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The impact of replacing barley by dehydrated orange pulp in finishing pig diets on performance, carcass quality, and gaseous emissions from slurry

P. Ferrer [a,b,1], S. Calvet [b], P. García-Rebollar [c], A.I. Jiménez-Belenguer [d], P. Hernández [b], O. Piquer [e], A. Cerisuelo [a,*]

[a] *Centro de Investigación y Tecnología Animal, Instituto Valenciano de Investigaciones Agrarias, Segorbe, Castellón, Spain*
[b] *Instituto de Ciencia y Tecnología, Universitat Politècnica de València, Valencia, Spain*
[c] *Departamento de Producción Agraria, Universidad Politécnica de Madrid, Madrid, Spain*
[d] *Escuela Técnica Superior de Ingeniería Agronómica y del Medio Natural, Universitat Politècnica de València, Valencia, Spain*
[e] *Departamento de Producción y Sanidad Animal, Salud Pública Veterinaria y Ciencia y Tecnología de los Alimentos, Universidad CEU-Cardenal Herrera, Valencia, Spain*

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ABSTRACT

Using agricultural by-products such as dehydrated orange pulp (**DOP**) in animal feeds is of interest to increase pig sector sustainability. With this aim, an assay was carried out to assess the effects of increasing inclusion levels of DOP in pig diets regarding animal performance, carcass quality, and environmental impact. Four experimental diets were designed, a control diet (T1) and three more diets with increasing levels of DOP with 80, 160, and 240 g/kg of DOP for diets T2, T3, and T4, respectively. One hundred and sixty growing pigs were used in the experiment. Growth performance (average daily gain, **ADG**; average daily feed intake, **ADFI** and feed conversion ratio, **FCR**) and *in vivo* backfat thickness (**BF**) and loin depth (**LD**) gain were recorded during the finishing phase (from 70 to 130 kg BW). Faecal samples were incubated for bacteria enumeration. At slaughter, carcass characteristics and meat quality traits were measured, and subcutaneous fat was sampled to analyse the fatty acid (**FA**) profile. Additionally, the slurry excreted by the animals was measured, characterised and subjected to a gaseous emission assay during its storage. The final BW and overall ADFI, ADG and FCR were similar among treatments. *In vivo* final LD and BF gain decreased ($P \leq 0.10$) as the inclusion level of DOP increased. No differences were observed in carcass characteristics with the inclusion of DOP, except carcass weight that decreased linearly ($P = 0.05$) with DOP. Regarding the FA profile of the subcutaneous fat, the ratio of total monounsaturated to saturated FA increased with the inclusion level of DOP. Neither slurry excretion and characterisation nor bacterial counts from faeces showed any significant difference among treatments. The inclusion of DOP led to greater CH_4 emissions in mg per L of slurry and hour, whereas these differences disappeared when expressed in mg per animal and day. In all, it has been demonstrated that the inclusion of DOP up to 240 mg/kg in pig diets had minor effects on growth performance, carcass quality traits or gaseous emissions from slurry, favouring the circular economy strategy and pig sector sustainability.

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Implications

The orange juice industry offers different ingredients, such as dehydrated orange pulp which can be used in animal feeding to boost the livestock sector's circular economy. In the present study, including high levels (240 g/kg) of orange pulp in pig diets did not impair growth performance or carcass quality traits and had no adverse effects on gaseous emissions associated with the slurry storage per pig. Overall, these results can help producers to design practical diets with orange pulp, as a tool to face the current pig

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[*] Corresponding author at: Centro de Investigación y Tecnología Animal, Instituto Valenciano de Investigaciones Agrarias, Pol. La Esperanza 100, 12400, Segorbe, Castellón, Spain.

E-mail address: cerisuelo_alb@gva.es (A. Cerisuelo).

[1] *Present address: FISABIO-Public Health, Foundation for the Promotion of Health and Biomedical Research in the Valencian Region, Avenida Catalunya 21, 46020 Valencia, Spain.*

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sector challenges regarding animal health and its environmental impact.

Introduction

The supply of feed ingredients for animal production is a global concern worldwide because of the increasing demand for animal products and the limited availability of crops in a climate change scenario. Furthermore, these crops usually compete with human food, and their availability for animal feeds will decrease (Makkar and Ankers, 2014). Replacing part of the cereals used in feeds by local agro-industrial by-products such as citrus pulp could increase the food systems' circularity by recycling non-edible plant materials and reduce the environmental carbon footprint of pig meat production.

Citrus is one of the major fruit products worldwide, covering a relatively stable surface of almost 10 million hectares and a world production of over 140 million tonnes per year (FAOSTAT, 2021). The transformation of citrus fruits, mainly oranges, into juice (30 % of the world production) generates a massive amount of by-products (49–69 % of the fresh weight of fruits processed; Martínez-Pascual and Fernández-Carmona, 1980) in the form of citrus pulp. The chemical composition of citrus pulp has been reviewed in several studies (Bampidis and Robinson, 2006; de Blas et al., 2018). It is influenced by the type of fruit and varieties, seasonal conditions, maturity, juice extraction system and further processing, such as dehydration. In general terms, citrus pulps are typically rich in sugars and fibre but low in CP and phosphorus.

Dehydrated citrus pulp (**DOP**) has been successfully included in pig fattening diets replacing cereals, but the maximum level at which it can be included without affecting growth performance is variable among studies (from 100 to 225 g/kg; Watanabe et al., 2010a; Amorim et al., 2014; Strong et al., 2015). Additionally, its effects on carcass and meat quality are inconsistent. While Watanabe et al. (2010b) described no deleterious effects on meat quality with the inclusion of 300 g/kg, Strong et al. (2015) reported adverse effects on carcass characteristics and lean quality with the inclusion of 150 g/kg of citrus pulp in finishing pig diets. The reasons for this inconsistency are unknown, but they could be related to the nutritional quality of DOP. Although it has high fibre content (260 g/kg of NDF), the concentration of soluble fibre is particularly high in DOP (around 300 g/kg; De Blas et al., 2018) in contrast to other fibrous by-products. These characteristics make citrus pulps relevant energy sources for pigs (Ferrer et al., 2021), with reported minor effects on dietary nutrient digestibility when included at moderate levels (up to 150 g/kg; Beccaccia et al., 2015). However, it has been extensively demonstrated in animals and humans that fibre can affect feed intake at high inclusion levels because of its effects on gut fill and satiety (Ratanpaul et al., 2019).

Furthermore, recent studies report that the inclusion of DOP in pig diets might affect gas emissions from slurry and soils, probably due to its type of fibre and the presence of bioactive compounds such as polyphenols. In this regard, short-term studies with dietary inclusions of 150–500 g/kg of DOP (Beccaccia et al., 2015; Ferrer et al., 2021) showed a low ratio of nitrogen (**N**) excreted in urine: N in faeces and a decrease of ammonia N emitted per kg of initial N in the pig slurry. Additionally, a 65 % reduction in nitrous oxide emission was observed when the slurry from animals fed 150 g/kg DOP was applied to soils (Sanchez-Martín et al., 2017). However, its effects on methane (**CH_4**) emission from slurry storage are not apparent, as the biochemical CH_4 potential of slurry tends to increase with dietary DOP levels up to 200 g/kg (Antezana et al., 2015) but decrease with 500 g/kg compared to control diets without DOP (Ferrer et al., 2021).

Far from being considered an antinutritional factor, some beneficial effects have been recently recognised for dietary fibre, especially soluble and fermentable fibre like the one in DOP. Besides energy provision, recent studies suggest that fibrous agro-industrial by-products in pig diets may improve gut health through their fermentation in the distal gastrointestinal tract. This fermentation will promote beneficial gut bacteria, supporting intestinal integrity and proper immune function (Moset et al., 2015; Jha et al., 2019). The objective of the present work was to evaluate the consequences of including high levels of DOP (up to 240 g/kg) in balanced finishing pig diets from an integrative point of view. This evaluation includes the effects on growth performance, carcass quality, faecal microbiology and gas emissions from the slurry. This information will help to assess the optimal inclusion levels of this by-product in terms of productivity and sustainability.

Material and methods

Animals, diets and experimental design

One hundred and sixty growing castrated males, progeny of Duroc-Danbred × (Landrace × Large White) of 25.3 ± 3.0 kg initial BW were used in the experiment. At arrival, pigs were identified and distributed according to BW in 32 pens and two rooms (16 pens per room and five animals per pen). All the animals were phase-fed two common commercial feeds before the beginning of the experimental period. At 71.2 ± 7.32 kg BW, pens were assigned to four different treatments (eight pens/treatment) according to average pen weight and SD within a pen. These treatments consisted of a control feed (T1) and three more experimental diets with increasing levels of DOP: 80, 160 and 240 g/kg of DOP for diets T2, T3 and T4, respectively. A local fruit juice producer (Zuvamesa, Sagunto, Spain) provided the DOP that was included replacing barley in diets T2, T3 and T4. Diets were formulated to be isocaloric and isoaminoacidic using the coefficient of total tract apparent digestibility (**CTTAD**) of energy for the same DOP source previously determined by Ferrer et al. (2021) and by adjusting the addition of the rest of the ingredients. The maximum DOP inclusion level was chosen from the results obtained in previous studies (Amorim et al., 2014; Beccaccia et al., 2015; Strong et al., 2015). Detailed DOP and experimental diet composition are given in Tables 1–3. Diets were offered *ad libitum* in dry form (pelleted) and provided until slaughter (128 ± 9.75 kg BW) for 50 days. Free access to water was provided during the experimental period.

Growth performance, carcass and meat quality

Pigs were individually weighed, and *in vivo* backfat (**BF**) and loin depth (**LD**) were measured at the beginning and the end of the experimental period. Feed intake per pen was calculated as the difference between the amount of feed offered over the experimental period and the amount of feed remaining in the feeders on the last day of the study. The average daily gain (**ADG**), average daily feed intake (**ADFI**) and feed conversion ratio (**FCR**) were calculated. *In vivo* BF and LD were measured at the P2 position (located at the level of the last rib, at 6.5 cm of the vertebral column) using a two-dimensional (B-mode) ultrasound device (Agroscan A16, Angoulême, France) as described by Cerisuelo et al. (2010). Additionally, BF and LD gain was calculated from initial and final measurements. Pigs were slaughtered at the end of the experimental period. Fasting was practised for approximately 12 h before slaughter in all animals, and carcass weight (hot carcass weight) was measured. At approximately-two-hour

Table 1
Chemical composition of dehydrated orange pulp (DOP) used in the pig diets (g/kg DM, unless otherwise specified).

Analysed chemical composition	DOP
DM, g/kg fresh matter	882
Ash	61.4
Gross energy, MJ/kg DM	17.4
Digestible energy, MJ/kg DM[1]	13.9
CP	81.0
Ether extract	15.5
NDF[2]	195
ADF[2]	130
Lignin	17.9
Total Dietary Fibre	531
Soluble Fibre	336
Sugars	355

[1] Calculated from the coefficient of total tract apparent digestibility of energy previously determined in Ferrer et al. (2021).
[2] Ash-free.

postmortem (during the chilling process), meat colour components at the *Gracillis* muscle were recorded using a portable CR300 Minolta Chromameter (Konica Minolta, Osaka, Japan). Additionally, subcutaneous fat was sampled at the second cervical vertebrae level, as in Ferrer et al. (2020), to analyse the fatty acid (**FA**) profile at the left side of the carcass of 20 animals per treatment randomly selected.

Faecal microbiota by culture-based methods and metabolites

Faecal samples were aseptically removed directly from the rectum of 16 animals per treatment (two animals per pen) on days 42 and 43 of the experimental period for bacterial (total anaerobic bacteria, *enterobacteria*, *lactobacilli* and *bifidobacteria*) enumeration. The samples of each pen were pooled and treated as a pen sample. Within two hours after collection, faecal samples were diluted at 1:10 (1 g faeces in 9 mL of peptone water), and decimal dilutions were prepared. The number of colony-forming units per gram (CFU/g faeces) was analysed as described by Ferrer et al. (2020).

Slurry measurements and gas emission

In one of the experimental rooms, the slurry pit was divided into eight separate compartments that allowed the collection of the slurry excreted by the animals housed in two consecutive pens, independently from the rest. During the last 20 days of the trial, the slurry excreted by the animals housed in this room (four pens/treatment and two slurry pits/treatment) was quantified according to its height in the pit at the end of this period. Afterwards, the slurry in each pit was homogenised with a pump, and a representative sample was pumped to two tanks of 120 l of capacity per pit (470 mm diameter and 800 mm height), leaving a 200 mm headspace between the slurry surface and the top of the tank. Overall, 16 tanks were filled with 90 l of slurry each and sampled during the fill-in for chemical characterisation. The tanks were placed in a mechanically ventilated room for eight weeks simulating outdoor slurry storage. Ammonia and CH_4 emissions were measured once per week as described by Calvet et al. (2017) and Hassouna and Eglin (2015), respectively. The static chamber method was used to measure CH_4 emissions by placing airtight lids on the 16 tanks for 3 min and alternating room air measurement for another 3 min between consecutive tanks. The emission factor was calculated as the slope of the linear part of the concentration increase curve, multiplied by the volume enclosed in the chamber headspace.

Chemical analysis

The DOP and experimental feeds were analysed for DM, ash, starch, total dietary fibre and ether extract according to the Association of Official Analytical Chemists (AOAC, 2000) procedures. Total sugars were analysed according to the method of Luff-Schoorl (Lees, 1975). NDF, ADF and ADL concentrations were determined sequentially according to the Van Soest procedure (Van Soest et al., 1991). The contents in SF were estimated from the difference between total dietary fibre and NDF corrected by CP content in the residue. The gross energy concentration was measured in an isoperibol bomb calorimeter (Parr 6400, Parr Instruments Co., Moline, IL, USA). Total N was measured by combustion using Leco equipment (model FP-528, Leco Corporation, St. Joseph, MI, USA), and CP was estimated as N content × 6.25. The proportion of neutral and acid detergent insoluble CP was determined following the standardised procedures in Licitra et al. (1996).

The fatty acid profile of the experimental feed samples and the subcutaneous fat was measured according to O'Fallon et al. (2007). Fatty acid methyl esters were prepared and analysed in a Focus Gas Chromatograph (Thermo, Milan, Italy). The fatty acid profile was calculated as the proportion of saturated, monounsaturated and polyunsaturated fatty acid in grams per 100 g of fatty acid.

Slurry samples were analysed for pH in duplicate and DM, ash and organic matter, ether extract, fibre and GE following the same methodology used for DOP and feeds. The total ammoniacal N and total Kjeldahl N were analysed by steam distillation as for the faeces. To avoid N volatilisation, the slurry subsample used for total ammoniacal N analyses was acidified with HCl immediately after the samples were collected.

Statistical analysis

Data were analysed using SAS® (Statistical Analysis System) System Software (version 9.1, SAS Institute Inc., Cary, North Carolina, EEUU). Differences in initial and final BW, BF and LD and ADG, ADFI, FCR, carcass and meat quality traits among treatments were analysed as a completely randomised design, using a one-way ANOVA model with type of diet as the main effect. The influence of DOP inclusion was also studied using linear and quadratic contrasts. Faecal microbial counts were $\log_{10}$ transformed before analysis. The experimental unit was the pen for ADG, ADFI, FCR, initial and final BW, and microbial counts. In contrast, the experimental unit was the individual pig for the carcass and meat quality measurements. Gas emission results (mg/L and h) are presented as the average emission rate during the experiment. These data were also calculated in mg/animal and day (considering the amount of slurry excreted), and both were statistically analysed, together with initial slurry characterisation, with the pit as the experimental unit. Data validation was approached by calculating information on the Validation and/or Assurance quality procedure and output.

Results

The statistical analysis showed no significant influence ($P > 0.05$) of the room and its interaction with dietary treatments for any of the traits studied, so this effect was excluded from the model.

Dehydrated orange pulp and experimental diet composition

The DOP used in the study (Table 1) shows a high content in total dietary fibre (it accounts for over 50 % of the DM, 531 g/kg

Table 2
Ingredient content (g/kg as fed) and chemical composition (g/kg DM, unless otherwise specified) of the experimental pig diets.

	Treatments[1]			
Item	T1	T2	T3	T4
Ingredients				
Barley	240	160	80	0
Corn	200	200	200	200
Wheat	350	343	336	330
Soybean meal	159	163	167	172
Dehydrated orange pulp	0	80	160	240
Palm oil	17.4	21.8	26.2	30.6
Calcium carbonate	11.9	8.9	6.0	3.1
Monocalcium phosphate	8.9	9.6	10.3	11.1
Sodium chloride	3.3	3.2	3.1	3.0
Sodium bicarbonate	2.0	2.0	2.0	2.0
Methionine	0.34	0.42	0.50	0.58
Sulphate L-Lysine	3.48	3.59	3.69	3.80
L-Threonine	0.54	0.59	0.64	0.69
Choline chloride	0.6	0.6	0.6	0.6
Vitamin-mineral premix[2]	3.0	3.0	3.0	3.0
Analysed chemical composition				
DM, g/kg fresh matter	892	891	885	886
Ash	50.6	53.8	52.1	51.3
CP	180	176	176	175
Ether extract	33.2	36.8	39.0	43.1
NDF[3]	131	133	142	141
ADF[3]	33.9	39.4	54.3	49.3
Lignin	3.95	4.11	4.10	3.90
NDICP	10.9	19.0	16.8	24.5
ADICP	1.40	1.70	1.90	2.70
Total Dietary Fibre	162	188	212	220
Soluble Fibre	31.2	55.7	69.8	79.5
Sugar	46.0	69.0	89.0	97.0
Starch	449	413	369	370
Gross energy, MJ/kg	18.4	18.4	18.5	18.7
Calculated chemical composition[4]				
Digestible energy, kcal/kg	3 417	3 416	3 415	3 414
Net energy, kcal/kg	2 400	2 400	2 400	2 400
Calcium	7.0	7.0	7.0	7.0
Phosphorus	5.3	5.3	5.3	5.3
Standardised ileal amino acids				
Lysine	8.6	8.6	8.7	8.7
Methionine	2.6	2.7	2.7	2.7
Methionine + Cystine	5.4	5.3	5.3	5.2
Threonine	5.5	5.8	5.8	5.8
Tryptophan	1.8	1.8	1.8	1.8
Isoleucine	6.0	5.9	5.9	5.9
Valine	7.0	6.9	6.8	6.7

Abbreviations: NDICP = Neutral detergent insoluble CP; ADICP = Acid detergent insoluble CP.

[1] T1 = 0 g/kg dehydrated orange pulp; T2 = 80 g/kg dehydrated orange pulp; T3 = 160 g/kg dehydrated orange pulp; T4 = 240 g/kg dehydrated orange pulp.

[2] Vitamin–mineral premix in the finishing phase provided per kg of feed: retinol, 6 500 IU (E672); cholecalciferol, 1 860 IU (E671); α-tocopherol, 10 mg; menadinone, 0.6 mg; thiamine, 0.8 mg; riboflavin, 3.2 mg; pyridoxin, 1.0 mg; cobalamin, 0.02 mg; niacin, 12 mg; pantothenic acid, 9.60 mg; choline clorure, 116 mg; Fe, 72 mg as $FeSO_4 \cdot 7H_2O$; Cu, 16 mg as $CuSO_4 \cdot 5H_2O$; Zn, 80 mg as ZnO; Mn, 40 mg as MnO; I, 1.44 mg as KI and Se, 0.20 mg as Na_2SeO_3.

[3] Ash-free.

[4] Calculated values based on FEDNA (2019) and digestible energy of dehydrated orange pulp from Ferrer et al. (2021).

Table 3
Fatty acid (FA) profile of the experimental pig diets (g/kg as fed).

	Treatments[1]			
Item	T1	T2	T3	T4
Total FA (mg/100 g feed)	3.48	3.78	3.91	4.24
Saturated fatty acids (SFAs; mg/g total FA)	307	321	330	342
Monounsaturated fatty acids (MUFAs; mg/g total FA)	297	314	327	342
Polyunsaturated fatty acids (PUFAs; mg/g total FA)	396	365	343	316
PUFA/SFA	1.29	1.14	1.04	0.924
MUFA/SFA	0.965	0.981	0.992	1.00

Abbreviations: SFA = saturated FA; MUFA = monounsaturated FA; PUFA = polyunsaturated FA.

[1] T1 = 0 g/kg dehydrated orange pulp; T2 = 80 g/kg dehydrated orange pulp; T3 = 160 g/kg dehydrated orange pulp; T4 = 240 g/kg dehydrated orange pulp.

DM) and sugars (355 g/kg DM). Regarding the different fractions of fibre partitioning, DOP presents a high content in soluble fibre (336 g/kg DM) and ADF (130 g/kg DM) and a low content of ADL (17.9 g/kg DM). As a result of the increased dietary levels of DOP from 80 to 240 g/kg (Table 2), treatments 2 to 4 showed a higher SF, total dietary fibre and sugar content than the control diet

(T1). The T4 diet showed the highest fibre fractions (124 and 30 % higher content of soluble fibre and total dietary fibre) and sugars (111 %) compared with the T1 diet. Regarding the fatty acid profile (Table 3), monounsaturated FAs and saturated FAs were greater, while polyunsaturated FA levels were lower in DOP diets because of the higher inclusion of palm oil than in T1.

Growth performance, carcass and meat quality

The results of growth performance are summarised in Table 4. The overall growth performance data and inter-assay CV of body composition data are provided in Supplementary Tables S1 and S2. No statistical differences among treatments were observed for initial BW, final BW and overall ADG, ADFI and FCR. Regarding the *in vivo* final LD and BF, the inclusion of DOP decreased linearly ($P < 0.05$) LD but did not affect final BF. However, LD and BF gain during the experimental period decreased linearly ($P \leq 0.10$) with DOP levels.

Including DOP in pig diets slightly reduced carcass weight ($P = 0.050$) but did not significantly affect carcass yield or fat depth at the *gluteus medius* (Table 5). Meat colour was not affected by the dietary treatments. Regarding the fatty acid profile of the subcutaneous fat, total fatty acid followed a quadratic effect ($P < 0.05$) with DOP inclusion levels. Likewise, the saturated FA values decreased ($P < 0.05$), and the monounsaturated FA increased ($P < 0.001$) as the inclusion of DOP in diets was increased, following a lineal tendency ($P < 0.05$). Therefore, the ratio of monounsaturated/saturated FA was highest ($P < 0.001$) in pigs fed diets supplemented with DOP compared with T1, and this ratio increased ($P < 0.001$) as the level of DOP in the diets increased. The concentration of polyunsaturated FA in the subcutaneous fat was similar among treatments.

Faecal microbial counts

Bacterial counts from faeces (Table 6) did not show any significant differences ($P > 0.05$) among treatments. The ratio *lactobacilli: enterobacteria* was also similar in all treatments (T1: 1.54, T2: 1.55, T3: 1.52 and T4: 1.52; SEM: 0.055).

Slurry composition and gas emission

The slurry produced ranged from a minimum of 8.06 in T2 to a maximum of 9.85 l/animal and day in T1, with no statistical differences among treatments (Table 7). Regarding the slurry composition at the beginning of the gas emission study, none of the traits analysed was significantly different among treatments. High variability between replicates from the same treatment was observed from the standard error. The intra-assay CV of slurry composition data and gas emission is provided in Supplementary Table S3. However, a numerical tendency was detected in all parameters towards an increase from T1 to T3 and a decrease in T4. No significant differences were observed in the amount of NH_3 emitted, whereas CH_4 emission tended ($P < 0.01$) to be higher with DOP diets and increased significantly with the inclusion level being 55 and 36 % higher in T3 and T4, respectively, compared to T1. When the emissions were expressed in mg per animal and day, considering the volume of slurry produced, non-significant differences were observed.

Discussion

The DOP used in this study contained a high amount of total dietary fibre, soluble fibre and sugars, averaging 531, 336 and 274 g/kg DM, respectively, indicating that this ingredient is rich in highly available carbohydrate fractions and thus, in digestible energy. These values are similar to those published in the literature (Bampidis and Robinson, 2006; De Blas et al., 2018; FEDNA, 2019), except for sugars, which concentration is particularly high in the DOP used in the present study. During the processing of the DOP used in this study, a re-addition of citrus molasses to the lime takes place before the drying operation, which may explain its higher sugar content. In all, the high sugar content and the fermentability of its fibre make the DOP used in the present study an excellent ingredient to be included in heavy pig diets from a nutritional point of view. In fact, contrary to most of the studies (O'Sullivan et al., 2003; Amorim et al., 2014; Strong et al., 2015) that reported maximum inclusion levels of 150 g/kg of DOP in growing pig diets, the inclusion of 240 g/kg of DOP in the present study was possible without any adverse effects on growth performance, including feed efficiency. The good quality of the DOP tested in this study compared to others, together with the fact that the experimental diets were formulated with matrix values of this same citrus pulp (obtained in *in vivo* trials; Ferrer et al., 2021), might be responsible for the good results obtained in the present study.

The studies mentioned above point to a reduction in feed intake as the main reason for limiting dietary DOP levels, related to the unpalatability of the by-product. In the present study, the inclusion of DOP reduced numerically feed intake. This might indicate that DOP inclusion levels greater than 240 g/kg can compromise animals' performance. It is known that high levels of fibre sources in diets can limit voluntary feed intake due to an increase in the satiety feeling (Ratanpaul et al., 2019). Although it is not clear, fibres sources like pectin (high levels in citrus pulp) can increase satiety in pigs due to its high water retention capacity and effects on delaying gastric emptying (Drochner et al., 2004). This effect can also depend on the age of the animals since this can affect their ability to ferment fibre and the potentially detrimental effects of fibre in feed intake (Jha et al., 2019). Thus, the optimum level of DOP inclusion in diets in terms of performance seems to be highly dependent on DOP quality (amount and type of fibre, sugars or even dehydrating method), the precision in feed formulation and the age of the animals to be fed with DOP.

Regarding carcass traits, it is well known that an increase in the fibre fraction in pig diets can lead to a lower carcass yield due to an increased weight of both the content and tissue of the stomach, large intestine, colon and cecum (Coble et al., 2018).

In the present study, carcass weight decreased with the inclusion of DOP, and carcass yield was numerically (although not significant) different among treatments. This suggests that our DOP can lightly increase organs' weight, as Watanabe et al. (2010b) suggested.

Fat depth at the *gluteus medius* and meat colour were not affected by the inclusion of DOP in diets. Watanabe et al. (2010b) reported a linear reduction of L*, a*, and b* values as the dietary levels of citrus pulp increased. The authors associated this darker, less red, and less yellow meat with the reduction of corn levels in diets when including citrus pulp. Other studies also observed differences in meat colour due to changes in fatty acid composition derived from including dried corn distillers grains with solubles in diets. In this regard, Swiatkiewicz et al. (2021) suggested that dried corn distillers grains with solubles lead to greater monounsaturated FA levels, a lower C18:2n-6 content and a lighter meat colour. These changes, when they occur, are of interest because they can affect consumer purchase intentions. Nonetheless, in the present study, DOP replaced barley, and the effects on meat colour are less evident.

On the other hand, the FA profile of the subcutaneous fat was affected by the experimental diets. The proportion of monounsaturated FA increased, and the saturated FA decreased, leading to an increase in the monounsaturated/saturated FA ratio with DOP

Table 4
Effect of the inclusion level of dehydrated orange pulp in pig diets on growth performance.

Item	Treatments[1]				SEM	*P*-value		
	T1	T2	T3	T4		Treatment	Linear effect	Quadratic effect
Initial BW, kg[2]	71.81	70.58	71.81	70.76	2.16	0.963	0.845	0.967
Final BW, kg[2]	128.87	127.48	128.20	126.83	1.46	0.949	0.642	0.999
Average daily gain, kg/d[2]	1.16	1.16	1.15	1.14	0.029	0.979	0.704	0.932
Average daily feed intake, kg/d[2]	3.33	3.20	3.19	3.18	0.068	0.330	0.122	0.357
Feed conversion ratio, g feed/g gain[2]	2.85	2.78	2.78	2.78	0.071	0.884	0.525	0.648
Initial backfat thickness, mm[3]	8.13	7.97	8.02	7.88	0.317	0.956	0.623	0.974
Final backfat thickness, mm[3]	13.40	13.64	12.50	12.38	0.644	0.389	0.143	0.767
Initial loin depth, mm[3]	40.15	38.16	37.67	38.07	0.811	0.142	0.068	0.145
Final loin depth, mm[3]	53.92	51.33	50.52	50.21	1.035	0.057	0.012	0.272
Backfat gain, mm[3]	5.78	5.46	4.49	4.49	0.443	0.082	0.016	0.711
Loin gain, mm[3]	14.08	13.17	12.85	12.14	0.837	0.426	0.102	0.902

[1] T1 = 0 g/kg dehydrated orange pulp; T2 = 80 g/kg dehydrated orange pulp; T3 = 160 g/kg dehydrated orange pulp; T4 = 240 g/kg dehydrated orange pulp.
[2] n = 40.
[3] n = 16.

Table 5
Effect of the inclusion level of dehydrated orange pulp in pig diets on carcass, meat quality and fatty acid (FA) in the subcutaneous fat.

Item	Treatments[1]				SEM	*P*-value		
	T1	T2	T3	T4		Treatment	Linear effect	Quadratic effect
Carcass characteristics[2]								
Carcass weight, kg	95.38	94.38	93.02	92.09	1.280	0.275	0.050	0.976
Carcass yield, %	74.60	74.55	73.08	73.00	1.370	0.736	0.304	0.995
Fat depth at the GM[3], mm	1.77	1.71	1.55	1.68	0.074	0.169	0.205	0.181
Meat quality[2]								
Meat colour[4]								
Lightness (L*)	36.73	36.22	36.16	37.56	0.521	0.838	0.803	0.379
Redness (a*)	8.43	8.77	8.86	8.00	0.411	0.434	0.512	0.148
Yellowness (b*)	3.18	2.91	3.04	3.12	0.132	0.476	0.944	0.178
FA in subcutaneous fat[5]								
Total FA, mg/100 g subcutaneous fat)	68.25^{ab}	69.70^{ab}	70.10^{a}	67.00^{b}	0.753	0.019	0.356	0.005
SFA, mg/g total FA	329^{a}	328^{a}	316^{b}	323^{ab}	2.831	0.003	0.012	0.111
MUFA, mg/g total FA	480^{c}	486^{b}	494^{ab}	500^{a}	2.958	<0.001	<0.001	0.968
PUFA, mg/g total FA	189	187	189	183	2.624	0.279	0.163	0.448
Ratio PUFA/SFA	0.572	0.571	0.597	0.566	0.010	0.160	0.848	0.730
Ratio MUFA/SFA	1.45^{c}	1.49^{b}	1.57^{a}	1.55^{ab}	0.021	<0.001	<0.001	0.239

Abbreviations: SFA = saturated FA; MUFA = monounsaturated FA; PUFA = polyunsaturated FA.
[1] T1 = 0 g/kg dehydrated orange pulp; T2 = 80 g/kg dehydrated orange pulp; T3 = 160 g/kg dehydrated orange pulp; T4 = 240 g/kg dehydrated orange pulp.
[2] n = 40.
[3] GM = *Gluteus medius* muscle.
[4] Measured at the *Gracillis* muscle level.
[5] n = 20.

Table 6
Effect of the inclusion level of dehydrated orange pulp in pig diets on faecal bacteria counts (Log_{10} CFU/g fresh faeces).

Item	Treatments[1,2]				SEM	*P*-value		
	T1	T2	T3	T4		Treatment	Linear effect	Quadratic effect
Total anaerobic bacteria	7.97	7.51	7.40	7.41	0.289	0.466	0.175	0.425
Bifidobacteria	8.21	8.62	8.30	8.69	0.166	0.138	0.147	0.943
Enterobacteria	6.22	6.32	6.34	6.14	0.233	0.923	0.834	0.525
Lactobacilli	9.51	9.69	9.50	9.28	0.156	0.330	0.213	0.199

[1] T1 = 0 g/kg dehydrated orange pulp; T2 = 80 g/kg dehydrated orange pulp; T3 = 160 g/kg dehydrated orange pulp; T4 = 240 g/kg dehydrated orange pulp.
[2] n = 16.

inclusion. Moset et al. (2015) reported similar results with the inclusion of ensiled citrus pulp at levels up to 100 g/kg diet. However, the reason why DOP in diets can affect the fatty acid profile of the subcutaneous fat is unknown. One possibility is that increased palm oil and DOP could have affected the subcutaneous fat profile. In this regard, the fatty acid profile in diets showed increases in monounsaturated FA, as in the case of subcutaneous fat. However, saturated FA and polyunsaturated FA followed different tendencies in diets and subcutaneous fat. Saturated FA increased and polyunsaturated FA decreased in diets, and in the subcutaneous fat, saturated FA decreased, and polyunsaturated FA did not change. Palm oil is mainly saturated, but monounsaturated FAs are also present in this ingredient, and its inclusion in diets could have influenced the fatty acid profile. However, the effects on saturated FA and polyunsaturated FA concentration in subcutaneous fat might be explained by the negative influence of DOP inclusion on dietary fat digestibility as shown by Antezana et al. (2015). This effect has been related to the binding of bile acids by pectins, resulting in a lower capacity to emulsify dietary fat (Drochner et al., 2004). The reduced digestibility might be more relevant in

Table 7
Effect of the inclusion level of dehydrated orange pulp in pig diets on slurry characteristics and gas emissions.

Item	Treatments[1,2]					*P*-value		
	T1	T2	T3	T4	SEM	Treatment	Linear effect	Quadratic effect
Slurry production, l/animal and day	9.85	8.06	9.02	9.51	2.09	0.931	0.995	0.613
Slurry characteristics								
DM, g/kg	13.00	19.26	24.99	17.53	10.55	0.877	0.703	0.551
Organic Matter, g/kg	8.28	12.2	17.3	11.4	7.90	0.875	0.704	0.566
Total Ammoniacal Nitrogen, g/l	2.66	2.43	3.01	2.38	0.821	0.942	0.946	0.822
Total Kjeldhal Nitrogen, g/kg	3.05	3.52	3.73	3.04	1.18	0.963	0.976	0.646
NDF, g/kg	3.90	6.13	7.01	4.43	3.58	0.915	0.886	0.538
ADF, g/kg	0.99	1.69	2.14	1.04	1.16	0.873	0.909	0.481
ADL, g/kg	0.38	0.63	0.78	0.37	0.42	0.875	0.954	0.480
Ether Extract, g/kg	2.00	2.45	5.14	2.00	2.45	0.773	0.818	0.505
pH	7.06	7.10	7.26	7.03	0.165	0.765	0.934	0.444
Concentration of gases emitted, mg/l and h								
Ammonia	0.155	0.137	0.176	0.139	0.051	0.940	0.966	0.868
Methane	0.106	0.106	0.173	0.147	0.013	0.049	0.029	0.357
Total gas emission, mg/animal and day								
Ammonia	35.54	26.71	31.87	34.06	9.89	0.923	0.988	0.608
Methane	25.05	20.34	35.64	33.49	5.91	0.349	0.199	0.839

[1] T1 = 0 g/kg dehydrated orange pulp; T2 = 80 g/kg dehydrated orange pulp; T3 = 160 g/kg dehydrated orange pulp; T4 = 240 g/kg dehydrated orange pulp.
[2] n = 2.

the case of saturated compared to unsaturated fatty acid because of its lower polarity and ability to be absorbed and stored in the carcass fat. Ndou et al. (2019) showed that when saturated fat sources are added to a diet containing pectin as the only source of dietary fibre, the ileal digestibility of total fatty acid is depressed more than in cellulose-containing diets. This could support the lower saturated FA amount in the subcutaneous fat when pigs are fed DOP.

Citrus pulp contains high levels of bioactive compounds (polyphenols, essential oils, carotenoids and vitamin C) with antioxidant properties (Kasapidou et al., 2015) that can affect metabolism and enhance animal health. Dietary fibre is mainly fermented in the proximal colon, producing lactic acid and short-chain fatty acids, promoting the growth of beneficial bacteria in the gut, improving the gut mucosal health as well as the immune system of pigs (Jha et al., 2019). Other studies using ensiled citrus pulp showed evident decreases in faecal *Enterobacteria* counts when included at levels of 100–150 g/kg in pig diets (Cerisuelo et al., 2010; Moset et al., 2015). However, neither of these effects were observed in the present study, and the reasons for the lack of differences might be related to the high volatile fatty acid contents and low pH of ensiled citrus pulp diets (Canibe and Jensen, 2003). Furthermore, the high limitation of cultured-based techniques to assess the changes induced by animal feeding on the diversity and dynamics of the gastrointestinal microbiota could explain the lack of effects observed in this case.

Regarding slurry production and composition, the inclusion of DOP did not show differences compared to the control diet (T1). Ferrer et al. (2020) and Morazán et al. (2015) reported increased slurry excretion when including ingredients with considerable amounts of lignified fibre, resulting in higher faecal DM production. Our results align with those provided by Beccaccia et al. (2015) where moderate levels of DOP did not severely affect nutrient digestibility and improved dietary fibre digestibility compared to other by-products with a higher content in lignin. Concerning gas emission from the slurry, the dietary inclusion of fermentable fibre like the fibre of citrus pulp (pectin and hemicellulose) has been reported as an effective tool to reduce the amount of N excreted in urine and the ammonia losses during manure storage (Antezana et al., 2015; Beccaccia et al., 2015; Ferrer et al., 2021). In the present study, contrary to expected, ammonia emission from the slurry was unaffected. These results could be explained due to differences in DOP and diet composition among studies or the methodology used (reconstituted fresh slurry vs pit stored slurry). In the present assay, diets were isonutritive, and the nutritive quality of DOP was high. This could have promoted that a high proportion of soluble fibre (mainly pectins) disappear in the small intestine, diminishing the potential effect of dietary DOP levels in the slurry composition.

On the other hand, CH$_4$ emission rates, expressed in mg per L and h, increased with the inclusion level of DOP ($P < 0.05$). This could be related to the numerical, although not significant, increase in the slurry nutrient concentration (especially organic matter) in T3 and T4 compared with T1. However, the high variability observed between slurry replicates prevented these differences from being significant. This variability in the slurry composition when pigs are housed in groups, as in commercial conditions, has been documented in other studies and can be related to differences in the animal behaviour (water and feed intake competition and spillage; Bornett et al., 2000). It is worth noting that a numerical reduction in carbon volatile solid contents is observed in the slurry of T4 compared with the rest of the treatments, probably due to the numerical reduction of feed intake observed in this group. However, when CH$_4$ emissions are expressed in mg per animal and day, these differences disappear due to the lack of differences in slurry production among treatments.

Conclusion

Thus, the results obtained in the present study may increase the interest in using DOP in pig nutrition from a growth performance point of view. It has been demonstrated that levels up to 240 g/kg in diets did not negatively affect growth performance, body composition or carcass quality traits. Additionally, the DOP used in the present study did not affect faecal microbial counts. However, the higher Monounsaturated FA:saturated FA ratios in BF with increased dietary levels of DOP suggest that soluble fibre could alter fatty acid digestibility according to fatty acid saturation. From an environmental point of view, high dietary levels of DOP did not affect excreta volume but increased CH$_4$ emission per L of slurry. However, these differences disappeared when expressed per pig and day. Then, using DOP in pig diets can favour the circular economy strategy and contribute to the animal feeding sector's economic, social and environmental sustainability.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2022.100659.

Ethics approval

The experimental procedure was approved by the Ethics Committee of the Universitat Politècnica de València (registration number 2016/VSC/PEA/00024).

Data and model availability statement

Part of the data (performance and ultrasound measures) can be found on the IVIA repository (ReDivia; https://redivia.gva.es) and is available upon request.

Author ORCIDs

A.C., https://orcid.org/0000-0002-3545-6978
P.G.R., https://orcid.org/0000-0001-9469-1313
P.H., https://orcid.org/0000-0001-7857-7334
A.I.J., https://orcid.org/0000-0002-3329-7221
S.C., https://orcid.org/0000-0001-6639-9892

Author contributions

S.C., P.G.R., and A.C. were involved in conceptualisation and funding acquisition, project administration, resources, supervision and validation. P.F., S.C. and A.C. performed the formal analysis and visualisation. P.F. prepared the original draft of the manuscript. A.I.J., P.H., O.P., A.C., S.C. and P.G.R. contributed to data curation, investigation, methodology, reviewing and editing the manuscript.

Declaration of interest

None.

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References

Amorim, A.B., Thomaz, M.C., Ruiz, U., Martínez, J.F., Pascoal, L.A.F., Daniel, E., Watanabe, P.H., Rosalen, D.L., 2014. Citrus pulp and enzyme complex for growing and finishing pigs. Revista Brasileira de Saude e Producao Animal 15, 369–380.

Antezana, W., Calvet, S., Beccaccia, A., Ferrer, P., De Blas, C., García-Rebollar, P., Cerisuelo, A., 2015. Effects of nutrition on digestion efficiency and gaseous emissions from slurry in growing pigs: III. Influence of varying the dietary level of calcium soap of palm fatty acids distillate with or without orange pulp supplementation. Animal Feed Science and Technology 209, 128–136.

Association of Official Analytical Chemist (AOAC), 2000. Official methods of analysis. AOAC, Arlington, VA, USA.

Bampidis, V.A., Robinson, P.H., 2006. Citrus by-products as ruminant feeds: A review. Animal Feed Science and Technology 128, 175–217.

Beccaccia, A., Calvet, S., Cerisuelo, A., Ferrer, P., García-Rebollar, P., De Blas, C., 2015. Effects of nutrition on digestion efficiency and gaseous emissions from slurry in growing-finishing pigs. I. Influence of the inclusion of two levels of orange pulp and carob meal in isofibrous diets. Animal Feed Science and Technology 208, 158–169.

Bornett, H.L.I., Morgan, C.A., Lawrence, A.B., Mann, J., 2000. The effect of group housing on feeding patterns and social behaviour of previously individually housed growing pigs. Applied Animal Behaviour Science 70, 127–141.

Calvet, S., Hunt, J., Misselbrook, T.H., 2017. Low frequency aeration of pig slurry affects slurry characteristics and emissions of greenhouse gases and ammonia. Biosystems Engineering 159, 121–132.

Canibe, N., Jensen, B.B., 2003. Fermented and non-fermented liquid feed to growing pigs: Effect on aspects og gastrointestinal ecology and growth performance. Journal of Animal Science 81, 2019–2031.

Cerisuelo, A., Castelló, L., Moset, V., Martínez, M., Hernández, P., Piquer, O., Gómez, E., Gasa, J., Lainez, M., 2010. The inclusion of ensiled citrus pulp in diets for growing pigs: Effects on voluntary intake, growth performance, gut microbiology and meat quality. Livestock Science 134, 180–182.

Coble, K.F., Derouchey, J.M., Tokach, M.D., Dritz, S.S., Goodband, R.D., Woodworth, J. C., 2018. Effects of withdrawing high-fiber ingredients before marketing on finishing pig growth performance, carcass characteristics, and intestinal weights. Journal of Animal Science 96, 168–180.

De Blas, J.C., Ferrer, P., Rodríguez, C.A., Cerisuelo, A., García-Rebollar, P., Calvet, S., Farias, C., 2018. Nutritive value of citrus co-products in rabbit feeding. World Rabbit Science 26, 7–14.

Drochner, W., Kerler, A., Zacharias, B., 2004. Pectin in pig nutrition, a comparative review. Journal of Animal Physiology and Animal Nutrition 88, 367–380.

FAOSTAT, 2021. Food and Agriculture Organization of the United Nations. Citrus Fruits Statistical Compedium 2020. FAO, Italy, Rome.

Fedna, 2019. Tablas FEDNA de composición y valor nutritivo de alimentos para la fabricación de piensos compuestos, 4ª edición. Fundación Española para el Desarrollo de la Nutrición Animal, Madrid, Spain.

Ferrer, P., 2021. Valorisation of Mediterranean agro-industrial by-products in pig production as feed and anaerobic co-digestion of slurry. Universitat Politècnica de València, Valencia, Spain.

Ferrer, P., Calvet, S., García-Rebollar, P., De Blas, C., Jiménez-Belenguer, A.I., Hernández, P., Piquer, O., Cerisuelo, A., 2020. Partially defatted olive cake in finishing pig diets: Implications on performance, faecal microbiota, carcass quality, slurry composition and gas emission. Animal 14, 426–434.

Ferrer, P., García-Rebollar, P., Calvet, S., De Blas, C., Piquer, O., Rodríguez, C.A., Cerisuelo, A., 2021. Effects of orange pulp conservation methods (Dehydrated or ensiled sun-dried) on the nutritional value for finishing pigs and implications on potential gaseous emissions from slurry. Animals 11, 1–14.

Hassouna, M., Eglin, T., 2015. Mesurer les émissions gazeuses en élevage: gaz à effet de serre, ammoniac et oxydes d'azote [ISBN : 2-7380-1375-9]. Diffusion INRA-ADEME, Paris, France.

Jha, R., Fouhse, J.M., Tiwari, U., P., Li, L., Willing, B.P.,, 2019. Dietary fiber and intestinal health of monogastric animals. Frontiers in Veterinary Science 6, 48.

Kasapidou, E., Sossidou, E., Mitlianga, P., 2015. Fruit and Vegetable Co-Products as Functional Feed Ingredients in Farm Animal Nutrition for Improved Product Quality. Agriculture 5, 1020–1034.

Lees, R., 1975. Food Analysis: Analytical and Quality Control Methods for the Manufacturer and Buyer. Leonard Hill Books, London, UK.

Licitra, G., Hernández, T.M., Van Soest, P.J., 1996. Standardisation of procedures for nitrogen fractionation of ruminant feed. Animal Feed Science and Technology 57, 347–358.

Makkar, H.P.S., Ankers, P., 2014. Towards a concept of sustainable animal diets [Animal Production and Health Report no. 7]. FAO, Rome, Italy.

Martínez-Pascual, J., Fernández-Carmona, J., 1980. Composition of citrus pulp. Animal Feed Science and Technology 5, 1–10.

Morazán, H., Alvarez-Rodriguez, J., Seradj, A.R., Balcells, J., Babot, D., 2015. Trade-offs among growth performance, nutrient digestion and carcass traits when feeding low protein and/or high neutral-detergent fiber diets to growing-finishing pigs. Animal Feed Science and Technology 207, 168–180.

Moset, V., Piquer, O., Cervera, C., Fernández, C.J., Hernández, P., Cerisuelo, A., 2015. Ensiled citrus pulp as a by-product feedstuff for finishing pigs: nutritional value and effects on intestinal microflora and carcass quality. Spanish Journal of Agricultural Research 13, e0607.

Ndou, S.P., Kiarie, E., Walsh, M.C., Ames, N., de Lange, C.F.M., Nyachoti, C.M., 2019. Interactive effects of dietary fibre and lipid types modulates gastrointestinal flows and apparent digestibility of fatty acids in growing pigs. British Journal of Nutrition 121, 469–480.

O'Fallon, J.V., Busboom, J.R., Nelson, M.L., Gaskins, C.T., 2007. A direct method for fatty acid methyl ester synthesis: Application to wet meat tissues, oils, and feedstuffs. Journal of Animal Science 85, 1511–1521.

O'Sullivan, T.C., Lynch, P.B., Morrissey, P.A., O'Grady, J.F., 2003. Evaluation of Citrus Pulp in Diets for Sows and Growing Pigs. Irish Journal of Agricultural and Food Research 42, 243–253.

Ratanpaul, V., Williams, B.A., Black, J.L., Gidley, M.J., 2019. Review: Effects of fibre, grain starch digestion rate and the ileal brake on voluntary feed intake in pigs. Animal 13, 2745–2754.

Sanchez-Martín, L., Beccaccia, A., De Blas, C., Sanz-Cobena, A., García-Rebollar, P., Estellés, F., Marsden, K.A., Chadwick, D.R., Vallejo, A., 2017. Diet management to effectively abate N2O emissions from surface applied pig slurry. Agriculture, Ecosystems and Environment 239, 1–11.

Strong, C.M., Brendemuhl, J.H., Johnson, D.D., Carr, C.C., 2015. The effect of elevated dietary citrus pulp on the growth, feed efficiency, carcass merit, and lean quality of finishing pigs. The Professional Animal Scientist 31, 191–200.

Swiatkiewicz, M., Olszewska, A., Grela, E.R., Tyra, M., 2021. The Effect of Replacement of Soybean Meal with Corn Dried Distillers Grains with Solubles (cDDGS) and Differentiation of Dietary Fat Sources on Pig Meat Quality and Fatty Acid Profile. Animals 11, 1277.

Van Soest, P.J., Robertson, J.B., Lewis, B.A., 1991. Methods for dietary fiber, neutral detergent fiber and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74, 3583–3597.

Watanabe, P.H., Thomaz, M.C., dos Santos-Ruiz, U., dos Santos, V.M., Fraga, A.L., Pascoal, L.A.F., da Silva, S.Z., de Faria, H.G., 2010a. Effect of inclusion of citrus pulp in the diet of finishing swines. Brazilian Archives of Biology and Technology 53, 709–718.

Watanabe, P.H., Thomaz, M.C., dos Santos-Ruiz, U.S., dos Santos, V.M., Masson, G.C.I., Fraga, A.L., Pascoal, L.A.F., Robles-Huaynate, R.A., da Silva, S.Z., 2010b. Carcass characteristics and meat quality of heavy swine fed different citrus pulp levels. Arquivo Brasileiro de Medicina Veterinária e Zootecnia 62, 921–929.