



Quality of Carcass and Fat of Pigs Receiving Diets with Sorghum, Canola Expeller and Peas

Bauza R^{1*} , Barreto R¹ , Silva D¹ , Bratschi C¹ 

¹ Universidad de la República, Facultad de Agronomía, Departamento de Producción Animal y Pasturas. Garzón 780, 12900 Montevideo, Uruguay. *Email: rbauza@fagro.edu.uy

Recibido: 01/10/17 - Aceptado: 25/02/19

Abstract

In order to determine the effect on carcass and fat characteristics of replacing maize and soybean meal (SM) with low tannin sorghum (LTS) and canola expeller (CE), respectively, 42 pig carcasses from seven feeding systems were studied: T1, Maize/SM; T2: LTS/SM grain; T3: LTS/SM wet grain silo; T4: Maize/wet grain sorghum MT/SM silo; T5: Maize/sorghum grain MT/SM; T6: Maize/(CE/peas); T7: LTS grain/(CE/peas). The pigs were slaughtered with an average live weight of 108 ± 2 kg. Carcass length, dorsal fat thickness, loin eye area, meat/fat ratio in steak, intramuscular fat content, and lipid profile were evaluated. There were no differences between treatments in carcass characteristics. Intramuscular fat content was higher in T4 pigs. Diets with CE substituting SM presented higher content of $\omega 3$ acids. It is concluded that the replacement of maize with LTS in diets for fattening pigs does not change the composition of carcasses nor the lipid profile of the dorsal fat. The replacement of SM with a mixture of CE and peas does not affect carcass characteristics but changes the lipid profile, with an increase of $\omega 3$.

Keywords: pigs, LT sorghum, canola expeller, carcasses, lipid profile

Calidad de carcasa y grasa de cerdos recibiendo dietas con sorgo, expeller de canola y arveja

Resumen

Con el objetivo de determinar el efecto sobre las características de la carcasa y la grasa de la sustitución del maíz y la harina de soja (HS) por sorgo bajo tanino (SBT) y expeller de canola (EC) respectivamente, se evaluaron 42 carcasas de cerdos provenientes de siete sistemas de alimentación: T1, Maíz/HS; T2: Grano de SBT/HS; T3: Silo de grano húmedo de SBT/HS; T4: Maíz/silo grano húmedo de sorgo MT/HS; T5: Maíz/grano de sorgo MT/HS; T6: Maíz/(EC/arveja); T7: Grano de SBT/(EC/arveja). Los cerdos se faenaron con un peso vivo promedio de 108 ± 2 kg. Se evaluaron largo de res, espesor de grasa dorsal, área del ojo del lomo, relación carne/grasa en el bife, contenido de grasa intramuscular y perfil lipídico de grasa dorsal. No se observaron diferencias entre tratamientos para las características de carcasa. El contenido de grasa intramuscular fue mayor en los cerdos de T4. Las dietas con EC en sustitución HS presentaron mayor contenido de ácidos $\omega 3$. Se concluye que la sustitución del maíz por SBT en dietas para cerdos en engorde no provoca cambios en la composición de las canales ni en el perfil lipídico de la grasa dorsal. La sustitución de la HS por una mezcla de EC y arveja no afecta las características de las carcasas pero provoca cambios en el perfil lipídico, con aumento de los $\omega 3$.

Palabras clave: cerdos, sorgo BT, expeller de canola, carcasas, perfil lipídico

Introduction

Swine product quality refers to the composition characteristics of the carcasses, determined by the proportion of the different deposited tissues and the composition of those tissues, involved in carcass and meat quality concepts⁽¹⁾⁽²⁾.

Quality concept varies based on the perspective of each link in the production chain. For the producer, it is associated with lean tissue content, growth rate and feed conversion ratio; the consumer values sensory aspects, physical appearance, hygienic quality and preparation and use simplicity⁽³⁾; the industrial sector considers fat color and consistency, which determine its stability and preservation capacity⁽⁴⁾⁽⁵⁾; while nutritionists emphasize the aspects associated with the nutritional quality of the product, especially those related to lipid composition and its relationship with cardiovascular health⁽⁵⁾⁽⁶⁾⁽⁷⁾.

Lipid content of pork is very variable, between 1, 5 and 13%, being determined by food, sex, breed and slaughter weight⁽⁵⁾⁽⁶⁾⁽⁸⁾. The intramuscular fat, or marbling, is associated with the tenderness, juiciness and aroma of the meat, considering that for optimum organoleptic quality the meat should have between 2 and 2.5% of intramuscular fat⁽³⁾. Sensory attributes, such as taste and tenderness, are adversely affected below 2%, while nutritional quality is affected above 3.5%⁽⁹⁾. Capra and others⁽¹⁰⁾ conclude that commercialized pork cuts in Uruguay, except for bondiola, can be classified as lean meats (<10% fat content) or very lean (<5% fat content).

From the industrial point of view, firm fats, with a high degree of saturation and greater resistance to rancidity are attempted. Fat firmness is directly related to the ratio between saturated fatty acids (SFA) and polyunsaturated fatty acids (PUFA): fats are solid at room temperature when there is a high proportion of SFA and as the degree of unsaturation increases, the melting point decreases to liquid at room temperature⁽⁸⁾. Stearic (C18:0) and linoleic (C18:2) fatty acids have a high correlation with fat consistency, being the ratio (18:0):(18:2) used to define the degree of firmness⁽⁵⁾. Daza and Buxadé⁽⁴⁾ consider a fat soft when the stearic:linoleic ratio is lower than 1.47. For its part, regulations of the Parma Consortium establish an upper limit of 15% linoleic acid in fresh hams.⁽¹¹⁾

In monogastrics, part of the fatty acid intake is deposited directly in the tissues, therefore, the lipid profile of the diet is reflected in the composition of body deposits⁽¹²⁾⁽¹³⁾. There is

also dependence on the genetic type, since high fat content genotypes tend to have a higher SFA and a lower UFA proportion⁽¹³⁾, while lean genotype pigs have less fatty acids *a novo* synthesis. The lipid composition of these carcasses reflect to a greater degree the dietary fat composition⁽⁸⁾⁽¹⁴⁾. In surveys carried out in Uruguay, it is concluded that the lipid profile of commercialized pigs has low levels of SFA, while high and very variable levels of monounsaturated and polyunsaturated fatty acids respectively, with high dependence on the type of food received⁽⁵⁾⁽¹⁵⁾.

In humans, the saturated fatty acids intake raise the concentration of low density lipoproteins (LDL), associated with the occurrence of coronary diseases. When PUFA replace SFA, LDL are reduced, but high density lipoproteins (HDL) also decrease, while MUFA reduce LDL levels without modifying HDL levels. Most PUFA are grouped into two series: the $\omega 6$ series that includes linoleic, essential fatty acid, and the $\omega 3$ series, which includes linolenic acid⁽¹⁶⁾. The challenge in pork production is to reduce meat SFA content and increase the amount of monounsaturated (oleic-omega 9) and polyunsaturated fatty acids (linoleic-omega 6 and linolenic-omega 3), which are associated with cardiovascular health benefits⁽⁶⁾⁽¹⁵⁾.

Meat of pigs on maize-based diets has a higher content of linolenic acid, compared to diets based on other cereals, which is favorable to human health, but associated with a higher risk of alteration due to rancidity and lower industrial quality, while the oleic acid content decreases⁽⁶⁾⁽¹⁶⁾.

In the case of sorghum, although it contains 10% less lipids than maize⁽¹⁷⁾, 83% of them consist of unsaturated fatty acids, of which 56% is linoleic acid, which makes pigs on diets based on sorghum generate fats with higher content of monounsaturated and polyunsaturated fatty acids, mainly linoleic and oleic acids, with respect to diets based on maize⁽⁶⁾⁽¹⁶⁾.

Numerous studies maintain that the substitution of soybean meal for canola meal in the feeding of finishing pigs does not affect carcass characteristics, as long as the same levels of digestible amino acids and the energetic concentration of the diet are maintained⁽¹⁸⁾⁽¹⁹⁾⁽²⁰⁾⁽²¹⁾⁽²²⁾⁽²³⁾⁽²⁴⁾. On the other hand, Caine and others⁽²⁵⁾ observed that the carcasses of pigs on diets with canola expeller had a higher content of intramuscular fat or marbling.

Canola oil is rich in MUFA, n-6 and n-3, highlighting its linolenic acid content⁽²⁶⁾. Diets with expeller or canola meal increase the MUFA and C18:3 content, decreasing the proportion of C18:6 in pigs fat, reducing the n-6:n-3 index

and the fat melting point. As a consequence, its industrial value is reduced, although the quality from the nutritional point of view is improved⁽¹³⁾.

No differences were observed in carcass characteristics of pigs on diets where soybean meal was replaced by forage peas, supplemented with synthetic amino acids, compared to control diets based on maize-soybean meal⁽²⁷⁾⁽²⁸⁾⁽²⁹⁾ or barley-soybean meal⁽³⁰⁾⁽³¹⁾.

Regarding the composition of body lipids, Thacker and others⁽²⁷⁾ and Chrenková and others⁽³¹⁾ observed that diets where peas replaced soybean meal increased the ω 3 fatty acid content and decreased the ω 6 of dorsal fat, which significantly reduced the ω 6: ω 3 ratio, considered beneficial for consumer's health.

The general objective of this study was to determine the effect of the use of sorghum, canola and pea expeller in fattening pigs diets on the quality characteristics of carcass and lipid composition of body fat.

Material and methods

Carcasses from pigs that during the fattening period received the following experimental diets were evaluated: T1 (control): maize/soybean meal; T2: Low tannin sorghum grain, dry ground/soybean meal; T3: Low tannin sorghum wet grain silo/soybean meal; T4: (Maize + sorghum with medium tannin content wet grain silo)/soybean meal; T5 (Maize + medium tannin content sorghum grain, dry ground)/soybean meal; T6: Maize/(canola expeller + peas); T7: Low tannin sorghum grain, dry ground/(canola expeller + peas).

Experimental conditions during fattening period

The experimental protocol was approved by the Ethics Committee on the Use of Animals, endorsed by resolution of the Council No. 1546, Agronomy College. Pigs were housed in the Porcine Testing Station of the Sayago Farm of the Agronomy College. From the beginning of the fattening period (35 ± 1.5) until they were sent to the slaughter plant, animals were housed in individual pens, with a front feeder pan, with ad libitum access to drinking water by means of automatic pacifier-type troughs.

Animals

The carcasses from the slaughter of 42 castrated male pigs were evaluated. They were assigned at a rate of six animals per treatment that had received the experimental diets in the period from 35 to 105 kg of live weight. The pigs were of uniform genetic type due to a terminal cross formed by the mating of mothers of Large White x Landrace crosses and a boar of Landrace x Pietrain cross.

Experimental feed

Diets were formulated according to the recommendations of NRC⁽³²⁾ for fattening categories. Two diets were used for each treatment depending on the growth phase of the animals (growing or finishing), using the same food, varying the proportions in each stage to adjust to the nutritional requirements. Rations were supplied at will throughout the experimental period and the same diet was continued until the animals were transferred to slaughter. Tables 1, 2, 3 and 4 show, respectively, the chemical composition of the foods used, the percentage

Table 1. Chemical composition of used foods

%	Maize	Sorghum MT	Sorghum LT	Silo sorghum LT	Silo sorghum MT	Pea	Canola expeller	Soybean meal
Dry matter	87.92	83.97	85.58	70.65	64.61	88.08	90.02	85.86
% Dry base								
Ashes	0.85	1.86	1.79	1.70	2.11	3.02	7.37	6.45
Crude Protein	8.38	9.21	8.27	8.73	8.94	21.03	37.74	53.57
Neutral detergent fiber	15.20	19.32	17.71	22.90	32.37	20.65	36.81	13.37
Ether Extract	4.03	1.49	2.65	3.30	1.95	2.75	3.62	1.8
Gross energy (Mcal/kg) (*)	4.42	4.33	4.37	4.42	4.33	4.51	4.60	4.7
Condensed tannins %	—	2.3	0.2	< 0.1	1.3	—	—	—

(*) GE estimated from chemical composition and combustion heat of fractions

Table 2. Composition of growing experimental diets.

Ingredients (% dry base)	T1	T2	T3	T4	T5	T6	T7
Maize ground grain	69.29	—	—	35.34	35.29	47.59	—
Sorghum LT ground grain	—	68.21	—	—	—	—	45.92
Sorghum MT ground grain	—	—	—	—	33.71	—	—
Sorghum LT wet grain silo	—	—	70.82	—	—	—	—
Sorghum MT wet grain silo	—	—	—	35.36	—	—	—
Soybean meal	27.46	28.47	26.00	26.15	27.69	—	—
Canola expeller	—	—	—	—	—	24.87	25.69
Pea ground grain	—	—	—	—	—	24.33	25.14
Vit Min Concentrate	3.26	3.32	3.18	3.16	3.31	3.21	3.25
Chemical composition dry base							
Dry matter %	87.52	87.76	73.60	77.78	86.89	89.72	89.09
Ashes %	5.09	5.11	4.88	4.91	4.84	5.81	5.77
Crude Protein %	21.45	21.06	21.33	21.59	21.53	21.24	21.02
Neutral detergent fiber %	13.55	14.32	14.92	15.41	14.85	23.27	21.25
Ether Extract %	2.61	2.56	2.25	2.71	2.89	5.31	4.24
Gross energy (Mcal/kg DM) (*)	4.42	4.41	4.42	4.43	4.43	4.45	4.45
Digestible energy (Mcal/kg DM) (**)	3.66	3.62	3.61	3.60	3.63	3.52	3.58

(*) GE estimated from chemical composition and combustion heat of the fractions.

(**) DE estimated from Noblet's equation (1993) $DE \text{ kcal/kg DM} = 949 + 0.789 * GE - 43 * C - 41 * NDF$.

Table 3. Composition of finishing experimental diets.

Ingredients (% dry base)	T1	T2	T3	T4	T5	T6	T7
Maize	76.23	—	—	38.66	38.62	60.56	—
Sorghum LT ground grain	—	74.85	—	—	—	—	58.55
Sorghum MT ground grain	—	—	—	—	37.23	—	—
Sorghum LT wet grain silo	—	—	78.00	—	—	—	—
Sorghum MT wet grain silo	—	—	—	38.80	—	—	—
Soybean meal	21.03	22.43	19.29	19.82	21.43	—	—
Canola expeller	—	—	—	—	—	18.56	19.58
Pea ground grain	—	—	—	—	—	18.16	19.15
Vit Min Concentrate	2.71	2.72	2.71	2.72	2.72	2.72	2.72
Chemical composition dry base							
Dry matter %	88.38	86.32	73.26	78.78	86.90	85.39	86.48
Ashes %	5.79	6.16	5.15	6.34	5.51	6.06	6.17
Crude Protein %	19.89	19.40	19.30	19.37	19.10	19.24	19.58
Neutral detergent fiber %	11.63	12.12	12.95	11.23	11.56	22.68	23.25
Ether Extract %	3.52	2.96	2.55	3.21	2.98	3.53	3.24
Gross energy (Mcal/kg DM) (*)	4.41	4.36	4.38	4.37	4.39	4.39	4.38
Digestible energy (Mcal/kg DM) (**)	3.70	3.67	3.57	3.66	3.69	3.60	3.57

(*) GE estimated from chemical composition and combustion heat of the fractions.

(**) DE estimated from Noblet's equation (1993) $DE \text{ kcal/kg DM} = 949 + 0.789 * GE - 43 * C - 41 * NDF$.

Table 4. Lipid profile of finishing experimental rations, total fatty acids %.

Fatty acid	T1	T2	T3	T4	T5	T6	T7
16:0 (palmitic)	12.25	13.26	13.81	13.71	14.16	10.15	10.30
16:1 n-7 (palmitoleic)	0.13	0.46	0.47	0.67	0.32	0.30	0.80
17:0 (margaric)	0.10	0.10	—	0.10	0.12	—	—
18:0 (stearic)	2.47	1.97	1.64	2.74	2.44	1.80	2.20
18:1 trans (elaidic)	—	0.29	—	1.51	0.26	—	—
18:1 n-9 (oleic)	30.97	30.26	29.48	33.99	29.50	31.50	36.60
18:1 n-7 (vaccenic)	0.16	0.95	1.07	1.22	0.76	—	—
18:2 n-6 (linoleic)	50.65	47.41	49.87	41.95	46.86	48.00	36.70
18:3 n-3 (α -linolenic)	1.72	2.09	2.34	2.01	1.76	4.27	4.70
20:0 (arachidic)	0.44	0.16	0.32	0.37	0.32	0.50	0.30
20:1 n-9 (eicosenoic)	0.19	0.16	0.15	0.17	0.18	0.30	0.30
% Saturated fatty acids (SFA)	16.13	17.37	16.01	17.47	19.21	13.20	13.20
% Monounsaturated fatty acids (MUFA)	31.45	32.14	31.17	37.56	31.02	34.90	43.60
% Polyunsaturated fatty acids (PUFA)	52.37	49.50	52.21	43.96	48.62	50.20	41.40
PUFA:SFA ratio	3.25	2.85	3.26	2.52	2.53	3.80	3.14
$\omega 6:\omega 3$ ratio	29.45	22.68	21.31	20.87	26.63	11.15	7.81

and chemical composition of growing and finishing diets, and the lipid content and lipid composition of the diets used in the finishing period.

Chemical analyzes of the food and experimental diets were carried out in the Animal Nutrition Laboratory of the Agronomy College. Determinations of tannin content in sorghums were conducted in the Grain Quality Laboratory of INIA-La Estanzuela. The lipid content and the lipid profile of the diets were determined in the Fats and Oils Laboratory of the Chemistry College.

Slaughter and carcass evaluation

As the animals reached the weight corresponding to the end of the behavior test (108.51 ± 2.34 kg live weight) they were sent to slaughter in the ARDISTAR slaughter plant, located in La Tablada, Montevideo. A 24-hour fasting was carried out prior to the slaughter by ceasing the food supply from the day before the planned transfer to the slaughter plant. The slaughter was performed by following the routine procedure used in the industrial plant, previously

desensitizing by electrocution, subsequently exsanguinating by sectioning arteries and veins of the brachiocephalic trunk, continuing the slaughter line with blanching, peeling and eviscerating. In the final stage of the slaughter process, after the head is separated, the carcasses are cut longitudinally in two half carcasses, which are moved to a cold chamber.

Carcass measurements and sampling

Measurements were taken at the end of the slaughter line, before entering the cold chamber, following the procedure used by Capra and others⁽⁷⁾. Carcass length (from the front edge of the first rib to the center of the pubic symphysis) was measured with a measuring tape on the hanging left half-carcass, as well as dorsal fat thickness (average of the measurements on the dorsal midline at the points corresponding to the last rib and gluteus medius muscle).

A cross section was made on the left half-carcass at the level of the last rib, including the loin eye, the bone and the

subcutaneous fat included in the steak or «pork rib» according to its commercial definition. The exposed area of this cut was traced so as to determine the area.

Samples of subcutaneous fat and longissimus dorsi muscle were removed on the dorsal line of the left half-carcass, at the level of the last rib, being frozen and sent to the laboratory to determine lipid profile and intramuscular fat content, respectively.

Meat quality characteristics

By scanning the areas traced in the slaughter plant and applying the area determination program IMAJE J⁽³³⁾, the loin eye area (muscle longissimus dorsi), corresponding to the subcutaneous fat included in the steak, and the meat:fat ratio in the steak were established.

The intramuscular fat content of the longissimus dorsi muscle samples extracted in the slaughter plant was determined. This was conducted in the Fats and Oils Laboratory of the Chemistry College, by quantitative extraction of the intramuscular lipids of the meats by Folch Method⁽³⁴⁾.

Lipid profile determinations

They were carried out in the Fats and Oils Laboratory of the Chemistry College using gas chromatography. The lipids extraction was done at room temperature with hexane:isopropanol in a 3:2 ratio. The extracted fat was derivatized according to the IUPAC 2.301 technique to obtain the methyl esters and then the analysis was carried out by gas chromatography (according to AOCS Ce 1c-89, AOCS Ce 1f-96 technique). A Shimadzu equipment model 14B was used, equipped with a Supelco SP-2560 capillary column.

From the analysis of the dorsal fat samples, the relationships between saturated, monounsaturated and polyunsaturated fatty acids, expressed as a percentage of total fatty acids, were evaluated; and the concentration of stearic, oleic, linoleic and linolenic fatty acids was studied for each of the feeding systems evaluated.

Parameters evaluated

With the slaughter data, the following carcass characterization indicators were evaluated: carcass length (cm); dorsal fat thickness (mm); eye loin area (cm²) and meat:fat ratio in the steak (%).

From the lipid profiles of the dorsal fat samples, the following were evaluated: % of saturated fatty acids (SFA); % monounsaturated fatty acids (MUFA); % polyunsaturated fatty acids (PUFA); PUFA:SFA ratio; concentration of stearic, oleic, linoleic and linolenic fatty acids expressed as a percentage of total fatty acids; $\omega 6$ and $\omega 3$ concentration; $\omega 6:\omega 3$ ratio.

Model and statistical analysis

A random parcel design was applied, with the observation unit being each carcass. The adjusted model corresponds to a random variable with normal distribution, with the following general formula:

$$y_{in} = \mu + D_i + \varepsilon_{in}$$

where: y_{in} is the response variable; D_i the effect of the received diet; ε_{in} the experimental error.

Results were analyzed by means of the F test with precision levels of 1 and 5%, performing, in case of finding significant differences, the means comparison using the test of least significant difference (LSD) at the same significance levels.

Results and discussion

The carcasses corresponding to treatment 5 (substitution of 50% of maize by dry ground grain of high tannin sorghum) could not be evaluated due to reasons related to the trial logistics. However, it was possible to obtain and analyze the dorsal fat samples for this treatment, therefore, it is still included in the study description.

Table 5 shows the characteristics obtained for the carcasses studied. No significant differences were observed in the carcasses length when maize was replaced by low tannin sorghum, presented as ground grain or as wet grain silo, using soybean meal as the only protein supplement. The same result was observed when 50% of the maize was replaced by wet grain silo of medium tannin sorghum. When all of the soybean meal was substituted for a combination of canola expeller and peas, there was no difference in length compared to the rest of the diets when the cereal was low tannin sorghum. However, when maize was used combined with canola and pea expeller, the carcasses were shorter than those of animals fed with T1. This result differs from what Maupertuis and others⁽¹⁹⁾ and Chrenková and others⁽³¹⁾ observed and cannot be attributed to differences in the animals genetic potential as mentioned by Campion⁽³⁾, since all of them are

from the same origin and time. Observations indicate that the animals of treatment 6 had a longer adaptation period to start a regular food intake, which could have affected the initial development, resulting in shorter animals.

Carcass dorsal fat thickness was similar between treatments. Observed values are greater than the obtained by other authors such as Braun and others⁽¹⁴⁾ and Silva and others⁽³⁵⁾ in Argentina or Bauza and others⁽³⁶⁾ in Uruguay, who mention values ranking from 20 to 26 mm. Nevertheless this observed thickness is smaller than the mentioned by Barlocco and others⁽³⁷⁾ in animals with Pampa crosses or by Dobao and others⁽³⁸⁾ for Iberian pigs; being very similar to what was reported by Petrocelli and others⁽³⁹⁾ in its study of characterizing the carcasses received in the slaughter plants in Uruguay. Aspects associated with the animals' genetic potential and the free feeding system used in this trial may be the cause for the observed subcutaneous fat content.

Results from the loin eye area of carcasses from T1 were similar to those reported by other authors⁽³⁾⁽⁴⁰⁾ for pigs with similar genetic characteristics. No differences were found for this indicator between T1, T2, T3 and T6, being significantly smaller ($p \leq 0.01$) in carcasses from pigs fed with wet grain silo of medium tannin content sorghum substituting 50% of maize supplemented with soybean meal (T4) and also from pigs fed with diets based on low tannin sorghum, supplemented with canola expeller and peas (T7). The loin eye area is very important for the carcass value when destined to fresh consumption, since it is negatively correlated with the subcutaneous fat content, considered as undesirable, and determines the useful percentage of the «pork rib», as shown in Table 5. As pointed out by Hurnik⁽⁴⁰⁾ the loin eye area is determined by the genetic potential of the animals and likewise its expression depends on the protein balance of the diets, mainly on the available lysine content. The smaller loin areas obtained from diets based on silo of medium tannin sorghum would be associated with the lower digestible protein content of this diet. Moreover, we observed that all diets that contain sorghum grain substituting maize present smaller loin eye area, which would be related to the lower bioavailable lysine content of this cereal⁽⁴¹⁾⁽⁴²⁾. The substitution of soybean meal for the mix of canola expeller and peas did not affect the loin area in the based maize diet, while in the combination with LT sorghum the result was lower, which allows us to infer that the effect was due to cereal and not to the substitution of soybean meal. Regarding fat area and meat content percentage in the

steak, the values follow the same trends as the loin eye area. It is important to highlight the fact that these values are considered to determine the consumer's performance «on the plate».

The intramuscular fat content was significantly higher ($p \leq 0.01$) in the cattle from T4 and T6 diets. The observed value for T4 treatment is above the maximum admitted value from the point of view of nutritional quality mentioned by Fernández and others⁽⁹⁾. In the other treatments the intramuscular fat content was within the range considered desirable both for fresh consumption and for its industrialization by Echenique⁽⁵⁾ and Campion⁽³⁾. The high content of intramuscular fat observed in T4 can be associated with an imbalance in the digestible energy:digestible protein ratio, given the lower use of the protein of sorghum with a medium tannin content.

Table 6 shows the lipid profile results of the dorsal fat of cattle from the different treatments. No differences were detected between diets in the saturated, monounsaturated and polyunsaturated fatty acids content, although differences were observed ($p \leq 0.01$) between treatments in the content of ω -3 and ω -6 fatty acids. The canola expeller diets produced lipids with a higher ω 3 content, reflecting the higher concentration of linoleic acid in them, in accordance with Bertol and others⁽¹³⁾ observations. On the other hand, ω 6 concentrations are very similar between treatments, also reflecting the lipid composition of the original diet. Considering ω 6: ω 3 ratio, it is observed that the best ratios between these types of fatty acids are obtained from diets including canola and pea expeller, which is of great interest from the consumer's health point of view, as established by Bañón and others⁽⁴³⁾ and Apple and others⁽¹²⁾. Considering that peas have an extremely reduced lipid content, as noted by Bauza and others⁽³⁶⁾, it can be concluded that the canola expeller is responsible for the difference in the body fat composition.

Conclusions

It is possible to replace maize with low tannin sorghum, presented as dry grain or wet grain silo in diets for fattening pigs, without affecting carcass composition or the lipid profile of dorsal fat.

The inclusion of wet grain silo of medium tannin sorghum in substitution of 50% of the maize grain has a negative effect on the muscular development of the carcasses that is reflected in a smaller loin eye area and causes an increase in the intramuscular fat content.

Table 5. Carcass and meat characteristics.

	T1	T2	T3	T4	T5	T6	T7
Carcass length (cm)	80.17 ± 2.32Aa	78.50 ± 2.07ABab	78.83 ± 1.33ABa	79.83 ± 2.04Aa	n/d	76.00 ± 2.76Bb	78.58 ± 1.80ABab
Dorsal fat thickness (mm)	30.08 ± 2.85Aa	27.95 ± 3.44Aa	27.83 ± 2.44Aa	31.42 ± 3.40Aa	n/d	29.58 ± 2.08Aa	26.13 ± 3.10Aa
Loin eye area (cm ²)	59.55 ± 5.41Aa	51.84 ± 6.62ABbc	52.06 ± 4.68ABbc	45.40 ± 2.38Cd	n/d	55.25 ± 6.56Aab	50.02 ± 5.29Bc
Fat area in the steak (cm ²)	37.64 ± 2.16Aa	39.71 ± 2.60Aab	46.31 ± 3.84ABb	47.58 ± 4.92Bc	n/d	42.16 ± 3.89ABb	40.05 ± 3.28Aab
Meat in the steak %	60.02 ± 4.24Aa	57.45 ± 3.75Aa	53.46 ± 3.58Ab	51.08 ± 4.87Bb	n/d	58.17 ± 4.52Aa	57.09 ± 3.87Aa
Intramascular fat %	2.94 ± 0.61Bb	3.33 ± 0.53Bb	2.77 ± 0.64Bb	4.42 ± 0.32Aa	n/d	3.51 ± 0.66Aa	3.02 ± 0.49Bb

Table 6. Dorsal fat lipid profile.

	T1	T2	T3	T4	T5	T6	T7
Saturated %	39.87 ± 2.39Aa	39.55 ± 0.72Aa	39.10 ± 1.59Aa	39.51 ± 1.92Aa	40.89 ± 1.60Aa	39.95 ± 3.00Aa	38.00 ± 3.98Aa
Monounsaturated %	49.28 ± 2.43Aa	49.22 ± 0.67Aa	49.96 ± 0.93Aa	48.99 ± 1.33Aa	46.36 ± 2.27Aa	47.78 ± 1.66Aa	50.18 ± 2.73Aa
Polyunsaturated %	9.29 ± 0.71Aa	9.47 ± 0.27Aa	9.00 ± 1.48Aa	9.71 ± 1.59Aa	9.63 ± 1.62Aa	10.83 ± 3.44Aa	10.35 ± 4.32Aa
PUFA:SFA ratio	0.23 ± 0.02Aa	0.24 ± 0.01Aa	0.23 ± 0.05Aa	0.25 ± 0.05Aa	0.24 ± 0.04Aa	0.28 ± 0.11Aa	0.28 ± 0.15Aa
Stearic acid 18:0 %	13.02 ± 2.09Aa	12.93 ± 0.78Aa	12.43 ± 0.47Aa	12.68 ± 0.75Aa	14.30 ± 1.15Aa	13.98 ± 2.10Aa	13.50 ± 2.42Aa
Palmitic acid 16:0 %	24.97 ± 0.71Aa	24.82 ± 0.23Aa	24.78 ± 1.25Aa	24.96 ± 1.42Aa	24.73 ± 0.48Aa	24.18 ± 0.98Aa	22.83 ± 2.14Aa
Oleic acid 18:1 n-9 %	43.82 ± 2.06Aa	43.55 ± 0.14Aa	43.59 ± 0.89Aa	43.04 ± 1.23Aa	41.38 ± 2.58Aa	42.45 ± 1.43Aa	44.60 ± 2.09Aa
Linoleic acid 18:2 n-6 %	8.85 ± 0.41AB b	8.73 ± 0.22B b	8.08 ± 0.90B b	8.73 ± 1.11B b	8.93 ± 0.88AB b	8.43 ± 0.88 B b	9.18 ± 3.90A a
Linolenic acid 18:3 n-3 %	0.45 ± 0.06 Aa	0.55 ± 0.06 ABC ab	0.53 ± 0.05 ABC ab	0.50 ± 0.08 ABC a	0.48 ± 0.10 AB a	0.63 ± 0.10 BC bc	0.68 ± 0.10 C c
ω6:ω3 ratio	19.83 ± 1.65Aa	15.93 ± 1.50Bb	15.42 ± 1.60Bb	21.46 ± 1.80Aa	19.08 ± 1.94ABa	13.60 ± 1.28Bb	15.62 ± 1.44Bb

Substituting soybean meal for a mixture of canola expeller and forage peas in combination with maize grain or low tannin sorghum grain does not affect pig's carcass characteristics.

Pigs on diets where soybean meal has been replaced by a mixture of canola expeller and forage peas in combination with maize grain or low tannin sorghum grain, presented a lipid profile of dorsal fat with higher content of $\omega 3$ fatty acids, decreasing the $\omega 6:\omega 3$ ratio compared to diets with soybean meal, which is considered beneficial to consumers' cardiovascular health.

It is recommended to investigate the use of diets with canola expeller supplemented with synthetic lysine as the main protein source and its effect on the lipid profile of pigs' fat.

Acknowledgments

To Diego Cattivelli and the staff of the slaughter plant Ardistar, for their support when carrying out the measurements and sampling. To Mario Michelazzo, who made the determinations of the loin eye area in the samples obtained. To María Antonia Grompone and the staff of the Fats and Oils Laboratory of the Chemistry College.

Authors' contribution

RB: experiment design, writing, result analysis; RBD: laboratory analysis, participation in the interpretation of results and writing; DS: laboratory analysis, participation in the interpretation of results; CB: statistical processing.

References

- De Caro A, Basso CP, Allea G, Premezzi D, Basso RL. El contenido de magro de canales porcinas y su relación con variables de calidad y origen. *InVet* [Internet]. 2005 [cited 2019 Apr 25]. 7(1):11-7. Available from: <http://www.scielo.org.ar/pdf/invet/v7n1/v7n1a01.pdf>.
- Urkijo E, Eguinoa P, Labairu J. Como se valora la calidad de la canal y la calidad de la carne. In: *Universo Porcino: El portal del cerdo* [Internet]. [place unknown]: Universo Porcino; 2009 [cited 2019 Apr 25]. [about 6 p.]. Available from: http://www.aacporcinos.com.ar/articulos/carne_porcina_09-09_como_se_valora_la_calidad_de_la_canal_y_la_calidad_de_la_came.html.
- Campion DS. Calidad de la carne porcina según el sistema de producción [graduate's thesis. Internet]. Argentina: Universidad Católica Argentina, Facultad de Ciencias Agrarias; 2013 [cited 2019 Apr 25]. 49 p. Available from: <http://bibliotecadigital.uca.edu.ar/repositorio/tesis/calidad-carne-porcina-produccion.pdf>.
- Daza A, Buxadé C. La calidad de la carne del cerdo blanco. In: *Producción porcina: Aspectos claves*. Madrid: Mundi-Prensa; 2000. p. 239-57.
- Echenique A. Efecto de la alimentación sobre la calidad de la carne y la grasa del cerdo. *Agrociencia* (Uruguay). 2007; Volumen Especial:55-63.
- Braun RO, Pataccini GE, Scoles GE, Cervellini JE. Productividad y calidad de grasa corporal en cerdos alimentados con cereales crudos y extruidos. *Arch Zootec*. 2007;56(215):299-308.
- Capra G, Echenique A, Grompone M, Bauza R, Gonzalez A, Silva D. Evaluación de la inclusión de grano de soja desactivado, afrechillo de arroz integral o suero de queso en la dieta de cerdos en engorde: 2. Efecto sobre la calidad de canal y carne. *Agrociencia* (Uruguay). 2007; Volumen Especial: 53-7.
- US Grains Council. Manejo de la calidad de la grasa del cerdo cuando se alimentan cantidades altas de DDGS a porcinos en crecimiento y finalización. In: *Manual del Usuario de DDGS del Consejo Norteamericano de Granos* [Internet]. 3rd ed. Washington: US Grains Council; 2016 [cited 2019 Apr 26]. 11 p. Available from: <http://ita-grains.org/wp-content/uploads/2016/12/DDGS-Manual-Capitulo-23.pdf>.
- Fernández X, Monin G, Talmant A, Hourot J, Lebet B. Influence of intramuscular fat content on the quality of pig meat: 2. Consumer acceptability of *m. longissimus lumborum*. *Meat Sci*. 1999;53(1):67-72.
- Capra G, Salle L, Cozzano S, Nardo D, Martínez Borche R, Márquez R, Luzardo S, Brito G, De Souza G, Costas G. Valor nutritivo de la carne de cerdo producido en Uruguay [Internet]. In: *Engormix Porcicultura*. [place unknown]: Engormix; 2017 [cited 2019 Apr 25]. [about 8 p.]. Available from: <https://www.engormix.com/porcicultura/articulos/valor-nutritivo-carne-cerdo-t41156.htm>.
- Cardén A. Factores genéticos que afectan la calidad de la carne. *Rev Tecnol Agropecu*. 1998;4:1-9.
- Apple JK, Maxwell CV, Galloway DL, Hutchison S, Hamilton CR. Interactive effects of dietary fat source and slaughter weight in growing-finishing swine: I. Growth performance and longissimus muscle fatty acid composition. *J Anim Sci*. 2009;87(4):1407-22.
- Bertol TM, De Campos RML, Ludke JV, Terra NN, De Figueiredo EAP, Coldebello A, Dos Santos JI, Kawski VL, Lehr NM. Effects of genotype and dietary oil supplementation on performance, carcass traits, pork quality and fatty acids composition of backfat and intramuscular fat. *Meat Sci*. 2013;93(3):507-16.
- Braun RO, Cervellini JE, Esteves Leyte R. Calidad de las reses de cerdos mejorados alojados en pistas al aire libre. *Rev Fac Agron UNLPam*. 2000;11(1):43-8.

- 15) Capra G, Repiso L, Fradiletti F, Martínez R, Cozzano S, Márquez R. Efecto de la dieta de cerdos en crecimiento sobre el valor nutritivo y la aptitud tecnológica de la carne y grasa. *INNOTEC*. 2011;6:11-20.
- 16) Braun RO, Pataccini GE. Evaluación de ácidos grasos en las carcasas de cerdos alimentados con sorgo termoprocesado durante el crecimiento y la terminación. *Rev Fac Agron UNLPam*. [Internet] 2013. [cited 2019 Apr 25];28(1):25-35. Available from: <http://www.biblioteca.unlpam.edu.ar/pubpdf/rev-agro/v23n1a03braun.pdf>.
- 17) De Blas C, Mateos GG, García-Rebollar P, editors. *Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos*. 3rd ed. Madrid: FEDNA; 2010. 502 p.
- 18) Rojo Gómez A, Pérez Mendoza V, Bayardo Uribe A, Correa Cardona HJ, Cuarón Ibarquengoytia JA. Pasta de canola como suplemento proteico en dietas para la finalización de cerdos. *Téc Pecu Méx*. 2001;39(3):179-92.
- 19) Maupeertuis F, Quiniou N, Royer E, Guibert J, Quinsac A, Peyronnet C. Effets d'une utilisation continue et du mode de distribution du tourteau de colza sur les performances des porcs charcutiers. *Journées de la Recherche Porcine*. 2011;43:67-72.
- 20) Okrouhlá M, Stupka R, Cítek K, Sprysl M, Brzobohaty L, Kluzaková E. The effect of replacing soybean meal with rapeseed meal on the production performance and meat chemical composition in pigs. *Res Pig Breed* [Internet]. 2012 [cited 2019 Apr 25];6:36-9. Available from: <http://www.respigbreed.cz/2012/1/8.pdf>
- 21) Little K. The effects of feeding canola meal from high protein or conventional varieties of canola seeds on pork quality [master's thesis. Internet]. Urbana (IL): University of Illinois; 2014 [cited 2019 Apr 25]. 76 p. Available from: <https://www.ideals.illinois.edu/handle/2142/50645>.
- 22) Smit MN, Seneviratne RW, Young MG, Lanz G, Zijlstra RT, Beltranena E. Feeding increasing inclusions of canola meal with distillers dried grains and soluble to growing-finishing barrows and gilts. *Anim Feed Sci Technol*. 2014;189:107-16.
- 23) Mejicanos G, Sanjavan N, Kim IH, Nyachoti CM. Recent advances in canola meal utilization in swine nutrition. *J Anim Sci Technol*. 2016 [cited 2019 Apr 25];58:7. Available from: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4754856/>.
- 24) Peñuela LM, Moreira I, De Oliveira PL, Gomez A, Diaz LM, De Lima Costa C. Desempenho e características quantitativas e qualitativas de carcaças de suínos alimentados com farelo de canola. *Rev Caatinga* [Internet]. 2016. [cited 2019 Apr 25];29(3):735-41. Available from: http://www.scielo.br/scielo.php?pid=S1983-21252016000300735&script=sci_abstract&tlng=pt.
- 25) Caine WR, Aalhus JL, Dugan MER, Lien KA, Larsen IL, Costello F, McAllister TA, Stanford K, Sharma R. Growth performance, carcass characteristic and pork quality for pigs fed diets containing meal from conventional or glyphosate-tolerant canola. *Can J Anim Sci*. 2007;87:517-26.
- 26) National Research Council. *Nutrient requirements of swine*. 10th rev ed. Washington (DC): National Academy Press; 1998. 212 p.
- 27) Thacker PA, Racz VJ, Soita HW. Performance and carcass characteristics of growing-finishing pigs fed barley-based diets supplemented with Linpro (extruded whole flaxseed and peas) or soybean meal. *Can J Anim Sci* [Internet]. 2004 [cited 2019 Apr 25];84:681-8. Available from: <http://www.nrcresearchpress.com/doi/pdf/10.4141/A04-025>.
- 28) Stein HH, Everts AKR, Sweeter KK, Peters DN, Maddock RJ, Wulf DM, Pedersen C. The influence of dietary fields peas (*Pisum sativum* L.) on pig performance, carcass quality, and palatability of pork. *J Anim Sci*. 2006;84:3110-7.
- 29) Newman DJ, Harris EK, Lepper AN, Berg EP, Stein HH. Effects of pea chips on pig performance, carcass quality and composition, and palatability of pork. *J Anim Sci*. 2011;89(3):3132-9.
- 30) Njoka J, Honeyman M, Miller T. Effects of feeding Iowa-Grown field peas on finishing pig [Internet]. [place unknown]: Iowa State University; 2008 [cited 2019 Apr 25]. 5 p. Animal Industry Report: AS 654, ASL R2359. Available from: http://lib.dr.iastate.edu/ans_air/vol654/iss1/108.
- 31) Chrenková M, Formelová Z, Chrastinová L, Feak P, Ceresňáková R, Lahucky R, Poláčiková M, Bahelka I. Influence of diets containing raw or extruded peas instead of soybean meal on meat quality characteristics in growing-finishing pigs. *Czech J Anim Sci* [Internet]. 2011 [cited 2019 Apr 25];56(3):119-26. Available from: <http://www.agriculturejournals.cz/publicFiles/36594.pdf>.
- 32) National Research Council. *Nutrient requirements of swine*. 11th ed. Washington (DC): National Academy Press; 2012. 420 p.
- 33) National Institute of Health (US). *IMAGE J: image Processing and Analysis in Java* [Internet]. Version 1.8.0_112. Bethesda: NIH; 2016 [cited 2019 Apr 26]. Available from: <https://imagej.nih.gov/ij/index.html>.
- 34) Hara A, Radin NS. Lipid extraction of tissues with a low-toxicity solvent. *Anal Biochem*. 1978;90(1):420-6.
- 35) Silva PS, Campagna DA, Maiztegui L, Somenzini D, García P, Font MT, Di Masso RJ. Espesor y composición de la grasa dorsal en cerdos a campo restringidos en días alternos en dos épocas del año. *Rev Arg Prod Anim*. 2006;26:181-91.
- 36) Bauza R, Capra G, Bratschi C. Evaluación de la arveja forrajera como alimento para cerdos en engorde. *Agrociencia* (Uruguay). 2013;17(2):91-8.
- 37) Barlocco N, Carballo C, Vadell A. Rasgos de comportamiento productivo y características de canal de tres biotipos de cerdos en condiciones de producción a campo. *Agrociencia* (Uruguay). 2007; Volumen Especial: 35-8.

- 38) Dobao MT, Rodríguez J, Silio L, Toro MA, de Pedro E, García de Siles JL. Crecimiento y características de canal en cerdos ibéricos, Duroc-Jersey x Ibérico y Jiaying x Ibérico. *Inv Agrar: Prod Sanid Anim* [Internet]. 1987 [cited 2019 Apr 25];2(1):9–23. Available from: [http://www.uco.es/ispg/archivos/documentos/Documentos/Ficha%2003%20AnalesINIA%201987%20r\(1\).pdf](http://www.uco.es/ispg/archivos/documentos/Documentos/Ficha%2003%20AnalesINIA%201987%20r(1).pdf).
- 39) Petrocelli H, Costas G, Urbín G, Puig A. Caracterización de las plantas de faena y los cerdos destinados a la faena. In: *Evaluación bioeconómica de sistemas de producción de cerdos*: F.P.T.A. 130. Montevideo: INIA; 2003. p. 19–33.
- 40) Hurnik D. Loin eye size and what factors drive it?. In: *The pig site* [Internet]. [place unknown]: 5m Enterprises; 2004 [cited 2019 Apr 25]. [about 3 p.] Available from: <http://www.thepigsite.com/articles/1110/loin-eye-size-and-what-factors-drive-it/>.
- 41) Ward TL, Southern LL. Sorghum amino acid-supplemented diets for the 50 to 100 kilogram pig. *J Anim Sci*. 1995;73:1746–53.
- 42) Tokach M, Goodband B, DeRouchey J. Sorghum in swine production feeding guide [Internet]. Texas: Sorghum checkoff; 2012 [cited 2019 Apr 25]. 28 p. Available from: <https://www.sorghumcheckoff.com/assets/media/feedingguides/swineguideforweb.pdf>.
- 43) Bañón S, Granados MV, Cayuela JM, Gil MD, Costa E, Garrido MD. Calidad de la grasa obtenida a partir de cerdos magros. *Anales Veterinarios (Murcia)*. 2000;16:77–88.