brazil, pp. 111–113.

Surek D, Maiorka A, Oliveira SG, Dahlke F and Krabbe EL 2011. Ácido linoléico conjugado na nutrição de suínos sobre desempenho zootécnico, características de carcaça e rendimentos de cortes. Ciência Rural 41, 2190–2195.

Thiel-Cooper RL, Parrish Jr FC, Sparks JC, Wiegand BR and Schinckel AP 2001. Conjugated linoleic acid changes swine performance and carcass composition. Journal of Animal Science 79, 1821–1828.

Trapp SA, Rice JP, Kelly DT, Bundy A, Schinkel AP and Richert BT 2002. Evaluation of four ractopamine use programs on pig growth and carcass characteristics. Purdue University, Swine Research Report, 62–71. Retrieved on 20 May 2017, from http://www.ansc.purdue.edu/swine/swineday/sday02/9.pdf

Watkins LE, Jones DJ, Mowrey DH, Anderson DB and Veenhuizen EL 1990. The effect of various levels of ractopamine hydrochloride on the performance of finishing swine. Journal of Animal Science 68, 3588–3595.

Weber TE, Richert BT, Belury MA, Gu Y, Enright K and Schinckel AP 2006. Evaluation of the effects of dietary fat, conjugated linoleic acid, and ractopamine on growth performance, pork quality, and fatty acid profiles in genetically lean gilts. Journal of Animal Science 84, 720–732.

Webster MJ, Goodband RD, Tokach MD, Nelssen JL, Dritz SS, Unruh JA, Brown KR, Real DE, Derouchey JM, Woodworth JC, Groesbeck CN and Marsteller TA 2007. Interactive effects between ractopamine hydrochloride and dietary lysine on finishing pig growth performance, carcass characteristics, pork quality, and tissue accretion. Professional Animal Scientist 23, 597–611.