Received: 18 April 2019 | Revised: 5 August 2019 | Accepted: 20 September 2019

DOI: 10.1111/jfpp.14233

SPECIAL ISSUE

Journal of Food Processing and Preservation | Institute of Food Science + Technology ifst | WILEY

Physicochemical analysis of ham from entire male pigs raised with different feeding and housing conditions

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Funding information

PIGS+CARE is co-financed by the European Regional Development Fund (FEDER) through COMPETE 2020 (Operational Program for Competitiveness and Internationalization)., Grant/Award Number: POCI-01-0247-FEDER-017626

Abstract

This study aims to investigate the effect of feeding and housing conditions on physicochemical characteristics of cooked hams produced with meat from entire male pigs. Meat from boars raised under different conditions of housing and feeding (two housing conditions and three levels of inulin added to feed) was used to produce six batches of cooked hams following a standard manufacturing process. Texture profile analysis (hardness, cohesiveness, and chewiness), color analysis, pH, and moisture content were determined. ANOVA and principal component analysis were carried out. Results showed that 6% of inulin added to feed led to significantly lower values of hardness and chewiness. Improved housing conditions hams presented lower pH values. Except for a^* parameter (red color), no significant interactions between the two categorical variables, housing and diet, were found. Housing conditions and inulin feeding may have affected meat characteristics; therefore, adjustments of current cooked ham processing parameters might be necessary.

Practical applications

This study is part of a broader project where the main objective is to determine whether the housing conditions and the addition of inulin to pig feed lead to the reduction or elimination of the boar taint. Also, there is the need to determine if the meat characteristics are appealing to the consumers and viable for the industry, since the characteristics of entire male's meat may pose new challenges in meat processing. In line with this, the objective of this study was to determine the effect of different feeding and housing conditions of boars in the physicochemical characteristics of cooked ham, in order to determine the viability of the use of entire male's meat for cooked ham production.

1 | INTRODUCTION

Castration of male piglets still is a common practice in most European countries, despite available evidence suggesting that castration at any age is painful (Gunn et al., 2004). Pork production stakeholders have declared to ban surgical castration by 2018 in the European Union (Morlein et al., 2015), but the progress of this declaration still ongoing, with efforts being made to reach this goal by 2024 (De Jonckheere & Nalon, 2018). Male piglets are castrated primarily to prevent the development of the objectionable sensory perceived odor or flavor of boar taint in meat (Fredriksen, Johnsen, & Skuterud, 2011; Gunn et al., 2004; Wauters et al., 2017). Boar taint is described as an unpleasant odor which becomes especially intense when pork is cooked (Mathur et al., 2012) and is mainly associated with the presence of skatole and androstenone. Introduction of inulin in feed and the improvement of housing conditions can reduce boar taint (Aluwe et al., 2013; Backus et al., 2016; Bilić-Šobot, Čandek-Potokar, Kubale, & Škorjanc, 2014; Byrne, Thamsborg, & Hansen, 2008; Hansen et al., 2008; Kjos, Overland, Fauske, & Sorum, 2010). Housing conditions and genetic selection can also have a favorable effect in this matter (Backus et al., 2016). Raising entire male pigs has some economic advantages as boars possess the advantage of superior growth over castrates, generally leaner carcasses, and compared to castrates, less feed is needed in order to achieve the same final weight (Morlein et al., 2015; Wauters et al., 2017). Aluwe et al. (2013) compared meat with entire and castrated males and found differences in pH, colur, drip loss, and cooking loss that did not largely influence meat quality or palatability.

2 | MATERIALS AND METHODS

2.1 | Experimental design, housing, and feeding

A total of 60 entire male pigs of a crossbreed (progeny of Large White × Landrace gilts sired by Pietrain boars) were raised in a pig farm in Vila Nova de Poiares, Coimbra, Portugal. A commercial diet, containing wheat, corn, barley, soybean, oilseed rape, sunflower, and wheat bran, was given to all pigs until 5.5 months of age, ad libitum access. Then, the animals were separated into six trial groups, according to the type of housing and percentage of inulin added to commercial feed, as described in Table 1. All received 2.8 kg per pig per day of the commercial feed described above and four groups feed included 3% or 6% inulin (commercial dried chicory—Fibrofos 60), for 2 months until slaughter. Improved housing conditions consisted in a larger area (1.9 m^2 vs. 1.0 m^2 per animal), easier access to water and environmental enrichment accessories (toys). Transportation was carried to meet legal wellness conditions (2.5 m^2 per cell, 5 pigs in each cell). The shipment and transportation of the improved housing group to the slaughterhouse was carried out with stress-reducing procedures (arrival in daylight to the slaughterhouse and slaughtered upon arrival day, waiting less hours).

2.2 | Cooked ham production

Pork carcasses were shipped to a meat processing factory and kept at −18°C for 5 weeks. Then, seven hams (approximately 50 kg of meat) from each condition were selected in order to produce six batches of cooked hams, corresponding to the trials described in Table 1 following current manufacturing procedures. Hams were injected with a brine solution, massaged, and tumbled during 3 hr and then cooked in ham molds, followed by chilling and mold disassembly. Cooked ham samples were coded as N0% (control), N3%, N6%, C0%, C3%, and C6%, where "N" means normal housing, "C" improved housing, and 0, 3, and 6 correspond to percentage of added inulin in animal feed.

TABLE 1 Housing conditions, inulin feed composition, and number of pigs for each trial

Pen	Housing	Added inulin in feed	Number of pigs
A	Normal	0%	10
B	Normal	3%	10
C	Normal	6%	10
D	Improved (+Care)	0%	10
E	Improved (+Care)	3%	10
F	Improved (+Care)	6%	10

2.3 | Physicochemical analysis

Samples of cooked ham were kept in its original package at refrigeration temperatures (4 ± 1°C) for 1 week prior to analysis. Samples were opened and cut into slices of 4 cm thick for texture profile analysis (TA.XT2 plus texture analyzer Stable Micro Systems TPA) to assess hardness, chewiness, and cohesiveness (15 replicates). Test conditions were 10-P cylindric probe; test speed 5 mm/s; pre-test speed 1 mm/s, post-test speed 5 mm/s; distance 10.0 mm; and trigger force 0.04903 N. pH was also determined (Crison pH25+ equipment), according to Portuguese standard NP3441:2018 (3 replicates). Samples were minced and dried in an oven at 103 ± 2°C in order to determine moisture content, as described in NP1614:2009 (3 replicates). Ham color measurements were performed in accordance to the CIE L^*, a^*, and b^* color system described by Honikel, (1998), using a Minolta colorimeter CR-300 (Konica Minolta Tokyo, Japan). Ten replicates were performed by placing the measuring head over each ham slice.

2.4 | Statistical analysis

ANOVA was performed for the two categorical variables (housing and inulin addition in feed), followed by *post hoc* Fisher's least significant difference (LSD). Groups of treatments, housing conditions, and feeding conditions were set as the independent variables and the physicochemical parameters (hardness, cohesiveness, chewiness, color, pH, and moisture content) defined as dependent variables. Significant differences were set at $p < .05$. Data mining was performed to investigate differences with a principal component analysis (PCA) based on correlations. These statistical approaches were carried out using the Statistica for Windows software package, version 7 (Stat Soft Inc., Tulsa, USA).

3 | RESULTS AND DISCUSSION

Cooked hams produced with meat from entire male pigs raised under different conditions of housing and feeding were analyzed. Results are shown in Table 2. Regarding cohesiveness no significant differences between two categorical variables, housing and feeding ($p < .05$), were found although minor differences were noticeable when groups of animals were individually compared by post hoc LSD test. With respect to hardness and chewiness, hams from animals

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TABLE 2 Cooked ham physicochemical parameters (mean and standard deviation) obtained in the experiments

Groups	Hardness (N)	Cohesiveness	Chewiness (N)	pH
N0%	6.36 ± 1.39[a]	0.54 ± 0.11[ab]	2.69 ± 1.10[ab]	6.23 ± 0.03[ab]
N3%	5.46 ± 1.82[b]	0.57 ± 0.12[a]	2.54 ± 0.94[ab]	6.30 ± 0.10[a]
N6%	4.59 ± 1.18[c]	0.51 ± 0.06[b]	1.81 ± 0.53[c]	6.28 ± 0.09[a]
C0%	5.74 ± 1.62[ab]	0.53 ± 0.07[ab]	2.76 ± 1.13[a]	6.19 ± 0.10[b]
C3%	6.05 ± 1.54[ab]	0.52 ± 0.09[b]	2.82 ± 1.04[a]	6.16 ± 0.08[b]
C6%	4.62 ± 0.97[c]	0.52 ± 0.07[b]	2.21 ± 0.81[bc]	6.16 ± 0.09[b]
ANOVA *p*-values				
housing	1.000	0.226	0.057	0.000
inulin%	0.000	0.134	0.000	0.768
housing*inulin%	0.054	0.220	0.630	0.198
Groups	Moisture%	*L*	*a*	*b*
N0%	75.08 ± 0.39[b]	62.65 ± 1.99[ab]	13.53 ± 2.04[bc]	5.38 ± 1.18[c]
N3%	74.96 ± 1.54[b]	61.80 ± 2.97[b]	15.23 ± 1.91[a]	5.79 ± 1.27[bc]
N6%	75.49 ± 0.76[ab]	62.61 ± 2.69[ab]	14.28 ± 1.82[abc]	6.52 ± 1.98[ab]
C0%	74.93 ± 1.09[b]	63.09 ± 3.15[a]	14.89 ± 1.61[a]	6.73 ± 1.12[a]
C3%	75.56 ± 0.60[ab]	63.07 ± 1.76[a]	14.74 ± 2.24[ab]	6.38 ± 1.96[ab]
C6%	76.17 ± 0.69[a]	62.99 ± 2.07[ab]	13.84 ± 1.80[b]	6.73 ± 1.30[a]
ANOVA *p*-values				
housing	0.150	0.053	0.615	0.001
inulin%	0.041	0.580	0.016	0.060
housing*inulin%	0.352	0.529	0.009	0.096

Note: Different letters in the same column indicate a significant difference ($p < .05$) using LSD.

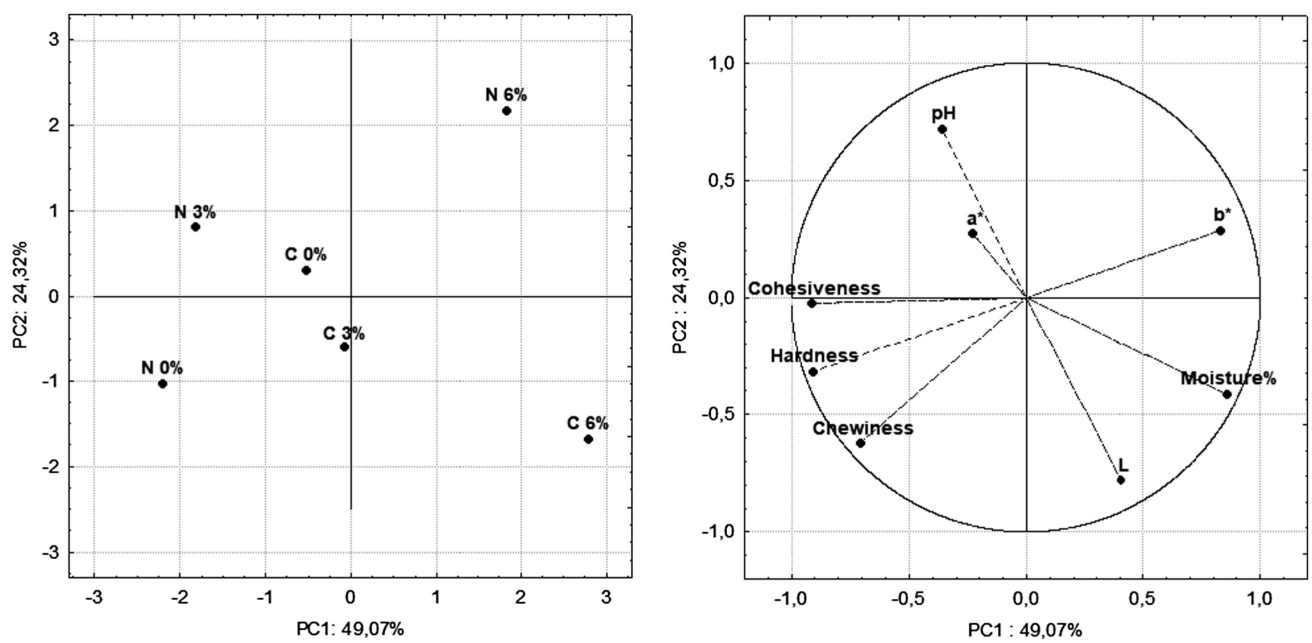

FIGURE 1 Principal component analysis determined parameters: score plot for the mean classification of condition groups (left) and Eigen vectors plot (right). N-normal housing; C-improved housing. 0%, 3%, and 6% is the value of added inulin in feed

with 6% of added inulin in feed were less hard ($p < .01$) than others. Groups with "normal" housing showed higher pH values ($p < .01$), but still within the expected range for cooked hams (Dima, Neagu, Cercel, & Alexe, 2014; Tomovic et al., 2013). Concerning color measurement, the parameter a^* (red color) showed higher values in hams' groups with 3% of added inulin (N3% and C3%), the parameter b^*

TABLE 3 Variable contributions for principal components, based on correlations

Variable	PC1	PC2
Hardness	0.211,040	0.052,271
Cohesiveness	0.212,559	0.000,312
Chewiness	0.126,432	0.199,392
pH	0.032,833	0.264,892
Moisture%	0.187,034	0.088,410
L	0.041,334	0.313,653
*a**	0.013,137	0.038,663
*b**	0.175,632	0.042,406

(yellow) was higher in groups with improved housing, and parameter *L** (lightness) was lower in normal housing. Results also showed that moisture content is affected by diet type (p = .041), where the 6% groups showed higher values. The interaction housing versus added inulin had p values higher than .05, exception made for *a**, meaning that the two variables are not correlated.

PCA (Figure 1) was used to investigate correlations between the tested physicochemical parameters and group conditions. PC1, which represents 49.07% of total data, correlates variables such as hardness, cohesiveness, moisture content, and *b** values, while PC2 representing 24.32% of total data, samples are grouped by pH and *L* values (Figure 1 (right plot) and Table 3). From this output, on PC1 axis, it is possible to observe groups according to inulin content: samples with 0% and 3% have higher scores of hardness, cohesiveness, and chewiness, whereas groups with 6% of added inulin show the lowest scores. With respect to moisture content, groups C3%, N6%, and C6% present the highest values. Along with PC2 axis, separation between groups is not clear; however, it can be extracted that the normal housing groups fed with 3% and 6% of inulin presented higher pH values and lower *L* values (darker hams).

A sensory study on the effect of housing and inulin addition in boar taint reduction of belly meat from boars submitted to the same raising and feeding conditions revealed that boar taint odor and flavor was strongly perceived in meat samples from pigs fed with no addition of inulin and no improved housing conditions (Pereira Pinto, Reis, Barbosa, & Vaz-Velho, 2018). The manufacturing process of cooked ham (as described in 3.2—cooked ham production) is optimized for hams of barrows and gilts with 5/6 months raised under normal conditions and fed with commercial feeds. Modern hams contain less meat and more water, although the final quality mainly depends on the raw material and the processing conditions where several binders have been used, including starch, carrageenan, and soy proteins (Toldrá, Mora, & Flores, 2010). The manufacture of this product made from boars' meat must be evolving in order to improve the functionality of these meats. Physicochemical parameters of cooked hams produced for this experiment could have been quite different if ham processing parameters were adjusted to boars' meat characteristics.

4 | CONCLUSIONS

From this study, it is possible to conclude that raising pigs under different housing and feeding conditions aiming the reduction of boar taint can lead to slight changes in meat features, which is reflected in the physicochemical characteristics of hams: the increase of inulin in feed resulted in more humid, softer, and less cohesive cooked hams. The other factor studied, the housing condition, appeared to have affected by hams in pH value and color (normal housing led to darker and more reddish hams). Although some studies had shown that inulin presence in pig's diet can reduce meat boar taint, some of the current processing parameters used to manufacture hams needs to be adjusted to face the new raw material characteristics and overtake the softness and the ionic acidity found in the studied ham samples. Further studies are being developed in order to assess the use of uncastrated pigs' meat in other processed products, such as bacon or gammon, by optimizing the process parameters.

ACKNOWLEDGMENTS

The project PIGS + CARE (POCI-01-0247-FEDER-017626) is co-financed by the European Regional Development Fund (FEDER) through COMPETE 2020 (Operational Program for Competitiveness and Internationalization). The feeding/housing experiments were conducted by Escola Superior Agrária de Coimbra.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

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REFERENCES

Aluwe, M., Langendries, K. C. M., Bekaert, K. M., Tuyttens, F. A. M., De Brabander, D. L., De Smet, S., & Millet, S. (2013). Effect of surgical castration, immunocastration and chicory-diet on the meat quality and palatability of boars. *Meat Science*, *94*(3), 402–407. https://doi.org/10.1016/j.meatsci.2013.02.015

Backus, G. B. C., van den Broek, E., van der Fels, B., Heres, L., Immink, V. M., Knol, E. F., … van Wagenberg, C. P. A. (2016). Evaluation of producing and marketing entire male pigs. *Njas-Wageningen Journal of Life Sciences*, *76*, 29–41. https://doi.org/10.1016/j.njas.2015.11.002

Bilić-Šobot, D., Čandek-Potokar, M., Kubale, V., & Škorjanc, D. (2014). Boar taint: Interfering factors and possible ways to reduce it. *Agricultura (Slovenia)*, *11*(1/2), 35–48.

Byrne, D. V., Thamsborg, S. M., & Hansen, L. L. (2008). A sensory description of boar taint and the effects of crude and dried chicory roots (*Cichorium intybus* L.) and inulin feeding in male and female pork. *Meat Science*, *79*(2), 252–269. https://doi.org/10.1016/j.meatsci.2007.09.009

De Jonckheere, S., & Nalon, E. (2018). New EU political impetus to end painful piglet castration. Retrieved from https://www.eurogroupforanimals.org/new-eu-political-impetus-to-end-painful-piglet-castration

Dima, C., Neagu, C., Cercel, F., & Alexe, P. (2014). Sensory, physico-chemical and microbiological properties of cooked ham with beta-ciclodextrin loaded with coriander and pimento essential oils. *Journal of Agroalimentary Processes and Technologies*, *20*, 319–329.

Fredriksen, B., Johnsen, A. M. S., & Skuterud, E. (2011). Consumer attitudes towards castration of piglets and alternatives to surgical castration. *Research in Veterinary Science*, *90*(2), 352–357. https://doi.org/10.1016/j.rvsc.2010.06.018

Gunn, M., Allen, P., Bonneau, M., Byrne, D. V., Cinotti, S., & Fredriksen, B. (2004). Welfare aspects of the castration of piglets. Scientific report on the scientific panel for animal health and welfare on a request from the Commission related to welfare aspects of the castration of piglets (Question No., EFSA-Q-2003-091). *European Food Safety Authority Journal*, *91*, 1–18.

Hansen, L. L., Stolzenbach, S., Jensen, J. A., Henckel, P., Hansen-Moller, J., Syriopoulos, K., & Byrne, D. V. (2008). Effect of feeding fermentable fibre-rich feedstuffs on meat quality with emphasis on chemical and sensory boar taint in entire male and female pigs. *Meat Science*, *80*(4), 1165–1173. https://doi.org/10.1016/j.meatsci.2008.05.010

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*, *49*(4), 447–457. https://doi.org/10.1016/s0309-1740(98)00034-5

Kjos, N. P., Overland, M., Fauske, A. K., & Sorum, H. (2010). Feeding chicory inulin to entire male pigs during the last period before slaughter reduces skatole in digesta and backfat. *Livestock Science*, *134*(1–3), 143–145. https://doi.org/10.1016/j.livsci.2010.06.120

Mathur, P. K., ten Napel, J., Bloemhof, S., Heres, L., Knol, E. F., & Mulder, H. A. (2012). A human nose scoring system for boar taint and its relationship with androstenone and skatole. *Meat Science*, *91*(4), 414–422. https://doi.org/10.1016/j.meatsci.2012.02.025

Morlein, D., Schiermann, C., Meier-Dinkel, L., Trautmann, J., Wigger, R., Buttinger, G., & Wicke, M. (2015). Effects of context and repeated exposure on food liking: The case of boar taint. *Food Research International*, *67*, 390–399. https://doi.org/10.1016/j.foodres.2014.11.037

Pereira Pinto, R., Reis, N., Barbosa, C., & Vaz-Velho, M. (2018). Sensory evaluation of meat from entire male pigs raised with different feeding and housing conditions. *Millenium - Journal of Education, Technologies, and Health*, *2*(7), 59–65. https://doi.org/10.29352/mill0207.05.00196

Toldrá, F., Mora, L., & Flores, M. (2010). Cooked Ham. In *Handbook of meat processing* (pp. 299–311). Iowa, USA: Wiley-Blackwell. doi:10.1002/9780813820897

Tomović, V. M., Jokanović, M. R., Petrović, L. S., Tomović, M. S., Tasić, T. A., Ikonić, P. M., … Šošo, M. M. (2013). Sensory, physical and chemical characteristics of cooked ham manufactured from rapidly chilled and earlier deboned *M. semimembranosus*. *Meat Science*, *93*(1), 46–52. https://doi.org/10.1016/j.meatsci.2012.07.015

Wauters, J., Verplanken, K., Vercruysse, V., Ampe, B., Aluwe, M., & Vanhaecke, L. (2017). Sensory evaluation of boar meat products by trained experts. *Food Chemistry*, *237*, 516–524. https://doi.org/10.1016/j.foodchem.2017.05.128

How to cite this article: Pereira Pinto R, Reis N, Barbosa C, Pinheiro R, Vaz-Velho M. 2022. Physicochemical analysis of ham from entire male pigs raised with different feeding and housing conditions. *J Food Process Preserv*, 46:e14233. https://doi.org/10.1111/jfpp.14233