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Actitud dels consumidors, alternatives d'alimentació i efecte del tipus genètic sobre la qualitat de la canal i de la carn en el porc ecològic

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TESI DOCTORAL

Actitud dels consumidors, alternatives d'alimentació i efecte del tipus genètic sobre la qualitat de la canal i de la carn en el porc ecològic.

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Memòria presentada per optar al grau de Doctora per la Universitat de Lleida
Programa de Doctorat en Ciència i Tecnologia Agrària i Alimentària (RD 99/2011)

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INFORME D'IDONEITAT PER PART DELS DIRECTORS DE TESIS

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Que la memòria titulada ***"Actitud dels consumidors, alternatives d'alimentació i efecte del tipus genètic sobre la qualitat de la canal i de la carn en el porc ecològic"***, elaborada per **Immaculada Argemí i Armengol**, ha estat realitzada sota la nostra direcció, s'ajusta al pla de recerca proposat i compleix els requisits exigits per la legislació vigent per optar al grau de Doctora per la Universitat de Lleida.

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Abstract

Organic pig production is gaining **interest** in Europe (almost 1 million pigs stocked), although it accounts for the lowest shares, when compared to other organic livestock farming productions, partly because insufficient **local supply of organic feed**, the high investment in pig barns and the **high premium prices** that **consumers** have to pay. The conversion into organic pig farming in Europe has been fuelled by consumers concern about the consequences of the industrialised agriculture, such as food scandals, the animal welfare and the **environmental impacts** of intensive pig production systems. However, there is a lack of information about the nutritional value of the feedstuffs and the feeding strategies in organic pig, as well as about the variation factors of pork carcasses and their use as indicators of the health and welfare status of organic pig. Organic pig production may be conducted with different **genetic types** (rustic vs. commercial) and the **carcass** lean outcome can differ, however, the contribution of each effect to **meat quality** characteristics (volatile compounds and fatty acids) is not well established.

With this background, the aims of this Ph.D. were: **i)** to evaluate the impact of consumers' culinary skills on their niche pork meat attitudes and purchasing cues in two countries **ii)** to study the technical and economic viability in formulating rations 100% organic for pigs using locally-grown sources **iii)** to analyse the effects of husbandry system (conventional vs. organic) on different carcass variables of finishing pigs (live-weight, back-fat thickness, lean content and income) and the prevalence of condemnation outcomes at the abattoir **iv)** to evaluate the potential role of genetic type and lean grade, on average daily gain, carcass and pork quality (technological characteristics as colour and shear force, and chemical factors as fatty acid composition and volatile compounds) under organic husbandry.

In the **first chapter**, a sample of 974 pork consumers answered on-line survey with questions regarding their purchasing habits, product involvement and intrinsic and extrinsic or credence attributes, an also expressed willingness to pay (WTP) for different product scenarios, appearance and origin of pork loin. On average, WTP premium was 11.8% for marbled pork, 20.0% for outdoor pork and 24.3% for organic. Credence cues of pork claiming health issues (antibiotics and hormone residues) rather than the food-related lifestyle clustering as consumer's culinary skills defined the WTP for niche pork in Spain and Portugal.

In the **second chapter**, a representative sample of organic feed ingredients were selected from feed millers and farmers from Catalonia: cereals (n=22), cereal by-products (n=4) and vegetable protein concentrate (n=25). From these raw materials, diets for pigs were formulated for the different physiological phases, adjusted to the nutritional recommendations (Spanish, FEDNA and French, ITAB). The diets could be performed without soybean and including instead other Mediterranean protein sources when using French standards. The environmental impacts of diets, assessed through life-cycle analysis by means of the database ECOALIM, was higher in piglets and lower in pregnant sows, and much higher when formulating according to Spanish (FEDNA) compared to French (ITAB) Recommendations. The economic valuation of the diets (purchase or self-production) proved that a business model that integrates agriculture and livestock farming would be more profitable.

In the **third chapter**, 6,540 carcasses pigs were examined in Avinyó abattoir, from conventional (n=4,707) and organic farming (n=1,833), to evaluate carcass grading (VCS 2000) variables and photographic scale (MLC 1985) for skin lesions. Organic husbandry increased lumbar back-fat thickness and reduced lean content in summer compared to autumn season. In summer, back-fat thickness (both lumbar and thoracic rib) was greater while lean content was lower in castrates than in gilts. Skins lesions tended to be lower, but liver condemnations were greater in organic than in conventional husbandry.

In the **fourth chapter**, 48 pigs from two genetic types raised from 12 sows (26 pigs were PietrainxLandracexLarge-White and 22 DurocxGasconxDuroc), 32 carcasses (3 pigs/litter) and loin meat from 24 pigs (2 pigs/litter) were sampled. Effects of genetic type and lean grade on average daily gain, carcass and pork quality (technological and fatty acid composition and volatile compounds) were analysed. These genetic types slaughtered at different weights (105 kg and 90 kg, respectively) to achieve similar target carcass fatness. After the slaughter, carcasses were classified according their lean grade (<60% or ≥60% lean). The 75%Duroc showed lower growth performance, carcass weight and dressing out than the 50%Pietrain. The pork loin from Duroc genetic type had lower redness (a*) and it was tougher than their Pietrain counterparts. Lean grade was not associated with earlier differences in growth or carcass performance or technological meat characteristics. In addition, genetic type did not affect fatty acids profile of meat. The leaner carcasses (≥60% lean) had lower C12:0 and C20:3 n-3, lower saturated fatty acids (SFA) and higher monounsaturated fatty acids (MUFA)/SFA ratio content than the fattier carcasses (<60%). Short-chain alcohols were lower in cooked pork from Pietrain and in leaner carcasses compared to the samples from Duroc crossbreds and fattier pigs. A greater amount of volatile compound hexane,2,4,4-trimethyl (an aliphatic hydrocarbon) but lower carbon disulphide (sulphur compound) was detected in pork from leaner carcasses compared to fattier pork. More Duroc crossbreds were associated with greater concentrations of cyclopropane pentyl- (an aromatic hydrocarbon) and lower concentration of methanethiol (volatile sulphur compound). Most of the volatile compounds detected in the present study came from lipid oxidation.

Resum

La producció porcina ecològica està guanyant un **interès creixent** a Europa (aproximadament amb un milió de caps), tot i ésser el percentatge més baix en comparació a altres produccions ramaderes ecològiques, derivat, en part, per la insuficient disponibilitat de **matèries primeres ecològiques locals**, l'elevada inversió a les granges i el **sobre-cost que ha de pagar el consumidor**. El desenvolupament a l’alça de la porcicultura ecològica a Europa es deriva de la preocupació dels **consumidors** per les conseqüències de l'agricultura industrial, els escàndols alimentaris, el **benestar animal** i l’**impacte ambiental** de la producció porcina intensiva. Tanmateix, existeix una manca d’informació sobre el valor nutritiu del ingredients de la dieta i les **estratègies d’alimentació** per porcí ecològic, així com del factors de variació de la qualitat de les seves canals i dels seus indicadors de salut i benestar en aquest model productiu. Així mateix, la producció de porcí ecològic es pot dur a terme amb diferents tipus genètics (rústics vs. comercials) i el rendiment de magre de la **canal** pot variar, tot i que, la contribució de cada efecte a les característiques de **qualitat de la carn** (àcids grassos i compostos volàtils) no estan ben establertes.

Amb aquests antecedents, els objectius d’aquesta tesi eren: **i)** avaluar l’impacte de l’habilitat culinària del consumidor sobre el factors que alteren la voluntat de compra de carn de porc de qualitat diferenciada, en consumidors de dos països **ii)** estudiar la viabilitat tècnica i econòmica en la formulació de racions 100% ecològiques, utilitzant matèries primeres locals **iii)** analitzar l’efecte del sistema de producció (convencional vs. ecològic) en diferents variables de canal de porc (pes, espessor de grassa, contingut magre i ingressos) i la prevalença de decomisos a l'escorxador **iv)** avaluar l’impacte del tipus genètic i percentatge de magre, sobre el creixement diari, la qualitat de la canal i la carn de porc (aspectes tecnològics com el color i la duresa, i aspectes químics com la composició en àcids grassos i compostos volàtils) en producció ecològica.

En el **primer capítol**, una mostra de 974 consumidors de carn van respondre a una enquesta en línia sobre qüestions relacionades amb els seus hàbits de compra, fidelitat en el producte i atributs intrínsecs i extrínsecs o de confiança, i també s'expressava la voluntat de compra per a diferents escenaris d’aparença i origen del llom de porc. De mitjana, l’extra cost assumible per un llom de porc gras va ser del 11,8%, per porc criat a l’exterior el 20,0% i per un porc en producció ecològica el 24,3%. A Espanya i Portugal la voluntat de compra de carn de porc amb un preu superior és més associada amb la preocupació per temes de salut (preocupació sobre

residus de medicaments i hormones) que amb aspectes de l'estil de vida com les habilitats culinàries dels consumidors.

En el **segon capítol**, es va seleccionar una mostra representativa de matèries primeres ecològiques de fàbriques de pinsos i productors de Catalunya: cereals (n=22), subproductes de cereals (n=4) i concentrat de proteïnes vegetals (n=25). A partir d'aquestes matèries primeres, les dietes de porcí es van realitzar per les diferents fases fisiològiques, ajustades a les necessitats nutricionals, sense soja i utilitzant fonts proteiques mediterrànies, en base les recomanacions espanyoles (FEDNA) i franceses (ITAB). En l'avaluació dels impactes ambientals de les dietes, mitjançant la base de dades ECOALIM i a través d'un anàlisi del cicle de vida, va ser major l'impacte de les dietes de garrins i menor la de les truges gestants, i més gran quan es formulava segons FEDNA, respecte a ITAB. En la valoració econòmica de les dietes (compra o autoproducció), seria més rendible un model de negoci que integrés l'agricultura i la ramaderia.

En el **tercer capítol**, es van examinar 6.540 canals a l'escorxador d'Avinyó, procedents de la producció convencional (n=4.707) i ecològica (n=1.833), per avaluar la classificació de la canal (VCS 2000) i lesions a la pell amb escala fotogràfica (MLC, 1985). La producció ecològica va incrementar el gruix de la grassa lumbar i va reduir el contingut de magre a l'estiu respecte a la tardor. A l'estiu, l'espessor de grassa subcutània (lumbar i dorsal) va ser superior, mentre que el percentatge de magre era més baix en mascles castrats que en femelles. Les lesions de la pell tendien a ser menors, però els decomisos de fetge eren superiors en producció ecològica que en convencional.

En el **quart capítol**, 48 porcs procedents de dos tipus genètics diferents de 12 truges (26 porcs PietrainxLandracexLarge-White i 22 porcs DurocxGascóxDuroc), 32 canals (3 porcs/ventrada) i 24 lloms (2 porcs/ventrada) van ser mostrejats. Es van analitzar els efectes del tipus genètic i del contingut de magre sobre el creixement diari, la qualitat de la canal i la carn de porc (qualitat tecnològica, perfil d'àcids grassos i compostos volàtils), quan eren sacrificats a diferents pesos (105 kg i 90 kg, respectivament) per aconseguir un engreixament similar de la canal. Després del sacrifici, les canals es van classificar segons els seu contingut de magre (<60% o ≥ 60% de magre). Els porcs de genètica 75%Duroc van mostrar un menor ritme de creixement, pes de la canal i rendiment, en comparació a la genètica 50%Pietrain. El llom de porc de genètica Duroc presentava menys intensitat de color vermell (a*) i la carn era més dura que els seus homòlegs de Pietrain. El contingut de magre no es va associar a diferències prèvies en el creixement o el rendiment de la canal o característiques tecnològiques de la carn. El tipus genètic no va afectar al perfil d'àcids grassos de la carn. Per contra, les canals magres (≥60% magre) tenien un menor contingut de C12:0 i C20:3 n-3, menor contingut d'àcids grassos saturats (AGS) i un major ratio d'àcids grassos monoinsaturats (AGMI)/AGS que les canals més grasses (<60%). El contingut d'alcohols de cadena curta era menor en la carn cuinada de genètica Pietrain i canals magres que en la genètica Duroc i canals grasses. Es va detectar una major presència del compost volàtil hexà, 2,4,4-trimetil (hidrocarbur alifàtic), però menor de sulfur de carboni (compost de sofre) a les canals més magres, en comparació amb les més grasses. La genètica Duroc es va associar exclusivament amb una proporció més alta de ciclopropà pentil (hidrocarbur aromàtic) i més baixa de metanotiol (compost de sofre). La majoria dels compostos volàtils detectats en el present estudi provenien de l'oxidació lipídica.

Resumen

La producción porcina ecológica está ganando **interés** en Europa (aproximadamente con un millón de cabezas), aun representando un porcentaje muy bajo en comparación a otras producciones ganaderas ecológicas, derivado, en parte, por la insuficiente disponibilidad de **materias primas ecológicas locales**, la elevada inversión en las granjas y el **sobrecoste que debe pagar el consumidor**. El desarrollo al alza de la porcicultura ecológica en Europa se deriva de la preocupación de los **consumidores** por las consecuencias de la agricultura industrial, los escándalos alimentarios, el **bienestar anim**al y el **impacto ambiental** de la producción porcina intensiva. Sin embargo, existe una falta de información sobre el valor nutritivo de los ingredientes de la dieta y las **estrategias de alimentación** para porcino ecológico, así como los factores de variación de la calidad de sus canales y de sus indicadores de salud y bienestar en este modelo productivo. Asimismo, la producción de porcino ecológico se puede llevar a cabo con diferentes tipos genéticos (rústicos vs. comerciales) y el rendimiento de magro de la **canal** puede variar, aunque, la contribución de cada efecto en las características de **calidad de la carne** (compuestos volátiles y ácidos grasos) no está bien establecida.

Con estos antecedentes, los objetivos de esta tesis eran: **i)** evaluar el impacto de la habilidad culinaria del consumidor sobre los factores que alteran la voluntad de compra de carne de cerdo de calidad diferenciada, en consumidores de dos países **ii)** estudiar la viabilidad técnica y económica en la formulación de raciones 100% ecológicas, utilizando materias primas locales **iii)** analizar el efecto del sistema de producción (convencional vs. ecológico) en diferentes variables de canal de cerdo (peso, espesor de grasa, contenido magro e ingresos) y la prevalencia de decomisos en el matadero **iv)** evaluar el impacto del tipo genético y porcentaje de magro, sobre el crecimiento diario, la calidad de la canal y la carne de cerdo (aspectos tecnológicos como el color y la dureza, y aspectos químicos como la composición en ácidos grasos y compuestos volátiles) en producción ecológica.

En el **primer capítulo**, una muestra de 974 consumidores de carne respondió a una encuesta en línea sobre cuestiones relacionadas con sus hábitos de compra, fidelidad en el producto y atributos intrínsecos y extrínsecos o de confianza, y también se expresaba la voluntad de compra para diferentes escenarios de apariencia y origen del lomo de cerdo. De media, el sobrecoste asumible por un lomo de cerdo graso fue del 11,8%, por cerdo criado en el exterior el 20,0% y por un cerdo en producción ecológica el 24,3%. En España y Portugal la voluntad de compra de carne de cerdo con un precio superior se asocia más a la preocupación por temas de salud (preocupación

sobre residuos de medicamentos y hormonas) que con aspectos del estilo de vida como las habilidades culinarias de los consumidores.

En el **segundo capítulo**, se seleccionó una muestra representativa de materias primas ecológicas de fábricas de piensos y productores de Cataluña: cereales (n=22), subproductos de cereales (n=4) y concentrados de proteína vegetal (n= 5). A partir de estas materias primas se formularon dietas de porcino para las diferentes fases fisiológicas, ajustadas a las necesidades nutricionales en base las recomendaciones españolas (FEDNA) y francesas (ITAB). Se obtuvieron dietas para porcino ecológico sin soja y utilizando fuentes proteicas mediterráneas al emplear las recomendaciones nutricionales francesas (ITAB). Los impactos ambientales de las dietas evaluados mediante la base de datos ECOALIM y a través de un análisis del ciclo de vida, fueron mayores en las dietas de lechones y menores en cerdas gestantes, y mayor cuando se formulaba según FEDNA, respecto a ITAB. En la valoración económica de las dietas (compra o autoproducción), se comprobó que sería más rentable un modelo de negocio que integrara la agricultura y la ganadería.

En el **tercer capítulo**, se examinaron 6.540 canales en el matadero de Avinyó, procedentes de la producción convencional (n=4.707) y ecológica (n=1.833), para evaluar las variables de clasificación de la canal (VCS 2000) y lesiones en la piel con escala fotográfica (MLC, 1985). La producción ecológica incrementó el espesor de la grasa lumbar y redujo el contenido de magro en verano respecto en otoño. En verano, el espesor de grasa subcutánea (lumbar y dorsal) fue superior, mientras que el porcentaje de magro era más bajo en machos castrados que en hembras. Las lesiones de la piel tendían a ser menores, pero los decomisos de hígado eran superiores en producción ecológica que en convencional.

En el **cuarto capítulo**, 48 cerdos procedentes de dos tipos genéticos diferentes de 12 cerdas (26 cerdos PietrainxLandracexLarge-White y 22 cerdos DurocxGasconxDuroc), 32 canales (3 cerdos/camada) y 24 lomos (2 cerdos/camada) fueron muestreados. Se analizaron los efectos del tipo genético y del contenido de magro sobre el crecimiento diario, la calidad de la canal y la carne de cerdo (calidad tecnológica, perfil de ácidos grasos y compuestos volátiles) cuando eran sacrificados a diferentes pesos (105 kg y 90 kg, respectivamente) para conseguir un estado de engrasamiento de la canal similar. Tras el sacrificio, las canales se clasificaron según su contenido de magro (<60% o ≥ 60% de magro). Los cerdos de genética Duroc mostraron un menor ritmo de crecimiento, peso de la canal y rendimiento, en comparación a la genética Pietrain. El lomo de cerdo de genética Duroc presentaba menos intensidad de color rojo (a*) y la carne era más dura que sus homólogos de Pietrain. El contenido de magro no se asoció a diferencias previas en el crecimiento o el rendimiento de la canal o características tecnológicas de la carne. El tipo genético no afectó al perfil de ácidos grasos de la carne. Por el contrario, las canales magras (≥60% magro) tenían un menor contenido de C12:0 y C20:3 n-3, menor contenido de ácidos grasos saturados (AGS) y una mayor ratio de ácidos grasos monoinsaturados (AGMI)/AGS que las canales más grasas (<60%). El contenido de alcoholes de cadena corta era menor en la carne cocinada de genética Pietrain y canales magras que en la genética Duroc y canales grasas. Se detectó una mayor presencia del compuesto volátil hexano, 2,4,4-trimetil (hidrocarburo alifático), pero menor de sulfuro de carbono (compuesto de azufre) en las canales más magras, en comparación con las más grasas. La genética Duroc se asoció exclusivamente con una proporción más alta de ciclopropano pentil (hidrocarburo aromático) y más baja de metanotiol (compuesto de azufre). La mayoría de los compuestos volátiles detectados en el presente estudio procedían de la oxidación lipídica.

Llista de publicacions

Aquesta tesi ha donat lloc a les següents publicacions:

Article I

I. Argemí-Armengol, D. Villalba, G. Ripoll, A. Teixeira, J. Álvarez-Rodríguez. 2019. *Credence cues of pork are more important than consumers' food-related lifestyles to boost their purchasing intention*.

Estat: publicat a Meat Science (online), volum 154, agost 2019, 11-21.
https://doi.org/10.1016/j.meatsci.2019.04.001

Article II

I. Argemí-Armengol, D. Villalba, M. Tor, J. Álvarez-Rodríguez. 2018. Estrategias de alimentación, evaluación del impacto ambiental y valoración económica de dietas de porcino ecológico.

Estat: en revisió a Archivos de Zootecnia, maig 2019.

Article III

I. Argemí-Armengol, D. Villalba, G. Ripoll, J. Álvarez-Rodríguez. 2019. *Genetic but not lean grade impact on growth, carcass traits and pork quality under organic husbandry.*

Estat: publicat a Livestock Science (online), volum 227, setembre 2019, 75-81.
https://doi.org/10.1016/j.livsci.2019.07.001

Article IV

I. Argemí-Armengol, D. Villalba, M. Tor, C. Pérez-Santaescolástica, L. Purriños, J.M. Lorenzo, J. Álvarez-Rodríguez. 2019. *The extent to which genetics and lean grade affect fatty acid profiles and volatile compounds in organic pork.*

Estat: publicat a PeerJ (online), 17 juliol, PeerJ 7:e7322
https://doi.org/10.7717/peerj.7322

Llista de comunicacions i treballs en revistes tècniques i de divulgació

Revistes tècniques i de divulgació

- I. Argemí-Armengol, D. Villalba, J. Álvarez-Rodríguez. 2018. Nuevas estratègies de alimentación en el porcino ecológico. Suis, ISSN 1699-7867, 151: 12-20.

- I. Argemí-Armengol, D. Villalba, J. Álvarez-Rodríguez. 2019. Factors de variació en la producció de canals de porcí ecològic i convencional. Quaderns Agraris, ISSN 0213-0319. *En revisió, febrer 2019.*

- I. Argemí-Armengol, C. García-Romero. 2016. Cría del porcino blanco ecológico en España, Ganadería, ISSN 1695-1123, 101: 49-53.

Comunicacions a congressos internacionals:

- Argemí-Armengol I; Villalba D; Ripoll G; Latorre M.A; Álvarez-Rodríguez J. Genetic but not lean grade impact on growth, carcass traits and pork quality under organic husbandry. 64th International Congress of Meat Science and Technology (ICoMST), Melbourne, Australia, 12th-17th August 2018. 2 pp.

- I. Argemí-Armengol, D. Villalba, G. Ripoll, A. Teixeira, M. A. Latorre, J. Álvarez-Rodríguez. Are consumers' culinary skills related to their purchasing attitudes towards pork?. ASAS-CSAS Annual Meeting and Trade Show, Austin, Texas, USA, 8th-11th July 2019.

- J. Álvarez-Rodríguez, J., Argemí-Armengol, I., Tor, M., Teixeira, A. y Villalba, D. Uso de árboles de decisión para analitzar la voluntad de compra de carne de cerdo diferenciado. I Congreso Iberoamericano de Marcas de Calidad de Carne y de Productos Cárnicos (MARCARNE-CYTED). Bragança, Portugal, 24-25 de octubre de 2019.

Comunicacions i pòsters a congressos nacionals:

- Argemí-Armengol, I., García-Romero, C. Contribución al manejo zootécnico y sanitario de la cría ecológica porcina en Cataluña. XII Congreso SEAE, 21-23 de septiembre de 2016, Lugo.

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Preàmbul i agraïments

Redactar aquesta part és el darrer pas en el tancament de la tesi, malgrat ocupi la primera secció. Sense revisions ni correccions. Però, sobretot, serveix per a recordar tota aquella gent, amb la que he compartit el viatge (de més de tres anys), molts amb un interès comú, i altres, pel seu suport.

La realització d'aquesta tesi doctoral no hagués estat possible sense l'ajut, de forma altruista, de molts professionals de la Catalunya rural, tant del sector primari, petits agricultors ecològics de cultius extensius, fàbrica de pinsos ecològics de la "Cooperativa de Salelles" (Bages) i la granja de porcí ecològic "dPagès" (Solsona; Marta i Martí), com veterinaris i personal de l'Escorxador Frigorífic d'Avinyó, S.A.

En primer lloc, agrair, sincerament, als directors i tutor de tesi, Dr. Javier Álvarez-Rodríguez i Dr. Daniel Villalba Mata (afectuosament, Javi i Dani), per haver acceptat dirigir-me aquesta tesi, on la meva situació personal, no us ho va posar gens fàcil. No obstant, a qualsevol hora, us he pogut consultar i trobar. Admiro com exerciu la docència i la recerca, amb vocació i compromís. A tots dos, moltes gràcies!

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En tercer lloc, i a nivell personal i familiar, vull recordar a qui un dia em va fer veure que tot és possible, al pare, Josep. Agrair el suport incondicional de la mare, Lourdes: "sense tu, no ho hagués fet". A qui m'ha acompanyat, i patit, en aquest viatge, al Jordi. Al germanet, Jordi, sempre positiu i qui sempre diu: "s'ha provar de fer". I dedicar-ho a elles, les meves filles, Laia i Aina: "perquè lluitant, s'hi pot arribar".

Tenim a penes
el que tenim i prou: l'espai d'història
concreta que ens pertoca, i un minúscul
territori per viure-la...
Cridem qui som i que tothom ho escolti.
I en acabat, que cadascú es vesteixi
com bonament li plagui, i via fora!,
***que tot està per fer i tot és possible**.*

Miquel Martí i Pol

Índex

1. Introducció

1.1. Antecedents

A la Unió Europea l'agricultura ecològica és regulada pel Reglament (CE) 834/2007, sobre producció i etiquetatge dels productes ecològics, i el Reglament (CE) 889/2008 que estableix les disposicions d'aplicació.

La producció porcina ecològica està guanyant un interès creixent a Europa (998.828 caps bestiar al 2017; increment de 47,6% en el període 2008-2017), encapçalada per Alemanya, amb 155.800 porcs ecològics (Willer et *al.*, 2019). Catalunya, amb 2.857 caps de porcí ecològic, lidera la producció a Espanya (9.968 caps, amb un increment del 77%, en el període 2014-2017) (MAPAMA, 2015; MAPA, 2018). El tipus d'explotació a Catalunya és familiar, similar a la tendència observada a Europa, per Prunier et *al*. (2013) en porcs i Blanco-Penedo et *al*. (2019) en boví de llet. El percentatge de producció porcina ecològica a Europa és baix, del 0,6% respecte el total de la cabana porcina, on els tres principals països són Dinamarca (2,9%), Àustria (2,6%) i França (2,1%) (Eurostat, 2019), principalment per la insuficiència de pinsos ecològics locals, la dificultat en la traçabilitat d'aliments importats certificats i l'elevat preu que el consumidor ha de pagar per la carn (Willer et *al.*, 2019). S'espera que la demanda global d'aliments d'origen animal s'incrementi un 50% al 2030, respecte l'any 2000, a causa del creixement de la població mundial, de l'augment de la renda i de la urbanització, principalment a les regions en desenvolupament (Alexandratos i Bruinsma, 2012).

Es calcula que el mercat ecològic europeu va arribar als 37.000 milions d'euros el 2017 i continua creixent (11%). El mercat més gran de productes ecològics és a Alemanya, amb una facturació de 10.040 milions d'euros (2017; 6.600 milions el 2011), seguit de França (7.921 milions) i Itàlia (3.137 milions d'euros). La major quota de mercat dels productes ecològics del mercat total europeu és a Dinamarca (13,3% del mercat total) i a Suècia amb el 9%. El consum per càpita més alt es troba a Suïssa amb 288 €/càpita. (FibL, 2019). La quota de mercat de la carn i productes carnis, segons dades del FiBL-AMI (Willer et *al.*, 2019), representa entre el 0,2%-5,6%, respecte el total del mercat d'ecològic; on destaca Suïssa amb el 5,6%, i a Espanya representa el 1,2%.

Majoritàriament, aquest desenvolupament en la producció ecològica moderna es deu a la preocupació pública per les conseqüències de l'agricultura industrialitzada o producció intensiva, en detriment del benestar animal, pol·lució en els aliments i la destrucció del paisatge i la biodiversitat (Jakobsen, 2018); en combinació amb polítiques europees pro-ecològiques (PDR 2014-2020, Reglament (CE) 1305/2013). En estudis comparatius sobre diferents aspectes de sostenibilitat entre la producció ramadera convencional *vs.* ecològica, s'ha determinat que el sistema convencional té uns ingressos més constants i una major producció per animal i unitat de temps, un índex de conversió baix, un menor ús de la terra i un potencial d'acidificació i eutrofització menor per unitat de producte. Per contra, el sistema ecològic té uns ingressos més elevats per animal i/o treballador, un menor impacte sobre la biodiversitat, i un menor potencial d'eutrofització i acidificació per unitat de terra; tot i que es necessiten més dades per concloure les diferències en ambdós sistemes (van Wagenberg et *al.*, 2017).

Rivera-Ferre (2006), en un estudi de granges ecològiques a Holanda, va determinar que les explotacions mixtes, producció porcina i agricultura, són les més sostenibles ambientalment quan es consideren aspectes com l'ús o aprofitament de N. Tot i això, la normativa europea accepta explotacions ramaderes sense terra amb altes densitats ramaderes, permetent una producció amb un possible dèficit de sostenibilitat.

Els estàndards de la Federació Internacional de Moviments d'Agricultura Ecològica (IFOAM) recomanen l'ús de races tradicionals, adaptades a l'ambient local, importants, tant per la conservació de la biodiversitat (Treasure Project H2020), com per l'obtenció de productes de qualitat diferenciada (Kušec, 2015). No obstant, les principals races utilitzades en porcí ecològic a Europa són les comercials, creuaments Large White x Landrace (♀) amb Pietrain o Large White o Duroc (♂) (Früh *et al.*, 2011). Minoritàriament s'utilitzen les races rústiques Saddleback i Tamworth a Anglaterra o la Mora Romagnola i Cinta Senese a Itàlia, però donen canals de baixa qualitat, segons classificació SEUROP, amb excés de grassa (Mathew, 2018). Les transaccions comercials convencionals actuals premien principalment la producció de carn magre (S, ≥60% magre), establint una relació antagònica entre el sistema de pagament i els diversos trets qualitatius, com el gust, aromes, tendresa i suculència, i descoratgen la producció de carn de porc amb alta qualitat alimentària (Bonneau i Lebret, 2010; Sundrum *et al.*, 2011). D'altra banda, el contingut de greix intramuscular és un tret comercialment valorat, ja que en millora la qualitat de la carn, tendresa, suavitat i gust (Wood *et al*., 2004; Font -i-Furnols *et al.*, 2012).

1.2. Objectius generals, específics i hipòtesis

L'objectiu general d'aquest estudi de doctorat era obtenir uns coneixements en porcicultura ecològica que puguin contribuir en el desenvolupament i millora d'aquest sector en el context de Catalunya i la resta de l'Estat Espanyol, tenint en compte les potencialitats del mercat (demanda del consumidor, productes de qualitat i saludables), les necessitats del ramader (estratègies alimentàries pel bestiar i autosuficiència) i la sostenibilitat a mitjà i llarg termini (ambiental i econòmica). Per fer-ho, els objectius específics a investigar van ser:

- Caracteritzar el **consumidor potencial** de la carn de porc ecològic.

- Estudiar la **viabilitat tècnica i econòmica** de formular dietes per porcí ecològic, amb matèria ecològica originària de Catalunya o zona pròxima.
- Analitzar els **efectes del model productiu** (ecològic vs. convencional) sobre diferents **variables comercials** de les canals de porc i **prevalença de lesions**.
- Avaluar els **efectes del tipus genètic** (rústic vs. comercial) sobre la **qualitat tecnològica, nutricional** i **organolèptica** en carn de porc ecològica.

Basat en aquests objectius, les hipòtesis que es van formular varen ser:

Hipòtesis 1: que l'habilitat culinària i l'origen geogràfic afecten la predisposició de pagar més per una carn de porc diferenciada.

Hipòtesis 2: que es podrien formular dietes per porcí ecològic prescindint de llavor de soja o el seu tortó (importat), mitjançant matèries primeres locals, en les cinc fases fisiològiques.

Hipòtesis 3: que existirien diferències a nivell quantitatiu i qualitatiu en les variables, de les canals de porc convencional en comparació a les provinents de porc ecològic.

Hipòtesis 4: la carn de porc ecològic (sacrificat a baix pes) de genètica grassa (75% gens Duroc) seria més vermella, més tendra i perdria menys aigua; i el perfil de la seva grassa intramuscular seria més mono-insaturat, en comparació amb una genètica més magre (50% gens Pietrain), sense que es veiés augmentat el seu contingut en àcids grassos saturats. A la vegada, això podria afectar als compostos volàtils produïts durant el cuinat de la carn.

La base d'aquesta tesi doctoral està constituït per quatre capítols, que donen suport a l'objectiu general, objectius específics i hipòtesis presentades anteriorment.

En el **capítol 1** de la tesi (**article I**), es va avaluar l'impacte de les habilitats culinàries dels consumidors de carn de porc (mitjançant enquesta on-line), sobre les seves actituds de compra i voluntat de pagar per productes diferenciats, en diferents contextos sociodemogràfics de Catalunya, Aragó i el Nord de Portugal.

En el **capítol 2** (**article II**), es va seleccionar i analitzar químicament una mostra representativa de matèries primeres ecològiques (cereals, concentrats de proteïna vegetal i ingredients fibrosos) de Catalunya i zona pròxima, i es va predir el valor energètic de cada aliment. En formular, es va minimitzar el número de matèries primes (2-4 tipus), prescindint inicialment de la soja i derivats, per poder aplicar-se fàcilment a la granja. En cada una de les dietes es va avaluar el seu impacte ambiental i es va realitzar un estudi econòmic per comparar entre el model d'autoproducció a granja i la compra a fàbrica de pinsos.

La qualitat de la canal, segons el sistema de producció (convencional vs. ecològic), es va estudiar al **capítol 3**, on es van analitzar a un escorxador comercial diferents canals, aleatòriament, durant diferents mesos de l'any, per avaluar els efectes del model productiu, l'època de l'any, el sexe i el tipus genètic, sobre diferents variables comercials de les canals de porc (pes, grassa dorsal i lumbar, magre estimat i ingressos). A més, es va avaluar la prevalença de lesions de pell i les proporcions d'òrgans decomissats en els diferents models productius.

El **capítol 4** (**articles III** i **IV**), a partir d'un experiment a granja de porcs ecològics i selecció de dos lots de genotips híbrids diferents, es va avaluar l'efecte del contingut de magre i el tipus genètic sobre el creixement diari, la qualitat de la canal (rendiment canal, espessor grassa), i la qualitat tecnològica de la carn (pH, color, tendresa i pèrdua d'aigua per descongelació i cocció); i la qualitat nutricional i sensorial, mitjançant el perfil d'àcids grassos de la carn crua i els compostos volàtils en carn madurada 8 dies i cuita.

2. Capítol I. Consumidors (Article I)

Credence cues of pork are more important than consumers' culinary skills to boost their purchasing intention

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Abstract

The role of consumers' culinary skills on purchasing cues of pork, with emphasis on niche demands (outdoor husbandry and/or certified organic), was assessed in cross-country regions of Spain (Catalonia and Aragon) and Portugal (North). A sample of 974 respondents answered an on-line survey with questions regarding consumer purchasing habits, product involvement and intrinsic and credence attributes. They also chose between two contrasting boneless pork loins and express willingness to pay (WTP) for different product scenarios with different pig farm facilities and for organic pork standards. Two optimal segments were identified based on food-related habits: 'uninvolved' and 'innovative cook lovers', both similarly balanced across socio-demographics, score for credence attributes or consumer involvement dimensions. Overall mean WTP premium across countries was 11.8% for marbled pork, 20.0% for outdoor pork and 24.3% for organic logo stamp. Credence cues of pork claiming health issues (absence of antibiotics and hormone residues) rather than consumers' culinary skills defined the WTP for niche pork in these regions.

Key words: Consumer decision-making; convenience; involvement; pig meat; Portugal; Spain.

1. Introduction

Niche pork is characterized by certain attributes which are not found in commodity pork. Organic pork may be considered a type of niche pork, with recognized standards in terms of animal husbandry and meat processing. In general, consumers' attitudes toward organic pork are based on beliefs associated with potentially less risk to their health, improved taste, environmental friendliness and improved welfare of the pigs (Abrams, Meyers, & Irani, 2010). However, it is also a widespread opinion that the attitudes that consumers express may not be strongly related to their purchase behavior (Grunert, 2006), as mirrored by the low market shares of, for example, organic meat. As an example, the organic swine sector is at present negligible in Spain and Portugal, as it represents only 0.04% and 0.03% out of total swine stocks. However, there are other European countries whose organic swine stocks accounts for approximately 2% out of total swine production (Austria, Denmark, Sweden and France) (Eurostat, 2018a). Niche production (and specifically certified organic meat) may experience advancements in the future, and it may be expected that certain customer segments would be willing to pay for a premium for this meat type. However, this issue has not been addressed thoroughly in Southern-European countries, where niche pork husbandry (apart from the well-known free-range Iberian pig, which is not raised by default under organic standards) is not so well developed.

Quality perception of meat has been largely based on intrinsic cues like the colour of the meat, the visible fat and the cut. On the other hand, only a few extrinsic cues have been easily available because fresh meat is a largely unbranded product. Some of these ‘adjectives’ or credence attributes are animal welfare, product safety, health claims and environment (D’Souza, Cleary, & Hewitt, 2017). Credence attributes play an important role in consumer choice, with these differing across countries. For example, the relative importance of production characteristics is bigger in Germany than in Poland, and they are related mostly to health and safety aspects, rather than to animal welfare (except for sow mobility claim in Germany) or environmental impact (Grunert, Sonntag, Glanz-Chanos, & Forum, 2018).

Consumers’ food-related lifestyles may affect purchasing cues of meat. Convenience-oriented consumers dislike food shopping, display less enjoyment in meal preparation, have fewer cooking skills, are accustomed to eating alone, and breaking down meals, whereas consumers that produce (or prosumers) receive utility in cooking (Casini et al., 2019). These consumer segments expressed differences in WTP for saving time in cooking, but little research is carried out to assess the effects of consumer culinary skills on purchasing cues of niche pork meat in Southern-European areas. This study aimed to evaluate the impact of culinary skills on their niche pork meat attitudes and purchasing cues in two country regions of North-Eastern Spain (Catalonia and Aragon) and the Northern region in Portugal (North). It was hypothesized that consumers’ culinary skills would shift their attitudes and purchase WTP for niche pork in these contrasting cross-country situations.

2. Material and methods

2.1. Research design and recruitment

Survey data were collected through an on-line questionnaire with consumers in two country regions of North-Eastern Spain (Catalonia and Aragon) and the Northern region in Portugal (North) during April-May 2018. The questionnaire was developed in three languages: Spanish, Portuguese and Catalan in order to meet a wide variety of demographic profiles in the sample, and Whatsapp distributed as well as e-mail linked through snowball sampling. Total sample size amounted to 987 respondents. A minimum level of product experience is needed to ensure that effects of involvement are accurately measured (Verbeke, & Vackier, 2004). Hence, it can reasonably be assumed that a person with very little experience towards fresh meat is also very little involved. To exclude this potential bias, all respondents claiming to neither eat fresh or processed pork meat nor were responsible for meat purchasing within their household (13 out 987, 1.3%) were removed from the initial sample, yielding a valid sample for the subsequent analyses of 974 respondents (Catalonia, n=442; Aragon and some other respondents from the rest of Northern Spanish area, n=342; and Northern Portugal, n=190), all of whom frequently consumed pork.

2.2. Questionnaire

The food-related lifestyle model (Grunert, 2006) was used as a conceptual framework in this study, as it has been considered as the intermediate level of a hierarchical cognitive system, and it distinguishes five elements: ways of shopping, cooking methods, consumption situations, quality aspects, and purchase motives. As involvement with the product category is likely to correlate with consumer experience (Sørensen, Grunert, & Nielsen, 1996), this study dealt with this state of mind that motivates consumers to identify with product offerings, their consumption patterns and consumption behavior.

Each respondent was asked questions regarding consumer purchasing habits (15 questions, dichotomic true/false statements) (Table 1) to collect information about cooking methods and consumption situation (Hoek, Luning, Stafleu, & De Graaf, 2004), and ways of shopping for pork (enjoyment of shopping, attitudes to advertising, importance of label information, importance of price, preference for specialty shops versus supermarkets and shopping list) (Bernués, Ripoll, & Panea, 2012). These previous questions were used to segment the consumers according to their culinary skills. Certain socio-demographic characteristics, such as age of respondent, place of residence, household characteristics, education level, and gender, as well as frequency of meat consumption were also collected (Table 2). Additional questions concerned consumer involvement with pork (7 questions, on a 7-point scale, with 1 indicating totally disagree and 7 indicating totally agreement) (Table 3) (Borgogno, Favotto, Corazzin, Cardello, & Piasentier, 2015).

The level of importance that consumers ascribe to different product cues that influence purchasing motives was assessed using a 5-point Likert scale, in which 1 = none or very little importance, 2 = little importance, 3 = average importance 4 = quite a lot of importance and 5 = great importance. The specific cues (20 questions) were selected from the literature, considering both intrinsic and extrinsic cues (Sepúlveda, Maza, & Mantecón, 2008; Chamorro, Miranda, Rubio, & Valero, 2012). Appearance (colour, drip loss) and fat content expectations were the intrinsic traits that were chosen, all of which are directly related to product appearance. The importance of other label factors that affect the purchasing cues were also ranked (label information, safety, traceability, known seller, quality certification, type of packaging, cooking ease, known brand, nutritional value, product, breed, price, type of cut, best before date, place of origin, slaughter method, slaughter date, cut weight).

The ranking of facts (as having visited a pig farm earlier) and beliefs (credence attributes such as animal welfare, animal husbandry, quality certification, breed/origin and certain health claims) related with the production process was assessed with 7 discrete response questions (yes/no/do not know), as follows: (i) Did you ever visit a pig farm? (ii) Do you think that pork contains hormone residues? (iii) Do you think that pork contains antibiotics residues? (iv) Do you think that pork contains a high level of fat? (v) Do you think that pork contains a high level of cholesterol? (vi) Do you think that pig husbandry guarantees animal welfare? (vii) Do you think that pig husbandry impairs the environment? (Table 4).

Choice-based pairwise tasks with graphical product simulations were found to be particularly suitable to measure preferences for products with strong visual components, such as visual fat content, which cannot accurately be represented by verbal scale items (Mueller, Lockshin, & Louviere, 2010). The consumers were asked to choice their purchase intention between two types of boneless two loins with contrasting fat contents (including subcutaneous and intermuscular fat) (Figure 1).

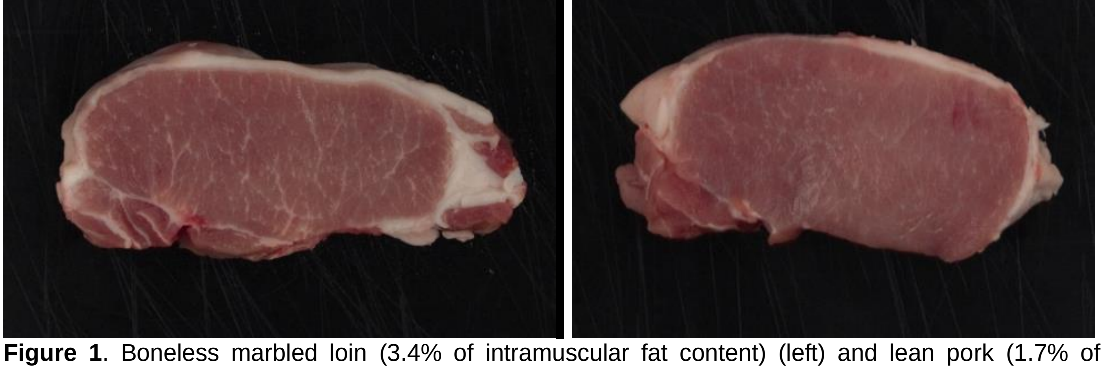

Figure 1. Boneless marbled loin (3.4% of intramuscular fat content) (left) and lean pork (1.7% of intramuscular fat content) (right).

In the contingent valuation approach, consumers state their WTP to procure the good. The use of this method is especially suitable to capture consumers' WTP for a specific product or characteristic in the absence of actual market data. As the methodological approach to calculate the respondents' WTP for specific meat is conditioned to the question format (Angulo, Gil, & Tamburo, 2005), the respondents were requested to note the maximum amount of money they were willing to pay for marbled boneless pork loin (Figure 1, left). The consumers had seven choices, with a price bid from 5 to 8 €/kg at 0.5 €/kg intervals in Spain, and a mark on 5.5 €/kg, that is the reference mean price for retail sliced boneless pork loin (MAPA, 2018b), and from 3.0 to 6 €/kg at 0.5 €/kg intervals in Portugal, and a mark on 3.5 €/kg, that is the mean price for retail sliced boneless pork loin in major supermarkets of the northern area (no reference Portuguese prices were available). Subsequently, they were asked for their WTP with the same procedure for pork coming from different finishing pig farm facilities (without any additional indication of quality label) in the Iberian Peninsula framework (Figure 2) as well as for organic pork, by showing them the declaration of the official European Union organic standards logo.

Figure 2. Pigs housed indoors with standard space allowance and concrete-slatted pens (left) and pigs housed with high space allowance and outdoor run (right).

2.3. Statistical analyses

Data analyses were carried out with JMP (13.0.01 version; SAS Institute Inc., Cary, NC). Consumer segmentation of pork meat based on culinary skills (food-related lifestyles dimensions) was accomplished through hierarchical clustering. Optimal number of clusters was identified at highest CCC (Cubic Clustering Criterion). Differences between clusters concerning socio-demographic variables and importance of extrinsic attributes were assessed with contingency tables with Pearson tests. Non-parametric Wilcoxon tests with pair-wise comparisons were conducted to cross the consumer clusters based on food-related lifestyles with their involvement scores, purchasing drivers and WTP for different pork loins. Partition tree predictive modelling was used as a data mining technique to predict willingness to pay for different picture scenarios (marbled loin, pigs housed indoors, pigs with outdoor run and organic logo) as a function of potential predictor variables (socio-demographics, lifestyles, credence attributes) using recursive partitioning. The partition algorithm searched all possible splits of predictors to best predict the response (WTP). These splits (or partitions) of the data were done recursively to form a tree of decision rules. The variables were selected according to G2 (likelihood-ratio chi-square) test of association (lower values indicate a better fit) and logworth (-log(p-value)) value. The Logworth values are the logs of adjusted p-values for the chi-square test of independence. Minimum size split in partition trees was set at 3% of the total sample size.

3. Results and discussion

3.1. Consumers that do not purchase meat (but indeed consumed meat)

Consumers that did not purchase meat nor did not consume pork were excluded from the analysis. However, a small proportion of consumers (n=50, 5.1%) that did not purchase meat were indeed pork consumers and were included in the study. This consumer type was mainly located in Catalonia (60%, compared to 18% in Aragon and 22% in Northern Portugal), they were gender-balanced (56% females), young adults (54% ranging 25-39 years), without children (60%), with higher education and living in an urban environment (>10,000 inhabitants) (64%). Thirty-six percent out of this category did not consume fresh pork, while only four percent did not consume any processed pork products.

3.2. Socio-demographics and involvement with pork in consumer clusters based on culinary skills

Consumer segmentation based on culinary skills is shown in Table 1. Two optimal clusters were identified based on food-related habits. Cluster 1 was named as ‘uninvolved’ because its components liked cooking to a lesser extent (P<0.001), normally ate out on working days (P<0.001), considered traditional recipes best (P=0.008), spent less time cooking (P<0.001), did not like changes in their meals (P<0.001), considered less important meal planning for family nutrition (P<0.001), enjoyed to a lesser extent shopping for food (P<0.001), payed less attention to advertisements (P=0.03) and food label information (P<0.001) and considered price of pork less important (P<0.001) than Cluster 2, that was named as ‘innovative cook lovers’, that liked cooking and making changes in their meals. Interestingly, the two clusters did not differ widely in their social consumption situation and ways of shopping, as the proportion of consumers enjoying eating out with family and friends, following a shopping list, preferring specialty shops or butchers rather than supermarkets, or over the counter purchases rather than packaged did not differ.

Table 1. Consumer segmentation based on food-related lifestyles

	Cluster 1 'uninvolved' (%)	Cluster 2 'innovative cook lovers' (%)	Pearson P-value
n	462	512	-
Cooking methods			
I like cooking	48.5	94.1	<0.001
Traditional recipes are best	78.8	71.3	0.008
I spend a lot of time cooking	10.4	32.0	<0.001
I like changes in my meals	28.8	92.8	<0.001
Meal planning is important for family nutrition	88.3	93.4	0.006
Consumption situation			
I normally eat out on working days	42.4	21.3	<0.001
I like going to restaurants with friends and family	87.2	87.3	0.97
I only eat pork meat at restaurants	13.2	15.4	0.32
Ways of shopping			
Do you enjoy shopping for food?	70.8	80.7	<0.001
Do you pay attention to advertisements?	47.2	54.3	0.03
Is food label information important for you?	87.2	95.5	<0.001
Is price of pork important for you?	61.3	87.5	<0.001
Do you prefer specialist shops/butchers rather than supermarkets to buy pork?	72.9	68.4	0.12
Do you follow a shopping list?	67.5	71.9	0.14
Do you think that is it better to purchase pork on retail desk rather than packaged?	74.7	72.3	0.40

In this study, pork purchased over the counter was preferred by consumers, although purchasing behaviour in Spain is evolving to supermarkets/hypermarkets in all meats, but especially in pork (55% of total market share) (MAPAMA, 2018a). The 'uninvolved' group was less concerned about advertisements, label information or price of pork than 'innovative cook lovers'. In another Spanish survey, the consumer segment that rated less importantly price and offers preferred purchasing organic food in specialist shops rather than in supermarkets (MAPAMA, 2017). In the present study, the difference between consumer segments regarding purchasing place did not reach statistical significance.

The socio-demographic characteristics according to the food-related lifestyle clustering are shown in Table 2. There was no significant difference across clusters (P>0.05) for country regions, ages, household characteristics, education, living environment and pork consumption habits. Cluster 1 ('uninvolved') tended to include less women compared to cluster 2 ('innovative cook lovers') (P=0.07).

Table 2. Socio-demographics according to the food-related lifestyle clustering.

		Cluster 1 'uninvolved' (%)	Cluster 2 'innovative cook lovers' (%)	Pearson P-value
n		462	512	-
Geographical area	Spain-Catalonia	47.4	43.6	0.28
	Spain-Aragon	35.1	35.2	
	Portugal-North	17.5	21.3	
Gender	Female	55.2	60.9	0.07
Age	25-39 years	37.5	41.0	0.25
	40-55 years	40.3	36.9	0.28
	>55 years	14.5	13.5	0.64
Household characteristics	Singles	12.1	10.4	0.71
	No children	56.9	54.1	0.38
Education	Higher	81.4	77.3	0.12
Living environment	Urban (>10,000 inhabitants)	60.8	65.2	0.34
	Medium sized (2,000-10,000 inhabitants)	21.4	19.7	
	Rural (<2,000 inhabitants)	17.8	15.0	
Most purchased pork joint	Boneless loin	54.6	55.1	0.80
	Spareribs and rib chops	15.8	14.8	
	Tenderloin and lean mince	19.5	21.3	
Frequency of fresh pork consumption	3-4 times/week	17.3	16.6	0.77
	1-2 times/week	50.4	53.3	
	Less than once/week	29.4	27.2	
Frequency of processed pork consumption (dry-cured pork products and cooked ham)	3-4 times/week	34.9	33.6	0.44
	1-2 times/week	31.8	31.8	
	Less than once/week	17.1	20.9	

Spain and Aragon account for 9.1% and 2.0% out of total EU-28 population, respectively (Eurostat, 2018a), and represent a comprehensive view of the South-European pork consumer profile. The three regions studied differ widely in pig farm density and/or human population density. For example, Catalonia (North-Eastern Spain) is a high populated region (235 inhabitants/km^2) with a very high presence of the swine sector (237 pigs/km^2), whereas Aragon (North-Eastern Spanish region attached to Catalonia) is a very low populated region (27 inhabitants/km^2) but has a rather high presence of the swine sector (148 pigs/km^2). On the opposite side of the Iberian Peninsula, the Northern region of Portugal is a moderately populated region (173 inhabitants/km^2) but has a very low presence of the swine sector (only 3 pigs/km^2) (INE, 2018a; INE, 2018b). In looking at the meat consumption behaviour, pork is the most consumed meat in Spain (49.1 kg/capita) and Portugal (43.7 kg/capita) (MAPA, 2018a; INE, 2018a), that have greater average pork consumption per capita than the EU-28 shares (40.7 kg/capita) (Eurostat, 2018a).

It is noteworthy that socio-demographics did not differ across consumers, with only a tendency towards more women in the ‘innovative cook lovers’ segment. Therefore, the food-related lifestyles were similar across countries (Spain vs. Portugal) and regions within Spain (Catalonia vs. Aragon). The density of pig production may affect the cultural perception of meat, as it has been reported that, in north European countries, consumers living in areas with higher levels of pig production consumed fresh pork more frequently than those in lower density areas (Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010). However, this was not evidenced in this south European area, which could be related to low rating of meat as healthy.

In the present study, at least half of the consumers ate pork once or twice a week and only approximately 17% consumed fresh pork 3-4 times per week. However, the proportion of consumers with frequent consumption (3-4 times per week) of processed pork products (e.g. dry-cured ham) doubled (34%) the frequency of consumption of fresh pork. This is in agreement with a previous European survey, where consumers chose fresh pork for special occasions or weekends, and more processed and convenient products for everyday occasions, when they consume pork alone or when socializing (Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010).

The principal factors underlying consumer involvement according to food-related lifestyle clustering are shown in Table 3. The questions responses are classed according to the 5 sub-dimensions of consumer involvement developed by Laurent & Kapferer (1985). Risk importance was the main scored sub-dimension of pork, and it was also lower in ‘uninvolved’ than in ‘innovative cook lovers’ ($P<0.05$). However, product importance, hedonic value, symbolic value and risk of probability did not differ between clusters ($P>0.10$).

Table 3. Involvement with pork meat (7-point category scale, with 1 indicating totally disagree and 7 indicating totally agreement) according to food-related lifestyle clustering.

	Cluster 1 'uninvolved	Cluster 2 'innovative cook lovers'	Pooled standard error	Wilcoxon P-value
Product importance				
I do not care at all about the pork eat	1.95	1.89	0.08	0.11
Pork is very important to my diet	3.65	3.80	0.07	0.14
Hedonic value				
I can say that I actually do not like to eat pork	2.27	2.29	0.08	0.88
I enjoy a meal with pork more than a meal without pork	3.34	3.33	0.07	0.80
Symbolic value				
You can tell a lot about a person based on his/her choice of meat	3.36	3.51	0.08	0.23
Risk importance				
I would find a bad choice of meat terrible	3.72	3.97	0.08	0.03
Risk probability				
I never know if I make the right choice of pork	3.29	3.23	0.08	0.50

Convenience orientation, that is defined as savings of time, physical energy, or mental energy that occurs during one or more of the phases of the home food production (deciding what to eat, purchasing, preparation, consumption and cleaning up), is also affected by other factors, notably food-related motives, like involvement with food (Grunert, 2006). In this study, consumer involvement with pork did not differ between consumer segments, except risk importance dimension, in which 'innovative cook lovers' would regret more a bad choice of meat compared to 'uninvolved' consumers. Consumers' satisfaction with taste (hedonistic value) is the main factor affecting overall satisfaction with pork meat and derived products (Resano et al., 2011), but in this study, the hedonistic value dimension was not different between both consumer segments.

The bulk of food products are still mainly targeted more at the uninvolved than at the food-loving consumer segments. Food-loving consumer segments typically like to retain degrees of freedom in their meal preparation (Grunert, 2006). This could explain that the proportion of 'innovative cook lovers' who liked changes in their meals was three times higher than the proportion of 'uninvolved' consumers expressing this attitude.

3.3. Purchasing drivers according to culinary skills clustering

The purchasing drivers according to culinary skills clustering are ranked in Figure 3. Regardless of lifestyle group, 'best before date', 'safety' and 'appeal (colour, drip loss)' were the most important criteria for purchase decision; all of them were scored over 4 on the importance scale. The next most important factors for the 'innovative cook lovers' cluster were 'label information' and 'quality certification', that tended (P=0.09) or were indeed rated higher (P=0.004), respectively, than ‘uninvolved’ consumers. By default, consumers may believe that conventional or unlabeled meat products contain perceived risks surrounding pork production and consumption, which could potentially lead to the devaluation of these products in a market where they become the ‘cheap’ or ‘generic’ products (Abrams, Meyers, & Irani, 2010). The labelling issue is strengthening in importance, as some other label information data have been proposed in Germany to promote organic animal products produced with local feed, such as feed imports declaration (Wägeli, Janssen, & Hamm, 2016). In fact, origin of pork was scored similarly to label information and quality certification. Thus, consumer cues related to both origin and brand are being used when choosing meat, as suggested by Banovic, Grunert, Barreira, & Fontes (2010). However, in this study, known brand was at the bottom of the purchasing drivers of pork, although quality certification had been one of the most scored.

In intermediate position (3 to 4 score rank), consumers rated (in this order): ‘origin’, ‘fat content’, ‘price’, ‘traceability’, ‘nutritional value’, ‘type of cut joint’, ‘type of packaging’, ‘product weight’, ‘known seller’, ‘product’, ‘cooking ease’, ‘slaughter date’ and ‘breed’. Both extrinsic (safety) and intrinsic (appeal) cues were important, regardless of consumer cluster. However, the fat content of meat fell to a secondary position as purchasing driver, at the same level to price. Ngapo, Martin, & Dransfield (2007a) observed that preferences differed considerably between individuals, between groups and between countries when comparing equivalent subsets of consumers taken from each country. According to them, most choices were based on two appearance characteristics, colour (dark or light red with no drip) and fat content (low), although some differences arose among countries (Spain and Portugal not included there). In the present study, fat content was scored similarly as a purchasing cue by both consumer clusters. In addition, respondents preferred purchasing the marbled over lean loin sample, regardless of cluster (68.4% vs. 67.2%, in ‘uninvolved’ compared to ‘innovative cook lovers’, P=0.69). This finding is in agreement with Font-i-furnols, Tous, Esteve-Garcia, & Gispert (2012), who found that nearly half of the consumers preferred marbled compared to lean loin slices, although according to their eating acceptability scores, all their consumers preferred loins with higher IMF levels. Accordingly, these authors suggested that a minimum intramuscular fat content ranging between 2.2% and 3.4% would be desired to ensure a good taste.

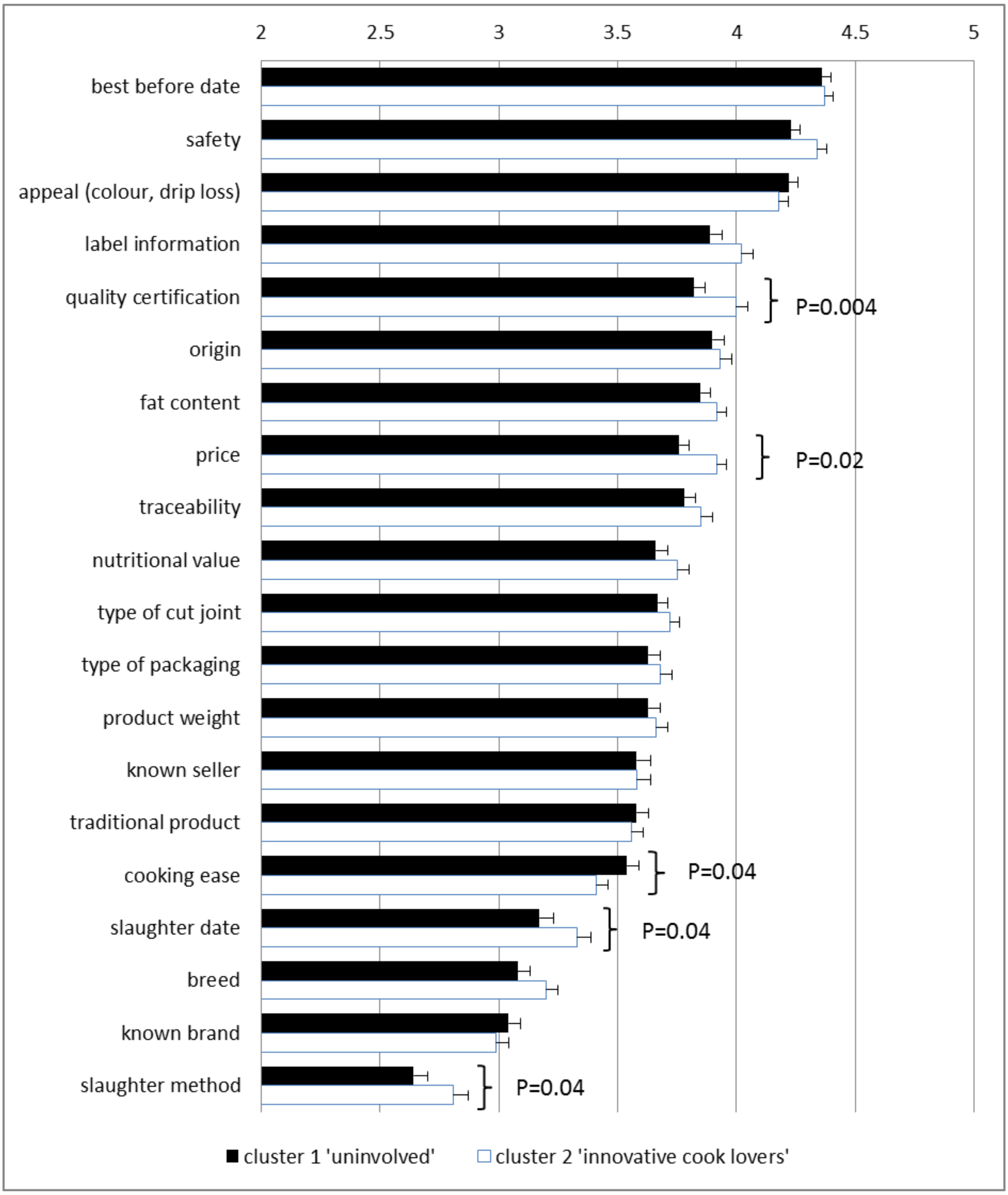

Figure 3. Purchasing drivers ranked according to food-related lifestyle clustering.

The increasing concern about health and safety issues may fuel an increased use of extrinsic cues not currently available in label information. In a German sample ranking pork extrinsic cues (as measured by both knowledge and importance), Grunert, Skytte, Esbjerg, Poulsen, & Hviid (2002) found that the top five were mainly related to healthiness and process characteristics (no pesticide residues, no genetically modified feed, fat percentage, animal friendly farm, and animal friendly transport) and not related with sensory quality. In beef, the most relevant cues or attributes perceived to signal that meat was not safe were expired 'use by' dates, foreign origin, the level of processing e.g. minced, offal or otherwise processed, and price (too cheap) (Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010).

Among intermediate ranked drivers, the ‘price’ importance and ‘slaughter date’ were greater (P<0.05) whereas ‘cooking ease’ was less valued (P=0.04) by ‘innovative cook lovers’ than by ‘uninvolved’ consumers, as verified by Bernués, Ripoll, & Panea (2012) in a consumer survey of lamb meat.

In a cross-sectional web-based survey in Belgium, Denmark, Germany, Greece, and Poland, Resano et al. (2011) concluded that tasty pork, easy to use and consume, with an adequate promotion of its healthfulness, and with a good price/quality relationship appears to be the key to satisfy pork consumers, regardless of country. However, in this study, the ‘innovative cook lovers’ consumer segment ranked the price of pork more importantly than ‘uninvolved’ consumers, suggesting that within each country, price is a key cue for most exigent consumers. This is in line with Grunert (2006), who identified two consumers segments based on ways of shopping: one segment (41% of consumers) is price conscious, with price being the major factor influencing their choice. The other segment (61% of consumers) was quality conscious, and used the price cue as a quality cue and not as a cost cue. In fact, more than 80% of the consumers thought that pork was not expensive (Ngapo, Martin, & Dransfield, 2007b).

The least rated criteria driving purchase intention were ‘known brand’ and ‘slaughter method’, although the latter was scored greater by ‘innovative cook lovers’ than by ‘uninvolved’ (P=0.04). According to a survey of the European Commission (2015a), the consumers who purchase meat are generally satisfied with the information available on meat and meat products (80% of respondents). The absence of apparent demand for additional information does not, however, preclude the possibility that consumers expect certain standards to be adhered to. The information regarding pre-slaughter stunning of animals was not spontaneously mentioned as a criterion for buying meat and only when directly asked, 72% of respondents indicated interest in receiving information on it. The afore-mentioned survey thereby concluded that for most consumers information on pre-slaughter stunning is not an important issue unless brought to their attention. However, this may gain importance for a certain proportion of motivated consumers, although it is unclear how consumers would actually act on this information if it was available.

3.4. Credence attributes views according to culinary skills clustering

Credence attributes concerns according to culinary skills clustering are shown in Table 4. Any of these quality cues differed between cluster groups (P>0.05). Most of the respondents had already visited a pig farm (77%), and more than half (59%) considered that pig husbandry guarantees animal welfare. However, more than half (52%) claimed that pig husbandry impairs the environment. From a health view, around 40% of respondents considered that pork contains hormone residues while nearly half of them (48%) claimed that pork contains antibiotics residues. In addition, approximately 40% of the sample considered that pork contains a high level of fat but only 30% claimed that pork had a high level of cholesterol.

Table 4. Credence attributes concerns according to the food-related lifestyle clustering.

	Cluster 1 'uninvolved'(%)	Cluster 2 'innovative cook lovers' (%)	Pearson P-value
N	462	512	-
I have already visited a pig farm	77.7	76.2	0.83
I think that pig husbandry guarantees animal welfare	57.1	60.7	0.43
I think that pig husbandry impairs the environment	52.8	51.6	0.62
I think that pork contains hormone residues	38.7	41.6	0.64
I think that pork contains antibiotics residues	48.5	47.5	0.94
I think that pork contains a high level of fat	40.5	40.4	0.90
I think that pork contains a high level of cholesterol	32.0	27.3	0.24

The present study revealed that some credence attributes were irrespective of consumer segment. More than half of consumers considered that animal husbandry guaranteed their welfare, but also more than half of respondents expressed a great concern about the environmental burden when raising pigs. In fact, 'housing and floor type' and 'efforts to protect soil, air and water at the farm' had been the items that had the strongest influence on citizens' evaluation of pig production systems (Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010). These authors found that people who care about animal welfare and small-scale pig production consumed less pork and/or in a more selective way. For example, the vegetarians have the same level of food-related motivation as other consumer groups, but a different motivational profile and distinctive, taste- and animal-welfare related reasons to justify their abstinence from eating meat (De Boer, Schösler, & Aiking, 2017). It should be noted that approximately 28% of the consumers included in this study consumed fresh pork less than once a week, and this proportion was similar in both consumer segments, so it may be expected that the yearly fresh pork consumption per capita will slowly decline, at least, until year 2025 (European Comission, 2015b).

3.5. Willingness to pay for different attributes of boneless pork loin

The cluster group based on culinary skills did not affect the WTP for marbled loin (5.63 vs. 5.55±0.05 €/kg, by 'uninvolved' and 'innovative cook lovers', respectively, P=0.25), loin from indoor husbandry (5.35 vs. 5.30±0.04 €/kg, respectively, P=0.47), loin from outdoor run husbandry (5.93 vs. 5.93±0.05 €/kg, respectively, P=0.87), or organic loin (6.17 vs. 6.14±0.05

€/kg, respectively, P=0.72).

The partition tree WTP for marbled loin (Figure 4) showed that, in each country, the best predictor was visual fat content preference. The consumers selecting to purchase marbled loin over lean loin would have paid more for it (+11.6% and +19.5% in Spain and Portugal, respectively) (log-worth>2). It is noteworthy that no differences could be detected between the two Spanish regions studied regarding WTP for any pork loin alternative. In Spain, the consumers that do not issue an opinion about the welfare conditions of pigs would have paid less for marbled pork loin. However, in Portugal, the WTP of marbled pork was higher when the consumers do not think that pork contains high level of fat.

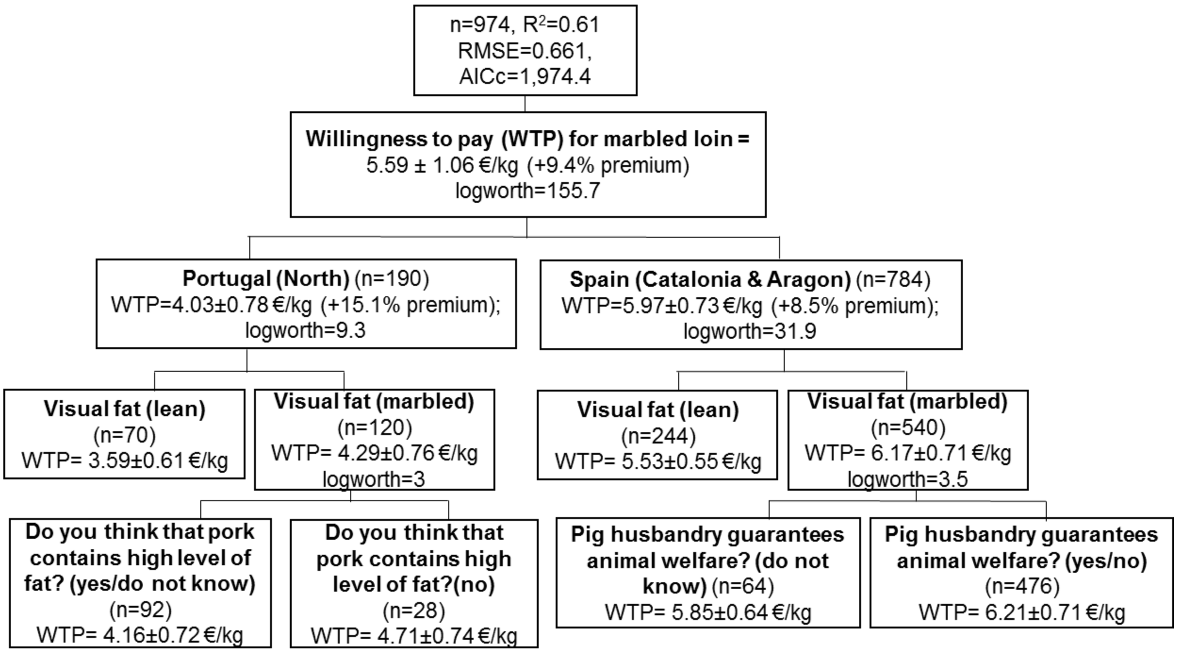

Figure 4. Willingness to pay partition trees for marbled loin (including subcutaneous and intermuscular fat). A price bid from 5 to 8 €/kg at 0.5 €/kg intervals was offered in Spain and from 3.0 to 6 €/kg at 0.5 €/kg intervals in Portugal. Premium was calculated over the country mean prices (5.5 €/kg in Spain and 3.5 €/kg in Portugal).

In this study, more than half of the consumers would prefer higher IMF content, and those who have chosen it would have paid more for marbled meat, regardless of country. Marketing strategies emphasizing the importance of marbling in eating quality would possibly help the consumers that reject high IMF levels to understand this intrinsic attribute of pork. This implies that the IMF content of pork loin may be increased (at least until 3.4%) across the Spanish and Portuguese markets to satisfy (at least) the expectations of half of the consumers. High marbling is normally found in organic pork due to dietary conditions in the pigs, which lack in-feed synthetic amino acids and may include full oilseeds or mechanically oil extracted (Alvarez-Rodriguez, Villalba, Cubilo, Babot, & Tor, 2016).

In Spain, the WTP for marbled pork varied according to their knowledge about pig welfare, while in Portugal the WTP for marbled pork depended on concern on its fat content. In general, the amount of visible marbling negatively affects the consumers' purchase intention most likely due to an unhealthy claim (Resurrección, 2003). However, it was shown that WTP for marbling is also affected by credence attributes as animal welfare knowledge. In this regard, it would appear that only a small proportion of consumers (at least in Australia) is willing to pay a premium for animal welfare, even though most would rate this as being very important (D'Souza, Cleary, & Hewitt, 2017). This could explain the unsteady response for higher WTP for marbled pork by both critical and non-critical consumers with regard to animal welfare.

The partition tree WTP for pork coming from indoor husbandry (Figure 5) was mainly affected by consumers' age in Spain (log-worth>2), since young adults (25-39 years old) would have paid less than the rest of age groups (-2.3%), whereas in Portugal the WTP differed between environmental concern views about pig production, as those unaware of that would have paid more than those doubtful or concerned about it (log-worth>2). The partition tree WTP for pork coming from farms having outdoor runs was best explained in Spain by concerns about antibiotics residues in pork (log-worth>2). The consumers considering that pork contained antibiotics residues would have paid more (+3.7%) for pork coming from farms having an outdoor run than those not concerned. In Portugal, the WTP for pork from farms having an outdoor production was affected by concern about hormone residues in meat, as those thinking that pork may contain hormone residues (yes or doubtful answer) would have paid less (-9.3%) than those not having this concern.

In Spain, elderly people are more likely to be satisfied with fresh pork and pork meat products (Resano et al., 2011), which could explain their higher WTP for standard pork raised in indoor facilities. In case of Portugal, the consumers avoiding penalties on the environmental hazards of pig production would have paid more for pork indoors, but this difference was not observed in Spain. In a Finnish study, the consumer environmental consciousness is yet unsure and the neutral stand is the most common attitude (Pohjolainen, Tapio, Vinnari, Jokinen, & Räsänen, 2016), however, the reduction of meat production was identified by 25% of consumers as a solution for environmental burden. Perhaps, the lower swine density in this northern Portugal area does not impair so far, the consumer view on commodity indoor pork.

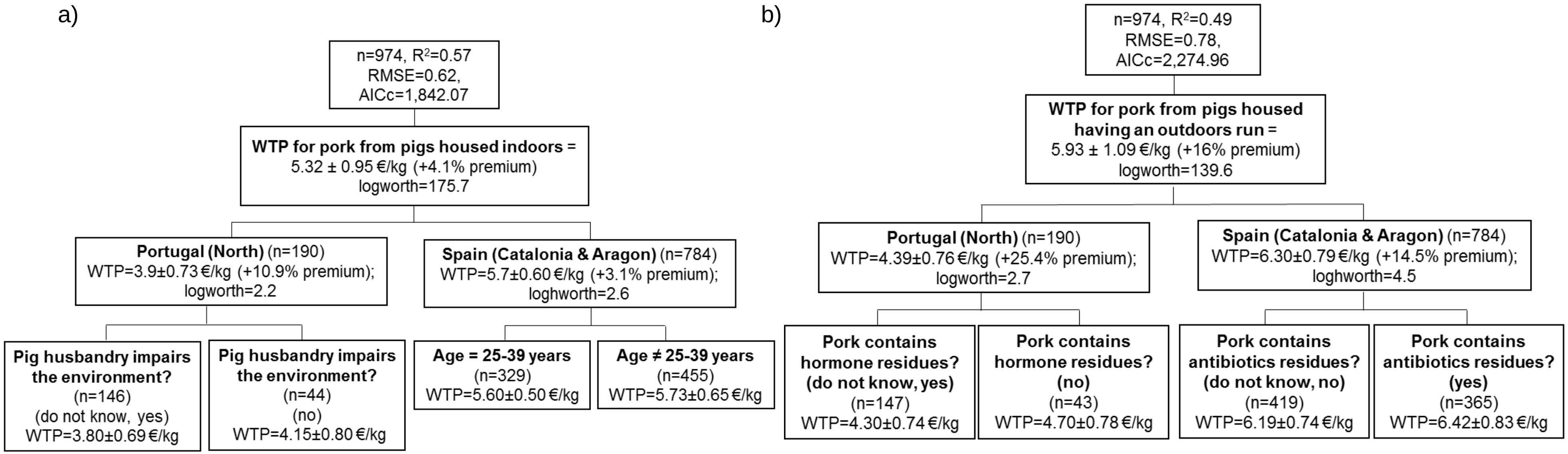

Figure 5. Willingness to pay partition trees for pork from pigs housed indoors (a) or having an outdoor run (b). A price bid from 5 to 8 €/kg at 0.5 €/kg intervals was offered in Spain and from 3.0 to 6 €/kg at 0.5 €/kg intervals in Portugal. Premium was calculated over the country mean prices (5.5 €/kg in Spain and 3.5 €/kg in Portugal).

The WTP for outdoor pork was cross-country affected by credence attributes (antibiotics residues concerns in Spain, and hormone residues in Portugal). However, the attitude towards process characteristics differed between countries, since in Spain the greatest WTP for outdoor pork was obtained by respondents concerned about presence of antibiotic residues in pork, while in Portugal it was expressed by respondents who did not think that pork may contain hormone residues, or, in other words, by consumers less concerned by public health hazards.

Finally, in Spain, the partition tree WTP for organic pork (Figure 6) was also explained mainly by concern about antibiotics residues, but this difference was not detected in Portugal, where women would have paid more for organic pork than men (+6.8%). In Spain, among the consumers that do not have an opinion or think that pork does not contain antibiotics residues, the subset of consumers with interest for level of pork fat would have paid more for pork loin (+10.2%).

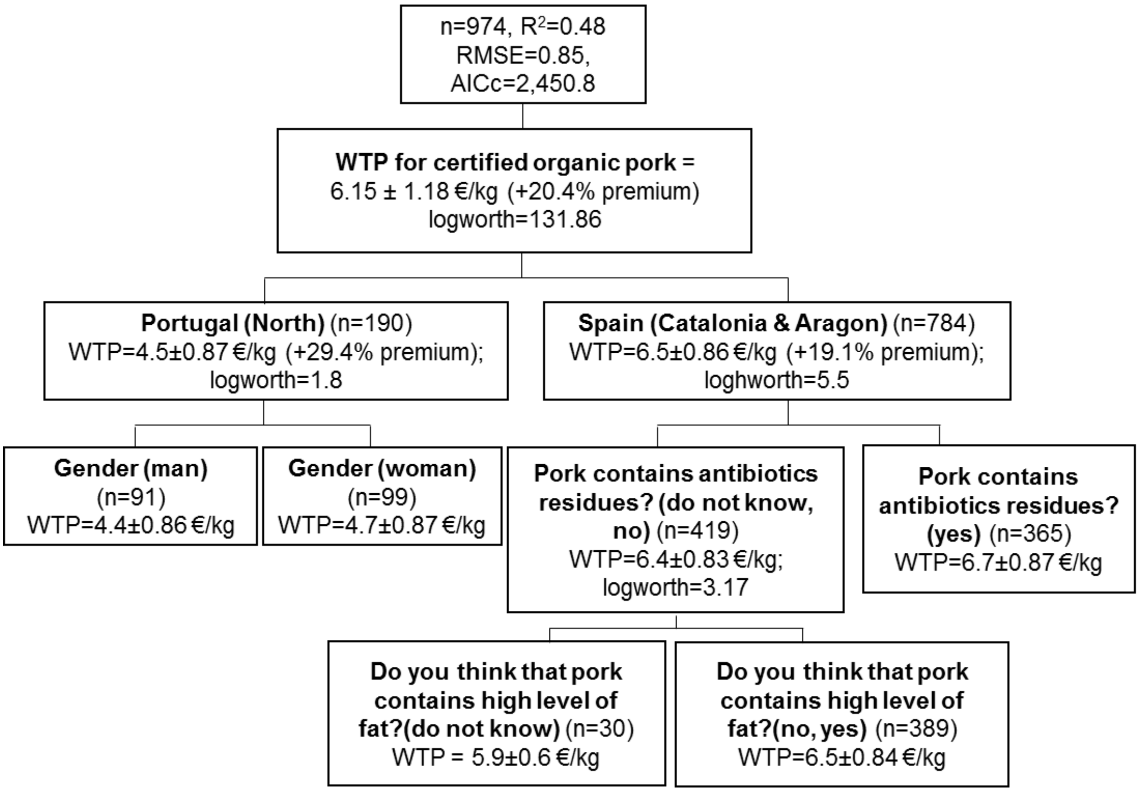

Figure 6. Willingness to pay partition trees for pork from certified organic husbandry (EU logo). A price bid from 5 to 8 €/kg at 0.5 €/kg intervals was offered in Spain and from 3.0 to 6 €/kg at 0.5 €/kg intervals in Portugal. Premium was calculated over the country mean prices (5.5 €/kg in Spain and 3.5 €/kg in Portugal).

In Spain, similarly to outdoor pork response, the WTP for organic pork was higher when the consumers were concerned about antibiotic residues in pork, but this outcome was not seen in Portugal. In fact, the perception of product safety had been one of the main WTP determinants for certified beef by Spanish consumers (Angulo & Gil, 2007). Perception of food safety risk is a psychological interpretation of product properties (Yeung & Morris, 2001), that can affect negatively pork choice. Education may enhance the positive effect of trust in information provided by public authorities and weaken the negative effect of trust in information provided by mass media, which normally contributes to amplify the negative perception of food safety (Angulo & Gil, 2007). It may be suggested that the greater pig density in Spain compared to Portugal, especially in the studied regions, is negatively affecting the public image of pork, when certain risks or hazards are shown in mass media.

An organically produced piece of meat was considered better not only in terms of its process characteristics, but also in terms of healthiness and sensory quality (Scholderer, Nielsen, Bredahl, Claudi-Magnussen, & Lindahl, 2004). In this mentioned study, consumers believed that when they tasted organic or free-range pork they actually perceived the quality of the meat was higher, irrespective of which type of meat they actually eat. In the present study, the factors affecting WTP for outdoor and/or organic pork by Spanish respondents proves that some credence attributes (as no presence of antibiotic residues) are not being accurately addressed or described in commodity pork. In addition, in case of Portugal, the

WTP for organic pork was higher in women than in men. This response does not seem cross-country steady, as in the USA it was the opposite (Vander Naald, & Cameron, 2011). Lagerkvist & Hess (2011) concluded from a meta-analysis that whether such a gender effect on WTP for farm animal welfare may exist, but was at least statistically severely confounded by related characteristics of the respondents that apply equally to men (for example, related with income or household children).

In a survey analyzing public perception of animal welfare in Spain (Maria, 2006), a high proportion of urban people agreed to pay more for animal products, if this greater price would guarantee a better welfare. In that study, there was a trend indicating a positive response in young women (university students). However, there was an inconsistency between the higher WTP and the actual consumption of welfare friendly products, which remained low. Accordingly, as citizens, people may hold views about various forms of meat production, but these may be only weakly reflected in their behaviour as consumers. For example, community attitudes can be critical with certain forms of meat production on animal welfare grounds, but consumers still buy the products of these systems, even though products with better animal welfare standards may also be available (Ngapo et al., 2004; Grunert, 2006; Verbeke, Pérez-Cueto, de Barcellos, Krystallis, & Grunert, 2010). In France, for example, 39% of households did not purchase any organic products, as the ‘all-organic’ basket costs a 62% premium over that of the ‘all-conventional’ basket. Across Europe, Switzerland has the highest per capita consumption of organic food, followed by Denmark and Sweden (FiBL, 2017).

In a recent study evaluating urban consumers’ WTP for pork with certified labels in China, there were cross-regional differences in this variable depending on their economic development (Wang, Ge, & Ma, 2018). Assuming that the gross domestic product (GDP) per capita is an approach measure for the economic activity, the current volume index of GDP per capita in purchasing power standards for Spain and Portugal is 92 and 77 (set at 100) (Eurostat, 2018a). As familiarity with the type of tested product is the main factor accounting for WTP (San Juán et al., 2012), the WTP for niche pork (outdoor and/or organic) in these countries is expected to progress forward depending on their economic trend. In fact, in a survey from Catalonia, meat was the most important food type that the organic consumers were willing to increase its purchase (37% out of organic consumers) (Gencat, 2015).

The overall mean WTP premium across countries was low for indoor pork image (7.0%), but increased for marbled (11.8%), outdoor pork (20.0%) and organic logo stamp (24.3%). However, the goodness of fit of the explanatory variables (based on R^2-square and Root mean square error, RMSE) was negatively related with the observed WTP value (lower R^2-square for higher WTP product). The overall scenario premiums were 8.9% lower in Spain than in Portugal. These shares are in agreement with the results from France and the Netherlands, where questionnaire responses suggested that almost half of consumers would pay 20% more for pork from pigs raised outdoors (Carpentier & Latouche, 2005). However, some other references suggest that consumers would offer only 5% extra, with about one-fifth of consumers willing to pay 20% extra for organic pork (Dransfield et al., 2005). In a study carried out in Canada and Germany to evaluate the influence of consumer knowledge on environmentally sustainable choices, it was found that about 20% of consumers in both countries were ready to adopt environmentally labeled food in their choices (Peschel, Grebitus, Steiner, & Veeman, 2016).

The current results are also in agreement with a recent meta-analytic study demonstrating that, in organic, credence attributes such as health, safety, nutrition, quality, environment, animal welfare, and production practices, are valued more than search and experience attributes (Massey, O'Cass, & Otahal, 2018). For example, for issues related to animal welfare, public mechanisms (including social media engagement) that engage and empower the consumer and that reconnect consumers directly with primary producers are likely to be important (Regan, Henchion, & McIntyre, 2018). In agreement with this, Akaichi, Glenk, & Revoredo-Giha (2019) have observed that the demand for organic animal products could be improved not only by selling its supposed superiority in terms of sustainability but also by promoting its advantages in terms of other attributes that are known to be highly valued by consumers such as animal welfare and nutritional content.

Despite the high sample size of the survey, some minor constraints may be found in this study. Firstly, it was not designed as a conjoint-choice experiment and thus it did not allow ranking the different WTP for each credence attribute. Secondly, the methodology of on-line questionnaires used and the snowball dispersion could lead to some biases. In this sense, some parameters of the results indicated a bias to higher levels of education in the sample than in the overall population (58.2% in Spain and 46.9% Portugal; MECD, 2017). This may have increased their concern about credence attributes of pork, but the conclusions of the study are not altered. In fact, the main socio-demographics (age structure, gender and household characteristics) of the sample used were fairly good in representing the average consumer in that region.

4. Conclusions

The hypothesis that consumers' culinary skills would shift their attitudes towards niche pork was not supported. However, it was proven that credence cues of pork claiming health issues (absence of antibiotics and hormone residues) defined the WTP for niche pork (coming from pigs raised on outdoor paddocks and/or specifically certified organic pork) in these three country regions. In Northern Portugal, there was also a gender segmentation of WTP for organic pork, as women expressed higher WTP than men.

These results can be helpful for niche pork producers (outdoor husbandry and/or certified organic) to design marketing policies focused on perceived quality attributes (outdoor housing conditions improving animal welfare and/or organic management with minimum use of medication) rather than targeted at specific consumer segments based on food-related lifestyles. It is highlighted that consumers, irrespective of culinary skills, seek additional requirements for the pork value chain, which has to fulfill the functions of delivering both meat and more extrinsic cues in label information.

5. Acknowledgements

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3. Capítol II. Alimentació (article II).

Estrategias de alimentación, evaluación del impacto ambiental y valoración económica de dietas de porcino ecológico

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Resumen

El principal desafío en alimentación para porcino ecológico es garantizar que los alimentos de la dieta cumplan los requerimientos nutricionales, en particular en proteína y perfil de aminoácidos, al finalizar la moratoria de uso de hasta un 5% de alimentos no ecológicos en las raciones, prevista para 2020. Así, este trabajo se planteó para proponer una estrategia de alimentación y analizar la viabilidad nutricional, económica y ambiental de formular raciones con alimentos alternativos, producidos localmente. Se seleccionó una muestra representativa de productos de cultivos ecológicos, de acuerdo con el Reglamento (CE) 834/2007 y 889/2008, de fábricas de piensos y productores de Cataluña y zona próxima: cereales (n=22), subproductos de cereales (n=4) y concentrados de proteína vegetal (n=25). Las dietas se formularon para las diferentes fases fisiológicas, ajustadas a las recomendaciones nutricionales españolas (FEDNA, convencional) y francesas (ITAB, ecológicas). Se formularon dietas prescindiendo de la soja (torta de presión y soja integral) según recomendaciones nutricionales francesas y utilizando fuentes proteicas adaptadas al clima mediterráneo (alverjón, habas, guisantes y alholva) y cereales de invierno (centeno, trigo, cebada y triticale). Los impactos ambientales de las dietas (por unidad de pienso compuesto producido) en cuanto a demanda de fósforo, uso de energía no renovable, eutrofización, acidificación, cambio climático y ocupación de tierra, evaluados mediante el análisis de ciclo de vida de la base de datos francesa ECOALIM (2016), resultan mayores en lechones y menores en cerdas gestantes, y notablemente superiores si se formula según FEDNA vs. ITAB. En la valoración económica de las dietas (compra frente a autoproducción), resultaría más rentable un modelo de negocio con integración agropecuaria.

Palabras clave: porcino, ecológico, cultivos locales, valor nutritivo, análisis ciclo de vida.

Abstract

The main dietary challenge for organic swine feeding is ensuring that feed fulfils the nutrient requirements, in particular to protein and amino acid profile, after the expiration that allow producers to include up to 5% non-organic feed within their rations, which is expected to 2020. Thus, this work was designed to propose an organic feeding strategy and to analyse the nutritional, economic and environmental viability of locally produced feedstuff use. A representative sample of organic feed ingredients were selected, according to EC No 834/2007 and No 889/2008, in feed mills and producers from Catalonia and nearby area: cereals (n=22), cereal by-products (n=4) and protein concentrate (n=25). Diets were formulated for the different physiological phases, adjusted to the Spanish (FEDNA, conventional) and French (ITAB, organic) nutritional recommendations. Diets were formulated without soybean expeller or full-fat soybean when using French standards, using instead other protein sources adapted to the Mediterranean climate (Narbonne vetch, beans, peas, and fenugreek) and winter cereals (rye, wheat, barley and triticale). The assessment of environmental impacts (phosphorus demand, non-renewable energy, eutrophication, acidification, climate change and land occupation) of the diets (per unit of produced feed), through life-cycle analysis by means of the database ECOALIM (2016), was higher in piglets and lower in pregnant sows, and much higher when formulating according to FEDNA vs. ITAB standards. In the economic valuation of the diets (purchase or self-production), a business model that integrates agriculture and livestock farming would be more profitable.

Keywords: swine, organic, local crops, nutritive value, life cycle assessment.

1. Introducción

La formulación de dietas en porcino ecológico es más compleja que en convencional, ya que la ausencia de disponibilidad de materias primas encarece su coste y existen especificaciones de uso de ciertos ingredientes que difieren de la alimentación porcina convencional. Las diferencias más importantes, además de una procedencia de producción agraria ecológica, son: la necesidad de ofrecer forraje a los animales (pasto, heno, ensilado o paja), la prohibición de utilizar aminoácidos sintéticos (que puede condicionar la cobertura de las necesidades de aminoácidos esenciales si el nivel de proteína bruta de la dieta no es elevado), la prohibición de utilizar ingredientes provenientes de cultivos modificados genéticamente y la necesidad de utilizar tortas de oleaginosas procedentes de extracción mecánica (presión), de acuerdo con los Reglamentos (CE) 834/2007 (DOUE, 2007) y 889/2008 (DOUE, 2008). Según el Reglamento de ejecución 505/2012 (DOUE, 2012), que modifica el artículo 19 del Reglamento (CE) 889/2008, en el caso de cerdos y aves, al menos el 20% de la alimentación debería producirse en la misma zona, con el objetivo de fomentar la sostenibilidad productiva, integrando agricultura y ganadería. A partir del 1 enero de 2021, el nuevo Reglamento de producción ecológica, Reglamento (CE) 848/2018, será aún más restrictivo: incremento de alimento de la zona (de 20% a 30%) y la utilización del 100% de materias ecológicas en monogástricos (excepción en lechones hasta 35 kg) (DOUE, 2018a y b).

Según Calvar *et* al. (2010), la alimentación representa el 80% del coste de producción de la carne de cerdo ecológico. Por ello, la valoración de la autoproducción de materias puede tener un papel fundamental, siendo una práctica más establecida en granjas de rumiantes que en monogástricos. Aunque una parte de los ingredientes de la dieta proceden de procesos tecnológicos complejos (tortas de presión con o sin extrusión), otros ingredientes serían fáciles de producir y valorizar directamente en la granja.

El valor nutritivo de las materias primas ecológicas utilizadas en alimentación animal puede diferenciarse de las convencionales, dado que en agricultura ecológica no se utiliza abono mineral, limitando en algún caso el contenido de proteína bruta en las materias primeras ecológicas (Berry *et* al., 2002; Tejido *et* al., 2011). El aporte de forraje es obligatorio, y su potencial nutritivo puede contribuir a las necesidades de nutrientes y energéticas en los monogástricos (Rivera *et* al, 2001; Edwards, 2003; Früh, 2016; Wüstholz *et* al., 2017), aunque no se ha valorado suficientemente. Además, existe una falta de información sobre evaluaciones económicas de diferentes estrategias de producción de alimentos en las granjas de porcino.

El objetivo del presente trabajo es proponer dietas para porcino ecológico en las diferentes fases fisiológicas (gestación, lactación, lechones, crecimiento y acabado), eligiendo preferentemente materias primas locales, prescindiendo inicialmente de la soja y sus derivados, y minimizando el número de materias primas de la fórmula para poder aplicarse fácilmente en granja. Para las diferentes dietas también se evaluará el impacto ambiental de las mismas y se realizará un estudio económico comparando la autonomía de producción de la ración en comparación con la compra del pienso compuesto en una fábrica de piensos.

2. Material y métodos

2.1 Valor nutritivo de ingredientes

Se utilizó una muestra representativa de productos de cultivos ecológicos, producidos en Cataluña y comunidades próximas, tales como cereales (n=22), subproductos de cereales (n=4), y concentrados de proteína vegetal (n=25), procedentes de operadores certificados por los correspondientes Consejos de Producción Agraria Ecológica. Se determinó la composición química de cada uno de los ingredientes para estimar el valor nutritivo de los mismos. Las muestras se molturaron (diámetro 1 mm) y se analizaron los siguientes parámetros por duplicado: materia seca (MS), cenizas, extracto etéreo con hidrólisis previa (EE), almidón, proteína bruta (N x 6,25, PB), lisina (Lys), fibras ácido y neutro-detergente (FAD y FND) con adición de amilasa previa, fibra bruta (FB) calculada a partir de la FAD (INRA, 2018) y macrominerales (calcio y fósforo), siguiendo las metodologías de AOAC (2000). Se determinó el contenido de lisina (Lys) de las materias primas por UPLC-SRM previa hidrolisis en medio ácido (Álvarez-Rodríguez *et* al., 2018).

La predicción de la energía neta (EN) de los ingredientes se realizó con las ecuaciones recogidas en el Manual "EvaPig®" (Noblet *et* al., 2008), diferenciando entre adultos (EN_a) y crecimiento (EN_g), con el proceso siguiente:

-Energía bruta (**EB**, MJ/kg MS): EB = 17,57 + 0,0535 x PB + 0,2168 x EE + 0,0284 x FB – 0,1861 x cenizas.

-Energía digestible (**ED**, MJ/kg MS), se calcula diferenciando para la fase de crecimiento (ED_g) y adulto (ED_a):

ED_g = EB x Edg.

Digestibilidad de la energía en crecimiento (Edg, %) = 90,1 –1,57 x FB.

ED_a = ED_g + 4,2 x (1 –cenizas/100) x (1 –MOd / 100).

Digestibilidad de la materia orgánica (MOd, %) = 7,45 + 0,949 x EDg –0,04x PB.

-Energia neta (**EN**, MJ/kg MS) (misma ecuación para crecimiento y adultos, utilizando ED_a ò ED_g):

EN_a o EN_g = 0,703 x $ED_{a\ ò\ g}$ – 0,0404 x PB+ 0,0662 x EE + 0,0197 x almidón – 0,0409 x FB.

Donde la PB, EE, FB, almidón y cenizas están expresados en porcentaje (sobre MS).

Se determinó, además, el perfil de ácidos grasos de los ingredientes por cromatografía gas-líquido en columna capilar (SP2330; Supelco, Tres Cantos, Madrid, España) y detector tipo FID (Tor *et* al., 2015).

2.2 Formulación de dietas

Se creó una base de datos de diferentes ingredientes (n=27) que incluía cereales (cebada, centeno, avena, maíz, triticale, trigo), concentrados de proteína vegetal (alverjón, alholva, guisante de primavera, habas, yeros, soja entera, semilla de girasol, torta de girasol, torta de soja), subproductos de cereales (germen de maíz, harinilla de maíz, salvado de trigo), alimentos fibrosos (cascarilla de espelta, paja de cereal, granulado de alfalfa), aceite de soja y complementos vitamínico-minerales (carbonato cálcico, fosfato bicálcico, cloruro sódico, corrector vitamínico-mineral).

Se formularon piensos adaptados a cada fase fisiológica (lechones, cerdos en crecimiento-cebo y cerdas reproductoras en lactación y gestación), según las recomendaciones nutricionales para cerdo convencional de la Fundación Española para el Desarrollo de la

Nutrición Animal-FEDNA (2013) y para cerdo ecológico, según las recomendaciones conjuntas del instituto francés *Institut Technique de l'Agriculture Biologique*-ITAB e IFIP-*Institut du porc* (2014). Únicamente se ha tenido en cuenta las necesidades de proteína bruta y de lisina para garantizar las necesidades de aminoácidos, pero no ha sido posible considerar el concepto de proteína ideal, ya que no se disponía de resultados analíticos de composición de todos los aminoácidos esenciales.

Para establecer los límites máximos de incorporación de ingredientes, se consideraron los factores antinutritivos de éstos y su limitación en las raciones, tomando las recomendaciones de FEDNA e ITAB, respectivamente. En el alverjón, la alholva y los yeros no fue posible encontrar una referencia para su límite de incorporación en pienso, por lo que se tomaron los límites de los ingredientes más próximos de la misma familia (leguminosas) que ofrecían ambas instituciones, así como los estudios de Gómez-Izquierdo (2015) y Martín-Pedrosa *et* al. (2016).

Las fórmulas de pienso se resolvieron con un método de optimización lineal mediante el programa Winfeed® (Universidad de Cambridge, Cambridge, Reino Unido). En el caso que la solución de la fórmula mostrara ingredientes con un nivel de inclusión <2%, se han eliminado del inventario y se han reformulado nuevamente para obtener una nueva solución. Asimismo, se ha limitado la inclusión del número de cereales en cada fórmula, para facilitar su fabricación en granja. Para ello, se han considerado los dos cereales con mayor proporción en la solución de la fórmula, se han eliminado del inventario el resto y se ha reformulado nuevamente. En cuanto al concentrado de proteína vegetal, se ha procurado prescindir de la soja y sus derivados, y cuando no ha sido posible alcanzar los requerimientos recomendados, se ha introducido en el inventario. Se han tomado como límites de incorporación en la dieta los valores de diferentes ensayos de estrategias de formulación con resultados favorables, tanto en rendimientos productivos como bienestar animal, en cerdos de engorde y reproductoras, dónde utilizaban forrajes hasta un 15-30% en engorde y un 25-50% en gestantes (Edwards, 2003; ITAB, 2014; Jakobsen *et* al., 2014; Smith *et* al., 2014; Wüstholz *et* al., 2017). En todos los casos, se ha asumido un porcentaje constante de inclusión de corrector vitamínico-mineral del 0,4%.

En una primera fase se han formulado dietas para todos los tipos fisiológicos, mientras que en una segunda fase, se ha considerado la estrategia de fabricar tres fórmulas base (lechones, cerdos en crecimiento y cerdas lactantes) y el resto, gestantes y de cerdos en acabado, se han formulado a partir de ellas e incluyendo además un porcentaje de forraje y/o alimento fibroso (granulado de alfalfa, cascarilla de espelta, paja de cereal).

2.3 Impacto ambiental de las dietas formuladas

Para la evaluación del impacto ambiental de las dietas formuladas se ha utilizado la base de datos ECOALIM, que incluye los ingredientes más utilizados en el contexto francés, así como su inventario de impactos asociados (Wilfart *et* al., 2016), en función del método y origen de producción y/o transformación. Se seleccionaron los ingredientes de esa base de datos más parecidos a la base de datos propia. Los seis impactos considerados fueron la demanda de fósforo (PC, en kg P), la demanda de energía no renovable (CED, en MJ), el potencial de cambio climático (GWP, en kg CO_2-eq), acidificación (AP, en molc H+-eq), eutrofización (EP, en kg P-eq), y ocupación de tierra (LO, en m^2).

En la selección de los ingredientes de la base de datos ECOALIM se ha considerado: en los cereales, origen de agencia de almacenaje o fábrica de piensos, de producción y transformación a nivel nacional y abono mediante fertilizantes orgánicos; en el caso de leguminosas grano y girasol, cultivos nacionales y producidos directamente en campo; en el caso de harinas y subproductos de cereales, procedentes de molino nacional y origen en planta de transformación; en el caso de torta de presión de soja procedente de Estados Unidos, prensado nacional y en planta de transformación y finalmente en el caso de aceite de soja, procedente de Brasil, no asociado a deforestación, prensado nacional y planta de transformación.

En la evaluación del impacto ambiental de las dietas se han considerado los impactos por quilo de pienso producido, y según el consumo anual en las diferentes fases del ciclo productivo (1 cerda y su descendencia anual): número de partos por cerda y año (2), número de lechones por parto (10), días de gestación (114) y meses de crecimiento y engorde (7). La estimación del consumo de alimento por fase fisiológica y animal se ha considerado: el lechón (<30 kg de PV; ITAB, 2014) de 0,6 kg/día, el cerdo en crecimiento (<60 kg; ITAB, 2014) de 1,5 kg/día, el cerdo de engorde-acabado (<110 kg; ITAB, 2014) de 2,5 kg/día; en las gestantes de 2 kg/día y en lactantes de 5 kg/día. Las duraciones de cada fase fisiológica son: en lechones 84 días (correspondientes a 49 días de lactación y 35 días postdestete), cerdo en crecimiento 49 días y cerdo engorde-acabado 77 días; y las reproductoras de 225 días/año de gestación y 140 días/año en lactación (dos periodos de 49 días de lactación y 21 días de pre y postcubrición, total de 140 días).

2.4 Valoración económica del coste de los piensos en diferentes escenarios

Con las fórmulas de pienso obtenidas, se ha realizado una valoración económica, teniendo en cuenta dos escenarios: coste de compra en la fábrica de piensos vs. coste de autoproducción de las materias primas, calculado según el consumo anual de una cerda y su descendencia.

2.4.1 Costes de compra del pienso en fábrica de la zona

Según el Consejo Catalán de Producción Agraria Ecológica (CCPAE), en fecha de octubre de 2018, existían 24 operadores que comercializaban materias primas o compuestos para la elaboración de piensos. Se ha recogido el coste medio de compra en fábricas de piensos de Cataluña, especializadas en producción ecológica, siendo: gestantes de 0,38€/kg (impuestos y transporte incluidos), lactante de 0,44 €/kg, lechón de 1,09 €/kg y acabado de 0,44 €/kg.

2.4.2 Costes de autoproducción de la fórmula completa

En el cálculo del coste de autoproducción de las materias primas (cereales y leguminosas) se ha considerado el coste directo (alquiler de máquinas agrícolas y conductor) para producción de cultivos extensivos en secano, correspondiente a: trabajos primarios del suelo (abonado orgánico, laboreo con arada de discos, laboreo con chisel y laboreo con vibrocultor), trabajos secundarios (cultivador, arada de varillas flexible), cosecha y derivados (coste de siembra, coste de compra de semilla, cosechadora, segadora acondicionadora, rastrillar, picar, transporte y seguro), según el cultivo (Tabla 1). En la valoración se ha considerado el coste de producción del cultivo por familia más elevado, en cereales de 376 €/ha y en leguminosas de 464 €/ha. Se ha incluido el coste del seguro, el coste de la molienda, teniendo en cuenta como coste la amortización anual de los equipos de fabricación (silos, molino y mezcladora) y la energía eléctrica consumida (30€/T). En algunas materias primas ha sido necesario incluir su coste de compra: corrector vitamínico-mineral (2,00 €/kg), granulado de alfalfa (1,65 €/kg), salvado de trigo (0,30 €/kg), soja integral (0,84 €/kg), y torta de presión de soja (0,84 €/kg); según fábrica de piensos de referencia del año 2018 en Cataluña.

Tabla 1. Estimación de costes de semilla y maquinaria en agricultura ecológica

Cultivos		Leguminosas (€/ha)			Cereales (€/ha)	
		Guisante	Haba	Alverjón, Alholva	Cebada, Centeno	Triticale
Semilla						
	Coste de semilla (€/kg)	0,50	0,38	1,85	0,35	0,45
	Dosis de siembra (kg/ha)	170	150	120	180	170
	Coste (€/ha)	85	57	222	63	77
Trabajos maquinaria						
Laboreo primario suelo	Abonado (esparcir)	-	-	-	38	38
	Arada discos	28	28	28	28	28
	Chisel	31	31	31	31	31
	Vibro cultor	18	18	18	-	-
Laboreo secundario suelo	Cultivador	20	20	20	-	-
	Arada púas flexibles	-	-	-	15	15
Cosecha cultivos y derivados	Coste siembra	34	34	34	34	34
	Recolección y picar	90	90	90	-	-
	Recolección grano	-	-	-	61	61
	Embalar	-	-	-	30	30
Otros	Transporte paja	-	-	-	18	18
	Transporte grano	11	11	11	11	11
	Seguro	10	10	10	10	10
TOTAL, Costes (€/ha)		327	299	464	339	353

Fuente: Sabaté y Solé (2003); MAPAMA (2015)

La referencia de rendimientos de los cultivos se ha obtenido a través de la Generalitat de Cataluña (Gencat, 2017) y de datos de entrevistas a diferentes agricultores de producción ecológica suministradores de las materias primas analizadas (cereales y leguminosas). Los rendimientos estimados fueron: 3.500 kg/ha en cebada (*Hordeum vulgare*), 3.200 kg/ha en centeno (*Secale cereale*), 3.200 kg/ha en trigo (*Triticum aestivum*), 2.500 kg/ha en guisante (*Pisum sativum*), 1.500 kg/ha en haba (*Vicia fava var. Equina*) y 1.700 kg/ha en alverjón (*Vicia narbonensis*).

En los ingresos, se han considerado las posibles ayudas a agricultura ecológica, en base al cumplimiento de la condicionalidad que establece el artículo 92 del Reglamento (UE) 1306/2013. El cálculo se ha realizado de acuerdo al Plan de Desarrollo Rural de Cataluña para el período 2014-2020, dónde la ayuda a agricultura ecológica es de 145 €/ha (cereal secano) y la ayuda a ganadería ecológica es de 215 €/ha por cerda en ciclo cerrado y de

131 €/cerdo de engorde; con el requisito de tener como mínimo en la explotación la superficie agrícola de 0,30 ha/UGM en reproductoras y 0,23 ha/UGM en engorde, estableciendo un máximo subvencionable de 1,2 UGM/ha. Se ha tenido en cuenta un escenario de arrendamiento de la tierra de 176 €/ha (MAPA, 2016), dónde para alimentar a una cerda y su descendencia hace falta 2,5 ha/año, equivalente a 440 €/cerda.

3. Resultados y discusión

3.1 Valor nutritivo de los ingredientes

En la Tabla 2, se representan los resultados del análisis químico de nutrientes de las materias primas, dónde se ha estimado el valor energético para cerdas adultas y cerdos en crecimiento utilizado para la formulación de piensos. Los ingredientes más concentrados energéticamente (MJ/kg), de mayor a menor, son el aceite de soja, la semilla de girasol, la soja entera, el grano de maíz y el trigo; y los menos concentrados energéticamente son las habas, torta de girasol, granulado de alfalfa, cascarilla de espelta y paja de cereal. Si se compara la diferencia del valor energético entre adultas y crecimiento, destaca en mayor grado la paja de cereal (+2,02), cascarilla espelta (+1,72), granulado alfalfa (+1,45) y torta de presión de girasol (+1,07); y menos diferencia en aceite de soja (+0,12), triticale y maíz (+0,36) y trigo (+0,37). En la Tabla 3, se muestra el perfil de ácidos grasos de los ingredientes utilizados. En general, destaca la elevada ratio de ácidos grasos poliinsaturados/ácidos grasos saturados (AGPI/AGS) en la soja y sus derivados (torta de presión y aceite), el girasol entero y el maíz (así como algunos de sus derivados como las harinillas de maíz). Así mismo, es destacable la elevada ratio de ácidos grasos polinsaturados omega-6/ ácidos grasos polinsaturados omega-3 (AGPI n-6/AGPI n-3) en el caso de la semilla de girasol y su torta de presión, así como en los subproductos del maíz (harinillas y germen) y el maíz grano.

Tabla 2. Valor nutritivo y energético de ingredientes ecológicos para formulación piensos (% sobre materia fresca)

Materia prima	MS(%)	PB(%)	FB(%)	FND(%)	FAD(%)	EE(%)	Almidón(%)	Lys(%)	Ca(%)	P (%)	EN_a (MJ/kg)	EN_g (MJ/kg)
Cereales												
Avena	89,59	10,27	11,83	34,90	14,33	5,29	35,10	0,35	0,14	0,30	8,93	8,18
Cebada	89,78	9,88	6,28	28,26	7,84	2,88	47,83	0,36	0,07	0,26	9,83	9,29
Centeno	89,16	7,59	3,67	17,88	4,79	1,80	49,93	0,29	0,04	0,30	10,42	10,04
Maíz	87,61	7,27	3,13	12,52	4,14	4,70	62,61	0,22	0,01	0,25	11,30	10,98
Trigo	90,00	11,12	2,96	14,35	3,96	2,35	58,57	0,33	0,06	0,27	10,93	10,60
Triticale	89,90	10,10	2,82	13,75	3,79	1,97	57,12	0,31	0,04	0,27	10,87	10,54
Subproductos de cereales												
Germen maíz	90,33	15,55	12,44	27,50	15,04	22,61	22,07	0,56	0,07	1,29	11,53	10,84
Harinilla maíz	86,48	8,63	3,34	18,34	4,38	7,04	50,87	0,29	ND	0,48	11,05	10,68
Salvado trigo	88,47	15,00	7,88	30,79	9,70	4,08	30,35	0,50	0,06	0,66	9,10	8,50
Concentrados de proteína vegetal												
Girasol	94,00	16,27	18,10	30,92	21,67	44,89	1,99	0,43	0,21	0,34	14,44	13,53
Guisantes	87,99	20,26	7,15	18,14	8,84	1,82	45,49	1,30	0,26	0,31	9,45	8,96
Alverjón	88,10	26,98	10,62	17,70	12,90	2,20	37,10	1,43	0,08	0,19	8,88	8,28
Alholva	90,10	27,28	8,73	33,60	10,70	9,30	14,60	1,32	0,79	0,27	9,58	8,91
Habas	89,22	22,88	12,05	19,01	14,57	1,91	11,41	1,74	0,14	0,39	8,17	7,53
Soja entera	87,36	29,54	6,77	11,92	8,40	17,25	4,65	1,72	ND	ND	11,44	11,01
Torta presión girasol	93,48	29,70	19,71	37,93	23,55	7,81	3,95	1,06	0,47	0,83	7,45	6,45
Torta de presión soja	92,61	42,94	7,96	18,37	9,82	7,72	9,17	2,01	0,25	0,54	9,66	9,13
Yeros	90,07	16,37	9,42	19,71	11,50	2,55	39,97	0,89	0,60	0,18	9,40	8,83
Ingredientes fibrosos												
Cascarilla espelta	91,53	5,16	32,64	68,90	38,64	1,44	7,25	0,14	0,21	0,16	4,04	2,47
Granulado alfalfa	91,77	11,91	32,24	51,35	38,18	2,11	-	0,31	1,49	0,17	4,08	2,75
Paja de cereal	91,85	2,97	41,33	73,52	48,80	1,38	2,78	0,09	0,24	0,06	2,74	0,88
Aceites												
Aceite soja	99,82	-	-	-	-	99,44	-	-	-	-	32,27	32,15

Tabla 3. Composición de los ácidos grasos de ingredientes ecológicos para piensos (% sobre el total de ésteres metílicos de ácidos grasos detectados).

	AGS (%)	AGMI (%)	AGPI n-3 (%)	AGPI n-6 (%)	AGPI (%)	AGPI/AGS
Cereales						
Avena	19,54	38,16	2,01	40,27	42,28	2,17
Cebada	27,36	14,71	6,45	51,48	57,92	2,45
Centeno	17,97	14,15	11,04	56,84	67,88	3,78
Maíz grano	14,44	27,63	1,68	56,26	57,93	4,08
Trigo	19,93	15,71	4,99	59,40	64,39	3,24
Triticale	18,01	13,67	7,13	61,19	68,32	3,82
Subproductos de cereales						
Germen de maíz	15,12	28,2	1,12	55,56	56,67	3,75
Harinilla de maíz	13,4	25,36	1,69	59,55	61,24	4,57
Salvado de trigo	21,14	16,58	4,76	57,54	62,3	2,95
Concentrados de proteína vegetal						
Girasol entero	12,24	28,52	0,08	59,17	59,25	4,84
Guisantes	18,87	25,51	9,77	45,83	55,60	2,95
Alverjón	17,73	31,27	7,67	43,34	51,00	2,88
Habas	20,48	25,64	4,72	49,17	53,89	2,63
Soja entera	13,63	19,27	10,21	56,89	67,10	4,94
Torta de presión de girasol	14,44	44,1	0,36	41,11	41,47	2,87
Torta de presión de soja	18,50	18,91	10,75	51,84	62,59	3,38
Yeros	40,17	15,33	19,68	24,70	44,38	1,10
Ingredientes fibrosos						
Cascarilla de espelta	27,57	24,91	7,64	39,60	47,24	1,73
Granulado de alfalfa	28,62	24,71	15,72	30,87	46,59	1,70
Paja de cereal	48,52	10,69	14,44	25,92	40,35	0,90
Aceites						
Aceite de soja	13,44	25,80	8,42	52,35	60,77	4,53

AGS: suma de ácidos grasos saturados (C10:0; C12:0; C14:0; C16:0; C17:0; C18:0; y C20:0); AGMI: suma de ácidos grasos monoinsaturados (C16:1n-7; C17:1n-7; C18:1n-9; y C20:1n-9). AGPI: suma de ácidos grasos poliinsaturados (AGPI: C18:2n-6; C18:3n-3; C20:2n-6; C20:3n-6; C20:4n-6; C20:4n-6 y C22:6n-3).

Tabla 4. Ingredientes y contenido nutricional de dietas para porcino reproductor y engorde en ecológico (% sobre materia fresca).

	LACTANTES		GESTANTES		LECHONES		CRECIMIENTO		ACABADO	
Ingredientes (%)	ITAB	FEDNA	ITAB	FEDNA	ITAB	FEDNA	ITAB	FEDNA	ITAB	FEDNA
Avena				28,4						
Cebada		31,7								
Centeno	24,0	12,0	30,6	10,0	22,1		24,8	16,0	20,6	20,0
Maíz						29,5		14,0		26,9
Triticale	25,4		8,5		28,5	9,3	26,1		22,0	
Salvado de trigo			35,0	28,9					13,6	
Guisantes	18,1	15,4	20,0	16,0	15,1	10,0	15,0	20,0	14,8	17,6
Alverjón	10,0	10	3,6	7,0		10,0	10,0	18,5	9,4	
Alholva	10,0	10				5,0	10,0	2,5	10,0	
Habas	9,8		7,0	7,0		5,0	11,2	10,5	6,9	10,0
Soja		9,9			15,0	15,0		10,0		10,0
Torta soja		5,7			16,2	11,1		2,5		11,0
Aceite soja		1,9				1,8		3,7		2,0
Carbonato cálcico	1,0	1,0	1,3	1,2	1,3	1,2	1,1	0,4	1,3	0,9
Fosfato bicálcico	1,4	2,0	0,6	1,2	1,5	1,8	1,4	1,5	1,1	1,2
Corrector vitamínico-mineral	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4	0,4
Composición nutricional										
Materia seca (%)	89,4	89,6	88,9	89,1	89,8	89,2	89,4	89,1	89,3	89,2
EN (MJ/kg)	9,6	9,8	9,5	8,9	9,7	10,0	9,1	10,0	9,0	10,0
Proteína (%)	15,7	17,5	13,4	14,7	19,0	19,5	15,5	18,4	15,6	17,0
Lisina (Lys) (%)	0,8	1,0	0,6	0,7	0,9	1,0	0,8	1,0	0,8	0,9
Lys/EN	0,86	0,97	0,63	0,79	0,96	1,00	0,89	1,04	0,85	0,91
Fibra Bruta (%)	6,0	7,6	5.9	8,7	5,0	5,0	6,0	6,7	6,2	5,6
FND (%)	18,1	19,8	21,7	26,1	11,4	15,0	18,0	16,0	19,9	15,3
EE (%)	2,9	5,9	2,9	3,4	5,7	7,8	2,9	7,7	3,2	6,7
Almidón (%)	46,0	34,0	46,4	34,4	40,7	35,0	45,5	35,0	44,2	37,5
Calcio (%)	0,9	1,1	0,8	0,9	1,0	1,1	1,0	0,7	1,0	0,8
Fósforo (%)	0,6	0,7	0,5	0,6	0,6	0,6	0,6	0,6	0,6	0,5
AGPI/AGS	3,39	2,82	3,26	2,77	3,71	3,67	3,40	3,34	3,40	3,58

3.2 Formulación de dietas

3.2.1. Formulación según requerimientos de FEDNA e ITAB

La propuesta de formulación de dietas de porcino reproductor (gestantes y lactantes) y engorde (lechones, crecimiento y acabado) a partir del valor nutritivo de los ingredientes ecológicos recogidos se resumen en la Tabla 4.

Comparando la EN (MJ/kg), PB (%) y Lys (%) de las dietas formuladas atendiendo a las necesidades propuestas por ITAB y FEDNA, se constata que en todas las fases fisiológicas son superiores en FEDNA. En engorde los requerimientos son hasta 18% y 30% superiores en ENg y Lys, respectivamente, y en la fase de reproductoras son hasta un 11% y 19% superiores en ENa y Lys. Se observa que la relación Lys/EN es superior en FEDNA que en ITAB en todas las fases (lechones: 7,4%, crecimiento: 16,6%, acabado: 8,9%, y lactación: 13,9%), excepto en gestantes (-8,6%). Con los alimentos analizados, ha sido posible formular dietas en todas las fases, según FEDNA e ITAB, excepto en lechones, por no llegar a cubrir las necesidades del primer aminoácido limitante en cerdo (Lys FEDNA=1,35% y Lys ITAB=1,1%), resultando las fórmulas propuestas un 29% y un 25% deficientes en Lys, respectivamente.

Las dietas en base a los requerimientos de ITAB se han formulado prescindiendo del haba de soja y de la torta de soja, excepto en el pienso de lechones. En base a los requerimientos de FEDNA, sólo ha sido posible formular dietas sin soja en la fase de gestantes. A pesar de los objetivos iniciales, no se ha podido prescindir totalmente del haba de soja ya que su aporte de lisina se aproxima muy bien a los requerimientos, tanto de ITAB como FEDNA.

Las fórmulas planteadas se ven condicionadas por la mínima información existente acerca de los límites de incorporación de ciertas leguminosas poco caracterizadas para alimentación animal (alverjón, habas, yeros, alholva).

Para reducir el número de dietas en la granja, se ha propuesto la dieta de gestantes y acabado a partir de dos dietas núcleo de lactantes y crecimiento, respectivamente, ajustando las concentraciones de alimentos fibrosos (Tabla 5). El uso de forrajes es obligatorio en producción ecológica, pero el potencial de éstos para contribuir a las necesidades nutricionales de los monogástricos no es muy claro y a menudo no se tiene en cuenta en el plan de alimentación ni en gestantes ni en la fase de engorde. En una dieta completa (unifeed) mezclando pienso (con ingredientes mayoritarios: triticale y guisante) y ensilado de alfalfa, en cerdos en crecimiento, no se encontraron diferencias significativas en el crecimiento en comparación con una dieta a base de únicamente pienso (Wüstholz *et* al., 2017), apoyando el hecho que los forrajes pueden contribuir en parte al aporte de aminoácidos (Edwards, 2003; Früh *et* al, 2014). No obstante, la producción de forrajes en explotaciones de monogástricos no es habitual, y la disponibilidad de una gran oferta de piensos tampoco es operativa en casos de explotaciones de pequeño tamaño. Por ello, en cerdas gestantes sería posible utilizar como base el pienso de cerdas lactantes (75%) y añadir como alimentos fibrosos un 20,7% de salvado de trigo y 4,9% de paja de cereal de invierno picada, mientras en acabado sería posible mezclar un 10% de salvado de trigo con un 90% de pienso de cerdos en crecimiento.

Tabla 5. Ingredientes y contenido nutricional de las dietas de cerdas gestantes y de cerdos de acabado derivadas de la mezcla de un pienso núcleo de lactación y crecimiento, respectivamente, con ingredientes fibrosos.

	GESTANTES	**ACABADO**
Ingredientes (%)	*75% pienso de lactación + 25% alimento fibroso*	*90% pienso de crecimiento + 10% subproductos cereales*
Centeno	18,0	22,0
Triticale	19,0	23,5
Salvado trigo	20,7	10,0
Paja de cereal	4,9	
Guisantes	13,5	13,5
Alverjón	7,0	9,0
Alholva	7,0	9,0
Habas	7,0	10,0
Carbonato cálcico	0,8	1,2
Fosfato bicálcico	1,1	1,4
Corrector vitamínico-mineral	0,4	0,4
Composición nutricional (% sobre materia fresca, excepto EN, en MJ/kg) de la mezcla de ingredientes fibrosos con el pienso núcleo		
Materia seca	89,0	89,4
Energía	9,1	9,0
Proteína	14,0	15,5
Celulosa Bruta	8,0	6,2
Fibra Neutro-detergente	25,0	19,2
Extracto Etéreo	3,2	2,7
Almidón	41,1	39,4
Calcio	0,8	1,0
Fósforo	0,5	0,6
Lisina	0,6	0,8
AGPI/AGS	2,99	3,35

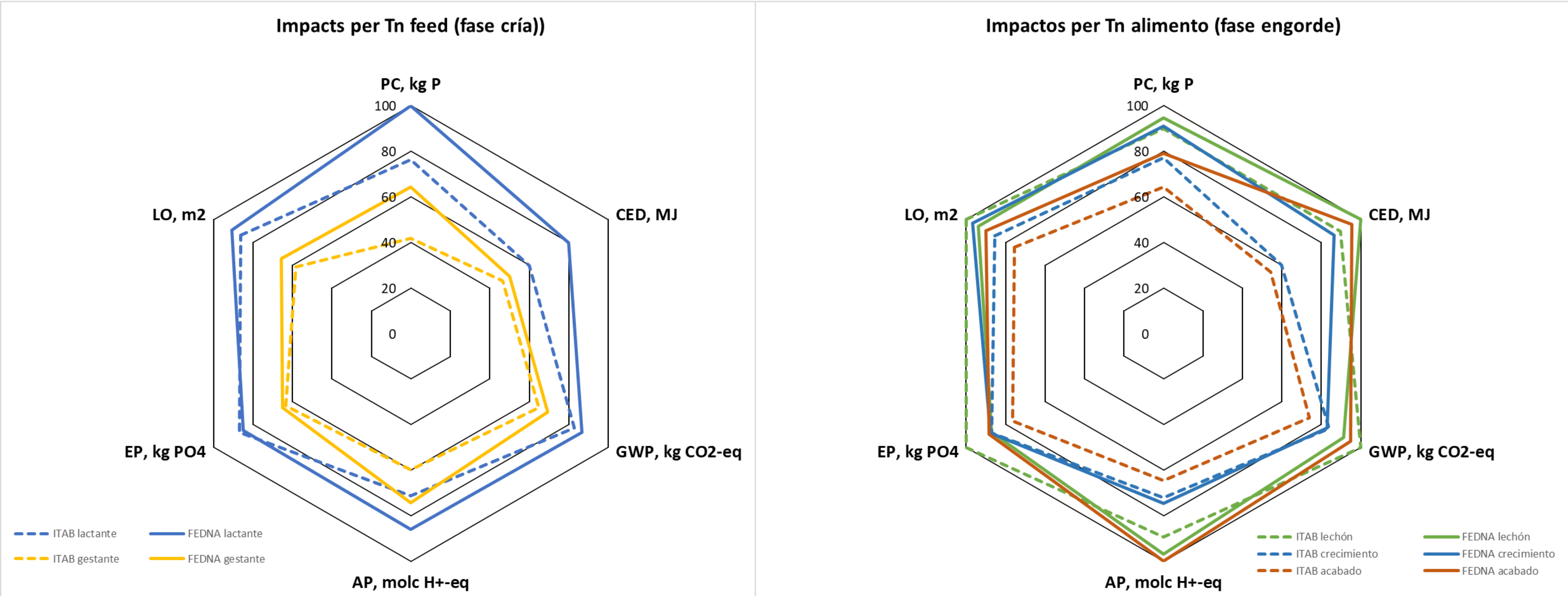
3.2.2. Evaluación impacto ambiental y evaluación económica de las dietas

La obtención de alimentos para la producción animal ocasiona un impacto ambiental asociado (importación de materias primas que compiten por la utilización de tierras para otros usos, consumo de combustibles fósiles, generación de gases de efecto invernadero, eutrofización, etc.). El análisis del ciclo de vida es la metodología más utilizada y reconocida para estimar el impacto de la producción animal (de Vries *et* al., 2010). El impacto ambiental de las dietas está influenciado por los tipos de ingredientes utilizados, donde algunos de ellos son incorporados en un pequeño porcentaje, pero su impacto ambiental por kg es elevado, por ejemplo, los fosfatos minerales (Garcia-Launay *et* al., 2014). En la actualidad existe información del impacto ambiental evaluado por análisis del ciclo de vida del porcino expresado por unidad de peso vivo producido. Sin embargo, en esos trabajos, se asume una composición de pienso estándar para realizar los cálculos, por lo que no se tienen en cuenta variaciones en los ingredientes que componen la fórmula. Los impactos ambientales estudiados: PC (kg), CED (MJ), GWP (kg CO_2-eq), EP (kg $PO_{4)}$, AP (molc H^+-eq) y LO (m^2), por tonelada de pienso de cada fórmula propuesta se representan en la Figura 1. Los impactos PC (kg P), CED (MJ) y AP (molc H+ eq), por T de pienso, se observa que son superiores según recomendaciones FEDNA respecto a ITAB. Esto puede deberse a que FEDNA propone piensos más concentrados en nutrientes, que requieren la inclusión de ingredientes más ricos en proteína, que tienen una mayor demanda de recursos (energía, agua y nutrientes) durante su proceso de producción. Por el contrario, en el caso del GWP (kg CO_2), LO (m^2) y el EP (kg PO_4) las dietas de lechones y crecimiento tienen más impacto según recomendaciones del Instituto francés (ITAB).

Las dietas formuladas con mayor impacto de PC son las de cerdas lactantes y lechones en base a FEDNA (9,03 y 8,55 kg P/T, respectivamente) y lechones según ITAB (8,13 kg P/T) y menor la de cerdas gestantes (3,78 kg P/T). Valores inferiores fueron encontrados por Garcia-Launay *et* al. (2016), dónde el impacto de una dieta estándar mixta (40% crecimiento / 60% acabado) convencional producía un impacto de demanda de fósforo de 3,4±0,36 kg P/T.

En cuanto al impacto CED, destacan las fórmulas, según FEDNA, de la fase de lechones y acabado (4.236 MJ/T pienso y 4.046 MJ/T pienso, respectivamente), próximas a los valores obtenidos por Garcia-Launay *et* al. (2016), de 4.442±351,2 MJ/T, formulando por objetivos económicos y ambientales. Para el impacto CED, valorado teniendo en cuenta el consumo de alimento anual, destaca la fase de acabado con 15.576 MJ/año y 8.844 MJ/año, según FEDNA e ITAB, respectivamente.

Figura *1*. Comparación Representación de los impactos ambientales por Tn de alimento fabricado, según recomendación FEDNA e ITAB-IFIP y fase fisiológica: (a) cerda y (b) crecimiento-engorde.



En la valoración del GWP, destaca con mayor impacto la dieta de lechón (ITAB) y acabado (FEDNA), de 424 kg CO_2/T y 403 kg CO_2/T, respectivamente, y el menor impacto del pienso de cerdas gestantes ITAB, con 275 kg CO_2/T. En dietas estándar (con leguminosas, tortas de oleaginosas, cereales y sin aminoácidos de síntesis química), Reckmann *et* al. (2016) obtuvieron valores similares en crecimiento (452 kg CO_2/T pienso) y acabado (479 kg CO_2/T), y superiores en gestantes (467 kg CO_2/T). Formular 1 kg de pienso para lechones según las recomendaciones de ITAB produce un mayor impacto del potencial de cambio climático (GWP), comparado con FEDNA; debido a la utilización de un porcentaje superior de centeno y triticale (51% en total), que tienen un menor rendimiento estimado de la cosecha (-20%, comparado con cebada), lo que implica un mayor impacto del potencial de cambio climático por unidad de producto, de forma similar a otros estudios, como Müller *et* al. (2010) y Asseng *et* al. (2015). En este sentido, Espagnol *et* al. (2018) han observado que el impacto de cambio climático es inferior para leguminosas como el guisante o habas debido a su capacidad para fijar el nitrógeno atmosférico, lo que reduce de forma importante las necesidades de fertilización de suelos y las emisiones de NO_2 asociadas. Según García-Launay *et* al. (2016), el impacto GWP de una dieta estándar mixta (40% crecimiento / 60% acabado) produce un impacto de 426±4,6 kg CO_2-eq/T de pienso.

Las fórmulas de acabado y lechones, según FEDNA, obtienen mayor impacto de AP, con valores de 8 molc H^+eq/T de pienso producido, similares a los obtenidos por García-Launay *et* al. (2016), de 9,0±0,58 mol H^+/T. Valorando el impacto por el consumo anual, resulta un 50% superior la dieta de más impacto (acabado) según FEDNA en comparación con ITAB (30 vs. 20 molc H+eq, respectivamente).

En la valoración del impacto EP (kg PO_4/T), destacan las fases de lechones y acabado, con un 5,1 kg PO_4/T y 4,5 kg PO_4/T, según ITAB y FEDNA, respectivamente. El valor similar de EP entre dietas puede ser debido, como en el caso de la acidificación, a su estrecha relación con la aplicación de fertilizantes minerales, prohibidos en producción ecológica. Reckmann *et* al. (2016), en la fase de crecimiento, obtuvo valores inferiores, de 3,95 kg PO_4/T, y en la fase de acabado, valores superiores, de 5,38 kg PO_4/T.

El último impacto valorado ha sido la ocupación de tierra (LO, m^2), dónde el valor más bajo se ha observado en la fase de acabado, con un valor de 1.748 m^2/T (ITAB), próximo al resultado de García-Launay *et* al. (2016), de 1.418±59,5 m^2. La dieta con mayor impacto es la de lechones, tanto en FEDNA como ITAB, de 2.310 y 2.171 m^2/T, respectivamente. Reckmann *et* al. (2016) observó que en la fase de crecimiento requiere una ocupación de 1.400 m^2/T, en lactación de 1.440 m^2/T, en gestación de

1.210 m^2/T y acabado de 1.510 m^2/T. Los sistemas ecológicos producen un menor rendimiento de los cultivos por superficie y eso requiere de mayor superficie que el sistema convencional (Müller *et* al., 2017).

La valoración de los diferentes impactos por el total de consumo anual es proporcional al consumo de pienso en las diferentes fases, siendo de menor a mayor (gestantes<lactantes<lechones<crecimiento<acabado). Früh *et* al. (2015) estimaron el consumo medio por cerdo de engorde en 300 kg y en cerda de 1.000 kg/año; en nuestro estudio los valores de consumo medio equivalen a 316,4 kg por cerdo engorde y en cerda de 1.150 kg al año.

Desde un punto de vista medioambiental, son más sostenibles las dietas formuladas según recomendaciones ITAB (Francia) que según recomendaciones FEDNA (España). Existe una relación inversamente proporcional entre la proximidad de las materias primas consumidas y el impacto ambiental de las mismas. Se desprende la necesidad de una materia prima proteica local para formular dietas en porcino ecológico en la fase de lechones, para contribuir a una verdadera producción ecológica, con bajo impacto ambiental asociado, ya que la soja requerida no se produce actualmente en España. No obstante, existe posibilidad de cultivo de leguminosas (alfalfa, trébol, esparceta), que pueden podrían ser buenas alternativas para garantizar las necesidades proteicas en el resto de las fases de producción (gestantes, lactantes, crecimiento y acabado). Sin embargo, la utilización de estos forrajes requeriría la implantación de mezcladoras unifeed en las explotaciones que permitieran picar el forraje y mezclarlo con el pienso, o disponer de comederos adaptados para la oferta de pacas de forraje, como ya se hace en explotaciones de centro Europa (Rivera *et* al. 2001, Rivera *et* al. 2006, Wüstholz *et* al., 2017)

Parte de la producción porcina ecológica (igual que la convencional) se basa en alimentación con piensos compuestos y mínimo uso de forrajes, y el aporte nitrogenado de las dietas deriva en gran parte de la soja y sus procesados, importados de Brasil, Italia o China, dónde el transporte en términos de huella de carbono (394 g CO_2-eq/kg alimento) es aproximadamente el mismo que la huella de carbono por cultivo y procesado (326 g CO_2-eq/kg alimento) (Kristensen *et al.*, 2011); además de la ocupación de territorio de la siembra de materias primas, en competición con los cultivos destinados a la producción humana (Hermansen *et* al, 2013).

La producción de piensos de porcino y aves contribuye de forma importante al impacto ambiental de la producción animal: representando el 50-85% del impacto sobre el cambio climático, el 64-97% del potencial de eutrofización, el 70-96% de la demanda de energía y casi el 100% de la ocupación de tierra, variando según el tipo de sistema de producción y localización geográfica (Wilfart *et* al., 2016). La soja y sus derivados son incorporados en un rango de un 10-29% en la ración de porcino, el incremento del cual se ha visto favorecido por el descenso del precio, generando un impacto potencial importante en cuanto a cambio climático (Basset-Mens *et* al., 2005; Thoma *et* al., 2011; Nguyen *et* al., 2011; Dourmad *et* al., 2014). La dieta con mayor impacto ambiental es la de lechones y la de menor impacto es la de cerdas gestantes, dónde en energía renovable resultan valores de 4.236 MJ *vs.* 1.971 MJ, respectivamente, en cambio climático 424 kg CO_2 *vs.* 275 kg CO_2; acidificación de 7,7 molc H^+-eq *vs.* 4,7 molc H+-eq; eutrofización 5,1 kg PO_4 *vs.* 3,2 kg PO_4 y ocupación de tierra 2.310m^2 *vs.* 1.349m^2 (Figura 1).

Tabla 6. Costes de compra de pienso vs en comparación con la autoproducción en una granja porcina ecológica de ciclo cerrado produciendo 20 cerdos por cerda y año.

Fase fisiológica	Consumo anual	Compra fábrica	Autoproducción
Gestante	450	172,26 €	107,52 €
Lactante	700	305,76 €	156,14 €
Lechón (<30 kg; hasta 12 semanas de edad)	1.008	1.095,90 €	943,88 €
Crecimiento (<60 kg; hasta 19 semanas de edad)	1.470	733,82 €	328,64 €
Acabado (< 110 kg; hasta 30 semanas de edad)	3.850	1.686,30 €	917,65 €
Coste de arrendamiento de tierras		0 €	440€
	TOTAL	3.994,04 €	2.893,84 €

*Incluye transporte e impuestos.

En la Tabla 6 se resumen los resultados de los costes de compra de alimentos en fábrica de piensos y costes de autoproducción, según recomendaciones nutricionales ITAB, para una cerda reproductora y su descendencia durante un año (20 cerdos). Se observa que la compra de pienso resulta un 28% más cara, si se compara con un modelo de producción autosuficiente a nivel de finca. En la valoración económica de las dietas ecológicas, resultaría más rentable un modelo de negocio con integración agropecuaria, especialmente en las fases de cerdos de crecimiento y acabado, ya que es dónde se abaratan más los costes. Para la producción del alimento consumido (7.450 kg de pienso anuales) por una cerda reproductora y 20 cerdos de descendencia, se requiere una superficie necesaria de 2,55 ha de cultivo de cereales (1 ha) y leguminosa (1,5 ha).

4. Conclusiones

Es posible formular dietas para porcino ecológico, utilizando como fuente proteica alverjón, habas, guisantes y alholva, y como fuente energética triticale, centeno, trigo y cebada, siguiendo las recomendaciones nutricionales de ITAB, excepto en la fase de lechones (<30kg). En el modelo francés, la relación Lys/EN es menos exigente y se requiere una menor proporción de concentrado proteico vegetal (41% según ITAB vs. 52 % según FEDNA) y más ingredientes fibrosos.

En la valoración ambiental de los impactos por unidad de pienso producido se observa que son superiores siguiendo las normas FEDNA que ITAB para la demanda de fósforo (kg P), energía no renovable (MJ) y acidificación (molc H+ eq). Por el contrario, en el impacto por cambio climático (kg CO_2), eutroficación (kg PO_4) y ocupación de tierra (m^2), las dietas de lechones y crecimiento tienen más impacto según recomendaciones del Instituto francés (ITAB). La dieta con mayor impacto ambiental es la de lechones y la de menor impacto la de cerdas gestantes.

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4. Capítol III. Canal.

Factors de variació en la producció de canals de porcí ecològic i convencional

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Abstract

This work aimed at analyzing the effects of husbandry system (conventional *vs*. organic), season (summer *vs*. autumn), gender (castrates *vs.* females) and genetic type (0 to 75% of Duroc genes) on different carcass variables of finishing pigs (live-weight, back-fat thickness, lean content and income) and the prevalence of condemnation outcomes at the abattoir. The study was conducted over 12 days from June to November 2016 in a Catalan abattoir, 6540 carcass pigs were examined, from conventional farming (*n=4707*) and organic (*n=1833*), from 94 batches. Organic husbandry increased lumbar back-fat thickness and reduced lean content in summer compared to autumn season (all $P<0,001$). Duroc genes affected positively the live-weight ($P=0,02$) and back-fat thickness ($P<0,001$). In summer, back-fat thickness (both lumbar and rib) was greater while lean content was lower in castrates than in gilts ($P<0,001$). Skin lesions were lower ($P=0,08$) but liver condemnations were greater in organic than in conventional husbandry (relative risk=5,98). In addition, there was less risk of skin lesions and liver and lungs condemnation in summer than in autumn. Collectively, these results were also mostly affected by the supplier.

Keywords: pigs, husbandry system, skin damage, carcass traits.

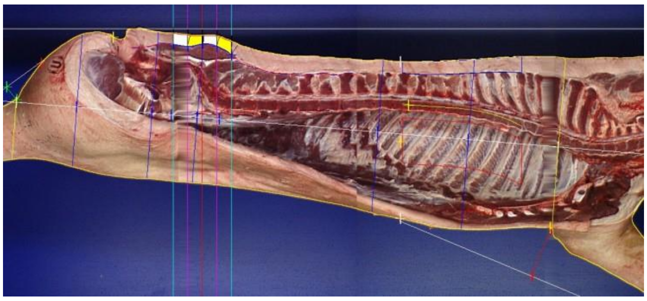
1. Introducció

El sector porcí representa el 13% de la Producció Final Agrària (PFA) i dins de les produccions ramaderes ocupa el primer lloc en quan a importància econòmica, amb el 35,6% de la Producció Final Ramadera a Espanya i el 8,2% de la PFA a la Unió Europea (MAPAMA, 2016; Eurostat, 2016). La carn de porc ocupa el primer lloc en tipus de carn produïda a Espanya i la UE-28. Tot i que, la cabanya porcina ecològica representa un 0,66% del total de porcs de UE-28 i el 0,04% a Espanya (Eurostat, 2016; MAPAMA, 2016). La producció ramadera està vivint canvis que responen a diferents exigències de la demanda i en la qualitat dels aliments, obrint un nou nínxol en el mercat. Les transaccions comercials de carn de producció convencional es realitzen mitjançant el sistema de classificació de canals S.E.U.R.O.P., uniformant la valoració de la qualitat de les mateixes segons el rang de percentatge de magre, amb fluctuacions periòdiques en els preus. Per la seva part, la comercialització ecològica no disposa de classificació estandarditzada i existeixen menys fluctuacions en els preus.

Aquest treball es va plantejar per analitzar els efectes del model de producció, l'època de l'any, el sexe i el tipus genètic, sobre diferents variables relacionades amb la canal de porc blanc (pes, grassa dorsal, magre i ingressos) i la prevalença de lesions i malalties en els decomisos a escorxador.

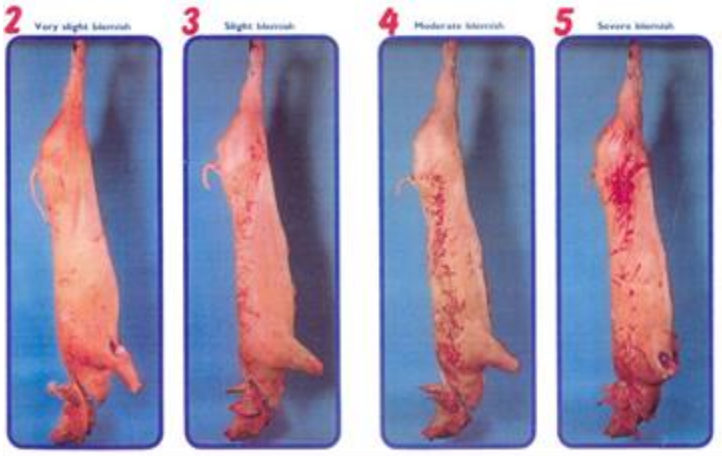
2. Materials i mètodes

Les dades van ser obtingudes aleatòriament en un escorxador comercial (Escorxador Frigorífic d'Avinyó, S.A., Barcelona), durant dos períodes consecutius, l'estiu i la tardor del 2016 (diferents dies de juny a novembre, *n= 12*). Es van inspeccionar 6.540 canals de porc (producció convencional, *n= 4.707*; producció ecològica, *n= 1.833*) de 94 lots d'un total de 24 proveïdors (convencional, *n= 17*; ecològic, *n= 7*). Els tipus genètics presentaven gran variabilitat, encara que aproximadament la meitat dels porcs controlats en ambdós models productius tenien un 50% de gens Duroc (41% *vs*. 65% en convencional y ecològic, respectivament). La proporció d'animals sense genètica Duroc va ser del 53% en convencional i del 29% en ecològic, respectivament. L'atordiment es va fer amb CO_2, pel posterior dessagnat, escaldat, pelat i evisceració, d'acord amb els procediments comercials estàndards, i les canals es van dividir per la meitat, es van pesar i classificar mitjançant un instrument autoritzat (Reglament CE 1249/2008) de visió artificial (VCS2000, E+V Technology GmbH, Oranienburg, Alemanya), que recollia com a mesures més representatives, l'espessor de grassa subcutània, lumbar a nivell de la última vèrtebra i dorsal entre la 3a i 4a última costella (Il·lustració 1).



Il·lustració 1. Mesures canal de porc, VCS 2000.

Les lesions de pell es van valorar segons *the UK Meat and Livestock Commission* (MLC, 1985), amb una escala de 1 a 5 (Il·lustració 2), i per la valoració estadística es va classificar en dues categories, 1=absència (valor 1 a 2 escala) i 2=presència (valor 3 a 5). Es van recollir, a més, la proporció de decomisos de vísceres (fetges, vesícules biliars i pulmons) i canals (abscessos, carn hemorràgica, animals coixos), determinades i comptabilitzades pels veterinaris oficials de l'empresa.



Il·lustració 2. UK Meat MLC 1985 and Livestock Commission, MLC 1985.

Les dades es van analitzar amb el paquet estadístic JMP Pro12 (SAS Institute Inc, Cary, NC, EEUU). El pes de la canal, la seva espessor de grassa subcutània, el percentatge de magre i els seus ingressos a venda, es van sotmetre a un anàlisis de variància, amb un model mixt que va incloure els efectes del model productiu (convencional vs. ecològic), l'època (estiu vs. tardor) i el sexe del porc (castrat vs. femella) i les seves interaccions dobles. Es va incloure com a covariable l'efecte del percentatge de gens Duroc (0 a 75%) i com a efecte aleatori el proveïdor (1 a 24). El nivell de significació pels efectes va ser de 0,05. Es descriuen les mitjanes mínim-quadràtiques i el seu error estàndard. La separació de mitjanes es va realitzar amb el test de Tukey.

Per un altra banda, es va comprovar l'associació entre les anteriors variables i els danys a la pell (presència vs. absència), així com els decomisos de vísceres (fetges, vesícules biliars i pulmons) i canals (abscessos, carn hemorràgica, coixos) mitjançant taules de contingència i un test chi-quadrat de Pearson, a més a més es va plantejar un model logístic de regressió per determinar el risc relatiu.

3. Resultats i discussió

Els factors de variació que afecten a les variables de la canal es resumeixen a la Taula 1. El **pes de la canal** no es va veure afectat pel model de producció i sí per l'efecte època de l'any. Mentre a la tardor no hi va haver diferències entre sexes en el pes de la canal (83,8 kg *vs.* 83,4±1,6 kg, en mascles castrats i femelles, respectivament), a l'estiu el pes dels mascles castrats va ser superior al de les femelles (84,0 kg *vs.* 81,2±1,6 kg, respectivament). El percentatge de gens Duroc va tenir un efecte significatiu en l'augment del pes de la canal (+0,5±0,2 kg per increment d'un 10%; *P*=0,02). Segons dades del MAPAMA (2016), a Espanya, durant el 2015, el pes mitjà de la canal de porcs comercials d'engreix va ser de 86 kg, i als extrems destaquen Catalunya, amb un 80,6 kg/canal, i Extremadura i Cantàbria amb un 130,9 kg/canal y 121,1 kg/canal, respectivament.

Taula 1. Classificació de canals de porcs a escorxador i el seu efecte sobre el model productiu, període i sexe.

	Model productiu				**Període**				**Sexe**			
	Eco	Con	EE	*Sig*	Est	Tar	EE	*Sig*	M	F	EE	*Sig*
Pes canal (kg)	82,3	83,9	1,6	*NS*	82,6	83,6	0,2	**	83,9	82,3	0,2	***
Grassa subcutània dorsal (entre 3a – 4a última costella)	27,5	26,4	0,8	*NS*	27,2	26,6	0,1	***	27,6	26,2	0,1	***
Grassa subcutània lumbar (última vèrtebra*)*	16,6	15,4	0,9	*NS*	16,6	15,5	0,1	***	16,9	15,1	0,1	***
Magra canal (%)	58,4	59,9	0,7	*NS*	58,9	59,4	0,1	***	58,5	59,7	0,1	***
Ingressos venta (€)	264,0	131,0	3,4	***	201,0	193,8	0,3	***	199,7	195,1	0,3	***

Con=convencional, Eco=ecològic; EE=error estàndard, Sig=significació; Est=estiu, Tar=tardor; % DC= percentatge gens Duroc. F=femelles, M=mascles; *, *P*<0,05; **, *P*<0,01; ***, *P*<0,001; NS, no significant (*P*>0,05).

Sobre el contingut de **grassa subcutània a nivell de la última vèrtebra lumbar**, es va observar una interacció entre el modelo productiu i l'època de l'any (*P*<0,05), amb una espessor superior a l'estiu que a la tardor en ecològic (17,4±1,5 *vs.* 15,9±1,5 mm; *P*<0,001), mentre la diferència entre èpoques va ser inferior en convencional (15,7 *vs*. 15,1±1,0 mm, respectivament). En el porcí ecològic és possible que en l'època càlida de l'any, degut a una menor ingestió, sigui més difícil garantir la cobertura de les necessitats de nutrients (especialment, d'aminoàcids essencials sense la utilització de la seva forma sintètica), i en conseqüència els porcs ecològics podrien haver crescut més lentament i/o haver-se engreixat més (Millet et al., 2005). La interacció sexe i època de l'any va afectar significament l'espessor de grassa lumbar, on els mascles van presentar una espessor superior a l'estiu que a la tardor (18,0±0,9 *vs.* 15,8±0,9 mm; *P*<0,001), i les femelles la diferència no va ser significativa (15,1±0,9 *vs.* 15,2±0,9 mm; *P*>0,05). El percentatge de gens Duroc va incrementar significativament l'espessor de grassa subcutània lumbar (+0,6±0,1 mm per increment d'un 10%; *P*<0,001).

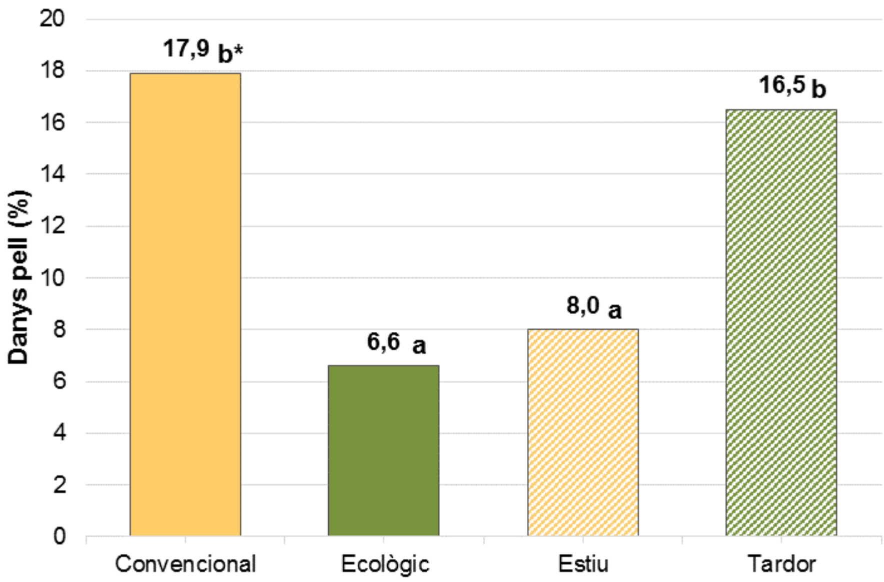
L'increment d'**espessor de la grassa subcutània dorsal**, entre la 3a i l'última costella, no es va veure afectat pel model productiu (*P*>0,05). Es va observar una interacció entre el sexe i l'època de l'any sobre l'espessor de grassa dorsal, mostrant els mascles castrats a l'estiu un espessor superior que a la tardor (28,4±0,8 *vs.* 26,9 ±0,8 mm, respectivament; *P*<0,001), mentre que en les femelles no hi van haver diferencies entre èpoques de l'any (26,0 *vs.* 26,4±0,8 mm, respectivament; *P*>0,05). De forma equivalent a l'espessor de grassa lumbar, el percentatge de gens Duroc va incrementar l'espessor de grassa subcutània dorsal (+0,6±0,1 mm per increment d'un 10%; *P*<0,001); encara que altres estudis de comparatiu entre Pietrain i Duroc no es van observar diferències significatives (Latorre et al., 2009), provablement perquè en aquell cas es tractava de porcs pesats (140 kg de pes viu i pesos de canal superior a 100 kg).

El **percentatge de magre** es va veure afectat per la interacció entre el model productiu i l'època de l'any (*P*<0,01), on en ecològic el percentatge de magra és inferior a l'estiu que a la tardor (58,0 *vs.* 58,8±1,0%; *P*<0,001), mentre en convencional, entre estiu i tardor, no es van observar diferencies (59,7 *vs.* 60,0±0,7%, respectivament; *P*>0,05). El mateix efecte es va observar en femelles en sistema ecològic, on en època freda presentaven un contingut de magre superior que en època més càlida (Hansen et al. 2006). Així mateix, es va detectar una interacció entre l'època de l'any i el sexe (*P*<0,001), on el contingut de magra va ser superior en femelles que en mascles (59,9 *vs.* 57,9±0,6% a l'estiu i 59,6 *vs.* 59,2±0,6% a la tardor, respectivament, *P*<0,001), encara que la diferència va ser superior a l'estiu que a la tardor (*P*<0,01). En femelles s'ha observat % de magre superior que en mascles castrats (Álvarez-Rodríguez et al., 2015). En altres treballs s'ha observat que en diferents models productius (exterior i/o amb patis), el percentatge de magra era superior en femelles que en mascles castrats (Strudsholm and Hermansen 2005).

En quan als **ingressos per venda**, es va observar un efecte significatiu en la interacció entre modelo productiu i l'època, on en la producció convencional els ingressos són superiors a l'estiu que a la tardor (139,5 *vs.* 122,3±3,8€/canal; *P*<0,001), mentre en producció ecològica els ingressos són més baixos a l'estiu que a la tardor (262,5 vs. 265,4±5,7 €/ canal). A l'estiu, la diferència positiva d'ecològic respecte la convencional és de 123 €/canal (+88%), mentre que a la tardor, l'ingrés extra ascendeix a 143,1 €/canal (+117%).

La **repetibilitat** de l'efecte aleatori proveïdor per les variables de pes canal va ser de 0,37, per la grassa subcutània dorsal entre la 3a i 4a última costella va ser de 0,36, per la grassa subcutània a nivell de l'última vèrtebra lumbar va ser de 0,37, i pel percentatge de magra va ser de 0,40. Per la seva part, la repetibilitat del proveïdor per l'import d'ingressos per canal va ser de 0,42. Aquests valors expliquen una part important de la variabilitat residual no recollida en el model amb els efectes fixes, el què evidencia l'elevat impacte del proveïdor sobre els resultats tècnics-econòmics de les canals a escorxador.

Els **danys a la pell** van tendir a diferir entre models de producció (Taula 2, Il·lustració 3, P=0,08), però es pot observar que hi ha major risc de lesions en convencional que en ecològic (P<0,05), encara que el risc relatiu és només del 1,09 (IC al 95% de 0,98-1,2). Per la variable època de l'any, hi ha més risc relatiu de danys a la pell a la tardor que a l'estiu (P<0,01). En el cas de l'efecte sexe, prevalen significativament les lesiones de pell en femelles (P<0,001) que en mascles castrats (18,76% *vs*. 5,76%, respectivament, P<0,001); al contrari d'altres estudis en el cas de lesions a la cua, on prevalen les lesions de cua en mascles més que en femelles (Harley et al., 2012). Aquesta diferencia pot ser deguda a que aquest escorxador únicament processa mascles castrats.

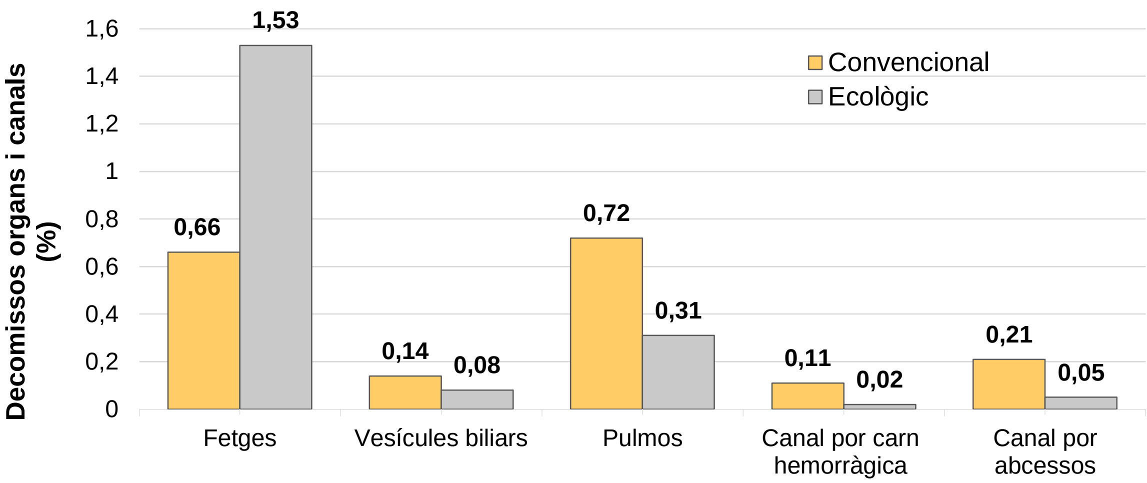


Il·lustració 3. Danys pell segons model producción i época de l'any.

Els **decomisos** de vísceres i/o canals van ser del 3,99% (n=261), i d'aquestes, un 11,49% corresponen a decomisos complets de canals. En la proporció de **fetges** decomissats (majoritàriament, por ascariasis) hi ha diferencies entre models productius (Taula 2, P<0,001), essent 5,98 veces superior el risc relatiu (RR) de decomís en ecològic que en convencional (IC al 95% de 4,2 a 8,5 veces més), confirmand els resultats trobats en altres estudis on preval el risc per ascariasis en porcí ecològic (Eijck and Borgsteede 2005; Alban, Petersen, and Busch 2015a;).

També existeix un risc de decomisos de fetges 2,4 vegades superior a la tardor que a l'estiu (IC al 95% de 1,54 a 3,74). Aquest decomís podria explicar-se perquè en ecològic no està permesa la desparasitació química preventiva, essent més difícil el control de certs paràsits, com *Áscaris suum* (pneumàtode intestinal), on un incorrecte buit sanitari de la zona d'estabulació (exterior i interior pavimentada) afavoreix el cicle biològic d'aquests patògens, elevant-se el risc de contaminació en èpoques amb temperatures càlides i humides (finals d'estiu plujós) (Alban, Petersen, and Busch 2015b).

En els decomisos de **pulmons** (majoritàriament, per pleuritis) no hi ha diferències significatives entre models de producció. No obstant, hi ha diferències significatives entre èpoques de l'any (P<0,001), on el RR de decomisos de pulmons és 5,71 vegades superior a la tardor que a l'estiu (IC al 95% de 2,3 a 14,2 vegades més), el que podria estar relacionat amb brots de malalties respiratòries en època humida. Per altre lloc, és ressalta el fet que en producció convencional es decomissen una major proporció de pulmons que fetges, mentre que en ecològic la resposta va ser a la inversa. Això es podria atribuir al major risc de malalties respiratòries per a un menor espai disponible en convencional respecte ecològic (0,65-0,75 m^2/animal *vs.* 2,3 m^2/animal).



Il·lustració 4. Decomisos d'òrgans i canals segons el model productiu.

En el cas de les **vesícules biliars**, no hi ha cap efecte significatiu del model de producció sobre el seu decomís (P>0,05), però s'observa una major proporció de decomisos d'aquest òrgan a l'estiui que a la tardor (P<0,001), encara que el risc de decomisos no pot considerar-se significativament diferent de 1. Els decomisos per **carn hemorràgica i abscessos** no s'han vist afectats ni pel model productiu (P<0,05) ni per l'època de l'any (P>0,05).

Taula 2. Proporció d'animals amb danys a la pell i vísceres i/o canals decomissades segons el model productiu i l'època de l'any.

	Model productiu			**Època de l'any**		
	Con	**Eco**	Sig	**Estiu**	**Tardor**	Sig
Danys a la pell (%)	17,91	6,61	0,08	8,01	16,51	*P*<0,001
Fetges decomissats %	0,66	1,53	*P*<0,001	0,35	1,83	*P*<0,001
Vesícules biliars decomissades (%)	0,14	0,08	0,52	0,21	0,0	*P*<0,001
Pulmons decomissats (%)	0,72	0,31	0,78	0,08	0,95	*P*<0,001
Decomisos de canal per carn hemorràgica (%)	0,11	0,02	0,46	0,08	0,05	0,06
Decomisos de canal por abscessos	0,21	0,05	0,42	0,11	0,15	0,40

Eco=ecològica; Con=convencional; Sig=significació.

4. Conclusions

En conclusió, el model productiu ecològic va incrementar l'espessor de la grassa subcutània lumbar (a nivell de l'última vèrtebra) i va reduir el contingut de magra a l'estiu. En ecològic existeix un menor risc de lesions de pell, però un major risc de decomisos de fetges per ascariasis. També s'ha observat un efecte de l'estiu en els porcs mascles castrats, en els que el contingut de grassa subcutània lumbar i dorsal és superior, i el percentatge de magra és inferior en aquesta època. A l'estiu hi ha menys risc de lesions en pell i decomisos de fetges i pulmons. Tots aquests resultats es van veure afectats pel proveïdor.

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5. Capítol IV. Qualitat tecnològica i nutricional de la carn.

5.1 Qualitat tecnològica de la carn (article III).

Genetic but not lean grade impact on growth, carcass traits and pork quality under organic husbandry

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Abstract

Organic pig production may be conducted with different genetic types and the carcass outcome can differ in fatness content, however, the contribution of each effect to meat quality characteristics is not well established. The objective of this study was to evaluate two genetic types (Duroc x (Gascon x Duroc), Duroc-sired vs. Pietrain x (Landrace x Large White), Pietrain-sired) slaughtered at a different weights to achieve similar target carcass fatness (90 kg or 105 kg of body-weight, respectively), and the effect of two carcass lean grades (<60% or ≥60% lean) on growth rates, carcass and pork quality under organic husbandry. The daily gain and carcass yield were lower in Duroc than in Pietrain-sired pigs. The post-mortem and ultimate pH, moisture, lightness (L*), yellowness (b*), cooking loss and intramuscular fat content of loin meat were not influenced by genetic type, while redness (a*) and tenderness (shear force) were lower in Duroc than their Pietrain counterparts. Partition tree analysis showed that the highest shear force (≥ 4.63 kg) and the highest fat depth at *Gluteus medius* muscle (≥16 mm) were associated with Duroc-sired pigs. The lowest redness (a*<2.23) was associated with leaner (≥60%) pork. The crossbred finishing pig including 75% Duroc genes showed lower growth performance, carcass weight and dressing out than the Pietrain sired crossbreds. Lean grade was not associated with earlier differences in growth, carcass performance or meat quality, except for a tendency for greater compression at 80%force in leaner raw pork.

Highlights

- The crossbred finishing pig including 75% Duroc genes and a local breed (Gascon) in maternal sire showed lower growth performance, carcass weight and dressing out than the Pietrain sired crossbreds.
- Slaughtered at similar carcass fatness degree, the pork loin from Duroc genetic type had lower redness (a*) and it was tougher than their Pietrain counterparts.
- Lean grade was not associated with earlier differences in growth, carcass performance or meat quality, except for a tendency for greater compression at 80%force in leaner raw pork.
- Under the current organic husbandry system, the Pietrain-sired pigs may be recommended.

Keywords: carcass fatness; daily gain; meat colour; shear force; intramuscular fat.

1. Introduction

Crossbreeding with Duroc breed as sire line allows the improvement of meat quality traits (Ramírez and Cava, 2007), including tenderness (Dilger *et al.*, 2010) and darkening of colour (Blanchard *et al.,* 1999; Lindahl *et al.,* 2006), particularly with improved maternal crossbreds (Landrace x Large-White). Likewise, Duroc breed is used to produce dry-cured pork products, since accumulates greater intramuscular fat and fat quality traits than other sire breeds as Pietrain, which is normally very lean (Affentranger *et al.,* 1996; Latorre *et al.,* 2009). The genetic influence on pork quality is based on the differences among breeds as well as the differences among animals within the same breed (Murray *et al.* 2001) and feeding strategies (Edwards, 2005, Sundrum *et al.,* 2011). However, the suitability of local and selected swine breeds (either in maternal or sire lines) under organic production system has been debated, as the local breeds are generally characterised by inferior growth rates and feed efficiency (Leenhouwers and Merks, 2013). The performance and products of local pig breeds may be practically untapped and market potential of their products unexploited (Sans *et al.,* 2004; Kušec *et al.,* 2018). As consequence it could be relevant for marketing of meat and meat products from European local pig genetic resources (Gascon, Berkshire, Euskal Txerria, Porco Celta, etc), often reared in traditional small-scale production system linked to a specific environment (Bozzi and Crovetti, 2013).

According to Eurostat (2017), 58% of pig carcases in European Union were graded as S (Lean Meat Content (LMC) ≥60%), whereas in the studies by Millet *et al.* (2004) and

Farke and Sundrum (2005), LMC of carcasses in organic pig production was about 55% on average (E grade). While being primarily focused on the production of lean meat and because of antagonistic relationships between several quantitative and qualitative traits such as flavour, tenderness and juiciness, the payment system does not honour and even discourages the production of pork with a high eating quality (Bonneau and Lebret, 2010; Sundrum *et al.,* 2011).

Organic pig diets cannot include in-feed crystalline amino acids and, unless high dietary crude protein is supplied, the amino acid requirements of pigs fail to be met in some periods; thereby they normally show greater carcass fatness (Millet *et al.,* 2005; Lebret, 2008). On the one hand, the intramuscular fat (IMF) content may be a desirable trait as it is the prominent criterion for eating quality of pork, well known for enhancing softness, tenderness and overall liking of pork (Wood *et al.,* 2004; Font-i-Furnols *et al.,* 2012). Otherwise, the meat colour is the most important intrinsic quality factor at the moment of the purchase since the consumer uses it as indicator of freshness (Ripoll *et al.,* 2012), and both of them can be affected by animal genetics and lean grade.

Therefore, the aim of the present study was to evaluate the effects of genetic type and lean grade on animal growth, carcass and meat characteristics of organic pork loin, slaughtered at a similar target carcass fatness.

2. Material and methods

2.1. Animals, experimental design and sampling.

The study involved a total of 48 pigs born between 15th December 2016 and 10th January 2017 in 2 batches (3 weeks apart), from two genetic types (n=26 animals were Pietrain x (Landrace x Large White) (Pi x (LD x LW) and n=22 animals were Duroc x (Gascon x Duroc) (Du x (Gc x Du)). The pigs were selected from 12 sow litters, 6 per genetic type. Half of the animals were females; the other half were castrated males. The Pi-sired pigs derived from Pi line of Selecció Batallé (Riudarenes, Girona, Spain) and the Du genetic types derived from Du line of German Genetic (Stuttgart-Plieningen, Germany). In total, 32 pig carcasses (around 3 pigs/litter) and loin meat from 24 pigs (2 pigs/litter) were sampled. All pigs had the same commercial diet *ad libitum* (Table 1). Treatments pigs were kept in accordance with the European Community standards for organic livestock and livestock products (EC-regulation 889/2008 supplementing the EC-regulation 834/2007). Briefly, the pigs from both genotypes were housed together in three concrete floor pens with a space allowance ≥2.3 m^2/pig (straw-bedded indoor area 7.6 x 3.1 m^2; outdoor area 5.9 x 3.2 m^2). Each pen had a dry single-space self-feeder (indoor area) and a square nipple drinker (outdoor area).

Table 1 Feedstuffs and chemical composition of compound feed (g/100 g fresh matter, as-fed basis unless otherwise stated).

Ingredients	*(g/100 g fresh matter)*
Barley	34.8
Maize	20.0
Wheat	13.4
Maize germ meal	4.0
Soybean pressed cake	12.3
Pea	10.0
Vegetable protein concentrate	2.0
Oil soybean	0.5
Calcium carbonate	0.9
Dicalcium phosphate	1.3
Sodium chloride	0.4
Vitamins and minerals	0.4
Calculated composition	
Metabolizable energy (MJ/kg)	9.5
Total lysine (%)	0.7
Analysed composition	
Gross energy (MJ/kg)	16.3
Crude protein	14.0
Crude fibre (%)	4.0
Ether extract (%)	3.7
Ash (%)	4.8

2.2. On-farm and abattoir measurements.

The individual body-weight (BW) was determined at the start of the growing phase (initial age 68±15 days) and prior to slaughter (after 20 hours of fasting) to calculate the average dairy gain (ADG) and killing out proportion. The BW at slaughter was set at approximately 105 kg (Pi-sired) or 90 kg (Du-sired) to reach similar lean content (around 60% lean in both genetic types). Slaughtering was performed in a nearby commercial abattoir (68 km away) (Escorxador Frigorífic d'Avinyó S.A., Barcelona, Spain). Pigs were brought in the morning (between 9:00 and 11:00) with a small truck provided with a relatively flat loading ramp. At the abattoir, animals were allowed 3-4 hours rest period with full access to water but not to feed. Pigs were stunned by CO_2 (concentration 87%) using a dip lift system, exsanguinated, scalded, skinned, eviscerated according to standard commercial procedures and split down the midline. Hot carcass weight was individually recorded before the carcasses were refrigerated in line processing at 2º C. The carcasses were graded with an automated image analysis system (VCS 2000, E+V Technology GmbH, Oranienburg, Germany) and classified in two classes (<60% and ≥60% LMC). Backfat thickness was measured at 3rd-4th last rib and over the *Gluteus medius* muscle (at its thinnest point). At 45 min *post-mortem*, the loins were excised from the carcass following the standard procedures of the abattoir and they were trimmed by an expert staff to eliminate part of the external fat for commercial requirements. Immediately afterwards, individual 10-cm caudal *Longissimus lumborum* was sampled (approximately 500 g), packaged in polyethylene bags and stored at 4ºC in darkness overnight.

One-day post-mortem, the samples of *L. lumborum* muscle were sliced in five slices (2 cm thickness each, ~100 g). The first slice was used to determinate pH, colour and proximate composition (moisture, IMF). The remaining four slices (cut starting from the cranial end, individually assigned to analyses) were used to determine drip losses (thawing and cooking), Warner-Bratzler shear force and compression tests at two aging days (1 and 8 days). Meat samples were stored at 4ºC during either 24 h (2 samples) or 8 days (2 samples) in the vacuum-packed plastic bag and stored at -20ºC until textural measurements.

2.3. Meat quality analyses.

The pH at 45 min at 24 h after slaughter was measured at a mid-lumbar position in the loin muscle, with a pH-meter equipped with a spear-tipped probe (Testo 205, Testo AG, Lenzkirch, Germany). The electrode was calibrated with a standard buffer solution at 25 °C for the measurements. Colour measurements were taken in duplicate after 30 min blooming, at 4-6 °C, by determining the CiELab colour coordinates (L*, lightness; a*, redness; and b*, yellowness) with spectrophotometer (CM-2600d Konica Minolta Sensing Inc., Osaka, Japan) with a measurement area diameter of 8 mm, including a specular component and a 0% UV, standard illuminant D65 that simulates daylight (colour temperature of 6504 K), 10° observer angle, and zero and white calibration. Because the steak was sliced perpendicularly to the fibre direction, colour measurement was made on the same direction of the fibres. The integrating sphere has a diameter of 52 mm, and the measurement area was covered with a dust cover CM-A149.

The samples were thawed in vacuum-packaged bags for 24 h at 4°C, removed from the packages, blotted dry for 20 min, and weighed. Thawing losses were calculated by dividing the difference in weight between the fresh and thawed samples by the initial fresh weight. A compression test was carried out in loin slice samples (a minimum of eight replicates), 1 cm^2 in cross-section, were cut with muscle fibres parallel to the longitudinal axis of the sample and were analysed using a modified compression device described by Lepetit (1989). That device avoids transversal elongation of the sample. Stress at 20 % and 80% of maximum compression was assessed using an

Instron 5543 (Instron Limited, Barcelona, Spain) machine with a probe speed of 50 mm/min, expressed in kg/cm^2.

Warner-Bratzler shear force (WBSF) test was performed on cooked meat. The loin samples were cooked by placing the vacuum bags in a water bath (75ºC) with automatic temperature control to internal temperature of 70ºC, controlled by thermocouples connected to a data logger. After cooking, samples were cooled at room temperature overnight and the percentage of cooking loss was recorded. The difference between pre- and post-cooking weights was divided by the pre-cooked weight to calculate cooking losses percentage. Samples were then cut parallel to the long axis of the muscle fibers into rectangular cross-section slices of 10 × 10 mm x 30 mm (height x width x length). Pieces (8/slice) were sheared perpendicular to the fiber orientation, with a Warner-Bratzler device attached to Instron model 5543 (Instron Ltd., Buckinghamshire, UK), and equipped with a 500 N load cell and a crosshead speed of 150 mm/min.

Moisture content was quantified according to the ISO recommended standards 1442:1997 (ISO 1997). Fat content was quantified using the Ankom procedure (AOCS Am 5–04) (AOCS 2004) with an Ankom extractor (XT10, Ankom Technology, Madrid, Spain). Loin slices were trimmed of intermuscular and subcutaneous fat prior to IMF analysis. Analyses were run in duplicate.

2.4. Statistical analysis.

The data were analysed with the JMP Pro 13 statistical software (SAS Institute, Cary, NC, USA) with a standard model including genetic type, lean content and sex as fixed effects. Single interactions between fixed effects were removed from the final model because they were non-significant ($P>0.05$). Values are presented as least square means ± standard error of the mean (SEM). The level of significance was set at 0.05, but tendencies were commented if the level of significance was below 0.10. Differences between least square means were assessed with the Tukey test. Partial correlations between texture parameters were also evaluated.

Classification trees (partition option from multivariate methods) from JMP Pro software were used to predict both genetic type and carcass grading as a function of potential predictor variables (pH, colour, moisture, IMF, fat thickness, water-holding capacity and shear force at 1 day and 8 days aged raw and cooked) using recursive partitioning. The variables were selected according to G2 (likelihood-ratio chi-square) test of association and logworth (-log(p-value)) value. The logworth values are the logs of adjusted p-values for the chi-square test of independence. These are adjusted to account for the number of ways that splits can occur. The partition algorithm imputes (that is, randomly assigns) values for the missing values, and this allows the variables that are poorly populated to be noticed, if they indeed help explain banding.

3. Results

3.1. Pig growth rates.

The initial age was not different between genetic types nor between lean grades. The initial and final BW was affected by genotype, being higher in Pi x (LD x LW) than in Du x (Gc x Du) pigs (P<0.01). The initial BW was affected by lean grade (P<0.05), but final BW did not differ (P>0.05), as shown in Table 2. As expected, the average daily gain was affected by genetics, the Pi x (LD x LW) pigs growing faster than their Du x (Gc x Du) counterparts (P<0.01). The age at slaughter did not differ between the genetic types and lean content grades (P>0.05). The pigs classed as leaner (≥60% lean) were heavier at the start of the growing period than those fattier (<60% lean) (*P*<0.05) and tended to grow slower during the fattening period than fattier pigs (P=0.06). Although the initial BW was similar across sexes (15.5±0.67 vs. 14.8±1.06 kg, in barrows and gilts, respectively; P>0.05), the ADG and thereby the slaughter BW was higher in barrows than in gilts (702±19 vs. 568±34 g and 100.5±1.16 vs. 93.8±2.06 kg, respectively; P<0.01).

Table 2 Growth performance of organic pigs as affected by genetic type and lean grade[1].

	Genetic type		Lean grade		SEM[1]	P-value[2]	
	Pi x (LD x LW)	Du x (Gc x Du)	<60%lean	≥60%lean		Genetic type	Lean grade
Initial age, days	69.0	71.2	68.1	72.1	2.90	0.61	0.47
Initial body weight, kg	16.9	14.3	14.1	17.1	0.65	0.007	0.02
Final body weight, kg	104.4	90.7	100.1	95.1	2.05	0.001	0.18
Age at slaughter, day	202	204	201	205	3.00	0.60	0.47
Average daily gain, g	663	593	654	602	15.5	0.003	0.06

[1]Values are presented as least square means ± standard error of the mean (SEM). The level of significance was set at 0.05, but tendencies were commented if the level of significance was below 0.10.
[2]Interaction genetic type x lean grade non-significant in any variable (P>0.05).

3.2. Carcass characteristics.

The effect of genetic type on carcass weight, carcass yield and fatness measurements are shown in Table 3. The carcass weight and dressing out were affected by genetic type, being higher in Pi x (LD x LW) than in Du x (Gc x Du) pigs (P<0.001). The backfat thickness and *subcutaneous* fat covering the *Gluteus medius* muscle were similar between genotypes (P>0.05). Lean content did not affect carcass weight and dressing out (P>0.05). There was significant effect of sex on carcass weight, being higher in barrows than in gilts (75.1±1.3 *vs.* 65.7±2.2 kg; *P*<0.01).

Table 3 Carcass traits of organic pigs as affected by genetic type and lean grade[1].

	Genetic type		Lean grade		SEM[1]	P-value[2]	
	Pi x (LD x LW)	Du x (Gc x Du)	<60%lean	≥60%lean		Genetic type	Lean grade
N carcasses	*13*	*19*	*18*	*14*			
Carcass weight (kg)	78.1	62.6	71.7	69.0	1.55	<0.001	0.33
Dressing out (%)	75.1	70.3	72.3	73.1	*0.78*	<0.001	0.56
Lean content (%)	59.4	59.2	56.4	62.2	*0.95*	0.95	0.002
Fat thickness (mm)							
Backfat depth[3]	25.4	25.4	26.7	24.2	1.65	0.98	0.37
M. Gluteus medius	16.5	16.6	18.3	14.8	1.45	0.94	0.14

[1]Values are presented as least square means ± standard error of the mean (SEM). The level of significance was set at 0.05, but tendencies were commented if the level of significance was below 0.10.
[2]Interaction genetic type x lean grade non-significant in any variable (P>0.05).
[3]Backfat depth 3rd-4th rib (mm, including the skin).

3.3. *Meat quality traits.*

The results concerning chemical composition and colour parameters of raw pork according to genetic type and lean content are detailed in Table 4. The loin pH at 45 min and 24 h post-mortem was not affected by genetics and lean grade (P>0.05). None of the CIELab colour attributes differed significantly between carcass lean groups (P>0.05). However, the redness (*a**) was greater in Pi x (LD x LW) than in Du x (Gc x Du) pigs (P<0.05), whereas lightness (*L**) and yellowness (*b**) did not differ between genetic types (P>0.05). Loins from Du x (Gc x Du) pigs did not differ from Pi x (LD x LW) pigs in IMF and moisture content (either in raw or cooked pork aged 1 day) (P>0.05). Likewise, these variables (IMF and moisture) were not statistically affected by lean grade (P>0.05). There was significant difference between sexes in redness index (a*), since loins from barrows had higher a* than those form gilts (3.22±0.26 *vs.* 1.86±0.41; *P*<0.05).

Table 4 Meat characteristics of fresh pork as affected by genetic type and lean grade[1].

	Genetic type		Lean grade		SEM	P-value[1]	
	Pi x (LD x LW)	Du x (Gc x Du)	<60% lean	≥60% lean		Genetic type	Lean grade
pH 45 min	6.20	6.38	6.27	6.30	0.13	0.32	0.89
pH 24 h	5.64	5.68	5.67	5.66	0.05	0.50	0.89
Lightness (L*)	51.87	52.56	53.88	50.85	1.13	0.65	0.20
Redness (a*)	2.96	2.12	2.57	2.51	0.29	*0.04*	0.90
Yellowness (b*)	6.51	6.85	6.64	6.71	0.50	0.61	0.94
Thawing loss (%) aging 1 day	6.80	4.80	4.50	7.00	1.40	0.33	0.27
Thawing loss (%) aging 8 days	8.40	6.00	6.40	8.00	1.15	0.14	0.45
Moisture (%)	66.60	65.90	65.90	66.60	1.10	0.66	0.68
IMF (%)	2.05	2.26	2.23	2.08	0.30	0.63	0.75

[1]Interaction genetic type x lean grade non-significant in any variable (P>0.05).

Cooking loss and the textural parameters of pork (aged 1 and 8 days), according to genetic type and lean content, are shown in Table 5. Cooking loss did not differ between genetic types or lean grades (P > 0.05). Resistance to cutting (WBSF) in pork aged 1 day was significantly lower in Pi x (LD x LW) than Du x (Gc x Du) (P=0.05), whereas no differences were observed between genetic types in pork loin aged 8 days (P>0.05).

Table 5 Meat cooking losses and texture (compression and shear force tests) of pork aged 1 and 8 days as affected by genetic type and lean grade[1].

	Genetic type		Lean grade		SEM	P-value[1]	
	Pi x (LD x LW)	Du x (Gc x Du)	<60% lean	≥60% lean		Genetic type	Lean grade
	Pork loin aged 1 day						
Cooking loss (%)	21.7	23.9	21.9	23.7	2.15	0.47	0.63
Stress 20% on raw pork (kg/cm^2)	1.1	1.3	1.2	1.1	0.17	0.47	0.57
Stress 80% on raw pork (kg/cm^2)	5.2	6.1	6.2	5.0	0.38	0.15	0.06
Shear force on cooked pork (kg)	4.3	5.4	4.4	5.3	0.39	*0.05*	0.22
	Pork loin aged 8 days						
Cooking loss (%)	27.5	25.5	26.2	26.8	1.27	0.26	0.76
Stress 20% on raw pork (kg/cm^2)	0.8	0.7	0.8	0.7	0.09	0.62	0.55
Stress 80% on raw pork (kg/cm^2)	5.7	5.9	6.0	5.6	0.60	0.86	0.74
Shear force on cooked pork (kg)	3.8	3.3	3.6	3.5	0.31	0.28	0.79

[1]Interaction genetic type x lean grade non-significant in any variable (P>0.05).

The differences between genetic types in meat tenderness through compression measurements (20% and 80% stress) in raw pork aged 1 and 8 days were not significant (P>0.05), and only a tendency for greater force at stress 80% was observed in leaner (≥60% lean) compared to fatter (<60% lean) pork aged 1 day (P=0.06).

There was a significant effect of sex on compression force at 80% stress (pork aged 1 day), since loin from gilts showed higher force than that from barrows (6.34±0.47 *v.* 4.92±0.34 kg/cm^2; P=0.05).In pork aged 1 day, the WBSF was weakly correlated with compression force at 20% and 80% stress (r=0.08-0.26; P>0.05), while in pork aged 8 days the WBSF showed a positive correlation with compression force at 20% stress (r=0.55; P<0.05) but not with compression force at 80% stress (r=0.06; P>0.05).

3.4. Partition trees based on genetic type or carcass lean grade.

The best partition tree of technological characteristics of organic pork based on genetic type resulted in two splits (Figure 1). The final coefficient of determination (R2) was 0.47. The Column Contributions report (based on G^2) showed that shear force of cooked meat (aged 1 day) and fat depth at *G. medius* muscle were the main predictors of genetic type in the partition tree model. More Pietrain-sired pigs (77.8%) showed lower shear force at day 1 post-mortem (threshold set by autoregressive splitting at

<4.63 kg), whereas more Duroc-sired pigs (92.3%) showed greater shear force (WBSF ≥ 4.63 kg). In this tougher meat, high fat depth at *G. medius* muscle (≥15 mm) was exclusively associated with Duroc-sired pigs (100%).

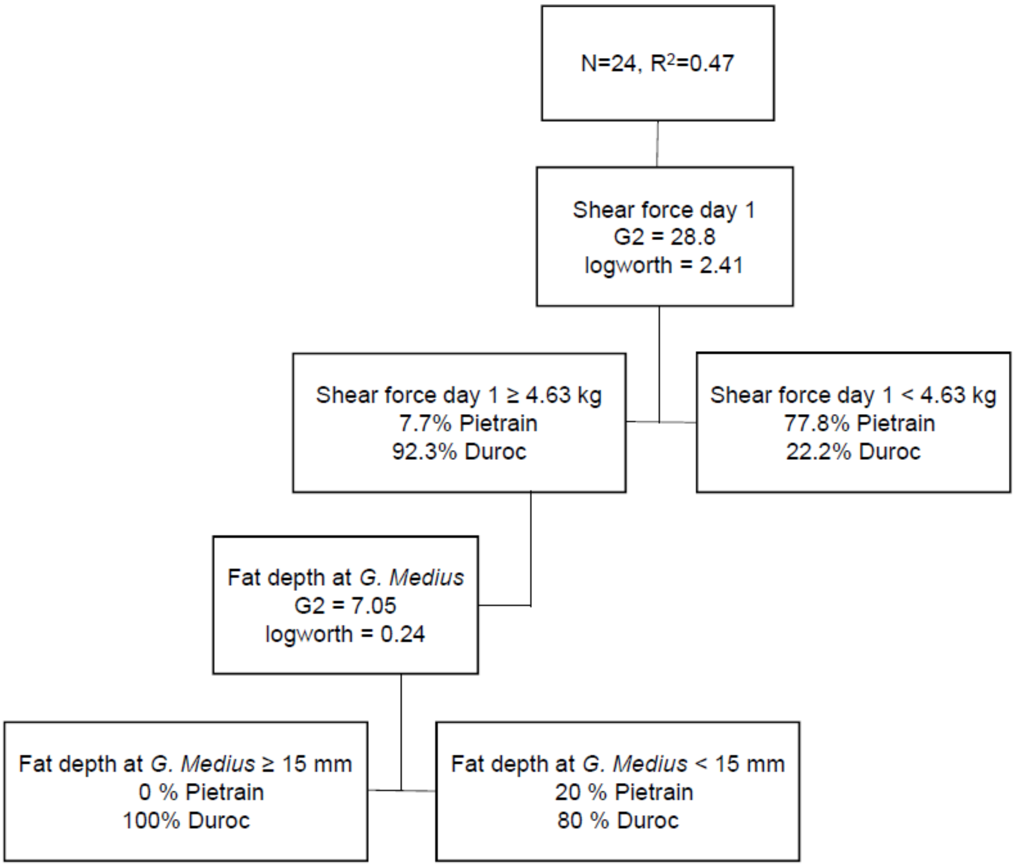

Fig. 1. Partition tree of technological characteristics of organic pork based on genetic type.

Another partition tree was developed for identifying technological characteristics of organic pork based on lean content (Fig. 2). The final R2 was 0.63. The column contributions report (based on G^2) showed that redness index (a*) of raw meat and fat depth at *G. medius* were the only predictors in the partition tree model. Pigs classified as leaner (≥60% lean) were associated exclusively (100%) with lower redness index (a*<2.23). More fatty pigs (<60% lean) (77.8%) showed higher redness index (a*≥ 2.23) at day 1 post-mortem. In this darker meat, high fat depth at *G. medius* muscle (≥16 mm) was associated exclusively (100%) with fattier pigs (< 60% lean).

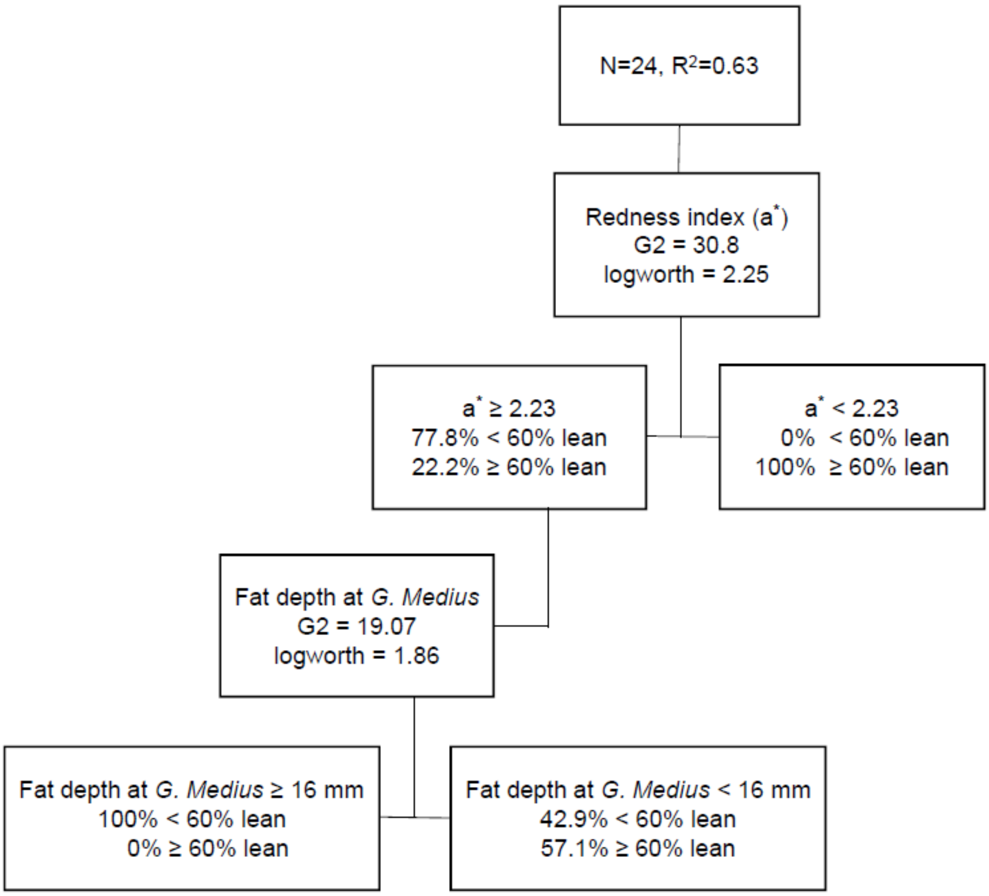

Fig. 2. Partition tree of technological characteristics of organic pork based on lean grade.

4. Discussion

This work evaluated the role of genetic type and lean grade on growth, carcass and meat quality characteristics of organic pork. These effects were assessed both independently and together (by testing its interaction). In the present study, the use of 75% Duroc-genes crossbreds was not optimal in terms of growth and carcass performance, when compared to the Pietrain crossbred, which is a genetic type widely used in Europe. In general, Pietrain-sired pigs show slightly lower growth performance but higher dressing out percentage than Duroc-sired pigs, leading also to heavier carcasses (García-Macías *et al.,* 1996; Edwards *et al.,* 2003; Latorre *et al.,* 2003; Ramírez and Cava, 2007). However, in another work, the use of a local genotype (Basque, very closed to Gascon) reduced the growth performance compared to Large-White purebred pigs (Alfonso *et al.,* 2005). Thus, the inclusion of local genotypes (as Gascon) in breeding schemes seems to impair the daily growth outcome of crossbreds, which may be a highlight of unimproved selection on this trait. However, the pig growth of sired Duroc pigs (around 600 g/day) was in the range of earlier reports under organic husbandry (Hansen *et al.,* 2006; Sundrum *et al.,* 2011 and Wüstholz *et al.,* 2017).

Although the sire breeds in this study were chosen according to their differences in fat content (Duroc represented a fatty pig and Pietrain a lean type), the overall lean content in the present study was tailored across genetic types by adjusting the body-weight at slaughter (nearly 10-15 kg less in Duroc-sired than in Pietrain-sired pigs). When using this approach, no differences between sire genotypes were detected in carcass fatness (backfat thickness and at depth at *G. medius* muscle), as reported by Latorre *et al.* (2009), in agreement with the present study.

In addition, no statistical differences were detected between genetic types in pH at 45 min and 24 h post-mortem, similarly to García-Macías *et al.* (1996) and Alonso *et al.* (2009), and their values were in line with the expected pH reduction during meat aging.

Researchers have reported conflicting results regarding the objective colour attributes of meat according to crossbreds. This study revealed no significant differences in lightness (L*) and yellowness (b*) values between samples of *L. lumborum* from Duroc- and Pietrain-sired pigs, which agrees with results of Edwards *et al.* (2003). Pork loins with L* values between 49 and 60 would on average have consistently good visual appeal (Warriss *et al.* 1995). In addition, the lower a* values in Duroc than in Pietrain progeny agreed with Brewer *et al.* (2002), Edwards *et al.* (2003), Edwards *et al.* (2008) and Latorre *et al.* (2009). The red colour of muscle is caused by the presence of haem pigments, hence CIE a* values of meat are positively correlated with the haem pigment and iron content (Estévez *et al.,* 2006). Thus, under the same feeding and housing conditions, the only colour attribute that differed across genetic types was redness. These a* value differences between genetic types (0.84 units) may be of practical significance as consumers can discriminate a* value differences of as little as 0.65 units depending on the light source under which samples are viewed (Zhu and Brewer, 1999). Slaughter weights for commercial pigs yielding fresh pork are rarely above 110 kg and this surely explains part of the lack of differences in IMF between crossbreds, since many autochthonous pig breeds, as Gascon, are normally raised until heavier weights (Sans *et al.,* 2004; Franci *et al.,* 2005) and thereby they are fattier than commercial pigs.

The expected higher IMF content in Duroc-sired pork may contribute to higher tenderness compared to Pietrain-sired pork (Huff-Lonergan *et al.,* 2002, Suzuki *et al.,* 2005). However, this was not proven in this experiment, as even the former had greater shear force at 1 day of aging than the latter.

Cooking loss from loin was not affected by genotype, which agrees with Brewer *et al.* (2002), Edwards *et al.* (2003) and Latorre *et al.* (2009) though it was higher at 8 days than at 1 day of aging. In addition, the pork loin from Duroc x (Gascon x Duroc) genetic type was tougher (greater shear force) than their Pietrain-sired counterparts, which differed from Edwards *et al.* (2003), who did not observed any difference between sires, and Blanchard *et al.* (1999), who observed an improvement in tenderness and lower shear force in cooked pork with higher level of Duroc genes inclusion. In this study, the differences in shear force between genetic types cannot be attributed to concomitant differences in IMF but to other physical and chemical components of muscle. For example, it has been found that hydroxyproline content (an indicator of collagen content) (Colgrave *et al.,* 2008) was greater in Duroc than in Pietrain crossbreds (Tor *et al.,* 2012).

In this study, ageing of pork loin slices for 8 days post-slaughter reduced shear force, compared to that aged for only 1 day, in agreement with the results found by Channon *et al.* (2004) and Álvarez-Rodríguez *et al.* (2018). Indeed, the shear force at 8 days of aging was within the range considered as tender pork by Van Oeckel *et al.* (1999) (3.9 kg) and Moeller *et al.* (2010) (3.4 kg). Compression force showed no differences between genetic types. This may reflect a lack of differences in tenderness as assessed by consumers, as the force values obtained for puncture test gave a greater degree of correlation with the sensory tenderness, hardness and elasticity than the shear test forces (Cierach and Majewska, 1997). However, it must be pointed out that more samples from Duroc-sired pigs had greater shear force than 4.63 kg (threshold value obtained from partition trees) and, within the tougher meat, pork from Duroc-sired pigs had greater subcutaneous fat depth at *Gluteus medius* (threshold found at ≥16 mm) than pork from Pietrain-sired pigs. It was noteworthy that ham fat depth had more discriminative power than backfat thickness in tree partitioning.

The used compression device allowed us to differentiate both components of meat stress, including stress due to muscle myofibrils (stress at a rate of compression of 20%) and the other due to total collagen (stress at a rate of compression of 80% (Lepetit, 1989). Aging affects the components responsible for meat toughness myofibrils and connective tissue (collagen) in different ways (Sacks *et al.,* 1988). Meat toughness decreases through aging due to a protease (μ-calpain) and its inhibitor (calpastatin), both of which regulate myofibrillar degradation and are the main source of variation in the final tenderness values (Koohmaraie and Geesink, 2006). Connective tissue breaks partially during aging (Nishimura *et al.,* 1998); therefore, aging does not modify the meat stress at 80 % but modify the meat stress at 20 %. On the other hand, both total collagen content and myofibrils plus the thermal solubility of collagen interfere on the WBSF. Because there were no differences in stress at 20% or 80%, but there were on WBSF, we can argue that differences between genetic types come from the solubility of collagen. That could explain that some authors reported the pork loin from Duroc genetic type was tougher than Pietrain counterparts, while Blanchard *et al.* (1999) reported the opposite and Edwards *et al.* (2003) who did not observe any difference between sires. We may suggest that the total collagen content was greater in Duroc than in Pietrain crossbreds (Tor *et al.,* 2012) but also, and more important, is less soluble.

In many studies, the influence of carcass fatness is not separated from that of genetic type, henceforth both effects are confounded. The approach used herein was to tailor the slaughter weight to compare similar carcass fatness levels across genetic types, but a range of carcass grades was obtained by this grouping. The leanest pigs (≥60% lean grade), regardless of genetics, grew slower than the rest of animals. This would highlight an association between daily growth and fat tissue growth, or, in other words, a not linear relationship between daily growth and muscle growth. Such response may be affected by the husbandry system, which involves greater animal exercise due to higher space allowance and potential drawbacks in essential amino acid requirements. Accordingly, Millet *et al.* (2005) concluded that higher growth rate under organic husbandry caused an extra fat deposition and that the individual daily feed intake would one of the determining factors for the daily gain.

Increased carcass fatness (or lower lean grade) did not affect the dressing out proportion, the colour attributes and the technological characteristics of pork (as pH or drip loss) (Álvarez-Rodríguez *et al.,* 2018), which was in line with the current results. However, tree partitioning revealed that higher carcass fatness (<60% lean) was related to higher redness of meat, especially when ham fat depth ≥16 mm. The redness (a*) values of meat are positively correlated with, not only the haem pigment and iron content (Estévez *et al.,* 2006), but with its IMF content (Karamucki *et al.,* 2013), which may explain this relationship under the present organic husbandry system.

5. Conclusions

The crossbred finishing pig including 75% Duroc genes and a local breed (Gascon) in maternal sire showed lower growth performance, carcass weight and dressing out than the Pietrain sired crossbreds. In addition, when they were slaughtered at similar carcass fatness degree, the pork loin from Duroc genetic type had lower redness (a*) and it was tougher than their Pietrain counterparts. Lean grade was not associated with earlier differences in growth, carcass performance or meat quality, except for a tendency for greater compression at 80%force in leaner raw pork. Therefore, under the current organic husbandry system, the Pietrain-sired pigs may be recommended.

Conflicts of Interest

The authors declare no conflicts of interest.

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5.2 **Qualitat nutricional de la carn** (article IV).

The extent to which genetics and lean grade affect fatty acid profiles and volatile compounds in organic pork

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Abstract

Niche production is intended to produce premium pork, but several husbandry factors may affect the meat fatty acid composition and aroma. Fatty acid profile (by GC-FID) of raw meat and volatile compounds (by SPME-GC–MS) of cooked meat were analysed in loin samples from two pig genetic types-75% Duroc (Du) and 50% Pietrain (Pi)(crossbreds that were slaughtered at different weights (90 kg and 105 kg, respectively) to achieve similar target carcass fatness, and the outcome carcasses were balanced for lean grade groups (<60% or ≥60% lean) within genotypes.

Genetic type did not affect fatty acids (FA) profile of meat. The leaner meat had lower C12:0 and C20:3*n*-3, lower saturated fatty acids (SFA) and higher MUFA/SFA ratio content than the fattier meat. Short-chain alcohols were lower in Pietrain and in leaner pork compared to the samples from Duroc crossbreds and fattier pork. A greater amount of hexane,2,4,4-trimethyl (an aliphatic hydrocarbon) but lower carbon disulphide (sulphur compound) content was detected in pork from leaner compared to fattier pork. Higher aromatics hydrocarbons were exclusively associated with Duroc crossbreds, and lower aliphatic hydrocarbons with pigs classified as fattier. Most of the volatile compounds detected in the present study came from lipid oxidation.

1. Introduction

The flavor of cooked meat is one of the most important sensory attributes for consumers to judge the quality and it is influenced by volatile compounds (VC), formed during cooking, contributing to the sense of taste that determine the meat aroma attributes (Calkins & Hodgen, 2007; Zhao *et al.*, 2017).

The amount and nature of aroma precursors present in pork depends on several factors including feed, ageing, gender, *post-mortem* treatment and genetic variations (Meinert et al., 2007). Crossbreeding with Duroc breed as sire line allows improving meat quality traits (Ramírez and Cava, 2007). Likewise, Duroc breed is used to produce dry-cured pork products, since accumulates greater intramuscular fat and fat quality traits than other sire breeds as Pietrain, which is normally very lean (Affentranger et al. 1996; Latorre et al. 2009b). Moreover, the amount of intramuscular fat in organic pork has been reported to be higher (Sundrum et al., 2000), and the fatty acid composition to be more unsaturated (Hansen et al., 2006).

This experiment had the hypothesis that different pig genotypes, under organic husbandry, react differently to same feeding, thereby showing different fatty acid profiles in Duroc than Pietrain crossbred pork. Moreover, the arisen volatile compounds contents of this cooked pork may also be affected.

Therefore, the objective of the present study was to evaluate the potential role of genetic type and lean grade on fatty acid composition and volatile compounds of pork under organic husbandry.

2. Materials & Methods

2.1 Animal management and meat sampling

A total of 48 pigs raised by 12 sows from two genetic types were used in this study. Twenty-six animals were Pietrain x (Landrace x Large White) (Pi x (LD x LW)) and 22 animals were Duroc x (Gascon x Duroc) (Du x (Gc x Du)). Half of the animals were females; the other half were castrates. The Pi genetic types derived from Pi line of Selección Batallé (Riudarenes, Girona, Spain) and the Du genetic types derived from Du line of German Genetic (Stuttgart-Plieningen, Germany). Pigs from both genotypes were housed together in three concrete floor pens with a space allowance ≥2.3 m^2/pig. The individual body-weight (BW) was determined at the start of the growing phase (initial age 68±15 days) and the BW at slaughter was set at approximately 105 kg (Pi) or 90 kg (Du) to reach a similar carcass fatness (lean content) between genetic types (around 60% lean). Pigs were kept in accordance with the European Community standards for organic livestock and livestock products (EC-regulation 889/2008 supplementing the EC-regulation 834/2007). All pigs had the same feed ad libitum, whose ingredients were barley grain (34.8%), maize grain (20.0%), wheat grain (13.4%), expeller soybean meal (12.3%), pea (10.0%), maize germ meal (4.0%), vegetable protein concentrate (2.0%), soybean oil (0.5%), minerals (2.6%) and vitamin-micromineral premix (0.4%). The feed had 140 g of crude protein and 37 g of crude fat per kg, with an analyzed fatty acid composition of 20.96 g SFA/100 g of identified FA, 19.98 g MUFA/100 g FA, 53.24 g PUFA n-6/100 g FA and 5.93 g PUFA n-3/100 g FA, and a calculated metabolizable energy content was 12.7 MJ/kg of feed. Pigs were stunned by CO_2 (concentration 87%) before slaughtering (Escorxador Frigorífic d'Avinyó S.A., Catalonia, Spain) using a dip lift system, exsanguinated, scalded, skinned, eviscerated according to standard commercial procedures and split down the midline. Hot carcass weight was individually recorded before the carcasses were refrigerated in line processing at 2º C. The carcasses were graded with an automated image analysis system (VCS 2000, E+V Technology GmbH, Oranienburg, Germany; DOUE, 2018) and classified in two classes (<60%, n=10 and >60% lean, n=14). Backfat thickness was measured at 3rd-4th last thoracic rib. At 45 min post-mortem, the loins were excised from the carcass following the standard procedures of the abattoir and they were trimmed by an expert staff to eliminate part of the external fat for commercial requirements. Immediately afterwards, individual 10-cm caudal *Longissimus lumborum* was sampled (approximately 500 g), packaged in polyethylene bags and stored at 4ºC in darkness overnight.

2.2 Sample selection and preparation

One-day post-mortem, 24 *L. lumborum* pork samples were selected and two slices (1 cm thickness, ∼100 g each) were vacuum-packaged in plastic bags. The first slice was used to determinate total intramuscular fat content (IMF) and fatty acid composition of raw pork, thus it was stored at -20ºC, freeze-dried and minced until analysis. The second slice was used to determinate volatile compounds of cooked pork aged 8 days. Thereby, loin slice was aged in dark at 4 ºC for one week and kept at -20ºC. Before cooking, these aged loin samples were thawed at 4 ºC during 24 h, and subsequently cooked by placing the vacuum bags in a water bath (95 ºC) with automatic temperature control to internal temperature of 70 ºC, controlled by thermocouples connected to a data logger. After cooking, samples were cooled at room temperature overnight, vacuum-packaged and stored at −20 °C for no longer than four weeks until analysis.

2.3 Fat and fatty acids (FA) content of meat

Loin slices were trimmed of intermuscular and subcutaneous fat prior to IMF analysis. Fat content was quantified using the Ankom procedure AOCS (2005) (Official Procedure Am 5–04) with an Ankom extractor (XT10, Ankom Technology, Madrid, Spain). Analyses were run in duplicate. Meat fatty acid (FA) methyl esters were directly obtained by transesterification using a solution of methanol/sulphuric acid 2% (v/v), 30 min heating at 80 ºC, centrifugation at 3,000 rpm during 5 min and collection of the final supernatant. Analysis of FA methyl esters were performed in duplicate by GC with a 30 m x 0.25 mm capillary column (Agilent DB-23, Agilent Technologies, Santa Clara, United States) and a flame ionization detector with helium as the carrier gas at 2 mL/min. The oven temperature program increased from 150 ºC at the first min, to 180º C at 35 ºC per min, and to 220 ºC at 5 ºC per min. The injector and detector temperatures were both 250 °C. Fatty acid composition was calculated as the relative percentage of each individual FA relative to total FA. Individual FA were identified by comparing their retention times with those from a known standard Supelco® 37 Component FAME Mix (Supelco, Bellefonte, PA, USA). The proportion of polyunsaturated (PUFA) (C18:2*n*-6; C18:3*n*-3; C18:3*n*-6; C20:2*n*-6; C20:3*n*-6; C20:3*n*-3 and C20:4*n*-6), monounsaturated (MUFA) (C16:1*n*-7; C17:1*n*-7; C18:1*n*-9; C18:1*n*-7c; C20:1*n*-9) and saturated (SFA) (C10:0; C12:0; C14:0; C16:0; C17:0; C18:0; and C20:0) FA contents were calculated.

2.4 Volatile compounds analysis (VC)

The extraction of the volatile compounds was performed using solid-phase microextraction (SPME) from the previously homogenized samples described in section ‘sample selection and preparation’ (pork aged 8 days). An SPME device (Supelco, Bellefonte, PA, USA) containing a fused-silica fibre (10 mm length) coated with a 50/30 mm thickness of DVB/CAR/PDMS (divinylbenzene/carboxen/polydimethysiloxane) was used and analysis was performed as following. For headspace SPME (HS-SPME) extraction, 1 g of each sample was weighed in a 20mL glass vial, after being ground using a commercial grinder. The vials were subsequently screw-capped with a laminated Teflon-rubber disc. The fibre was previously conditioned by heating in a Fiber Conditioning Station at 270 ºC for 30 min. The conditioning, extraction and injection of the samples was carried out with an autosampler PAL-RTC 120. The extractions were carried out at 37 ºC for 30 min, after equilibration of the samples for 15 min at the temperature used for extraction, ensuring homogeneous temperature for sample and headspace. Once sampling was finished, the fibre was transferred to the injection port the gas chromatograph-mass spectrometer (GC-MS) system.

A gas chromatograph 7890B (Agilent Technologies) was used with a DB-624 capillary column (30 m, 0.25 mm i.d., 1.4 µm film thickness; J&W Scientific, Folsom, CA, USA) coupled to a 5977B single quadrupole mass selective detector (Agilent Technologies, Palo Alto, USA). The SPME fibre was desorbed and maintained in the injection port at 260 ºC during 8 min. The sample was injected in split less mode. Helium was used as carrier gas with a flow of 1.2 mL/min (9.59 psi). The temperature program was isothermal for 10 min at 40 ºC, raised to 200 ºC at 5 ºC/min, and then raised to 250 ºC at 20 ºC/min, and held for 5 min: total run time 49.5 min. Injector and detector temperatures were both set at 260 ºC.

The mass spectra were obtained using a mass selective detector working in electronic impact at 70 eV, with a multiplier voltage of 850 V and collecting data at 6.34 scans/s over the range m/z 40-550. Compounds were identified by comparing their mass spectra with those contained in the NIST14 (National Institute of Standards and Technology, Gaithersburg) library, and/or by comparing their mass spectra and retention time with authentic standards (Supelco, Bellefonte, PA, USA), and/or by calculation of retention index relative to a series of standard alkanes (C5-C14) (for calculating Linear Retention Index, Supelco 44585-U, Bellefonte, PA, USA) and matching them data reported in literature. The results are expressed as quantifier area units (AU) x 10^4/g of sample.

Among the volatile compounds (VC) at the end of final stage, only compounds regarded as mainly representative for their presence and abundance to aroma have been take into account according to previous studies (Gorbatov 1980; Flores et al. 1997; Machiels et al. 2003; Domínguez et al. 2014a; Franco et al. 2014; Gravador et al. 2015; Benet et al. 2015; Zhao et al. 2017; Pérez-Santaescolástica et al. 2018; Flores 2018).

The VC were classified based on their origin (lipolysis, proteolysis and microbial), according to Dainty et al. (1985), Roger, Degas and Gripon (1988), Ruiz et al. (1999), Meynier et al.(1999), Carrapiso et al. (2002), Arnoldi (2003), Liu (2003), Machiels et al. (2003), Raes et al. (2003), Martín et al. (2006), Ramírez and Cava (2007), Calkins and Hodgen (2007), Narváez-Rivas et al. (2012), Fonseca et al. (2015) and Rivas, Gallardo and Camacho (2016), Pérez-Santaescolástica et al. (2019).

2.5 Statistical analysis

The data were analyzed with the JMP Pro 13 statistical software (SAS Institute, Cary, NC, USA) with a least square mean standard model including genetic type, lean grade and sex as fixed effects.. Differences ($P \leq 0.05$) between least square means were assessed with the Tukey test. Tendencies were reported when the P-value ranged between 0.05 and 0.10. A Spearman’s rank correlation analysis between FA and VC content was performed.

Classification trees (partition option from multivariate methods) from JMP Pro software were used to predict both genetic type and carcass grading as a function of potential predictor variables (19 fatty acids and 69 volatiles compounds) using recursive partitioning. The partition algorithm searched all possible splits of predictors to best predict the response (FA or VC). These splits (or partitions) of the data were done recursively to form a tree of decision rules. The variables were selected according to G2 (likelihood-ratio chi-square) test of association and logworth (-log(p-value)) value. The logworth values are the logs of adjusted p-values for the chi-square test of independence. These are adjusted to account for the number of ways that splits can occur. The partition algorithm imputes -that is, randomly assigns- values for the missing values, and this allows the variables that are poorly populated to be noticed, if they indeed help explain banding. If the logworth is greater than 2, the variable that is used in the branch is considered significant and should be included in the tree.

3. Results

3.1 Fatty acids composition of raw pork

The results concerning IMF and FA composition of raw pork (24 *h post-mortem*) according to genetic type and lean content is detailed in Table 1. Total IMF was not significantly affected by genetic type and lean grade (P >0.05). Nineteen FA were detected and quantified, which the percentage of oleic acid (C18:1*n*-9) was the highest, ranging from 36.5% to 38.8%, followed by palmitic acid (C16:0) from 21.9% to 23% and linoleic acid (C18:2*n*-6) from 15.1% to 16.4%. No significant differences were observed in FA contents between genetic types (P > 0.05). However, Du pigs tended to show higher SFA content than Pi pigs (P = 0.10), due to a tendency for higher proportions of palmitic acid (C16:0) and myristic acid (C14:0) (P = 0.08). Likewise, Du pigs tended to show higher dihomo-γ-linolenic acid (C20:3*n*-6) than Pi-sired pigs (P = 0.10).

On the contrary, individual FA differed between lean grades, especially the SFA lauric acid (C12:0) and the omega-3 PUFA eicosatrienoic acid (C20:3*n*-3), with leaner carcasses (≥ 60% lean) showing greater lauric acid content (P = 0.05) and lower eicosatrienoic acid content (P = 0.05) than fatter carcasses (< 60% lean). The leaner carcasses tended to show higher total SFA content than fatter carcasses (P = 0.10). Accordingly, the MUFA/SFA ratio of leaner carcasses (≥ 60% lean) was lower (P = 0.05) than in fatter carcasses (< 60% lean). However, the PUFA/SFA ratio in raw pork was not affected by lean content (P > 0.10). There were significant differences (P<0.05) between genders in the margaric acid (C17:0), oleic acid (C18:1*n*-9), cis-gadoleic acid (C20:1*n*-9) and MUFA/SFA ratio. Pork from females had more margaric acid (C17:0) than males (P < 0.05). However, the MUFA oleic acid (C18:1*n*-9) and cis-gadoleic acid (C20:1*n*-9) were higher in pork from males than in that of females (P <

0.05). Accordingly, the MUFA/SFA ratio was higher in pork from males than in that of females ($P < 0.05$).

Table 1 Fatty acid (FA) composition (g/100 g identified FA) in *L. lumborum* of pork as affected by genetic type and lean grade.

	Genetic type		Lean grade		SEM	P-value[†]	
	Pi x (L x LW)	Du x (Gc x Du)	<60% lean	>60% lean		Genetic type	Lean grade
N meat samples	8	16	15	9			
Fat (IMF)	2.05	2.26	2.23	2.08	0.03	0.63	0.75
Saturated FA (SFA)							
C10:0, capric	0.10	0.07	0.10	0.07	0.04	0.56	0.70
C12:0, lauric	0.11	0.10	0.12	0.08	0.01	0.64	0.05
C14:0, myristic	1.39	1.52	1.50	1.41	0.05	0.10	0.29
C16:0, palmitic	21.91	22.97	22.55	22.33	0.39	0.08	0.73
C17:0[1], margaric	0.30	0.40	0.36	0.34	0.04	0.13	0.79
C18:0, stearic	11.96	11.77	12.24	11.48	0.29	0.67	0.12
C20:0, arachidic	0.09	0.11	0.10	0.10	0.01	0.50	0.67
Sum of SFA	35.86	36.93	36.97	35.81	0.42	0.10	0.10
Monounsaturated FA (MUFA)							
C16:1*n*-7, palmitoleic	2.58	2.88	2.64	2.82	0.26	0.43	0.68
C17:1*n*-7, heptadecenoic	0.26	0.31	0.28	0.30	0.03	0.25	0.67
C18:1*n*-9[2], oleic	37.51	37.76	36.51	38.76	0.91	0.85	0.14
C18:1*n*-7c, cis-vaccenic	2.95	3.06	2.91	3.10	0.21	0.73	0.57
C20:1*n*-9[2], cis-gadoleic	0.57	0.56	0.57	0.56	0.02	0.58	0.85
Sum of MUFA	43.87	44.58	42.91	45.54	1.23	0.70	0.20
Polyunsaturated FA (PUFA)							
C18:2*n*-6, linoleic	16.36	15.18	16.39	15.16	1.20	0.51	0.53
C18:3*n*-6, γ-linolenic	0.11	0.10	0.10	0.11	0.02	0.74	0.73
C18:3*n*-3, *α*-linolenic	1.28	1.19	1.31	1.16	0.12	0.62	0.43
C20:2*n*-6, eicosadienoic	0.58	0.46	0.53	0.48	0.04	0.13	0.44
C20:3*n*-6, dihomo-γ-linolenic	0.25	0.19	0.22	0.23	0.02	0.10	0.82
C20:3*n*-3, eicosatrienoic	0.15	0.14	0.18	0.11	0.02	0.55	0.05
C20:4*n*-6, arachadonic	1.51	1.19	1.35	1.36	0.15	0.16	0.91
Sum of PUFA	20.23	18.46	20.08	18.61	1.40	0.40	0.52
PUFA/SFA ratio	0.57	0.50	0.55	0.52	0.04	0.31	0.70
MUFA/SFA ratio[2]	1.22	1.21	1.16	1.27	0.03	0.77	0.05

[1] Pork from gilts showed greater C17:0 than that of barrows (0.43 *vs.* 0.27±0.04%).
[2] Pork from barrows showed greater C18:1*n*-9, C20:1*n*-9 and MUFA/SFA ratio than pork from gilts (39.4 6 v. 35.82±1.04%; 0.61 v. 0.52±0.02%; 1.29 v. 1.14±0.03%, respectively).
[†] Interaction genetic type x lean grade non-significant in any variable ($P>0.05$).

3.2 Volatile compounds of cooked aged pork

A total of 69 VCs were determined and they were assigned to the following chemical families: 18 hydrocarbons, 13 aldehydes, 8 ketones, 7 carboxylic acids, 15 alcohols, 3 esters and ethers, 2 sulphur-containing and 3 furans. Alcohols and aldehydes accounted for the highest percentage (42.1% and 22.7%, respectively, as shown in

Figure 1a). The chemical families of VC were not affected by genetic type and lean grade (P > 0.10). However, Du pork tended to show higher aromatic and cyclic hydrocarbons content than Pi pork (P = 0.10). Fifty-nine out of the 69 identified VC were classified based on their origin (lipolysis, proteolysis and microbial), and 10 had an unknown origin. Lipolysis origin showed the highest level (72.4% out of total VC) (Figure 1b), followed by proteolysis and microbial activity. The origin group of VC were not significantly influenced by the genetic type or lean grade (P > 0.10). Meanwhile, pork classed as leaner had higher content of VC from unknown origin (P < 0.01).

The average contents of extracted VC of cooked aged pork are shown in Tables 2, 3 and 4. Through GC-MS analysis, there were several peaks in chromatogram that were not included in the list of VC, because most of them were tentatively identified as siloxanes or silanes and the most probable origin will be the trap (fiber). Concerning the effect of genetic type, there were only significant differences in the alcohol 1-pentanol content, which was greater in pork from Du than in pork from Pi pigs (P < 0.05). Likewise, lean grade affected the content of hydrocarbon hexane, 2,4,4-trimethyl in cooked aged pork, being greater in pigs classed as leaner (≥ 60% lean) than fattier pigs (< 60% lean) (P < 0.05). Nevertheless, fattier pigs (< 60% lean) had higher content of certain alcohols such as 1-butanol (P < 0.05) and 1-pentanol (P < 0.05) than leaner pigs (≥ 60% lean). The only significant differences between genders in VC were on the alcohols 1-butanol and phenylethyl, that were higher in pork from gilts than in that from barrows (6.7 vs. 2.9±0.97 and 13.4 vs. 2.0±3.2 AU x 10^4/g of cooked pork, P < 0.05, respectively).

Table 2 Effect of genetic type and lean grade on volatile compounds content; Hidrocarbons (expressed as AU x 10^4/g of cooked pork).

Volatile compounds	LRI	R	Genetic type		Lean grade		SEM	*P-value*†	
			Pi x (L x LW)	Du x (Gc x Du)	<60% lean	>60% lean		Genetic type	Lean grade
Aliphatic hydrocarbons									
Pentane	517	ms, lri,s	81.87	109.60	96.22	95.24	36.70	0.62	0.99
n-Hexane	563	ms, lri	75.92	60.85	64.97	71.80	23.03	0.66	0.84
Heptane	677	ms, lri	25.82	34.41	37.16	23.07	14.19	0.69	0.51
1-Octene	818	ms, lri	26.06	29.14	33.24	21.96	12.80	0.87	0.56
Octane	825	ms, lri,s	114.96	141.69	151.89	104.75	57.66	0.76	0.59
Nonane	940	ms, lri,s	73.77	158.53	137.17	95.13	36.03	0.13	0.44
Hexane, 2,4,4-trimethyl-	1074	ms, lri	78.86	74.10	21.90	131.06	27.66	0.91	0.02
Heptane, 3,3,4-trimethyl-	1094	ms, lri	3.02	3.34	3.23	3.13	0.58	0.72	0.91
Undecane	1119	ms, lri,s	59.35	59.84	56.39	62.80	8.56	0.97	0.62
Heptane, 4-methylene-	1132	ms, lri	11.04	18.94	18.01	11.97	4.10	0.21	0.33
Dodecane	1194	ms, lri,s	36.44	36.73	34.31	38.86	5.30	0.97	0.57
1-Nonene	1207	ms, lri	1.67	2.84	1.93	2.58	1.24	0.53	0.73
Tridecane	1264	ms, lri,s	14.34	13.95	13.69	14.60	2.30	0.91	0.79
1-Undecene, 9-methyl-	1279	ms,	0.65	0.66	0.53	0.77	0.10	0.94	0.11
Aromatic and cyclic hydrocarbons									
Toluene	807	ms, lri	9.27	9.22	8.65	9.85	1.77	0.99	0.65
Cyclopropane, pentyl-	819	ms, lri	6.26	33.25	21.94	17.56	13.40	0.19	0.83
Benzene, 1,3-dimethyl-	930	ms, lri	5.56	5.00	3.97	6.59	1.74	0.83	0.33
Phenol, 2,6-bis(1,1-dimethylethyl)-4-(1-methylpropyl)-	1493	ms, lri	7.13	6.42	5.57	7.99	2.41	0.85	0.51

LRI: Lineal Retention Index calculated for DB-624 capillary column (30m×0.25mm id, 1.4 μm film thickness) installed on a gas chromatograph equipped with a mass selective detector; R: Reliability of identification; lri: linear retention index in agreement with literature (Gorbatov, 1980; Flores et al., 1997; Machiels et al., 2003; Domínguez et al., 2014; Franco et al., 2014; Gravador et al., 2015; Benet et al., 2015; Zhao et al., 2017; Pérez-Santaescolástica et al., 2018; Flores, 2018); ms: mass spectrum agreed with mass database (NIST14); s: mass spectrum and retention time identical with an authentic standard.
†Interaction genetic type x lean grade non-significant in any variable (P>0.05).

Table 3 Effect of genetic type and lean grade on volatile compounds content: Aldehydes, Ketones and Carboxilic acids (expressed as AU x 10^4/g dry matter) of cooked pork.

Volatile compounds	LRI	R	Genetic type		Lean grade		SEM	*P-value*†	
			Pi x (L x LW)	Du x (Gc x Du)	<60% lean	>60% lean		Genetic type	Lean grade
Aldehyde									
Propanal	527	ms, lri,s	68.09	68.13	71.52	64.70	14.76	1.00	0.76
Butanal, 3-methyl-	661	ms, lri	6.68	18.93	17.97	7.64	11.79	0.49	0.56
Butanal, 2-methyl-	673	ms, lri	4.08	12.54	10.65	5.97	5.23	0.29	0.55
Pentanal	730	ms, lri,s	109.22	48.16	44.94	112.44	30.00	0.19	0.15
Hexanal	869	ms, lri,s	1655.35	845.03	878.54	1621.84	454.74	0.25	0.29
Heptanal	978	ms, lri,s	54.50	54.66	40.93	68.23	15.66	0.99	0.26
2-Heptenal, (Z)-	1042	ms, lri	4.39	5.42	4.79	5.01	0.66	0.31	0.82
Benzaldehyde	1050	ms, lri	10.24	7.37	8.50	9.11	2.58	0.46	0.87
2-Butenal, (Z)-	1051	ms, lri	27.86	47.01	46.61	28.26	9.34	0.18	0.20
Octanal	1071	ms, lri,s	13.35	14.87	11.18	17.04	4.22	0.81	0.36
2-Octenal, (E)-	1129	ms, lri	3.69	5.93	7.50	2.12	2.07	0.47	0.10
Nonanal	1154	ms, lri,s	15.05	15.39	13.01	17.43	4.27	0.96	0.49
2,4-Decadienal, (E,E)-	1322	ms, lri	1.00	1.06	0.64	1.42	0.30	0.89	0.10
Ketone							0,00		
Acetone	529	ms, lri	63.22	65.76	75.31	53.67	15.38	0.91	0.36
2-Butanone	595	ms, lri	5.78	8.79	11.44	3.13	2.76	0.47	0.06
2-Pentanone	722	ms, lri	5.39	4.09	6.30	3.18	1.48	0.56	0.17
2,3-Pentanedione	738	ms, lri	3.74	2.96	2.48	4.21	1.00	0.61	0.26
3-Hydroxy-3-methyl-2-butanone	820	ms, lri	3.71	0.61	2.54	1.78	1.17	0.09	0.67
1-Octen-3-one	931	ms, lri	2.63	2.27	2.58	2.31	0.65	0.71	0.78
2-Heptanone	971	ms, lri	35.59	42.72	44.93	33.38	7.94	0.55	0.34
2-Octanone	1064	ms, lri	2.68	2.88	2.07	3.48	0.74	0.86	0.22
Carboxilic acid									
Acetic acid	697	ms, lri	3.66	5.38	4.77	4.26	1.91	0.55	0.86
Acetoin	790	ms, lri	1106.92	859.55	1330.02	636.45	579.05	0.78	0.43
Butanoic acid	923	ms, lri	2.17	1.67	1.37	2.48	0.45	0.46	0.11
Butanoic acid, 3-methyl-	973	ms, lri	5.62	5.05	8.45	2.22	4.52	0.93	0.37
Pentanoic acid	1089	ms, lri	9.62	8.55	7.62	10.54	2.65	0.79	0.47
Pentanoic acid, 2-methyl-, anhydride	1142	ms, lri	13.64	15.36	14.22	14.77	2.99	0.70	0.90
Octanoic acid	1230	ms, lri	1.11	0.40	0.71	0.80	0.31	0.13	0.85

LRI: Lineal Retention Index calculated for DB-624 capillary column (30m×0.25mm id, 1.4 μm film thickness) installed on a gas chromatograph equipped with a mass selective detector; R: Reliability of identification; lri: linear retention index in agreement with literature (Gorbatov, 1980; Flores et al., 1997; Machiels et al., 2003; Domínguez et al., 2014; Franco et al., 2014; Gravador et al., 2015; Benet et al., 2015; Zhao et al., 2017; Pérez-Santaescolástica et al., 2018; Flores, 2018); ms: mass spectrum agreed with mass database (NIST14); s: mass spectrum and retention time identical with an authentic standard. †Interaction genetic type x lean grade non-significant in any variable (P>0.05).

Table 4 Effect of genetic type and lean grade on volatile compounds content: Ester, Eter, Alcohol, Furan and Sulfur (expressed as AU x 10^4/g dry matter) of cooked pork.

Volatile compounds	LRI	R	Genetic type		Lean grade		SEM	*P-value*†	
			Pi x (L x LW)	Du x (Gc x Du)	<60% lean	>60% lean		Genetic type	Lean grade
Ester and ether									
Acetic acid ethenyl ester	589	ms, lri	61.40	26.30	63.16	24.53	23.52	0.35	0.26
Ethyl Acetate	600	ms, lri	63.17	40.79	89.29	14.67	60.85	0.81	0.42
Acetic acid, butyl ester	1069	ms, lri	13.12	13.86	9.35	17.63	3.88	0.90	0.17
Alcohol							0,00		
1-Propanol, 2-methyl-	649	ms, lri	11.40	31.52	17.28	25.64	12.84	0.31	0.67
1-Butanol	709	ms, lri	3.51	6.10	6.49	3.12	0.875	0.06	0.02
3-Buten-1-ol, 3-methyl-	805	ms, lri	12.20	23.18	19.89	15.49	8.98	0.42	0.75
1-Butanol, 3-methyl-	811	ms, lri	138.99	239.02	215.79	162.22	81.29	0.42	0.66
1-Pentanol	850	ms, lri	237.22	356.03	356.48	236.77	31.46	0.02	0.02
2,3-Butanediol	913	ms, lri	61.86	24.44	57.87	28.43	19.28	0.20	0.28
2,3-Butanediol, [S-(R*, R*)]-	921	ms, lri	19.05	18.20	23.89	13.36	7.98	0.94	0.34
1-Hexanol	959	ms, lri	891.06	1886.34	1645.30	1132.10	413.83	0.12	0.42
1-Heptanol	1050	ms, lri	44.24	42.54	44.19	42.60	13.38	0.93	0.94
1-Octen-3-ol	1056	ms, lri	347.75	450.68	420.37	378.07	54.80	0.22	0.61
2-Ethyl-1-hexanol	1099	ms, lri	3.70	3.97	3.79	3.87	0.63	0.77	0.93
1-Octanol	1132	ms, lri	13.62	21.11	19.66	15.07	4.37	0.26	0.49
Phenylethyl Alcohol	1189	ms, lri	6.03	9.34	10.72	4.66	2.93	0.46	0.18
1-Nonanol	1207	ms, lri	4.16	5.83	3.19	6.79	2.66	0.68	0.37
1-Tetradecanol	1472	ms, lri	4.04	4.42	4.76	3.70	1.68	0.88	0.67
Furans									
Furan, 2-ethyl-	706	ms, lri	6.67	10.73	8.77	8.63	2.09	0.21	0.97
2-n-Butyl furan	948	ms, lri	4.01	4.54	4.24	4.31	0.95	0.71	0.96
Furan, 2-pentyl-	1043	ms, lri	79.08	103.76	94.44	88.41	21.71	0.45	0.85
Sulphur compounds									
Methanethiol	505	ms, lri	3.07	1.43	3.41	1.09	1.54	0.48	0.32
Carbon disulfide	535	ms, lri	11.24	9.95	10.93	10.26	1.76	0.63	0.80

LRI: Lineal Retention Index calculated for DB-624 capillary column (30m×0.25mm id, 1.4 μm film thickness) installed on a gas chromatograph equipped with a mass selective detector; R: Reliability of identification; lri: linear retention index in agreement with literature (Gorbatov, 1980; Flores et al., 1997; Machiels et al., 2003; Domínguez et al., 2014; Franco et al., 2014; Gravador et al., 2015; Benet et al., 2015; Zhao et al., 2017; Pérez-Santaescolástica et al., 2018; Flores, 2018); ms: mass spectrum agreed with mass database (NIST14); s: mass spectrum and retention time identical with an authentic standard.
†Interaction genetic type x lean grade non-significant in any variable (P>0.05).

3.3 *Correlations between Volatile compounds and Fatty acids*

Concerning hydrocarbons, the concentration of undecane (1-Undecene, 9-methyl-) was positively correlated ($0.41 \leq r \leq 0.53$; $P < 0.05$) with percentages of margaric acid

(C17:0), heptadecenoic acid (C17:1*n*-7), linoleic acid (C18:2*n*-6), alfa-linolenic acid (C18:3*n*-3), total PUFA, and also, PUFA/SFA ratio. However, the concentration of undecane was negatively correlated ($-0.43 \leq r \leq -0.47$; $P < 0.05$) with oleic acid (C18:1*n*-9) and cis-gadoleic acid (C20:1*n*-9). The concentration of 2,4,4-trimethyl-hexane showed a negative correlation ($-0.56 \leq r \leq -0.57$; $P<0.01$) with lauric acid (C12:0) and myristic acid (C14:0).

A positive correlation between the concentration of aldehyde 2-octanal,(E)- and myristic acid content (C14:0) ($r = 0.49$, $P < 0.05$, as well as between 2-octanal,(E)- and total SFA ($r = 0.55$; $P < 0.01$) was found. In contrast, the concentration of propanal, pentanal and hexanal aldehydes showed negative correlations ($-0.40 \leq r \leq -0.47$; $P < 0.05$) with contents of lauric acid (C12:0), myristic acid (C14:0) and arachidic acid (C20:0).

The concentration of 3-hydroxy-3-methyl-2-butanone (ketone) exhibited strong positive correlations ($r = 0.70$; $P < 0.001$) with contents of individual PUFA dihomo-γ-linolenic acid (C20:3*n*-6) and arachidonic acid (C20:4*n*-6). The concentration of both acetoin (ketone) and acetic acid ethenyl ester (ester) showed positive correlations ($0.62 \leq r \leq 0.65$; $P < 0.001$) with MUFA palmitoleic acid (C16:1*n*-7) content. On the contrary, the concentration of ethyl acetate, acetic acid ethenyl ester and acetoin showed negative correlations ($-0.42 \leq r \leq -0.49$; $P < 0.05$) with linoleic acid (C18:2*n*-6), gamma-linolenic acid (C18:3*n*-6), alfa-linolenic acid (C18:3*n*-3), total PUFA, and PUFA/SFA ratio.

The concentration of butanoic acid (carboxylic acid compound), 3-methyl- showed positive correlations ($r = 0.55$; $P < 0.01$) with the percentage of C14:0 and C16:0. However, the concentration of pentanoic acid had negative correlation with the content of C14:0 ($r = -0.43$; $P < 0.05$) but the former has a positive correlation with C18:3*n*-3 ($r = 0.41$, $P < 0.05$).

Regarding alcohols, the concentration of 1-Butanol, 3-methyl-, 2,3-Butanediol -[S-(R*, R*)]- and 1-octen-3-ol showed a positive correlation ($0.42 \leq r \leq 0.48$; $P < 0.05$) with the content of arachidonic acid (C20:4*n*-6) and dihomo-γ-linolenic acid (C20:3*n*-6). On the contrary, the concentration of 1-heptanol showed a negative correlation with the percentage of C20:4*n*-6 ($r = -0.57$; $P < 0.01$).

The concentration of carbon disulphide (sulfur compound), only showed a negative correlation with the content of lauric acid (C12:0) ($r = - 0.45$; $P < 0.05$). In contrast, the concentration of furans, 2-ethyl-, 2-n-butyl, and 2-pentyl-, showed a positive correlation ($0.44 \leq r \leq 0.46$; $P < 0.05$) with content of individual PUFA arachidonic acid (C20:4*n*-6).

3.4 Partition trees

The best partition tree of FA based on genetic type resulted in two splits (Figure 2a). The final coefficient of determination (R^2 square) for the validation set was 0.52. The column contributions report (based on G2) showed that PUFA/SFA ratio of raw meat and myristic acid (C14:0) are the main predictors of genetic type in the partition tree model. The lower PUFA/SFA ratio (< 0.48) was exclusively associated with Du crossbred pork (100%). Within the cooked aged pork showing higher PUFA/SFA ratio (≥0.48), more Pi crossbred pork (85.7%) showed lower C14:0 content (<1.4%), whereas Du crossbred pork (71.4%) had higher C14:0 (≥1.4%). Another partition tree (Figure 2b) was developed to identify VC profile of organic cooked pork based on genetic type. The final RSquare for the validation set was 0.58. The column contributions report (based on G2) showed that cyclopropane, pentyl- (cyclic hydrocarbon) and methanethiol (sulphur compound) are the main predictors of genetic type in the partition tree model. We found that higher cyclopropane, pentyl- content (≥ 12 AU x10^4/g) was exclusively associated at Du crossbred (100%). Within the cooked aged pork showing lower cyclopropane, pentyl- content (< 12 AU x10^4/g), more Du crossbred pork (66.7%) showed lower methanethiol (<0.8 AU x10^4/g), whereas higher methanethiol (≥0.8 AU x10^4/g) was exclusively associated with Pi crossbred pork (100%).

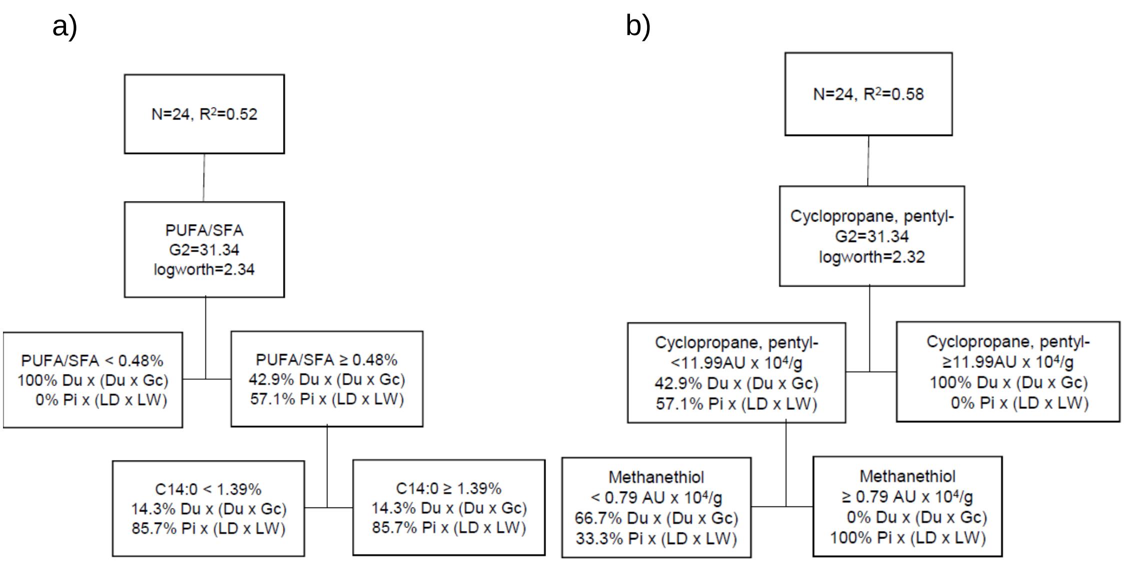

Figure 2 Partition tree of fatty acids (a) and volatile compounds (b) of organic pork based on genetic type, showing the two splits and the proportion of observations in each split.

The third partition tree of FA, based on lean content, showed two splits, and the proportion of observations in each split is shown in Figure 3a. The final coefficient of determination for the validation set was 0.51. Thus, the column contributions report (based on G2) showed that total SFA content of pork and margaric acid (C17:0) are the main predictors in the partition tree model. The higher SFA content (≥ 37.6%) was exclusively associated with pigs with higher level of fatness (< 60 % lean; 100%). Within the cooked aged pork having the lower SFA content (<37.5%), more fattier pigs (71.4%) showed lower C17:0 content (< 0.31%), whereas leaner pigs (88.9%) had higher C17:0 (≥ 0.31%). A fourth partition tree was developed to identify VC profile of organic cooked pork based on lean content (Figure 3b). The final RSquare for the validation set was 0.64. The column contributions report (based on G2) showed that hexane, 2,4,4-trimethyl and carbon disulphide were the main predictors in the partition tree model. Higher hexane, 2,4,4-trimethyl content (≥ 163 AU x10^4/g) was exclusively associated with pork classified as leaner (≥ 60 % lean; 100 %). Within the cooked aged pork having lower hexane, 2,4,4-trimethyl content (< 163 AU x10^4/g), carbon disulphide content was higher (≥ 8 AU x 10^4/g) in pork classified as fattier (< 60 % lean; 100 %). More pigs classified as leaner (57.1%) showed lower carbon disulphide content (< 8 AU x10^4/g) and lower hexane, 2,4,4-trimethyl content (< 163 AU x10^4/g) in cooked aged pork loin.

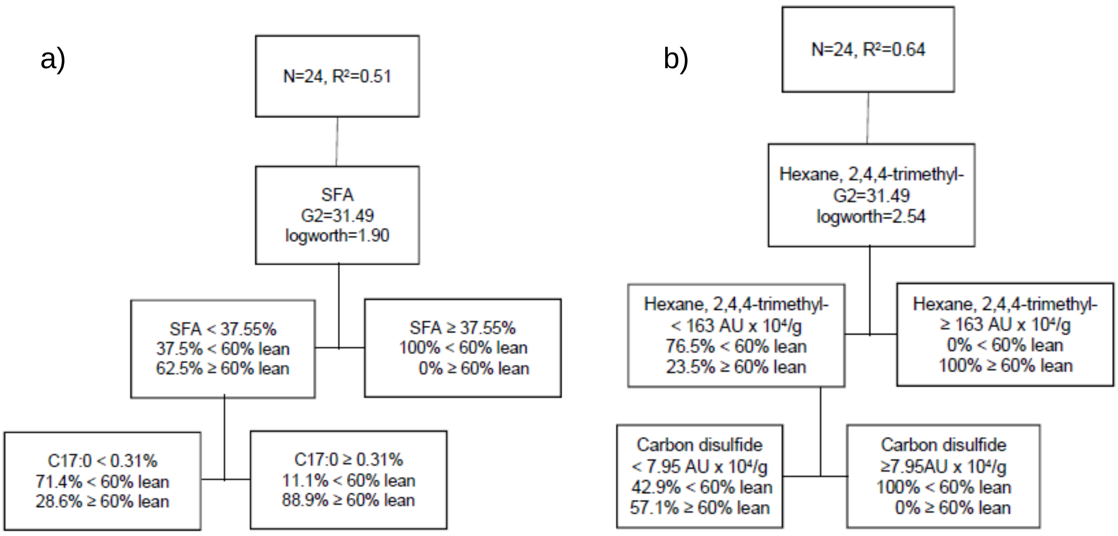

Figure 3 Partition tree of fatty acids (a) and volatile compounds (b) of organic pork based on lean grade, showing the two splits and the proportion of observations in each split.

4. Discussion

4.1 Fatty acids composition of raw pork

This study analyzed the relevance of genetic type and lean grade on fatty acid profiles and volatile compounds in pork under organic husbandry. These effects were assessed both independently and together (by testing its interaction). MUFA were the most prevailing group in the two pork genotypes studied (highest value for oleic acid, C18:1*n*-9), followed by SFA and PUFA. In the present study, 75%-Du crossbreds showed higher percentages of SFA in loin compared to their 50%-Pi counterparts, which had greater MUFA/SFA ratio. However, the results indicated that the individual intramuscular FA did not differ between genetic types (Du *vs.* Pi), possibly due to targeted lack of differences in carcass and meat fatness as well as similar age between them (Argemí-Armengol et al., 2019). Previous research demonstrates minimal differences in fatty acid composition among similar genetic types to those used in the current study. Our results agreed with Cameron et al. (1990) and Latorre et al. (2009b), who found only higher myristic acid (C14:0) concentrations in Du than in Pi genetics.

On the contrary, the leaner carcasses (> 60% lean) had lower acid lauric (C12:0) and eicosatrienoic acid (C20:3*n*-3) but greater MUFA/SFA ratio content than the fattier meat (< 60%).

While most SFA and MUFA can be efficiently synthesized *in vivo*, the lack of differences in PUFAs C18:2*n*-6 and C18:3*n*-3 proportions, which may be attributed to dietary factors (Calkins and Hodgen, 2007; Juárez et al., 2017), proves that both genetic types adapted similarly to the feed composition supply. Indeed, the SFA content of meat is positively correlated with carcass fatness (Fiego et al., 2005; Latorre et al., 2009a), which contributes to decrease the MUFA/SFA ratio and reduces the nutritional quality of pork (Scollan et al., 2017). Nevertheless, the lean content hardly affected the fatty acid groups either, probably because the lowest lean class was not excessively fatty, and due to their similar levels of intramuscular fat. In turn, the lower eicosatrienoic acid (C20:3*n*-3) content in leaner meat might be related to a lower feed intake pattern in lean compared to fatty pigs, which couples with their lower growth performance (Argemí-Armengol et al., 2019), and thereby this may reduce its biosynthesis from dietary C18:3*n*-3 (Sibbons et al., 2018).

4.2 Volatile compounds of cooked aged pork

While abundant research has been conducted regarding the VC derived from pork products (cooked and/or cured with long ripening periods), less information is available for meat. Thousands of volatile compounds are generated during thermal processing that belong to various chemical classes: hydrocarbons, alcohols, aldehydes, ketones, carboxylic acids, esters, furans, sulfuric compounds and others (Kosowska et al, 2017), which are produced through lipid oxidation, or through Maillard reaction or Strecker degradation (Mottram, 1998) or microbial degradation and others, which are responsible for meat flavour development. In the present study, higher cyclic hydrocarbons were observed in cooked loins from 75% Du compared to 50%-Pi crossbreds. More Du crossbreds were associated with greater concentrations of cyclopropane, pentyl- (an aromatic hydrocarbon), whereas more Pi crossbred pork had greater concentration of methanethiol (volatile sulphur compound from amino acid breakdown). Accordingly, methanethiol may not be a pleasant VC. Similarly, Benet et al. (2015) found greater methanethiol abundance in low than in high fat cooked cured ham. While most aliphatic hydrocarbons have not previously involved in meat aroma (Flores, 2018), methanethiol has been associated with sulfur and gasoline odor descriptors in pork broth from Chinese black-pig (Zhao et al., 2017) as well as with rotten eggs, sewage and cabbage in cured meat products (Flores, 2018). A greater amount of hexane 2,4,4-trimethyl (an aliphatic hydrocarbon) but lower carbon disulphide (sulfur compound) was detected in pork from leaner compared to fattier pork. According to Olivares et al. (2011), hexane is one of the volatile compounds come from lipid autooxidation. The sensory descriptions for hexane may be alkane and spicy (Pérez-Santaescolástica et al., 2018). Lorenzo and Domínguez (2014) reported that, compared with other cooking methods (grilled and roasted treatments), the application of heat for a short time led to a greater amount of hexane, and in general aliphatic hydrocarbons. In turn, carbon disulphide is an important intermediate of the Maillard reaction in the formation of heterocyclic compounds (Mottram and Mottram, 2002), but to our knowledge it seems uninvolved in aroma formation. Overall, even though Sánchez-Peña et al. (2005) reported that aliphatic hydrocarbons, because of their abundance, could play an important role in the aroma of dry-cured meat and play an important role in the overall flavor, their involvement in cooked loin primal may not be relevant.

4.3 Correlations between Volatile compounds and Fatty acids

The concentration of short-chain alcohols (mainly 1-pentanol and butanol) were lower in Pi and in leaner pork compared to the samples from 75% Du crossbreds and fattier pork, which may counterbalance the high values of methanethiol. In this regard, 1-pentanol is produced by the degradation of homologous aldehydes during lipid and amino acid oxidation (Garcia et al., 1991), and it has a mild odour, fruit and balsamic aroma (Calkins and Hodgen, 2007), which may favour the overall aroma from Du and/or fattier pork. Most of the linear alcohols identified are oxidative decomposition products of lipids. For example, 1-butanol can come from miristoleic acid (C14:1) and 1-pentanol from linoleic acid (C18:2*n*-6), 1-hexanol may be formed from palmitoleic (C12:1) and oleic acid (C18:1*n*-9), and 1-octanol from oleic acid oxidation (Forss, 1973; Flores et al., 1997). Among the volatile compounds, the levels of 1-butanol were significantly correlated with the aromas of French dry-cured ham (Buscailhon et al., 1994). The methyl and ethyl branched alcohols are probably derived from proteolysis, that is the Strecker degradation of amino acids (Martín et al., 2006; Narváez-Rivas *et al.*; 2012; Fonseca *et al.*, 2015).

Hexane 2,4,4-trimethyl was negatively associated with lauric acid (C12:0) and myristic acid (C14:0). In addition, the most representative aldehydes (pentanal and hexanal) were also negatively correlated with C14:0. Meynier et al (1998) found that hexanal was the major compound from the oxidation of *n*-6 fatty acids (mainly linoleic, C18:2*n*-6 and arachidonic acid, C20:4*n*-6) in pork loin, with odor descriptions for hexanal may be green (Zhao et al., 2017), which oxidized rapidly when heated (Wood et al., 2004).

The propanal aldehyde (with sensory attribute almond-like green and toasted) was present in all samples at same level, which was the main compound family in cooked foal meat in Domínguez et al. (2014b). Most PUFA (C18:2*n*-6, C18:3*n*-6, C18:3*n*-3 and C20:2*n*-6) were negatively correlated with acetoin (carboxylic acid) and acetic acid ethenyl ester (ester). The esters are formed from the interaction between free fatty acids and alcohols generated by lipid oxidation in the intramuscular tissue, specifically ethyl esters are formed through esterification reactions between ethanol and carboxylic acids (Peterson and Chang, 1982).

However, arachidonic acid (C20:4*n*-6) was positively correlated with some ketones and furans, which suggest that these compounds may be derived from the oxidation of *n*-6 fatty acids, and it would prove the susceptibility of PUFA to oxidation (Gravador et al, 2015). In this sense, Gandemer (2002) found that 2-pentylfuran in meat had sensory attributes as buttery and rancid, while Arnoldi (2003) found that it had odour notes as fruity and sweet; which it would have been generated during heating from linoleic acid (C18:2*n*-6) oxidation (Ruiz et al., 1999).

5. Conclusions

When pigs were slaughtered at similar carcass fatness, the 75%-Du had similar FA composition of loin meat compared to 50%-Pi genetic type, but Du genetics was prone to have low PUFA/SFA ratio (<0.48). However, the fattier carcasses (<60% lean) had a higher percentage of SFA (>37.6%) than leaner carcasses (>60% lean).

Overall, the aromatic and cyclic hydrocarbons in Du were higher than in Pi pork, which had higher content of carbon disulphide (sulphur compound). The Du and fattier pork presented higher amount of pentanol and butanol (alcohols), whereas leaner carcasses had the higher content of hexane 2,4,4-trimetil (aliphatic hydrocarbon). Most of the volatile compounds detected in the present study came from lipid oxidation.

Present results suggest that lean content rather than genetic type affected the FA composition of pork from pigs under organic husbandry which are slaughtered at light live-weights. However, the volatile compounds of cooked pork were dependent on both genetic type and lean grade. Understanding the contribution of each factor and their interactions will help the pork industry in the production of consistent premium products.

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6. Discussió general

L'objectiu d'aquesta tesi va ser obtenir més coneixements sobre qüestions rellevants en porcí ecològic i investigar sobre preferències dels consumidors de carn, alternatives d'alimentació en les diferents fases amb ingredients locals mediterranis, efecte del tipus genètic i l'engreixament de la canal en producció ecològica sobre la qualitat de la canal i característiques de la carn . Aquests factors són importants per obtenir resultats satisfactoris en tota la cadena productiva, tant pel criador de porcí (alimentació animal, **capítol II** i rendiment productius, **capítol IV**), l'escorxador (qualitat de la canal i aptitud tecnològica pel processat de la carn, **capítol III**) i acceptació i valoració de la carn pel consumidor final (atributs intrínsecs i extrínsecs de la carn que defineixen les actituds de compra, **capítols I i IV**).

6.1. Consumidor (capítol I)

Els resultats del consumidor de carn de porc analitzat en el **capítol I** (article I), en el context geogràfic de Catalunya, Aragó i nord de Portugal, mostren predisposició a adquirir carn de porc diferenciada, amb major greix visible, i criats en granges amb pati exterior i/o producció ecològica, estant disposats a pagar més per uns atributs de qualitat de la carn (benestar animal, mínim ús de medicaments que garanteixi l'absència d'antibiòtics i residus hormonals a la carn, i respecte pel medi ambient). Aquesta actitud no es veu afectada per les habilitats culinàries o hàbits de compra. Pel 55% dels europeus (Eurobarometer, 2019) la seguretat alimentària, juntament amb el preu, el gust, la nutrició i l'origen dels aliments, influeix en els seus hàbits alimentaris i opcions en la compra. Busch et *al.* (2019) van determinar que aspectes del sistema de maneig (slat vs. palla), en el context alemany, influenciaven en percepció de valoració de benestar dels porcs. Aquests resultats justifiquen la tendència a l'alça d'una producció porcina diferenciada, com és l'ecològica a Europa, amb un augment del 47,6% en la última dècada (Willer *et al*., 2019), i la demanda creixent del mercat ecològic europeu gairebé un 11%, segons dades del FibL (2019) en l'últim any (2017-2018).

Actualment, amb la proliferació de bactèries multi-resistents a antibiòtics i la necessitat de reduir-ne el consum en producció porcina, estem davant un nou desafiament pel sector. Espanya és el país de la Unió Europea on es venen més antibiòtics per animals de granja (362 mg ingredient actius/kg de biomassa animal; Eurobarometer, 2016), essent quatre vegades superior a Alemanya i el doble que la mitjana europea (Eurostat, 2017). Per contra, l'Eurobaròmetre (2019) confirma que un 44% dels consumidors els preocupa els antibiòtics i residus hormonals en carn. Així doncs, s’obre un nou nínxol de mercat pels productors de porcí a Espanya, ja que tot i ésser el segon país productor de porc convencional (per darrera d’Alemanya) es troba en onzena posició en porc ecològic (per darrera de Bèlgica); tot i que en superfície agrícola ecològica, en l’última dècada, Espanya és líder a la UE (Willer et *al.*, 2019).

No obstant, en aquest punt seria remarcable que el sobre-cost assumible pels consumidors per una carn de porc ecològica és d’aproximadament un 25%, que és un diferencial més baix que l’actual diferència de preu entre la carn de porc convencional i ecològica, que pot arribar al 200%.

6.2. Canal (capítol III)

Els estudis de l’efecte del sistema de producció sobre el benestar i la salut animal, les dades productives i sobre la qualitat de la canal són escassos (Früh et *al.*, 2014), on alguns s’han realitzat a granges (animal viu) i altres a escorxador (Leeb et *al.*, 2019). El nostre treball es va realitzar a escorxador (**capítol III**), valorant els decomisos i lesions a la pell de canals, de producció ecològica i convencional; a més de determinar altres factors de variació entre ambdós sistemes, com contingut de magre, greix subcutani (lumbar i dorsal), pes de la canal i ingressos per venda de canals.

De l’anàlisi de canals a escorxador comercial que sacrificava porcs provinents d’ambdós sistemes, es va observar que les lesions de pell tendien a ser més baixes en ecològic que en convencional, confirmant-se els resultats de treballs previs, on el sistema de producció ecològic impactava positivament sobre certs aspectes de benestar del porc criat a l’exterior o en ecològic (Alban et *al.*, 2015). En convencional es van decomissar una major proporció de pulmons que de fetges, atribuint-se a un major risc de malalties respiratòries degut a uns allotjaments més tancats, amb un menor espai disponible (0,65-0,75 m^2/animal convencional *vs*. 2,3 m^2/animal ecològic), i menys qualitat de l’aire (Guy et *al.*, 2002; Leeb et *al.*, 2019); mentre que en ecològic la resposta va ser a la inversa, i els decomisos de fetge poden ser deguts a malalties parasitàries com ascariasis (*Ascaris suum*), possiblement per la infestació després del deslletament per humitat en el terra de les corts (Alban et *al.*, 2015; Leeb et *al.*, 2019). Aquest fet evidencia la necessitat de tenir en compte el correcte estat del jaç i la realització de buits sanitaris entre lots en el porcí ecològic. En funció del tipus d’allotjament: a l’interior amb patis amb solera de formigó o engraellat, a l’exterior lliure amb sòl de terra i combinació d’ambdós, s’ha descrit a la bibliografia una variació en quant a endoparàsits i malalties en porc ecològic (Früh et *al.*, 2011; Früh et *al.*, 2014; Leeb et *al.*, 2019).

La cria en ecològic va fer incrementar l'espessor de greix subcutani (lumbar) de les canals, reduint-se el contingut de magre a l'estiu en comparació amb la tardor, atribuït a una menor ingestió i per tant amb dificultats per poder cobrir les necessitats nutricionals del porc (aminoàcids essencials), durant l'època més càlida, i afavorint d'aquesta manera la deposició de greix (Millet *et. al.*, 2005). El sistema de pagament de les canals a la UE a escorxadors valora positivament el percentatge de magre (classificació SEUROP), no obstant, una proporció important (68,4%) del consumidors estudiats (**capítol I**) valora positivament el contingut de greix (intramuscular i subcutani), existint, doncs, divergències a la cadena alimentària, motiu d'objecte d'estudi en el **capítol IV**. En ecològic no està permès la utilització d'aminoàcids sintètics de síntesi química i això dificulta que els aliments aportin el perfil d'aminoàcids requerits, sobretot si valorem ingredients locals i amb baix impacte ambiental en la seva producció, essent aquest l'objectiu principal del **capítol II.**

6.3. Alimentació (capítol II)

Els recursos en alimentació de proteïnes alternatives locals, analitzades al **capítol II**, adaptades al clima mediterrani (moreu, fenigrec, favó, i pèsol), tot i la manca d'informació prèvia en valors de digestibilitat i factors anti-nutritius, varen donar resultats de composició química i nutricional que van permetre formular les dietes per porcí ecològic, tot i que les formules contenien nivells inferiors en aminoàcids com lisina, respecte les utilitzades en convencionals. El fenigrec (*Trigonella foenum-graecum*) i el moreu (*Vicia narbonensis*) varen aportar valors nutritius de 27,25% PB i 1,32% Lys , mentre el moreu en va aportar 26,98% PB i 1,43% Lys, respectivament.

Amb la selecció de la mostra representativa de cereals, subproductes de cereals, oleaginoses i proteaginoses es va poder formular dietes en les diferents fases fisiològiques de porcí, segons recomanacions nutricionals espanyoles (FEDNA, convencional), i sobretot les franceses per ecològic (ITAB-IFIP), sense utilitzar soja i/o derivats, a excepció de la fase de garrins (<30 kg). Fins i tot, es van considerar en les fases de gestant i acabat una aportació d'aliment fibrós (en detriment del concentrat) que podria incorporar-se en el pinso, el que reduiria el risc de lesions de la mucosa gàstrica per la major mida de partícula (Holinger et *al.*, 2018). En aquest sentit, la normativa ramadera ecològica també exposa la necessitat d'oferir farratges en la dieta del porc ecològic, especialment per contribuir a incrementar el comportament exploratori (Zwicker et *al.*, 2012) que deriva en una reducció dels danys per manipulacions de cua o mossegades (Studnitz et *al.*, 2007). Fabrega *et al.* (2019), van determinar que la palla és el millor material d'enriquiment ambiental, tot i el poc valor nutritiu, aportant font de fibra.

La integració agropecuària a la finca permetria reduir els costos d'alimentació (28%) i incrementar el marge de benefici pel ramader, essent obligatori actualment un 20% d'autosuficiència alimentària segons el Reglament (CE) 889/2008, i a partir del 2021 passarà a ser el 30%, segons Reglament (UE) 2018/848. S'ha determinat que la superfície necessària per alimentar un truja i la seva descendència (20 porcs) a l'any, segons produccions mitjanes en clima mediterrani, és de 2,5 ha, corresponents a 1 ha de cereal i 1,5 ha de lleguminoses, facilitant la rotació i diversitat cultivada a la finca, article 5 i article 12 Reglament (CE) 834/2007, sobre producció ecològica. Un recent informe de la Comissió Europea (2019), sobre el balanç de proteïnes de pinso a la UE, durant període 2017/18, va determinar que només es produeix dins la UE el 26% del què es consumeix en soja i colza per elaboració de pinso. A Catalunya (2019), les granges de porcí ecològic no arriben a produir-se el 40% dels aliments a la pròpia granja, com sí que es va demostrar que succeïa a altres països d'Europa, com França, Suècia, Àustria, segons estudi europeu (Früh et *al.*, 2014).

Al voltant d'un terç de la producció mundial de cereals s'ofereix als animals (FAO, 2006), i els porcs com a omnívors representen una competència directa amb la població humana per als cultius disponibles. Segons les últimes dades de Idescat a Catalunya, la superfície agrària útil és 1.115.367 ha (any 2016) i segons MAPA (2018) hi ha 810.003 unitats ramaderes (URP) de porcí, equivalent a una relació de 0,73 URP porcí/ha (o el seu equivalent, 22,2 kg N/ha), sense tenir en compte altres espècies animals (cabrum i oví, boví, avícola, i altres minoritaris), confirmant la vulnerabilitat a la contaminació per nitrats en agricultura que procedeixen de fonts ramaderes, ja que podrien excedir-se els 170kg N/ha recomanats (Directiva 91/676/ECC).

S'ha avaluat l'impacte ambiental de les dietes mitjançant l'anàlisi del cicle de vida (de Vries et *al.*, 2010; Wilfart et *al.* 2016), ja que prèviament s'havia descrit que està influenciat pels tipus d'ingredients utilitzats (Garcia-Launay et *al.*, 2014). La dieta de garrins (per Tn de pinso fabricat) va ser la de més impacte i la de gestants la de menor impacte, ja que els valors resultants es dupliquen: consum d'energia renovable : 4.236 MJ *vs.* 1.971 MJ, respectivament), canvi climàtic: 424 kg CO_2-eq *vs.* 275 kg CO_2-eq; acidificació del medi: 7,9 molc H+-eq *vs.* 4,7 molc H+-eq; eutrofització: 5,1 kg PO_4 *vs.* 3,2 kg PO_4, i ocupació de terra 2.310m^2 vs. 1.349m^2.

En l'experiment a granja (**capítol IV**), es van alimentar dos creuaments genètics diferents (procedents de mare Duroc x Gascon i mascle finalitzador Duroc vs. mare Landrace x Large-White i mascle finalitzador Pietrain) amb el mateix concentrat per avaluar l'efecte del tipus genètic sobre la productivitat i la qualitat del producte. Es va observar que en la fase d'engreix el guany mig diari era diferent, 593g/dia vs. 663

g/dia, respectivament, per tant, caldria adaptar la composició química de les dietes a les necessitats nutricionals de la genètica per a ser més eficients. Actualment, comparant amb la producció convencional de porcs, en l'agricultura ecològica els rendiments dels cultius i l'índex de conversió de pinsos és més baix, provocant una pressió més alta sobre l'ús de la terra (van Wagenberg et *al.*, 2017).

Segons Sundrum et al. (2011), en la producció porcina, factors com, tipus d'alimentació, el sistema (aire lliure, ecològic, convencionals,...), el genotip i altres (sexe o pes al naixement), contribueixen a la infiltració de greix intramuscular (vetejat de la carn); el qual és apreciat per un 67,7% dels consumidors i disposats a pagar fins a 11,8% més que el preu mitjà de carn de llom (**capítol I**), independentment de l'origen ecològic de la carn. Per tal de valorar l'efecte raça del tipus genètic porcí sobre la qualitat nutricional i sensorial de la carn porc, en *Longissimus lumborum*, es va realitzar l'estudi de composició química de la carn del **capítol IV**.

6.4. Carn (capítol IV)

Els resultats de l'estudi de dues genètiques híbrides diferents, criades en producció ecològica, van mostrar que el creuament de races rústiques (75% gens Duroc i 25% Gascó) presentava un menor ritme de creixement, pes i rendiment de la canal en comparació amb el creuament de races comercials (25% Landrace, 25%Large-White i 50% Pietrain), àmpliament utilitzat a Europa, donant resultats productius similars a altres treballs previs (Edwards et *al.*, 1996; Latorre et *al.*, 2003). Així, un ramader que opti per l'elecció d'aquest dos creuaments, si el canal de comercialització i valoració de la canal de porc és el preu pagat a escorxador (segons classificació SEUROP) és recomanable la raça Pietrain a la línia paterna. No obstant, la diversificació de races porcines locals i sistemes productius alternatius, per obtenir productes d'alta qualitat nutricional i sensorial, acompanyat per una cadena comercial de la carn de porc més sostenible, té interès i és objectiu d'anàlisi i potenciació, com es demostra en el projecte "TREASURE", finançat per la Comissió Europea dins Horizon 2020 (núm. 634476).

El sacrifici a baix pes (90kg o 105kg, Duroc *vs*. Pietrain) per aconseguir un percentatge d'engreixament de la canal similar (≃60% magre), va donar a un llom sense diferències significatives de pH (a 45 min i 24 h *post-mortem*), de pèrdues d'aigua per cocció i de contingut de greix intramuscular entre ambdós tipus genètics (75%Duroc vs. 50%Pietrain). La genètica Duroc presentava un llom d'un color menys vermell (a*), una tendència a menor pèrdua d'aigua en carn madurada 8 dies i més dur (resistència al tallat, WBSF), a un dia de maduració, comparat amb la genètica Pietrain. Les canals més magres (≥60% de magre) tenien tendència a una major resistència a l'esforç del 80% de compressió a 1 dia de maduració, en comparació amb canals grasses (<60% magre). La duresa de la carn es va reduir en la carn madurada 8 dies, i va en la línia amb l'observat en altres treballs (Channon et *al.*, 2004; Álvarez-Rodríguez et *al.*, 2018). El creuament de Duroc va disminuir un 40% la duresa quan es va madurar 8 dies, respecte a 1 dia de maduració, a diferència del creuament amb Pietrain, que, va mantenir la duresa en valors de ≃4 kg. La textura és un paràmetre de qualitat sensorial valorat pel consumidor, ja que és un propietat que es detecta en el gust, facilitat per tallar-la i mastegar-la. Ambdós genètiques i percentatges de magres de canal van donar valors de duresa instrumental (WBSF), en carn cuita i madurada 8 dies, en la línia d'altres treballs (Moeller et *al.*, 2010; Van Oeckel et *al.*, 1999), amb valors de referència per carn tendre compresos entre 3-4 kg.

El consumidor analitzat estava disposat a pagar un 24,3% més per carn certificada amb l'eurofulla i valorava significativament la carn pels continguts nutricionals i saludables (absència d'antibiòtics i residus hormonals) (**capítol I**). En la segona part del treball d'anàlisi de la carn (**capítol IV, article IV**) es va determinar el percentatge de 19 d'àcids grassos en la carn: en major proporció, l'oleic (C18:1 cis9), seguit del palmític (C16:0) i el linoleic (C18:2 n-6). No es van observar diferències significatives entre els tipus genètics, només que la genètica 75%Duroc tendia a un major contingut d'àcids grassos saturats (AGS), respecte la 50%Pietrain. Les canals magres (>60% magre) van donar els mateixos resultats que treballs de Latorre et *al*. (2009), on el contingut de magre es correlacionava negativament amb el contingut total AGS i grassa intramuscular, contribuint a augmentar la relació AGMI/AGS i en conseqüència la qualitat nutricional de la carn (Scollan et *al.*, 2017). El gust de la carn cuita és un dels atributs sensorials més importants pel consumidor per valorar la qualitat, i està influenciat pels compostos volàtils formats durant la cocció que contribueixen en el gust de determinats aromes de la carn (Calkins & Hodgen, 2007; Zhao et *al.*, 2017). Es van identificar 69 compostos volàtils en la carn cuinada (madurada 8 dies), on la quantitat dels obtinguts de la família dels alcohols de cadena curta va ser més baixa en la genètica 50%Pietrain i els porcs magres, en comparació amb els 75%Duroc i grassos. El 1-pentanol es produeix per la degradació d'aldehids durant l'oxidació de lípids i aminoàcids (García et *al*., 1991), amb una olor suau, afruitada i aroma balsàmic, el què afavoriria la valoració sensorial global del Duroc i el porc gras. L'hidrocarbur aromàtic ciclopropà a altes concentracions es va associar exclusivament amb Duroc, mentre que baixes quantitats de ciclopropà, i altes del compost sulfur metanotiol es van relacionar amb les canals de tipus genètic 50%Pietrain.

7. Conclusions

1. La hipòtesi que el consumidor amb habilitats culinàries, es relacionaria amb una major predisposició a adquirir carn de porc diferenciada, no es va confirmar. No obstant, es va detectar que els senyals acreditatius d'una carn saludable i produïda amb un sistema de producció més sostenible ambientalment, com en cas de porc criat a l'exterior i/o porc ecològic, confirmaven la disposició del consumidor de pagar més per carn de porc de qualitat diferenciada.
2. Atenent a les zones geogràfiques estudiades (Catalunya, Aragó i nord de Portugal), no es van observar diferències entre elles, en la voluntat de compra del consumidor per la carn de porc, només es va detectar que a Portugal les dones estaven disposades a pagar més per porc ecològic que els homes (diferència entre sexes).
3. És possible nutricionalment i viable econòmicament formular dietes per porcí ecològic amb matèries primeres locals, utilitzant com a font proteica moreu, fava, pèsol i fenigrec, i com a font energètica, triticale, sègol, blat i ordi, d'acord a les recomanacions nutricionals de l'organisme francès ITAB-IFIP, excepte en la fase de garrins (<30kg).
4. Un model de negoci amb integració agropecuari a la pròpia granja és millor econòmicament que la compra externa de pinso, especialment en la fase de porc en creixement i acabat, on s'abarateixen més els costos.
5. En la valoració ambiental dels impactes, per tona de pinso produït, s'observa que són superiors seguint les normes de formulació de FEDNA, respecte a ITAB, per la demanda de fòsfor (kg P), energia no renovable (MJ) i acidificació (molc H+-eq). Per contra, l'impacte per canvi climàtic (kg CO_2-eq), eutrofització (kg PO_4) i ocupació de terra (m^2), és superior en les dietes de garrins i creixement segons recomanacions de necessitats nutricionals de l'Institut francès (ITAB). La dieta amb major impacte ambiental (per tona d'aliment) és la de garrins i la de menor impacte la de truges gestants.
6. En l'anàlisi de les canals per model productiu, es va observar que el pes de la canal era similar en ecològic i convencional. Tanmateix, en ecològic s'incrementava l'espessor del greix subcutani lumbar i es reduïa el contingut de magre a l'estiu, i existia un menor risc de lesions de pell i major risc de decomisos de fetges.

7. Per l'efecte època de l'any, es va determinar que a l'estiu i en porcs mascles castrats, el contingut de greix subcutània lumbar i dorsal era superior, i el percentatge de magre era inferior, en comparació amb les femelles; i a l'estiu existia menys risc de lesions en pell i decomisos de fetges i pulmons.
8. En l'avaluació de l'efecte del tipus genètic, entre dos creuaments híbrids, un de races rústiques (75% gens Duroc i 25% Gascona) i un de races comercials (25% Landrace, 25% Large White i 50% Pietrain), es va observar un menor ritme de creixement, pes i rendiment de la canal al utilitzar el creuament de races rústiques.
9. Quan es van sacrificar al mateix estat d'engreixament (percentatge de magre), no es va confirmar la hipòtesis que la carn de creuament rústic seria més vermella i tendra que la de creuament comercial, únicament es va observar una lleugera tendència a menor pèrdua d'aigua en el creuament rústic (carn madurada 8 dies).
10. La hipòtesis que el porc de genètica rústica (75%Duroc) tindria un perfil de la seva grassa intramuscular més mono-insaturat, sense augmentar el contingut d'àcids grassos saturats, no es va demostrar, ja que presentaven una composició similar d'àcids grassos en llom de porc. A més, aquest tipus genètic es va associar a una ratio PUFA/SFA menor que la genètica comercial (50%Pietrain). Els porcs més grassos tenien més percentatge d'àcids grassos saturats que els magres.
11. En general, amb la genètica 75%Duroc, el contingut de ciclopropà pentil (hidrocarbur aromàtic) era superior, respecte la 50%Pietrain, que presentava més contingut de metanotiol (compost sofrat). En 75%Duroc i porcs grassos hi havia més contingut de pentanol i butanol (alcohols), per contra, els magres tenien un contingut més elevat de hexà 2,4,4-trimetil (hidrocarbur alifàtic). La majoria dels compostos volàtils detectats al present estudi provenien de la oxidació lipídica.

8. Implicacions

Els resultats obtinguts en l'anàlisi del consumidor de carn de porc poden ajudar a un nínxol de productors de porcí, obrint noves oportunitats de mercat, dissenyant estratègies de producció i màrqueting encaminades a la percepció d'atributs de qualitat (producció amb jaç de palla i parcs exteriors per millorar el benestar animal, i maneig en ecològic amb el mínim ús de medicació), per sobre que les encaminades a segments de consumidors amb diferents habilitats culinàries i estils de vida.

En la mateixa línia, el consumidor valora factors extrínsecs en la informació de l'etiqueta: certificat de qualitat, relacionat a la salubritat i característiques del procés (absència de residus medicamentosos, aliments no modificats genèticament, més percentatge de grassa en llom i benestar animal).

A nivell tecnològic de la carn, en producció ecològica, i a un baix pes en el sacrifici, es pot recomanar, a nivell de classificació SEUROP, a productors i a escorxadors, l'elecció d'un creuament de línia materna híbrida (Landrace x Large-White) amb mascle finalitzador Pietrain, en comparació amb un creuament rústic (75% Duroc i 25% Gascó). Els resultats suggereixen millors rendiments de creixement, pes de les canals, més intensitat de vermell a carn (a*) i més tendresa.

Per contra, quan es va valorar la qualitat nutricional (àcids grassos i compostos volàtils) dels dos creuaments (rústic *vs.* moderna) i el contingut de magre a les canals, es va determinar que el percentatge de magre afectava més a la composició dels àcids grassos que el tipus genètic. Per contra, els compostos volàtils en carn cuita depenien tant del tipus genètic com el percentatge de magre. Per la indústria de la carn de porc, entendre la contribució de cada factor i les seves interaccions ajudarà a produir un productes de qualitat diferenciada.

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