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RESEARCH PAPER

Effects of ractopamine plus amino acids on growth performance, carcass characteristics, meat quality, and ractopamine residues of finishing pigs

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Abstract

C.A. Elmes, O.H. Bustamante, F.G. González, R.E. Larraín, and M. Gandarillas. 2014. Effects of ractopamine plus amino acids on the growth performance, carcass characteristics, meat quality, and ractopamine residues of finishing pigs. Cien. Inv. Agr. 41(3):297-308. The aim of the study was to evaluate the effects of adding ractopamine (RAC) and amino acids (AA) to the diet on growth performance, carcass characteristics, commercial cuts yield, meat quality and residues in liver and muscle. Ninety-two crossbred castrated pigs (97.96 ± 2.32 kg) were randomly assigned to one of two dietary treatments: a Control diet with 0 mg kg^{-1} of RAC and a RAC+AA diet with 10 mg RAC kg^{-1}, for the last 27 days. Pigs of RAC+AA group had greater average daily gain (ADG), gain to feed ratio (G:F) and final bodyweight ($P \leq 0.05$) and tended to have lower average daily feed intake (ADFI) ($p=0.084$) than Control pigs. Carcasses from RAC+AA animals were heavier than controls ($P \leq 0.05$). Dressing percentage and backfat depth were not affected ($P > 0.05$) by diet. Weights of head and skin were not different between treatments, but RAC+AA pigs had greater weights of boneless center loin, ribs, boneless ham and shoulders, tenderloin, neck, rear shank and trimmings ($P \leq 0.05$). The addition of RAC+AA did not affect crude protein and water content of loins but tended to reduce ether extract ($P=0.08$). Drip loss, pH, and cooking loss in pork were not different. Shear force tended ($P=0.092$) to be higher in RAC+AA. No differences in *L** and *b** color coordinates were found but *a** values were lower in RAC+AA. Hue angle and chroma did not differ. Confidence limits at 90% were determined for residues in muscle and liver, obtaining values from -2.7 to 3.4 μg kg^{-1} and -6.7 to 10.6 μg kg^{-1}, respectively, both below the limits established by Codex Alimentarius. Dietary inclusion of RAC+AA at 10 mg RAC kg^{-1} in the diet of finishing pigs improved growth performance and produced heavier carcasses and commercial cuts, had minimal effects in pork characteristics and produced pork and liver with RAC residues below limits from Codex Alimentarius.

Key words: Carcass measurements, finishing pigs, meat cuts, meat quality, ractopamine, residues.

Introduction

One of the main goals for the swine industry is to increase the efficiency of pork production and to produce lean and quality meat (Schinckel *et al*., 2003). Ractopamine Hydrochloride (RAC), marketed under the trade name of Paylean (Paylean®, Elanco Animal Health, Greenfield, IN), belongs to a class of drugs known as β-adrenergic agonists that modulate animal metabolism by increasing

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carcass muscle growth and secondarily decreasing carcass lipid accretion. Hence, the overall effects of RAC addition to the diets of finishing pigs are improving growth rate, improving feed efficiency, producing leaner carcasses and increasing carcass dressing (Moody *et al*., 2000).

Watkins *et al*. (1990) showed that by giving increasing concentrations of 5, 10 and 20 ppm of RAC kg^{-1} diet, a maximal response for ADG was achieved with 20 ppm of RAC kg^{-1} diet. Additionally, in a meta-analysis, Apple *et al*. (2007) showed that the addition of RAC to the diets of finishing pigs improved ADG from 0.85 kg d^{-1} in control animals to 0.95 kg d^{-1} for pigs fed with a 5 mg RAC kg^{-1} diet and to 0.94 kg d^{-1} for pigs fed with a 20 mg RAC kg^{-1} diet ($P \leq 0.001$). These authors also demonstrated an improvement in feed efficiency (G:F) ($P \leq 0.001$) from 0.30 to 0.33, 0.34 and 0.35 for pigs fed with a 0, 5, 10 and 20 mg RAC kg^{-1} diet, respectively. Likewise, Schinckel *et al*. (2002) showed that in high-lean-gain pigs, a 5 mg RAC kg^{-1} diet was effective to achieve a substantial improvement of pig performance. Thus, regardless of the RAC concentration used (5, 10 and 20 mg kg^{-1} diet), pigs gain lean tissue faster and more efficiently when RAC is included in the diet. Furthermore, the improvements in growth performance after RAC supplementation in the diets of finishing pigs usually improved carcass weight and dressing percentage (Stoller *et al*., 2003; Mimbs *et al*., 2005; Carr *et al*., 2009) and have minimal effects on meat quality (Armstrong *et al*., 2004; Fernández- Dueñas *et al*., 2008; Kutzler *et al*., 2011).

The Food and Drug Administration (FDA) approved RAC use in finishing pigs in December 1999 as a feed additive for the last 20.4 to 40.8 kg of live weight gain before slaughter. Most of the studies available on RAC use growth performance traits (Aalhus *et al*., 1990; Barker *et al*., 2005; Ross *et al*., 2011) or carcass measurements, meat quality and sensory attributes (Fernández-Dueñas, 2008; Kutzler *et al*., 2011), but few studies have reported tissue residue concentrations (*i.e*., muscle and liver). Some studies have focused on comparing techniques to quantify residues (Shishani *et al*., 2003; Qiang *et al*., 2007; Sakai *et al*, 2007), but to our knowledge, there are no complete studies using RAC that reported live animal performance, carcass and meat characteristics, and residue concentrations in target tissues. Thus, the objective of this study was to investigate the effects of the addition of RAC plus amino acids on growth performance, carcass characteristics, cuts yield, meat quality, sensory attributes and residues in liver and muscle of finishing pigs.

Materials and methods

This study was performed at the Center for Research, Technological Innovation and Training for the Pork Industry (CICAP) in Pirque, Región Metropolitana, Chile. Because the use of β-adrenergic agonists as feed supplements is prohibited in Chile, the authorities of the Ministry of Agriculture (through the Agricultural and Livestock Service, SAG) authorized the importation and use of Paylean 20® (Elanco Animal Health, Greenfield, IN) for research purposes (Extent Resolution Nº 000044 from Agricultural and Livestock Service, January 19th, 2012). Animals received care in accordance with the Guide for the Care and Use of Laboratory Animals (National Institute of Animal Science Animal Care Committee). Carcasses from RAC-fed animals were removed after slaughter from the food supply chain.

Animals and treatments

All animals were housed within a single barn equipped with 16 pens with concrete floors. Each pen (2.5 × 2.0 m) had a tube type wet-dry feeder (Rotechna®, Spain), and animals had *ad libitum* access to both feed and fresh water. A total of 92 crossbred male castrated Pig Improvement Company (PIC) pigs [PB 337 × GP 1050] –a high lean-gain genetic cross– that were 152 days old with initial weights of 97.96 ± 2.32 kg were randomly

assigned into one of two dietary treatments. Each treatment contained 8 pens with 5-6 pigs per pen (pen = experimental unit). Dietary treatments were a control diet with 0 mg kg^{-1} of RAC and a RAC + amino acid (AA) diet. The RAC + AA diet had 10 mg RAC kg^{-1} added to the diet and a higher content of amino acids, as indicated in Table 1. Diets were based on corn and soybean-meal and were iso-energetics. Both diets were formulated to meet or exceed the nutritional recommendations of NRC (2012). As mentioned above, diets were different in protein and amino acid content, and amino acids were added using soybean meal plus synthetic amino acids (L-Lysine, L-Threonine and DL-Methionine; Table 2), as recommended by the manufacturer of RAC and used by the industry. The control diet was formulated to have 13.42% CP and 0.73% standardized ileal digestible (SID) Lysine, as recommended by PIC for maximal growth, and the RAC+AA diet contained 16.49% CP and 0.91% SID Lysine. Diets containing RAC must contain at least 16% CP (NRC, 2012). Vitamins and minerals used in the experiment were formulated to meet or exceed the nutritional requirements of finishing pigs according to NRC (2012) (Table 1). The experimental period lasted 27 days before slaughter.

Table 1. Composition of experimental diets, as-fed basis.

Items	Control	RAC+AA[1]
Ingredients (%)		
Corn	77.20	68.9
Wheat middlings	6.00	6.00
Soybean meal	12.60	20.3
Poultry oil	1.50	2.20
L-Lysine sulphate 51%[2]	0.05	0.05
Threonine 98.5%	0.76	0.92
Methionine 84%	0.34	0.75
Calcium carbonate	9.50	9.20
Salt	6.00	6.00
Dicalcium Phosphate	3.00	1.30
Ronozyme P5000[3]	0.10	0.10
Ronozyme blend <20%[4]	1.00	1.00
Copper sulphate	0.50	0.50
Etoxiquine	0.20	0.20
Vitamin+mineral premix[5]	1.00	1.00
Chemical composition		
Dry Matter (%)	89.38	89.42
Moisture (%)	10.62	10.58
Ash (%)	4.84	4.73
Crude protein (%)	14.45	17.38
Crude fiber (%)	3.93	4.46
Ether extract (%)	5.01	5.88

[1]RAC + AA: contained 10 mg RAC kg^{-1} of diet and added amino acids.
[2]L-Lysine at 51%.
[3]Ronozyme® (CT) P5000 phytase provided by DSM Nutritional Products.
[4]Ronozyme blend <20% carbohydrase complex (β-glucanases, xylanases, pectinases, hemicellulases) provided by DSM Nutritional Products.
[5]Vitamin+mineral premix per kilogram of the diet provided by premix: Vitamin A, 4,840,000 IU; Vitamin D3, 990,000 IU; Vitamin E, 22,500 IU; Vitamin K3, 2.20 g; Riboflavin, 4.40 g; Vitamin B12, 22.00 mg; d-Pantothenic calcium, 14.30 g; Niacin, 22.00 g, Cu, 10.00 g; Fe, 65.00 g; Mn, 25.00 g; Se, 300.00 mg; I, 350.00 mg; Zn, 70.00 g; Antioxidant, 2.50 g.

Table 2. Amino acid composition of experimental diets (as-fed basis).

Items	Control	RAC+AA[1]
Lysine total (%)	0.84	1.05
Available[2] lysine (%)	0.73	0.91
Available methionine (%)	0.22	0.28
Available threonine (%)	0.48	0.59
Available tryptophan (%)	0.12	0.16
Available valine (%)	0.50	0.63
Available isoleucine (%)	0.42	0.54

[1]RAC + AA: contained 10 mg RAC kg-1 of diet and added amino acids.
[2]Availability of amino acids was estimated by FT-NIR spectrophotometry (www.adisseo.com).

Growth performance

The pigs and feeders were weighed at the beginning (d0) and at the end of the study (d27) to determine average daily gain (ADG, kg d^{-1}), average daily feed intake (ADFI, kg d^{-1}) and the ratio of gain to feed (G:F). Pig weights and feed intakes were recorded using an electronic scale (PESATRONIC, MECO-20014575PA-21X, Ohause, Brooklyn NY, USA).

Transport, slaughter and carcass measurements

At day 27, animals were transported approximated 110 km during the summer to the slaughterhouse at the city of Rancagua, Chile. Upon arrival, animals of each treatment were housed in two separate pens. Sixteen hours after arrival, pigs were electrically stunned, exsanguinated, scalded, and eviscerated, and each carcass was split into left and right sides. The slaughter procedure followed the packing plant's protocol, which was in accordance with the legal procedure for commercial pigs according to Chilean Meat Law 19,162. Individual hot carcass weight (HCW) was immediately registered, as was backfat depth on the midline at the 10th rib through the ribbed carcass. After 24 hours of chilling, cool carcass weight (CCW) was measured, and pork cuts were fabricated. Cuts were produced based on Chilean industry standard and are schematically presented in Figure 1. The following cuts from the left side of the carcass were weighed using an electronic balance scale (PRECISION, BL simplex 60Kg*20G): *lomo de centro* (boneless center loin), *lomo vetado* (boneless neck), *costillar* (ribs), *filete* (tenderloin), *pulpa de pierna* (boneless ham), *pulpa de paleta* (boneless shoulder), *cabeza* (head), *pernil de pierna* (rear shank), *recortes* (trimmings) and *plancha* (skin). Chilean commercial cuts are described by Luengo and Antmann (1999).

Meat quality

For evaluation of pork quality attributes, 16 loins from each treatment were sampled and transported to the Meat Laboratory at Pontificia Universidad Católica de Chile. Subjective marbling (NPPC, 1999) and objective color of loin chops were evaluated at the 10th rib on the seventh day after slaughter. Objective color was measured with a chromameter (Minolta CR-400, Osaka, Japan) at three different locations in each loin sample. Data were collected in CIE *L*a*b** color space. Lightness (*L**), redness (*a**), yellowness (*b**), chroma

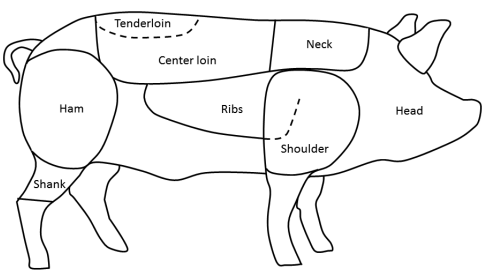

Figure 1. Schematic representation of evaluated pork cuts.

[or color saturation, $(a^{*2} + b^{*2})^{0.5}$], and hue angle [arctangent(b*/a*) × 360°/(2 × 3.14)] were evaluated using a 1 cm aperture, illuminant D65 and a 0° observer. Chop collection began anterior to the 10th rib and included a 2 cm-thick chop for measuring drip and purge loss, a 2 cm-thick chop for proximate analysis, and a 2 cm-thick chop for Warner-Bratzler shear, cooking loss, and pH. Proximate analysis was conducted according to the AOAC (1984). The final pH was measured on the seventh day after slaughter using a spear tip electrode (Mettler Toledo AG 8603, Schwerzenbach, Switzerland). Cooking loss was determined 8 days post mortem by measuring weight loss after cooking to 71°C in an open-hearth electric broiler (MGF 4620, Magefesa, Spain). Warner-Bratzler shear measurements were based on AMSA (1995).

Evaluation of RAC residues in liver and muscle

At the packing plant, 6 loin and 6 liver samples were randomly taken from RAC+AA animals, as were 3 loin and 3 liver samples from the control pigs. The samples were frozen at -20°C and delivered to Andes Control Laboratory (Santiago, Chile) for RAC residue quantification. RAC residues were measured using high performance liquid chromatography with tandem mass spectrometry (LC/MS/MS) as described by Blanca *et al*. (2005).

Statistical analysis

Animals were assigned to treatments using a complete randomized design. Statistical analysis was performed using the general linear model (GLM) procedure from the Statistical Analysis Systems Institute software package (SAS, Institute Inc., Cary, NC, USA) for all variables other than marbling score. The pen was considered the experimental unit. We considered significant differences when one-way ANOVA indicated a P-value ≤ 0.05, whereas P-values between 0.05 and 0.10 were considered to indicate a tendency for differences. Initial weight was considered as a covariance of pig weights. The marbling score was analyzed using the two sample non-parametric test of Wilcoxon (t approximation). For the RAC residues analysis in liver and muscle, a confidence interval was set at 90% for comparison with limits set by Codex Alimentarius (2011).

Results and discussion

Growth performance

The effects of RAC+AA on growth performance of finishing pigs are presented in Table 3. Average daily gain was 18.42% greater in pigs from the RAC+AA treatment compared with control pigs, and RAC+AA pigs were 5.07% heavier at the end of the study compared with control pigs. The feed efficiency, measured as G:F, was 22.58% greater in RAC+AA pigs. These results are consistent with the results from other authors (Apple *et al*., 2004; See *et al*., 2004; Rikard- Bell *et al*., 2009). Barker *et al*. (2005) reported an improvement of 16% in ADG with a 10 mg RAC kg^{-1} diet, whereas Dunshea (1993) obtained 21% greater ADG with a 20 mg RAC kg^{-1} diet. By contrast, Rikard- Bell *et al*. (2009) and Mimbs *et al*. (2005) found no

Table 3. Effects of the addition of ractopamine plus amino acids in the diet on growth performance and intake in finishing pigs.

	Control	RAC+AA[1]	SE[2]	P-value
Initial weight (kg)	97.62	98.29	0.58	0.583
Final weight (kg)	128.33	134.84	1.21	0.003
ADG (kg d^{-1})	1.14	1.35	0.04	0.001
ADFI (kg d^{-1})	3.68	3.54	0.04	0.084
Feed efficiency	0.31	0.38	0.01	< 0.001

[1]RAC + AA: contained 10 mg RAC kg^{-1} of diet and added amino acids.
[2]Pooled SE from ANOVA.

effect of RAC on ADG using 5 and 10 mg kg^{-1} diets, respectively.

There was a tendency (P = 0.084) for decreased ADFI in the RAC+AA group, which is similar to results observed by Armstrong *et al*. (2004). However, some authors reported an increased ADFI with a 10 mg RAC kg^{-1} diet (Mimbs *et al*., 2005) and even with a 5 mg RAC kg^{-1} diet (Rikard-Bell *et al*., 2009). In our experiment, we used a 10 mg RAC kg^{-1} diet throughout the experimental period (27 days), but it is also common to find studies that used a step-up feeding program that switches from an initial concentration of 5 mg kg^{-1} in the first 14 days to 10 mg kg^{-1} in the final 14 days. Regardless of the feeding program used, See *et al*. (2004) observed that either a step-up or a constant feeding program resulted in no differences in ADFI.

Improvement in weight gain was accomplished when extra lysine and amino acids were supplied in the diet with RAC (Apple *et al*., 2004; Carr *et al*., 2009). The recommended use by the manufacturer includes both RAC and an increased amount of AA in the diet, and this is also the common practice used by producers. However, increased weight gain was observed up to 1.15% total lysine in the diet, independent of RAC concentration (Pérez *et al*., 2005). The RAC+AA diet contained 1.05% total lysine, compared to 0.84% total lysine in the control diet. Thus, some improvement in ADG was expected even without the addition of RAC. Pérez *et al*. (2005) and Webster *et al*. (2007) found no significant interaction between RAC and lysine levels, but other authors have observed contrasting results (Armstrong *et al*., 2004; Carr *et al*., 2005).

Greater improvement in feed efficiency was reported when RAC and amino acids were added to the finishing diets (Mimbs *et al*., 2005; Apple *et al*., 2007; Groesbeck *et al*., 2007) independent of the supplementation period but dependent on the RAC concentration in the diet. We observed a 22.58% greater feed efficiency in the RAC+AA pigs vs. the control pigs, which is greater than the results reported by Barker *et al*. (2005), who showed a 16.13% improvement using an identical RAC concentration (10 mg kg^{-1} diet). Differences might be attributed to a shorter time of RAC supplementation (21 vs. 27 days), as shown in Barker *et al*. (2005), although it is known that the response to RAC decreases with duration of use. Edmonds and Baker (2010) also observed greater feed efficiency with increased protein and lysine concentrations in diets containing RAC, whereas Ross *et al*. (2011) found no effect on the same parameter when RAC was added without any extra protein and lysine.

Carcass measurements

The effects of RAC+AA on carcass measurements are shown in Table 4. Carcasses from RAC+AA pigs had greater HCW and CCW than control pigs. Similar results were reported by See *et al*. (2004) and Carr *et al*. (2009). Dressing percentage was not affected by RAC+AA, and this observation is consistent with the results of Marchant-Forde *et al*. (2003), despite the fact that they used a 20 mg RAC kg^{-1} diet. Nevertheless, other authors reported increased dressing percentage in pigs fed diets with 5 to 20 mg RAC kg^{-1} (Weber *et al*., 2006; Fernández-Dueñas *et al*., 2008; Agostini *et al*., 2011; Kutzler *et al*., 2011).

When comparing backfat depth at the 10^{th} rib, our results indicated that there were no significant differences between RAC+AA fed pigs and control pigs, which is consistent with the results of Armstrong *et al*. (2004), Xiong *et al*. (2006), and Kutzler *et al*. (2011). However, See *et al*. (2004), Carr *et al*. (2005) and Fernández- Dueñas *et al*. (2008) observed that there was a significant reduction in backfat depth in RAC fed pigs.

The effects of RAC+AA on commercial cuts yield are presented in Table 4. We observed no differences in head and skin weight between treatments, but all the remaining cuts from the RAC+AA

Table 4. Effects of ractopamine plus amino acids addition on carcass characteristics from pigs.

	Control	RAC+AA[1]	SE[2]	P-value
Hot carcass weight (kg)	102.81	108.62	0.98	< 0.001
Carcass dressing (%)	80.10	80.70	0.82	0.115
Cold carcass weight (kg)	100.28	106.06	0.97	0.001
Backfat depth (mm)	27.65	27.52	0.36	0.621
Head (kg)	7.60	7.74	0.06	0.217
Boneless center loin (kg)	3.67	3.92	0.05	0.021
Ribs (kg)	7.23	7.60	0.08	0.021
Boneless ham (kg)	8.54	9.69	0.19	< 0.001
Boneless shoulder (kg)	4.00	4.49	0.08	< 0.001
Tenderloin (kg)	0.53	0.61	0.01	< 0.001
Neck (kg)	1.92	2.02	0.02	0.008
Rear shank (kg)	2.59	2.71	0.03	0.033
Trimmings (kg)	5.75	6.10	0.07	0.003
Skin (kg)	10.30	10.42	0.10	0.554
Total (kg)	96.66	102.84	0.97	< 0.001

[1]RAC + AA: contained 10 mg RAC kg^{-1} of diet and added amino acids.
[2]Pooled SE from ANOVA.

group were heavier than those from the control group. See *et al*. (2004), Fernández- Dueñas *et al*. (2008) and Kutzler *et al*. (2011) observed that greater cutting yields in pigs were mainly caused by RAC addition instead of higher dietary protein levels, which is consistent with Carr *et al*. (2009), who observed increased cutting yields by adding RAC to the diet without increasing protein concentration in the diet.

Meat quality

The effects of RAC+AA on the chemical composition and meat quality parameters are presented in Table 5. RAC+AA addition did not affect the crude protein and dry matter content of loin muscle samples. By contrast, Dunshea *et al*. (1993) and Carr *et al*. (2009) found greater crude protein content in loin muscle samples of RAC supplemented animals compared to controls on a dry matter basis.

We observed a tendency (p = 0.082) for a reduction in ether extract in the RAC+AA pigs compared to the control pigs. The magnitude of the difference was greater than the difference reported by Dunshea *et al*. (1993) (18.25% vs. 8% in ether extract in pork from RAC fed animals). Additionally, Weber *et al*. (2006) found a reduction in Longissimus Muscle (LM) lipid content, from 2.4 to 1.92, in control vs. RAC fed animals. In our study, drip loss, pH, and cooking loss were not different between treatments. Kutzler *et al*. (2011) found that water holding capacity was 0.57% higher when RAC was added to a 6.2 mg kg^{-1} diet. We observed a tendency (P = 0.092) for higher Warner Bratzler shear in RAC+AA loins, which is consistent with the differences observed by Xiong *et al*. (2006).

There were no treatment differences in *L** and *b** color coordinates between treatments, but *a** was lower in RAC+AA pork. Additionally, hue angle and chroma did not differ between treatments. The effects of RAC on pork color are not consistent. Armstrong *et al*. (2004) and Xiong *et al*. (2006) observed no differences in *L**, which contrasts with the results of Kutzler *et al*. (2011),

Table 5. Effects of ractopamine and amino acids on chemical composition and meat quality characteristics in pigs.

	Control	RAC+AA[1]	SE[2]	P-value
Dry matter (%)	32.94	32.16	1.10	0.174
Crude protein (%)	67.78	70.08	4.00	0.269
Ether extract (%)	26.17	21.39	5.11	0.082
Drip loss24 (%)	4.64	3.45	2.32	0.322
Drip loss48 (%)	6.03	4.03	0.58	0.118
Purge loss (%)	7.65	6.27	0.65	0.304
pH	5.57	5.63	0.02	0.174
Cooking loss (%)	31.33	40.36	3.37	0.199
L*	58.26	60.10	0.60	0.193
a*	5.21	3.71	0.37	0.034
b*	8.16	6.33	0.36	0.055
Hue angle (°)	58.26	60.10	0.60	0.193
Chroma	9.72	7.29	0.49	0.420
Warner Bratzler Shear[3] (kg)	2.42	2.81	0.12	0.092

[1]RAC + AA: contained 10 mg RAC kg^{-1} of diet and added amino acids.
[2]Pooled SE from ANOVA.
[3]Warner Bratzler Shear measurements were based on AMSA (1995).

who observed a decreased *L** in pork from RAC fed pigs. Contrary to our results, Carr *et al*. (2005) reported a reduction in *b** using 10 and 20 mg RAC kg^{-1} diets, and Xiong *et al*. (2006) found no differences in *a**.

Regarding marbling scores, we did not observe differences between treatments (P = 0.42), with a median value of two for both groups. Likewise, Weber *et al*. (2006) and Athayde *et al*. (2012) found that subjective marbling scores were not affected by RAC, whereas Aalhus *et al*. (1990) and Armstrong al. (2004) observed a greater marbling score for RAC animals compared with non-treated animals.

Residues

The effect of RAC + AA on RAC in liver and muscle are presented in Table 6. Animals were slaughtered approximately 18 hours after the last feeding, and we found an average of 2.45 ± 0.68 µg of RAC residues kg^{-1} in loin samples and 6.79 ± 3.29 µg of RAC residues kg^{-1} in liver, which is under the maximum residue limits established by the Codex Alimentarius of 10 µg kg^{-1} and 40 µg kg^{-1} in muscle and liver, respectively (Codex Alimentarius, 2011). Qiang *et al*. (2007) fed pigs a diet with 18 mg kg^{-1} of RAC for 28 days. Animals were killed at days 0, 1, 2, 3, 7, 9 and 14 after withdrawing RAC. At day 0, an average of 2.58 µg kg^{-1} of RAC was observed in muscle. After day 1, the RAC concentration was below the lower level of detection in muscle, fat and serum. Similarly, Pleadin *et al*. (2012) observed that RAC concentrations in muscle tissue were below the lower level of detection (< 0.4 mg kg^{-1}) and that 7.21 ± 2.73 ng RAC g^{-1} in liver was detected after the first day of treatment interruption when dosing the animals with 0.1 mg kg^{-1} body weight (compared with approximately 0.3 mg kg^{-1} body weight in our study).

Confidence limits (at 90%) for RAC in muscle and liver were determined to be -2.7 to 3.4 µg kg^{-1} and -6.7 to 10.6 µg kg^{-1}, respectively, which are below the maximum limits of 10 µg kg^{-1} for muscle and 40 µg kg^{-1} for liver established by the Codex Alimentarius (Codex Alimentarius, 2011). Moreover, the maximum residues obtained both for muscle

Table 6. Ractopamine in muscles and liver of pigs fed ractopamine (10 mg kg^{-1} diet) and slaughtered 18 hours after withdrawal[1,2].

	Ractopamine concentration (µg kg^{-1})	
	Control	RAC+AA[3]
Animal	---------- Muscle ----------	
1	ND4	2.40
2	ND	2.83
3	ND	1.31
4		3.08
5		BQL5
6		2.62
Mean (µg kg^{-1})	-	2.45
Standard deviation (µg kg^{-1})	-	0.68
Coefficient of variation (%)	-	27.93
Animal	---------- Liver ----------	
1	ND	7.70
2	ND	5.70
3	ND	6.44
4		7.65
5		11.67
6		1.55
Mean (µg kg^{-1})	-	6.79
Standard deviation (µg kg^{-1})	-	3.29
Coefficient of variation (%)	-	48.50

[1]There were 2 treatments with 3 pigs in the control and 6 pigs in the RAC+AA fed animals.
[2]RAC residues were measured using high performance liquid chromatography with tandem mass spectrometry (LC/MS/MS) as described by Blanca *et al*. (2005).
[3]RAC + AA: contained 10 mg RAC kg^{-1} of diet and added amino acids.
[4]ND: not detected
[5]BQL: Detected, but below quantification limit.

and liver were 69.2 and 70.8% below the maximum residue limits established by the Codex.

According to the results obtained from this study, supplementation with RAC + AA produced most of the desirable effects described in the literature for growth and carcass characteristics, with the exception of dressing and backfat depth. Regarding meat quality characteristics, a tendency was observed for a RAC + AA diet to reduce ether extract, increase Warner Bratzler shear and reduce *a** in pork. Finally, residues found in muscle and liver were below Codex Alimentarius limits but higher than other values reported in the literature, which may be because of the higher supplementation dose or shorter withdrawal period prior to slaughter.

According to this study, dietary inclusion of RAC+AA at 10 mg RAC kg^{-1} in the diet of finishing pigs during the last 27 days of finishing produced greater weight gain and feed efficiency. Pigs fed RAC+AA produced heavier carcasses and commercial cuts with minimal effects on meat quality. Finally, RAC residues in muscle and liver were below Codex Alimentarius (2011) limits.

Resumen

C.A. Elmes, O.H. Bustamante, F.G. González, R.E. Larraín y M. Gandarillas. 2014. Efecto de la adición de ractopamina y aminoácidos en los parámetros de crecimiento, características de canal, calidad de carne y residuos de cerdos de engorda. Cien. Inv. Agr. 41(3):297-308. El objetivo de este estudio fue medir el efecto de la adición de ractopamina (RAC) y aminoácidos (AA) en la dieta sobre el crecimiento, características de la canal, rendimiento de cortes comerciales, características de la carne y residuos en hígado y músculo. Noventa y dos cerdos castrados (97,96 $\pm$ 2,32 kg) fueron asignados aleatoriamente a dos dietas: un Control con 0 mg kg^{-1} de RAC y a una dieta RAC+AA con 10 mg RAC kg^{-1}, durante los últimos 27 días de engorda. Los cerdos RAC+AA tuvieron mayor ganancia diaria de peso (GDP), eficiencia de conversión alimenticia (ECA) y peso final ($P \leq 0,05$) y tendieron a comer menos ($P=0,084$). Las canales del grupo RAC+AA fueron más pesadas ($P \leq 0,05$), pero son diferencias en rendimiento y espesor de grasa dorsal. El peso de cabeza y plancha no fue diferente, pero el grupo RAC+AA tuvo pesos mayores en el lomo de centro, lomo vetado, costillar, pulpa paleta, pulpa pierna, pernil y sobras ($P \leq 0,05$). La adición de RAC+AA no afectó la proteína cruda y materia seca del lomo, pero redujo el extracto etéreo ($P=0,08$). No hubo diferencia en la pérdida por goteo, y por cocción, ni en pH, pero la fuerza de corte tendió ($P=0,092$) a ser mayor en RAC+AA. No hubo diferencias en L^* y b^* pero sí en a^*, siendo más bajo en RAC+AA. El ángulo Hue y Chroma no difirieron. El intervalo de confianza al 90% determinó que los residuos en músculo e hígado fueron de -2,7 a 3,4 mg kg^{-1} y -6,7 a 10,6 mg kg^{-1}, respectivamente. La inclusión de RAC+AA en la dieta de cerdos de engorda, produjo canales y cortes comerciales más pesados, con efectos mínimos en características de la carne y con residuos de RAC bajo el límite del Codex Alimentarius.

Palabras clave: Calidad de carne, cerdos de engorda, cortes comerciales, ractopamina, residuos.

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