R. Bras. Zootec., 49:e20200009, 2020
https://doi.org/10.37496/rbz4920200009

Non-ruminants
Full-length research article

Revista Brasileira de Zootecnia

Brazilian Journal of Animal Science
e-ISSN 1806-9290
www.rbz.org.br

Feed efficiency and loin meat quality in Iberian pigs

Wendy Mercedes Rauw[1*], Juan María García Casco[2], Fernando Gómez Carballar[3], Eduardo de la Serna Fito[3], Patricia Palma Granados[2], Miguel Ángel Fernández Barroso[2], Luis Gomez Raya[1]

[1] Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, Departamento de Mejora Genética Animal, Madrid, Spain.
[2] Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria, Centro de I+D en Cerdo Ibérico, Zafra, Badajoz, Spain.
[3] Sánchez Romero Carvajal, Jabugo S.A., Jabugo, Spain.

***Corresponding author:**
rauw.wendy@inia.es

Received: January 25, 2020
Accepted: July 14, 2020

How to cite: Rauw, W. M.; García Casco, J. M.; Gómez Carballar, F.; Serna Fito, E.; Palma Granados, P.; Fernández Barroso, M. A. and Gomez Raya, L. 2020. Feed efficiency and loin meat quality in Iberian pigs. Revista Brasileira de Zootecnia 49:e20200009.
https://doi.org/10.37496/rbz4920200009

ABSTRACT - We investigated the ability to predict production performance in Iberian pigs in an extensive production system from measurements of feed efficiency measured intensively. The second objective of this work was to study the relationship between feed efficiency and meat quality (composition, juiciness, tenderness, color, and subcutaneous fatty acid composition) and if cooked and cured quality properties can be predicted by properties in fresh meat. Thirty Iberian sows received successively a restricted diet of concentrate ($P1_{concentrate}$) and acorns ($P2_{acorn}$) intensively and an *ad libitum* diet of acorns supplemented with a restricted amount of concentrate ($P3_{montanera}$) extensively. Pigs that were more feed efficient on concentrate were less feed efficient on acorns and had higher body weight gain during the *montanera*. Improved feed efficiency on acorns reduced the concentration of α-linolenic and linoleic fatty acid composition of subcutaneous fat. Faster body weight gain in *montanera* resulted in a desirable reduction in cooking loss and a reduction in palmitic acid content in subcutaneous fat, and a potentially undesirable reduction in meat redness. Tenderness in cooked or cured loin was not significantly related to tenderness in the raw product. Cooking loss was positively related to purge and centrifugal drip loss and to color coordinates a^*_{24} and b^*_{24} in raw samples. We conclude that feed efficiency and body weight gain may be improved in the traditional Iberian production system, with a positive effect on cooking loss but potentially resulting in paler meat.

Keywords: correlation, fatty acids, feed intake, meat quality, *montanera*, pig production

1. Introduction

The Iberian pig breed is the most important Mediterranean swine type (*Sus mediterraneus*), both in population size and in economic importance (González Fernández, 2003; Díaz-Caro et al., 2019). It is characterized by slow growth with a high potential for fat accumulation and low prolificacy; however, noble parts (i.e., higher priced parts) from pigs fattened on acorns are destined to a niche market of highly priced dry-cured processed meat. In Spain, in a production system called "*montanera*", after a period of restricted feeding on concentrate, the Iberian pigs roam the Mediterranean forest called the "*dehesa*": woodlands of evergreen oak trees, grass, herbs, and roots (Rodríguez Estévez et al., 2009). As a consequence, this production system is a model for extensive organic farming, providing animal freedom and welfare (Rodríguez-Estévez et al., 2012).

Selection programs are not common in extensively produced Iberian pig populations; however, there is an interest from the industry to develop breeding schemes aimed at improvement of growth rate, yield of premium cuts, high meat and fat quality, and feed efficiency (Muñoz et al., 2018). In intensive pig production, the efficiency of animals transforming feed into meat is a key element in the economic return of farm operations (Rauw, 2012); however, feed efficiency is also important to extensive production systems. An important aspect of Iberian pig production in *montanera* is the carrying capacity of available land, which depends on stocking density, climatic conditions, and maturation rate and fall of acorns (Lopez-Bote, 1998). With an average production of 11 kg of acorns per adult evergreen oak needed to obtain 1 kg of weight gain, Rodríguez-Estévez et al. (2012) estimated that a herd of pigs need as many trees as the expected total kg weight gain, translating to a stocking rate of less than 1 pig per ha of *dehesa* to achieve the minimum standard of 46 kg weight gain per pig.

Therefore, improvement of feed efficiency is of interest in extensively kept Iberian pigs. Feed efficiency, however, is difficult to record in animals under extensive conditions, since feed intake cannot be accurately recorded without sophisticated methods. For example, Prendiville et al. (2010) investigated the relationship between grazing behavior and feed efficiency in dairy cattle, and Meale et al. (2017) investigated the use of potential biological markers from blood, hair, and feces in young bulls to characterize differences in feed efficiency. Alternatively, as discussed by Rauw et al. (2006), feed efficiency in extensive production systems can be estimated instead in a controlled short-term experiment in intensively penned animals, either on the same individuals of interest or on a sub-group originating from the animal population of interest. Because there is a serious concern that improved feed efficiency may negatively affect meat quality traits (Gilbert et al., 2007), it is also important to evaluate this relationship, especially in a production system that ultimately relies on these traits for its economic survival.

The objective of this study was to investigate the ability to predict performance during *montanera* from measurements of feed efficiency measured intensively in an Iberian pig production system. The second objective was to study if feed efficiency and body weight gain affect several loin meat quality traits. We also investigated the relationship between the meat quality traits and the ability of indicators in raw meat to predict the quality of cooked and dry-cured loin products.

2. Material and Methods

A total of 30 purebred Iberian sows were used in this experiment. Pigs were located in Oropesa, Toledo, Spain (39°59'32" N, 5°7'10" W), and were individually marked before the start of the experiment. Animals were born between the 17th of July and 5th of August 2017, but their exact age was unknown. For Figure 1, which depicts trends over time, age is given based on an approximate day of birth on the 26th of July. All sows were treated with an anti-GnRH vaccine by intramuscular injection of 2 mL of Vacsincel (Zoetis, Madrid, Spain), an analogue protein conjugate of gonadotropin-releasing hormone, at five, six, and nine months of age. All procedures followed the Spanish policy for the protection of animals used in research and other scientific purposes (RD53/2013). Pigs were cared for following the guidelines of the Spanish Ministry of Agriculture (BOE, 2014).

The experiment consisted of three periods. Body weight (BW) and ultrasound measurements of backfat thickness (BFT; P2 position; Echoscan T-100, Import-Vet S.A., Barcelona, Spain) were recorded at the beginning and end of each period. From this, daily body weight gain (DBWG) was estimated in g/d and gain in BFT (BFTG) was estimated in mm/d, for each of the three periods. In the first period ($P1_{concentrate}$), between 19th of November and 19th of December 2018 (a total of 30 days), pigs were housed individually in one of 15 pens in one of two rooms and were fed 4 kg/d of a regular concentrate diet. The second period ($P2_{acorn}$) took place between 20th of December 2018 and 10th of January 2019 (a total of 21 days); pigs were fed 2 kg of concentrate and 4 kg of acorns daily during the first three days, after which they received 8 kg of acorns daily. In $P1_{concentrate}$ and $P2_{acorn}$, no feed was left over at the end of each period. Each individual pen was equipped with a stainless-steel feeder and a nipple drinker. Water was provided *ad libitum* during these periods. During the third period ($P3_{montanera}$), between 11th and 29th of January 2019 (a total of 18 days), all individuals were released to the *dehesa*. Because the availability of acorns in the field was insufficient, animals were group-fed with an additional 4 kg of concentrate per animal (a total of 120 kg), which is common practice in Iberian pig production when acorn availability is low. Individual intake could not be established during this production phase. Pigs had free access to water at all times. Feed conversion efficiency (FCE) during $P1_{concentrate}$ and $P2_{acorn}$ was estimated as DBWG divided by daily feed intake. This experimental design mimics commercial Iberian production, but incorporates an intensive production period to estimate feed efficiency on concentrate and on acorns. Our study is the first to estimate feed efficiency in purebred Iberian pigs.

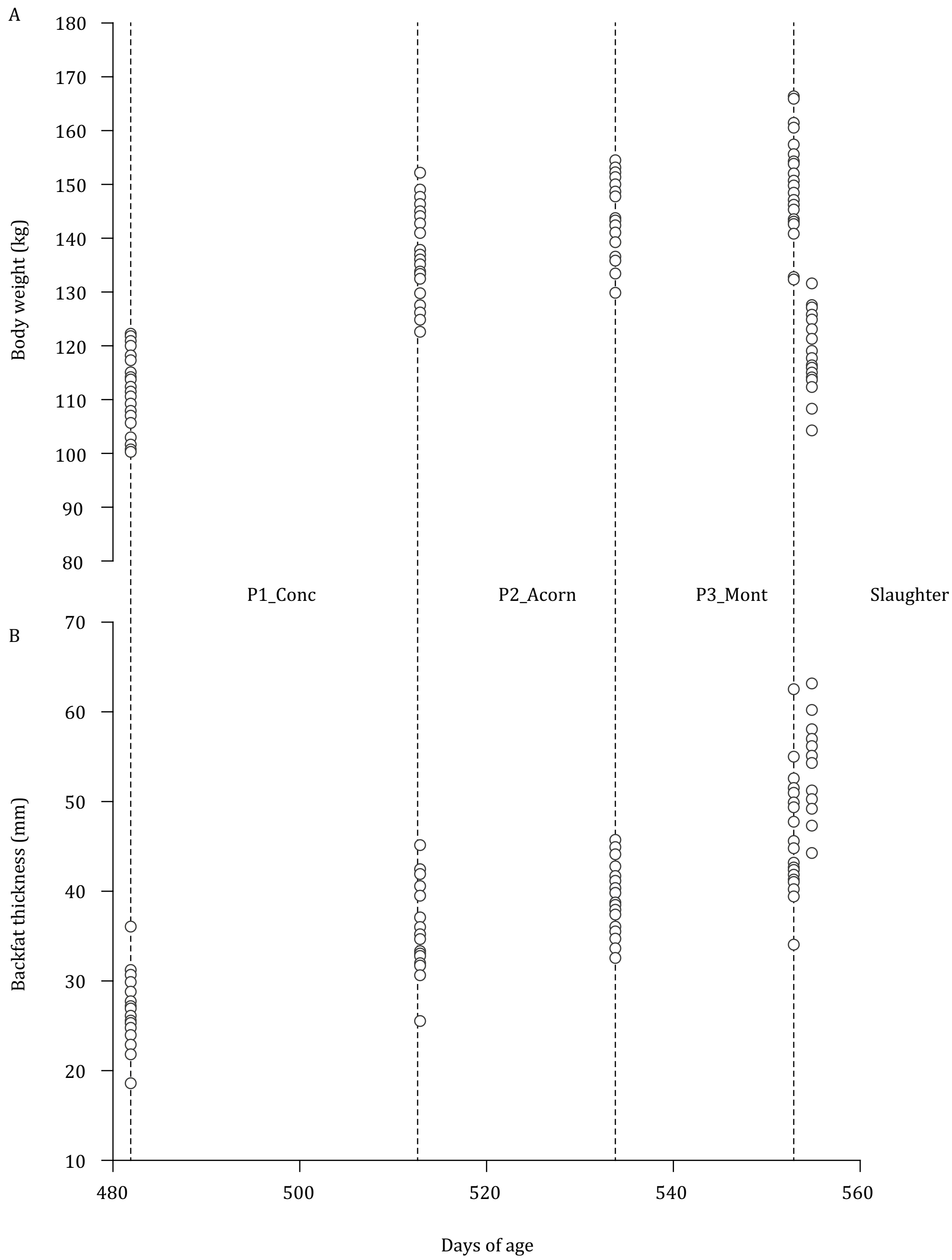

Figure 1 - Body weight (a) and backfat thickness (b) of each of 30 pigs at the beginning and end of $P1_{concentrate}$, $P2_{acorn}$, and $P3_{montanera}$ and carcass weight (a) and backfat thickness at slaughter (b).

The concentrate diet fed during $P1_{concentrate}$ was based on 38.2% barley, 21.5% corn, 15% wheat, 10% bran, 6.5% sunflower seeds, 3.0% sunflower oil, and 3.0% beet pulp; the remaining 2.8% consisted of a vitamin and mineral premix. It consisted of 10.5% protein, 7.4% fat, 5.4% crude fiber, and 44.7% starch and had a net energy content of 13623 kJ/kg. Composition of a sample of acorns provided as feed during $P2_{acorn}$ was evaluated; acorn kernels consisted of 44% moisture, and expressed on a dry matter basis, 5.9% crude protein, 8% crude fat, and 60.8% starch.

On the 31th of January 2019, all animals were slaughtered at a commercial processing plant. Pigs were stunned with CO_2, exsanguinated, scaled, and eviscerated according to standard commercial procedures. Hot carcass weight (HCW) was recorded (with head), and backfat depth (BFT_{sl}) was measured at the level of the last rib, 6.5 cm from the midline of the carcass (P2 position).

Subcutaneous fat samples were taken 10 cm from the tail insertion area in the coxal region of the carcass. Fatty acids analyses were carried out using gas chromatography (Agilent Technologies, 7890B GC System), following the procedures established by the Spanish government (Orden PRE/3844/2004; BOE, 2004). Fatty acids included the percentage lauric, myristic, palmitic, palmitoleic, margaric, margaroleic, stearic, oleic, linoleic, α-linolenic, arachidic, and gadoleic acid, and total unsaturated (UFA) and saturated (SFA) fatty acids.

Entire loins (*Longissimus dorsi*; LD) were removed from the vertebral column, which is common practice in the processing of slaughtered Iberian pigs. Loins were trimmed of external fat. One loin was used for analyses of meat quality in fresh and cooked samples; the second loin was used for analyses of meat quality in cured samples. In the first case, samples with a length of about 10-12 cm were taken from the first part of the front part of the muscle and stored in the refrigerator for meat quality analyses. The following day, meat was left exposed to air for 15 min to measure the CIELAB color coordinates lightness (L^*_{24}), redness (a^*_{24}), and yellowness (b^*_{24}) using a reflectance colorimeter (Minolta CR-400, illuminant D65). A meat sample of about 50 g was vacuum-packed and stored in liquid nitrogen, and the rest of the meat, approximately 700 g, was vacuum-packed and stored at −20 °C.

One week later, samples stored in liquid nitrogen were thawed. In a sample with a thickness of approximately 2 to 3 cm, taken from the center of the loin, intramuscular fat (IM_{Fat}), protein (IM_{Prot}), and moisture (IM_{Moist}) were predicted by near-infrared spectroscopy (NIRS) as described by Solís et al. (2001). Briefly, samples were minced in a meat mincer. Homogenized samples were inserted in circular quartz crystal capsules of 3.8 cm in diameter. The near-infrared spectrum was read with a spectrometer (Foss Iberia, FossNIRSystem 6500), between 400 and 2500 nm. The average of two readings was used for determination of IM_{Fat}, IM_{Prot}, and IM_{Moist} with the program WINISI (ISI, 1998).

Centrifugal drip was estimated according to Tejerina et al. (2012) with modifications. Samples of approximately 1.5 g were minced in a meat mincer, folded in filter papers Ø 90 mm and Ø 50 mm, and inserted in a Falcon centrifuge tube of 50 mL. Exudates were weighed following centrifugation at a speed of 4000 rpm for 20 min at 16 °C (Thermo Scientific, Sorvall, ST16R) and were expressed as a percentage of the original sample weight (CDrip, %). In addition, color was determined by measuring the amount of myoglobin (Mb, mg/g) in a thawed sample of approximately 2.5 g, following the method of Hornsey (1956) with modifications according to Alberti et al. (2005). After removal of external fat, blood vessels, and fascia, samples were minced in a meat mincer. Minced samples were put in a Pyrex glass reaction tube to which 0.5 mL milli-Q water and 10 mL acetone were added; mixing with a large rod assured that all of the meat sample homogenized with the reactant. Subsequently, 0.25 mL of 37% HCL was added and mixed horizontally; samples were stored in a dark fridge for 24 h. After 24 h, the content of the tube was filtered with filter paper of Ø 125 mm for 30 min. Optical density was measured at 512 nm in an optical UV-visible spectrophotometer (Thermo Scientific, Genesys 10S UV-VIS) using quartz cuvettes, against a blank sample tube (20 mL acetone + 1 mL milli-Q water + 0.5 mL of 37% HCL). Subsequently, Mb content (mg/g) was calculated as:

$$Mb = \{(V_{end} \times MW \times 1\ kg) / (\varepsilon \times W_{start} \times 1000)\} \times OD, \quad (1)$$

in which V_{end} = final volume of the sample (mL), MW = molecular weight of myoglobin (17000 u), ε = extinction factor (9.52), W_{start} = initial sample weight (g), and OD = optical density of the sample.

Between 37 to 58 days after slaughter, samples were taken from the −20 °C freezer, and purge from frozen meat upon thawing was measured as the difference between the weight of the cut before and after freezing, expressed as a percentage of the original weight (purge, %). About 400 g of the sample was used to obtain cylindrical meat specimens with a coring device with a diameter of 1.5 cm to evaluate meat tenderness in raw samples by compression force (CF) determination using a probe of 5 cm in diameter and compression until 75% of the original height of the specimen (CF_{Raw}, maximum force required to compress the sample, g/cm^2), and by using Warner-Bratzler shear force (SF) determination (SF_{Raw}, kg/cm^2) by means of a texture analyzer (TA.XT Plus, Stable Microsystems) as described by Honikel (1997). The remaining approximately 300 g of the sample was used to estimate cooking loss of thawed samples as the difference in weight before and after cooking the meat in water at a temperature of 70 °C for 1h, expressed as a percentage of the original weight (CookL, %). Subsequently, meat tenderness was also measured in the cooked samples by using Warner-Bratzler shear force determination (SF_{Cook}).

The second loin was traditionally cured by Sanchez Romero Carvajal S.A. following industry classified procedures. Briefly, loins were trimmed of external fat, and kept one day at a temperature between 0 and 21 °C. Loins were then rubbed with curing agents (salt and nitrite) and kept for two days at a temperature of 6 °C. Loins were cleaned with cold water and kept for a few days to dry completely. Once dry, loins were seasoned with an unknown mixture of spices based on Spanish paprika, oregano, and garlic, and hung for 48 h allowing for the seasoning mixture to penetrate. Then, loins were stuffed into gut tissue and dried for another two days at 18 °C. Loins were subsequently transferred to a room where a dry-aging process took place for approximately two months at a temperature between 12 and 14 °C. The exact length of the different procedures may deviate a little, according to industry classified procedures. Warner-Bratzler shear force determination (SF_{Cured}) and compression force determination (CF_{Cured}) were applied to samples of cured loins according to previously described methods.

In summary, loin meat quality traits included loin composition (IM_{Fat}, IM_{Prot}, IM_{Moist}), juiciness (CDrip, purge, and CookL), tenderness (CF_{Raw}, CF_{Cured}, and SF_{Raw}, SF_{Cook}, and SF_{Cured}), color (L^*_{24}, a^*_{24}, b^*_{24}, and Mg), and fatty acid composition (lauric [C12:0], myristic [C14:0], palmitic [C16:0], palmitoleic [C16:1], margaric [C17:0], margaroleic [C17:1], stearic [C18:0], oleic [C18:1 n-9], linoleic [C18:2 n-6], α-linolenic [C18:3 n-3], arachidic [C20:0], gadoleic [C20:1] acids, UFA, and SFA).

The proc MIXED procedure in SAS (Statistical Analysis System, version 9.4) was used for the statistical analyses of the individual repeated measurements FCE and BFTG.

$$Y_{ij} = \mu + Period_i + e_{ij}, \quad (2)$$

in which Y_{ij} = the phenotype measured on animal j, $Period_i$ = effect of period i ($P1_{concentrate}$, $P2_{acorn}$, $P3_{montanera}$); and e_{ij}~NID(0, δ^2e). Initially, the effect of room was included in the model, but since this was not significant, it was removed. "Period" was identified as the repeated effect in the model for each individual. The following variance-covariance structures for repeated measures were evaluated to describe individual observations on a trait by trait basis: Homogeneous Autoregressive (1) (AR(1)), Heterogeneous Autoregressive(1) (ARH(1)), Compound Symmetry (CS), Toeplitz (TOEP), and Unstructured (UN). The models included the random effect of the individual. Based on the fit statistics, the model chosen to analyze both traits was the unstructured variance-covariance structure. Data are presented as means ± SEM. Results are determined statistically significant with associated P levels of 0.05 or less. The SAS program was used for the calculation of Spearman correlation coefficients. Correlations were estimated after adjusting meat quality traits for the effect of HCW. Since the effect of day of measurement (37 to 58 days after slaughter) on purge, CF_{Raw}, CF_{Cured}, SF_{Raw}, SF_{Cook}, SF_{Cured}, and CookL was not significant, these traits were not adjusted for day of measurement in the calculation of the correlations. Correlation coefficients between r = 0.40 and 0.59 or between r = −0.40 and −0.59 are discussed as being "moderate"; correlations lower than 0.40 or greater than −0.40 are considered "weak", whereas those greater than 0.59 or lower than −0.59 are considered "strong".

3. Results

Body weight increased from an average of 111.5 (±1.17) kg at the start of the experiment to 137.8 (±1.39) kg at the end of $P1_{concentrate}$, 144.5 (±1.24) kg at the end of $P2_{acorn}$, and 150.2 (±1.52) kg at the end of $P3_{montanera}$ (Figure 1a). Backfat thickness increased from an average of 26.3 (±0.649) mm at the start of the experiment to 35.7 (±0.799) mm at the end of $P1_{concentrate}$, 38.8 (±0.692) mm at the end of $P2_{acorn}$, and 45.5 (±1.10) mm at the end of $P3_{montanera}$ (Figure 1b). Because a large part of the acorn cornel is rejected as indigestible fibrous material, pigs ate a considerably high weight in acorns per DBWG; therefore, as expected, $FCE_{P1concentrate}$ was significantly higher than $FCE_{P2acorn}$ (P<0.0001). The $BFTG_{P2acorn}$ was significantly lower than $BFTG_{P1concentrate}$ and $BFTG_{P3montanera}$; $BFTG_{P1concentrate}$ and $BFTG_{P3montanera}$ did not significantly differ (Table 1). At slaughter, HCW was on average 118.8 (±1.17) kg (Figure 1a), and BFT_{sl} was on average 53.9 (±0.815) mm (Figure 1b).

Pigs with higher $FCE_{P1concentrate}$ had lower $FCE_{P2acorn}$. The $DBWG_{P3montanera}$ was positively related with $FCE_{P1concentrate}$ but not with $FCE_{P2acorn}$ (Table 2). Pigs with higher $BFTG_{P1concentrate}$ had lower $BFTG_{P2acorn}$ (r = −0.59, P<0.001). The $BFTG_{P3montanera}$ was not significantly related with $BFTG_{P1concentrate}$ or $BFTG_{P2acorn}$.

Table 1 - Average (±SE) daily body weight gain (DBWG) and daily gain in backfat thickness (BFTG) during each of the three periods ($P1_{concentrate}$, $P2_{acorn}$, and $P3_{montanera}$) and the total period

	$P1_{concentrate}$	$P2_{acorn}$	$P3_{montanera}$	Total
DBWG (g/d)	875a (±19.0)	321b (±20.2)	299b (±37.5)	552 (±14.2)
FCE	0.219a (±0.00474)	0.0401b (±0.00252)		
BFTG (mm/d)	0.313a (±0.0238)	0.150b (±0.0326)	0.352a (±0.0527)	0.275 (±0.0152)

SE - standard error.
Within trait, values with a different letter differ (P<0.01).

Table 2 - Phenotypic correlation between feed conversion efficiency on concentrate feeding ($FCE_{P1concentrate}$) and on acorns ($FCE_{P2acorn}$), daily body weight gain in *montanera* ($DBWG_{P3montanera}$), backfat thickness at slaughter (BFT_{sl}); intramuscular fat (IM_{Fat}), intramuscular protein (IM_{Prot}), intramuscular moisture (IM_{Moist}), myoglobin content (Mg), cooking loss (CookL), and redness (a^*_{24}) in loin samples; and fatty acid composition of subcutaneous fat

	$FCE_{P2acorn}$	$DBWG_{P3montanera}$	BFT_{sl}	IM_{Prot}	IM_{Moist}	Mg	CookL
$FCE_{P1concentrate}$	−0.53*	0.40*					
IM_{Fat}	-0.34†						
IM_{Moist}	0.40*						
CookL		−0.45*					
a^*_{24}		−0.44*					
Mg		−0.31†					
Linoleic	−0.35†						
α-linolenic	−0.41*						
Margaric			−0.45*				
Margaroleic			−0.54**				
Gadoleic				−0.36*			
Myristic						0.39*	
Palmitoleic		−0.37*				0.41*	
Palmitic		−0.44*					0.40*
Oleic							−0.39*

Phenotypic correlations not given in this table were not significant.
† P<0.10; * P<0.05; ** P<0.01.

Samples with higher IM_{Fat} had lower IM_{Prot} and lower IM_{Moist}; samples with higher IM_{Prot} had higher IM_{Moist} (Tables 3 and 4). All juiciness parameters were related: purge was positively correlated with CDrip and CookL, and CDrip was positively correlated with CookL. Tenderness parameters showed a positive correlation between CF_{Raw} and SF_{Raw}, and samples with higher CF_{Cured} had higher SF_{Cured}. Color parameters showed a positive correlation between a^*_{24} with b^*_{24} and Mg, and between b^*_{24} with L^*_{24} (Tables 3 and 4).

Meat samples with a higher IM_{Fat} and a lower IM_{Prot} and IM_{Moist} had higher color values of yellowness (b^*_{24}) and lightness (L^*_{24}); samples with higher redness (a^*_{24}) had higher IM_{Fat}. Meat samples with a higher CDrip (a higher loss of juices) had higher SF_{Cook} (i.e., were tougher after cooking). Samples with higher purge after thawing had higher SF_{Cured} and CF_{Cured} (i.e., were tougher after curing). Redder samples, with higher a^*_{24}, had higher purge, CDrip, and CookL, (i.e., lost more juices), and samples with higher b^*_{24} had higher CookL. No significant relationships were detected between tenderness and color traits.

Table 3 - Mean (±SEM) of intramuscular fat (IM_{Fat}), protein content (IM_{Prot}), and moisture (IM_{Moist}), centrifugal drip (CDrip), purge, cooking loss (CookL), compression force in raw (CF_{Raw}) and cured samples (CF_{Cured}), shear force in raw (SF_{Raw}), cooked (SF_{Cook}), and cured samples (SF_{Cured}), lightness (L^*_{24}), redness (a^*_{24}), yellowness (b^*_{24}), myoglobin content (Mg) of loin samples, and fatty acid composition of subcutaneous fat

	Quality trait	Mean (±SEM)
Loin composition	IM_{Fat} (%)	3.67 (±0.198)
	IM_{Prot} (%)	21.9 (±0.142)
	IM_{Moist} (%)	72.2 (±0.242)
Juiciness	CDrip (%)	30.6 (±0.567)
	Purge (%)	2.64 (±0.208)
	CookL (%)	22.1 (±0.436)
Tenderness	CF_{Raw} (g/cm^2)	0.0624 (±0.00326)
	CF_{Cured} (g/cm^2)	5.49 (±0.319)
	SF_{Raw} (kg/cm^2)	2.09 (±0.0598)
	SF_{Cook} (kg/cm^2)	5.18 (±0.288)
	SF_{Cured} (kg/cm^2)	9.20 (±0.304)
Color	L^*_{24}	39.1 (±0.435)
	a^*_{24}	9.66 (±0.205)
	b^*_{24}	4.18 (±0.139)
	Mg (mg/g)	1.60 (±0.0444)
Fatty acid composition	Lauric acid [C12:0] (%)	0.0645 (±0.00115)
	Myristic acid [C14:0] (%)	1.28 (±0.0190)
	Palmitic acid [C16:0] (%)	19.9 (±0.125)
	Palmitoleic acid [C16:1 n-7] (%)	2.36 (±0.0489)
	Margaric acid [C17:0] (%)	0.366 (±0.00683)
	Margaroleic acid [C17:1] (%)	0.429 (±0.00939)
	Stearic acid [C18:0] (%)	8.59 (±0.137)
	Oleic acid [C18:1 n-9] (%)	54.6 (±0.166)
	Linoleic acid [C18:2 n-6] (%)	10.1 (±0.101)
	α-linolenic acid [C18:3 n-3] (%)	0.493 (±0.00650)
	Arachidic acid [C20:0] (%)	0.165 (±0.00462)
	Gadoleic acid [C20:1] (%)	1.57 (±0.0258)
	Unsaturated fatty acids (%)	69.6 (±0.213)
	Saturated fatty acids (%)	30.4 (±0.213)

SEM - standard error of the mean.

Pigs with higher $FCE_{P2acorn}$ had higher IM_{Moist} and tended to have lower IM_{Fat}. $FCE_{P1concentrate}$ and $FCE_{P2acorn}$ were not significantly related to any of the other meat quality traits. However, animals with higher $DBWG_{P3montanera}$ showed lower CookL and a^*_{24} and tended to have lower Mg. Higher $FCE_{P2acorn}$ was associated with a lower content of linoleic and α-linolenic acid; a higher $DBWG_{P3montanera}$ was associated with a lower content of palmitic and palmitoleic acids (Table 2).

Higher BFT_{sl} was related with a lower content of margaric and margaroleic acids (Table 2). Loin samples with higher IM_{Prot} contained less gadoleic acid. Samples with higher Mg contained more myristic and palmitoleic acids. A higher CookL was associated with a higher content of palmitic acid and a lower content of oleic acid (Table 2).

Table 4 - Phenotypic correlation between intramuscular fat (IM_{Fat}), protein (IM_{Prot}), and moisture (IM_{Moist}), purge, centrifugal drip (CDrip), cooking loss (CookL), Warner-Bratzler shear force in raw (SF_{Raw}), cooked (SF_{Cook}), and cured samples (SF_{Cured}), compression force in raw (CF_{Raw}) and cured samples (CF_{Cured}), and meat redness (a^*_{24}), yellowness (b^*_{24}), lightness (L^*_{24}), and myoglobin content (Mg) in loin samples

	IM_{Fat}	IM_{Prot}	IM_{Moist}	Purge	CDrip	CookL	CF_{Raw}	CF_{Cured}	a*24	b*24
IM_{Prot}	−0.76***									
IM_{Moist}	−0.84***	0.62***								
CDrip				0.53**						
CookL				0.50**	0.52**					
SF_{Raw}							0.42*			
SF_{Cook}					0.39*					
SF_{Cured}				0.48*				0.48*		
CF_{Cured}				0.56**						
a^*_{24}	0.55**	−0.35†		0.42*	0.46*	0.48**				
b^*_{24}	0.65***	−0.55**	−0.44*			0.54**			0.58***	
L^*_{24}	0.42*	−0.42*	−0.41*							0.78***
Mg									0.58**	

Phenotypic correlations not given in this table were not significant.
† P<0.10; * P<0.05; ** P<0.01; *** P<0.001.

4. Discussion

In the present study, pigs entered $P1_{concentrate}$ at approximately 112 kg (this is close to the weight at which pigs normally enter *montanera*) and 482 days of age, $P2_{acorn}$ at 138 kg and 513 days of age, and $P3_{montanera}$ at 145 kg and 534 days of age, and were slaughtered at approximately 150 kg and 555 days of age. As expected, the highest DBWG was obtained in $P1_{concentrate}$, followed by $P2_{acorn}$ and $P3_{montanera}$, whereas BFTG was highest in $P3_{montanera}$. Feed efficiency was considerably lower in $P2_{acorn}$ than in $P1_{concentrate}$. This is expected since pigs generally reject approximately 27% of the weight of the acorn as indigestible fibrous material (Lopez-Bote, 1998; Benito et al., 2006).

When given the same diet, body weight gain, feed intake, and feed efficiency in pigs are not necessarily related between the same trait measured in different periods along the growth trajectory (Rauw et al., 2006). This can be explained by changes in the growth pattern and the physiological relationship between growth and feed intake as the animal matures, for example, resulting from changes in the utilization of energy for maintenance vs. gain and changes in the composition of gain (Wellock et al., 2004; Patience et al., 2015). As a result, feed efficiency can in fact be considered different traits at different growth stages (Paganoni et al., 2017). Moderate to high correlations between feed efficiency in different phases of life indicate that selecting more feed efficient animals at younger ages can improve feed efficiency in mature animals; however, reranking of individuals for feed efficiency will result in low correlations that indicate that selection at earlier ages will not necessarily result in a positive response later in life (Gomes et al., 2012). Similarly, feed efficiencies estimated on different diets are to be considered different traits when this results in widely varying protein, lipid, or fiber contents (Patience et al., 2015); this is clearly the case in the present experiment in which feed efficiency is estimated on a concentrate diet vs. acorns. For example, Durunna et al. (2011) investigated the genetic correlation of feed efficiency traits in steers fed a grower (oats, hay, and feedlot supplement) or finisher (alfalfa pellets, oats, barley, and feedlot supplement) diet in two consecutive feeding periods to identify feed-efficient animals across all beef production segments. The genetic correlation of 0.50 for residual feed intake indicated the presence of a genotype × environment (diet) interaction, and the authors concluded that the dependency of residual feed intake on the feeding regimen may have serious implications when selecting animals in the beef industry. Similarly, commercial pigs are typically fed high-input diets based on corn and soybean meal in the Americas, whereas they are commonly fed diets based on wheat and barley with high amounts of added protein-rich coproducts in Western Europe (Godinho et al., 2018). Results by Godinho et al. (2018) showed that selecting pigs under a different diet from the diet used for growing-finishing performance could severely compromise residual energy intake during the grower phase.

Although the reranking of feed efficiency due to diet interaction typically results in a moderate to low or even non-significant correlation between feed efficiency measured on different diets, the results from our own study showed a significant negative relationship between $FCE_{P1concentrate}$ and $FCE_{P2acorn}$, indicating that pigs with high feed efficiency on a high-quality concentrate diet were less able to sustain feed efficiency on a high-fiber diet of acorns, whereas, vice versa, pigs that best performed on acorns were less feed efficient on the concentrate diet. This negative relationship may support literature that suggests that environmental (dietary) sensitivity is higher (i.e., robustness reduces) in animals that perform better under optimal (dietary) conditions (Rauw and Gomez-Raya, 2015); however, this relationship needs to be verified in a larger dataset including genetic relationships. Furthermore, our results showed a positive correlation of $FCE_{P1concentrate}$, but not of $FCE_{P2acorn}$, with $DBWG_{P3montanera}$. These results are particularly relevant to the traditional Iberian pig production system where restricted feeding on concentrate is deliberately used before fattening on acorns to increase fat deposition during finishing. Selection programs are not common in Iberian pig populations; however, a breeding scheme at Sanchez Romero Carvajal S.A. was initiated five years ago, to develop a selection line of purebred Iberian pigs aimed at high growth rate, yield of premium cuts, and high meat and fat quality (Muñoz et al., 2018); additionally, there is a clear interest to include a measure of feed efficiency in the breeding objective. Our results suggest that improvement of FCE during the traditional restricted feeding phase on concentrate may result in desirable results improving both feed efficiency and weight gain, whereas implementation of a costly additional period where pigs are fed an acorn diet does not appear to provide additional benefits.

It should be noted that our results are based on phenotypic correlations, which are comprised of genetic and environmental covariances. Although empirical evidence suggests that there is a robust relationship between phenotypic and genetic relationships, and thus that the use of phenotypic correlations as proxies for genetic correlations is appropriate (Sodini et al., 2018), the genetic correlation is potentially very different and may even have another sign; therefore, genetic relationships need to be confirmed in future research. In addition, further research should investigate the relationship between genetic parameters estimated under feed restriction and those estimated when intake is not restricted in *montanera*, as this places a different emphasis on the components of feed intake, maintenance requirements, and body weight gain (Schinckel and de Lange, 1996).

Negative implications of improvement of growth rate, lean content, and feed efficiency on meat quality is of concern in commercial pig production; however, information on the relationship, particularly with feed efficiency, is limited (Gilbert et al., 2017). This is particularly relevant if these traits are considered in a selection scheme in a pig production system that relies on these traits for its economic survival. In our study, neither $FCE_{P1concentrate}$ nor $FCE_{P2acorn}$, or $DBWG_{P3montanera}$ were related to the tenderness measurements in the raw, cooked, or cured products. Pigs with faster $DBWG_{P3montanera}$ had loins with a significantly lower CookL. Gilbert et al. (2007) observed a negative genetic correlation between feed efficiency with color parameter L*. In our study, neither $FCE_{P1concentrate}$ nor $FCE_{P2acorn}$ were related with meat color; however, loin meat of pigs with faster $DBWG_{P3montanera}$ had lower a^*_{24}; they also tended to have lower Mg ($r = -0.31$, $P = 0.096$). This observation is relevant since a reduction in meat redness may reduce consumers' acceptance (Font-i-Furnols and Guerrero, 2014).

According to Ruiz et al. (1998), muscle fatty acid profile reflects the feeding regime during the last phase of feeding, whereas lard reflects longer term differences. Our results show that pigs with higher $FCE_{P2acorn}$ had fat samples with a lower concentration of α-linolenic acid; samples tended to have also a lower concentration of linoleic acid ($r = -0.35$, $P = 0.059$). In addition, pigs with higher $DBWG_{P3montanera}$ had fat samples with lower concentrations of palmitic and palmitoleic acids. Summarized, our results indicate that FCE on acorns influenced fatty acid composition to some extent, but FCE showed no further relationship with any of the meat quality traits. Instead, faster $DBWG_{P3montanera}$ resulted in a desirable reduced cooking loss and in a potentially undesirable reduced redness of loins.

Noble parts of the Iberian pig (ham, shoulder, and loin) are solely destined for the production of dry-cured products. Their quality depends on an array of parameters and their interrelatedness, including intramuscular fat, juiciness, tenderness, color, and fatty acid composition. They are world-renown high-quality gourmet products that are protected by Spain's Designation of Origin rules for food products. The curing process consists of salting and drying and lasts approximately seven weeks for loins, nine months for shoulders, and two years for hams (Rodrigáñez et al., 1993). One of the main goals for the selection of heavy pigs for the production of dry-cured products is to find early indicators in the raw meat able to predict the quality of dry-cured products (Schivazappa et al., 2002; Marcos et al., 2013) or processed yields (Bonfatti and Carnier, 2020). In addition, early prediction of the water-holding capacity of meat during storage and processing based on fresh meat characteristics is essential for the meat industry due to its economic consequences (Bertram et al., 2003). Flavor and juiciness of cured pork are closely related to a high intramuscular fat content, which is considerably higher than that of pork from commercial breeds (Nieto et al., 2019). Furthermore, intramuscular fat content has been positively correlated to marbling, color, and tenderness (Warner, 2017) and determines the technological properties of the meat for dry-curing (Ventanas et al., 2005).

In a literature review, Nieto et al. (2019) presented an IM_{Fat} range of 3.0 to 19.7% in Iberian loin; therefore, the values in our study are on the low end. Generally, high IM_{Fat} levels contribute to reduced moisture losses during meat processing since fat shows a lower diffusion rate for water than lean (Ventanas et al., 2005). In the present study, IM_{Fat} in loin did not show any significant relationship with any of the juiciness or tenderness measurements, but it was moderately positively correlated with the color coordinates L^*_{24} and a^*_{24} and strongly positively correlated with b^*_{24}. Also, Latorre et al. (2008) observed a positive correlation between IM_{Fat} content and the redness coordinate a*.

Meat tenderness is determined by factors including sarcomere and myofibril length, post-mortem changes to myofibrils, the muscle fiber type, and water holding capacity (Tejerina et al., 2012). According to Olsson and Pickova (2005), generally, extensive production systems may be expected to decrease tenderness and increase the shear force of meat compared with conventional, intensive systems. However, Tejerina et al. (2012) observed a lower shear force of meat of Iberian pigs raised “de campo” than those raised intensively. Our estimate of SF_{Cook} (5.18 kg/cm^2) was similar to their estimate in meat from intensively raised pigs (5.20 kg/cm^2). As expected, our results show that tenderness decreased from raw to cooked and cured pork loin. Shear force values were positively related to compression force values within the raw or cured products; however, tenderness measurements in cooked or cured loin could not be predicted from values in the raw product.

The ability of fresh meat to retain moisture is one of the most important quality characteristics of raw meat products and is related to the product appearance, but may also influence the sensory quality of meat (Huff-Lonergan and Lonergan, 2005; Olsson and Pickova, 2005). In a review on the differences in meat quality between pigs raised in intensive or outdoor systems, Olsson and Pickova (2005) found that about half the studies reviewed indicated reduced water-holding capacity in outdoor systems. Lopez-Bote et al. (2008) did not find any difference in water-holding capacity of Psoas major from pigs reared in confinement or pigs reared in *montanera*, while Tejerina et al. (2012) observed a significantly higher purge in intensively reared pigs. For cured products, a higher water retention, often associated with a higher marbling, results in slower salt diffusion, lower seasoning losses, lower processing losses, and higher product quality (Čandek-Potokar and Škrlep, 2012). In our study, a purge of 2.65% falls within the range of 1-3% average loss in fresh retail cuts given by Huff-Lonergan and Lonergan (2005). Average CookL in our samples (22.1%) was a little higher than the 19.1% presented by Tejerina et al. (2012), but CDrip in our sample (30.6%) was considerably lower than the 59.3% by Tejerina et al. (2012). Our results showed a moderately positive correlation between all three measurements of juiciness; CookL could be moderately predicted from either purge or CDrip in raw samples. In addition, high purge was found to be a moderate predictor of reduced tenderness (both SF_{Cured} and CF_{Cured}) in cured loin samples, while high CDrip was a weak predictor of reduced tenderness (SF_{Cooked}) in cooked loin samples.

Meat color is one of the most important quality attributes influencing consumer's food choices, perceptions, and purchasing behavior (Pathare et al., 2013). The color of pork is influenced by the content of pigment, its chemical form, and meat structure (Olsson and Pickova, 2005). The psychometric index of lightness depends on several factors, including pH, water holding capacity, moisture, muscle structure, oxidation level of hemopigments, and lipid content (Muriel et al., 2002). Positive values of parameter a* are indicative of reddish colors and negative values for the greenish ones, whereas positive values of parameter b* are indicative of yellowish colors and negative values for the bluish ones (Pathare et al., 2013). Myoglobin, which role is to store and diffuse oxygen from the capillaries to the intracellular structures, is a pigment that gives meat the red color; its amount depends on species, breed, sex, muscle type, and activity (Lindahl, 2005). According to Olsson and Pickova (2005), activity in extensive production systems may affect meat color in different ways, either leading to darker or to paler, structurally affected meat. Andrés et al. (2000) observed that L* and b* values in *biceps femoris* and *tibialis cranealis* muscles were lower in Iberian pigs fattened intensively on concentrate than in Iberian pigs fattened extensively in *montanera*. However, meat of pigs raised outdoor in huts in the study of Gentry et al. (2002) was darker (lower L*) and redder (higher a*) than meat of pigs raised in indoor crates. The latter may be related to a change in muscle characteristics resulting from exercise, towards slow contraction, better vascularization, and more oxidative metabolism in animals raised outdoors (Vestergaard et al., 2000). Muriel et al. (2002) observed, in LD samples of purebred Iberian pigs fattened in *montanera,* color values of 47.3 for L*, 12.7 for a*, and 7.49 for b*. Values in our samples were lower, which may be due to the shorter *montanera* period in our experiment. Andrés et al. (2000) observed a negative relationship between L* and the level of Mb in *biceps femoris* and *tibialis cranealis* muscles of crossbred Iberian × Duroc pigs, but this relationship was not significant in our samples. However, supporting results by Johansson et al. (1991), in our study, the redness coordinate a^*_{24} was moderate to strongly positively correlated with the level of Mb. In addition, coordinates a^*_{24} and b^*_{24} were moderate predictors of CookL.

More than 60% of the fatty acid composition of acorns consists of oleic acid. Since the pig is a monogastric animal, fat of Iberian pigs raised in *montanera* consists of a higher concentration of oleic acid and a lower concentration of palmitic and stearic fatty acids than pigs raised in confinement on concentrate diets (Lopez-Bote, 1998). Oleic acid content of subcutaneous fat was higher in our samples than that reported by Niñoles et al. (2007; 53.3%) and Fernández et al. (2003; 52.4%) in Iberian pigs raised in *montanera*, by Daza et al. (2007) in Iberian pigs raised intensively on acorns (48.5%), and considerably higher than that reported in Iberian (41.8%), Landrace (42.4%), and Duroc (40.0%) pigs fed conventional concentrates (Ruiz et al., 1998; van Son et al., 2017). According to Juárez et al. (2017), both breed and diet are influential factors in explaining variance in oleic acid concentration. Various studies reported an overall positive effect of overall unsaturated fat content on juiciness and tenderness of fresh meat and meat products, whereas other studies found no effect (Ruiz-Carrascal et al., 2000). Our results supported the latter; however, a higher oleic acid content in fat samples was related with a lower cooking loss of loin samples; and vice versa, fat samples with higher amounts of palmitic acid had higher cooking loss.

Our results indicate that high CDrip was a weak predictor of reduced tenderness in cooked loin, while high purge was a moderate predictor of reduced tenderness in cured loin. In addition, high cooking loss could be moderately predicted from high purge, CDrip, a^*_{24}, b^*_{24}, and palmitic acid content in subcutaneous fat, and a lower oleic acid content in subcutaneous fat.

5. Conclusions

The positive correlation between feed efficiency on a concentrate diet and body weight gain during *montanera* shows that improvement of feed efficiency during an intensive restricted feeding phase on concentrate may result in desirable results improving both feed efficiency and weight gain in extensively kept animals. Inclusion of an intensive restricted feeding phase on acorns does not provide additional benefits. Improved feed efficiency on acorns reduces the concentration of α-linolenic and linoleic fatty acid composition of subcutaneous fat, but feed efficiency shows no further relationship with any of the meat quality traits. Faster body weight gain during *montanera* results in a desirable reduction in cooking loss, a reduction of palmitic acid content in subcutaneous fat and a potentially undesirable reduction in meat redness. Improved tenderness in cooked loin can be moderately predicted from low centrifugal drip loss, whereas improved tenderness in cured loin can be moderately predicted from low purge. Cooking loss can be moderately predicted from purge or centrifugal drip loss and from the color coordinates a^*_{24} and b^*_{24} in raw samples.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: W.M. Rauw, J.M. García Casco, F. Gómez Carballar and L. Gomez Raya. Data curation: W.M. Rauw, J.M. García Casco, F. Gómez Carballar and E. Serna Fito. Formal analysis: W.M. Rauw, P. Palma Granados, M.A. Fernández Barroso and L. Gomez Raya. Funding acquisition: W.M. Rauw and L. Gomez Raya. Investigation: W.M. Rauw, F. Gómez Carballar, E. Serna Fito, P. Palma Granados, M.A. Fernández Barroso and L. Gomez Raya. Methodology: W.M. Rauw, J.M. García Casco, F. Gómez Carballar, E. Serna Fito, P. Palma Granados, M.A. Fernández Barroso and L. Gomez Raya. Project administration: W.M. Rauw and L. Gomez Raya. Resources: F. Gómez Carballar. Supervision: J.M. García Casco and F. Gómez Carballar. Validation: J.M. García Casco. Visualization: W.M. Rauw and L. Gomez Raya. Writing-original draft: W.M. Rauw. Writing-review & editing: W.M. Rauw, J.M. García Casco, F. Gómez Caballar, E. Serna Fito, P. Palma Granados, M.A. Fernández Barroso and L. Gomez Raya.

Acknowledgments

This research was made possible by funding from SusAn project "Sustainability of pig production through improved feed efficiency" (SusPig, https://suspig-eranet.jimdosite.com/), an ERA-Net co-funded under European Union's Horizon 2020 research and innovation program (www.era-susan.eu), under Grant Agreement no. 696231, by project AGL2016-75942-R, "Caracterización molecular de la eficiencia alimentaria y de los caracteres reproductivos en cerdo Ibérico", and project IDI-20180002, "Desarrollow tecnológicos relacionados con la reproducción, el manejo y el hábitat del derdo Ibérico" financed by CDTI and FEDER.

References

Alberti, P.; Panea, B.; Ripoll, G.; Sañudo, C.; Olleta, J. L.; Hegueruela, I.; Campo, M. M. and Serra, X. 2005. Medición del color. p.216-225. In: Estandarización de las metodologías para evaluar la calidad del producto (animal vivo, canal, carne y grasa) en los ruminantes. Cañeque, V. and Sañudo, C., eds. MICYT-INIA, Ganadera, Madrid, Spain.

Andrés, A. I.; Ruiz, J.; Mayoral, A. I.; Tejeda, J. F. and Cava, R. 2000. Influence of rearing conditions and crossbreeding on muscle color in Iberian pigs. Food Science and Technology International 6:315-321. https://doi.org/10.1177/108201320000600406

Benito, J.; Albarrán, A. and García Casco, J. M. 2006. Extensive Iberian pig production grazing systems. p.635-645. In: Sustainable grassland productivity. Grassland Science in Europe, vol. 11.

BOE. 2004. Boletín Oficial del Estado, Orden PRE/3844/2004, de 18 de noviembre, por la que se establecen los métodos oficiales de toma de muestras en canales de cerdos ibéricos y el método de análisis para la determinación de la composición de ácidos grasos de los lípidos totales del tejido adiposo subcutáneo de cerdos ibéricos. Num. 283, p.38770-38779. Available at: <https://www.boe.es/eli/es/o/2004/11/18/pre3844/dof/spa/pdf>. Accessed on: Jan. 11, 2019.

BOE. 2014. Norma de Calidad. Real Decreto 4/2014, de 10 de Enero, por el que se aprueba la norma de calidad para la carne, el jamón, la paleta y la caña de lomo ibérico. Available at: <https://www.boe.es/buscar/pdf/2014/BOE-A-2014-318-consolidado.pdf>. Accessed on: Jan. 11, 2019.

Bertram, H. C.; Andersen, H. J.; Karlsson, A. H.; Horn, P.; Hedegaard, J.; Nørgaard, L. and Engelsen, S. B. 2003. Prediction of technological quality (cooking loss and Napole Yield) of pork based on fresh meat characteristics. Meat Science 65:707-712. https://doi.org/10.1016/S0309-1740(02)00272-3

Bonfatti, V. and Carnier, P. 2020. Prediction of dry-cured ham weight loss and prospects of use in a pig breeding program. Animal 14:1128-1138. https://doi.org/10.1017/S1751731120000026

Čandek-Potokar, M. and Škrlep, M. 2012. Factors in pig production that impact the quality of dry-cured ham: a review. Animal 6:327-338. https://doi.org/10.1017/S1751731111001625

Daza, A.; Menoyo, D.; Olivares, A.; Cordero, G. and López-Bote, C. J. 2007. Effect of Iberian pig feeding system on tissue fatty-acid composition and backfat rheological properties. Journal of Animal and Feed Sciences 16:408-419. https://doi.org/10.22358/jafs/66797/2007

Díaz-Caro, C.; García-Torres, S.; Elghannam, A.; Tejerina, D.; Mesias, F. J. and Ortiz, A. 2019. Is production system a relevant attribute in consumers' food preferences? The case of Iberian dry-cured ham in Spain. Meat Science 158:107908. https://doi.org/10.1016/j.meatsci.2019.107908

Durunna, O. N.; Plastow, G.; Mujibi, F. D. N.; Grant, J.; Mah, J.; Basarab, J. A.; Okine, E. K.; Moore, S. S. and Wang, Z. 2011. Genetic parameters and genotype × environment interaction for feed efficiency traits in steers fed grower and finisher diets. Journal of Animal Science 89:3394-3400. https://doi.org/10.2527/jas.2010-3516

Fernández, A.; de Pedro, E.; Núñez, N.; Silió, L.; García-Casco, J. and Rodríguez, C. 2003. Genetic parameters for meat and fat quality and carcass composition traits in Iberian pigs. Meat Science 64:405-410. https://doi.org/10.1016/S0309-1740(02)00207-3

Font-i-Furnols, M. and Guerrero, L. 2014. Consumer preference, behavior and perception about meat and meat products: an overview. Meat Science 98:361-371. https://doi.org/10.1016/j.meatsci.2014.06.025

Gentry, J. G.; McGlone, J. J.; Miller, M. F. and Blanton Jr, J. R. 2002. Diverse birth and rearing environment effects on pig growth and meat quality. Journal of Animal Science 80:1707-1715. https://doi.org/10.2527/2002.8071707x

Gilbert, H.; Billon, Y.; Brossard, L.; Faure, J.; Gatellier, P.; Gondret, F.; Labussière, E.; Lebret, B.; Lefaucheur, L.; Le Floch, N.; Louveau, I.; Merlot, E.; Meunier-Salaün, M.-C.; Montagne, L.; Mormede, P.; Renaudeau, D.; Riquet, J.; Rogel-Gaillard, C.; van Milgen, J.; Vincent, A. and Noblet, J. 2017. Review: divergent selection for residual feed intake in the growing pig. Animal 11:1427-1439. https://doi.org/10.1017/S175173111600286X

Gilbert, H.; Bidanel, J. P.; Gruand, J.; Caritez, J. C.; Billon, Y.; Guillouet, P.; Lagant, H.; Noblet, J. and Sellier, P. 2007. Genetic parameters for residual feed intake in growing pigs, with emphasis on genetic relationships with carcass and meat quality traits. Journal of Animal Science 85:3182-3188. https://doi.org/10.2527/jas.2006-590

Godinho, R. M.; Bastiaansen, J. W. M.; Sevillano, C. A.; Silva, F. F.; Guimarães, S. E. F. and Bergsma, R. 2018. Genotype by feed interaction for feed efficiency and growth performance traits in pigs. Journal of Animal Science 96:4125-4135. https://doi.org/10.1093/jas/sky304

Gomes, R. C.; Sainz, R. D.; Silva, S. L.; César, M. C.; Bonin, M. N. and Leme, P. R. 2012. Feedlot performance, feed efficiency, carcass traits, body composition, energy requirements, meat quality and calpain system activity in Nelore steers with low and high residual feed intake. Livestock Science 150:265-273. https://doi.org/10.1016/j.livsci.2012.09.012

González Fernández, J. R. 2003. El cerdo Ibérico en la dehesa. Aprovechamiento en la industria cárnica. p.75-85. In: 2ª Jornadas Ibéricas de razas autóctonas y sus productos tradicionales: ganadería ecológica. Valera Córdoba, M. M., ed. Sevilla, Spain.

Honikel, K. O. 1997. Reference methods supported by OECD and their use in Mediterranean meat products. Food Chemistry 59:573-582. https://doi.org/10.1016/S0308-8146(97)00002-2

Hornsey, H. C. 1956. The colour of cooked cured pork. I. - Estimation of the nitric-oxide-heam pigments. Journal of the Science of Food and Agriculture 7:534-540. https://doi.org/10.1002/jsfa.2740070804

Huff-Lonergan, E. and Lonergan, S. M. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Science 71:194-204. https://doi.org/10.1016/j.meatsci.2005.04.022

ISI. 1998. The complete software solution for routine analysis, robust calibrations and networking manual. FOSS NIRSystems/TECATOR. Infrasoft International, LLC. Silver Spring, MD, USA.

Johansson, G.; Tornberg, E. and Lundström, K. 1991. Meat colour in loin and ham muscles of normal meat quality from Hampsire, Swedish Landrace and Yorkshire pigs. p.394-397. In: Proceedings of the 37th International Congress on Meat Science and Tecnology. Kulmbach, Germany.

Juárez, M.; Dugan, M. E. R.; López-Campos, Ó.; Prieto, N.; Uttaro, B.; Gariépy, C. and Aalhus, J. L. 2017. Relative contribution of breed, slaughter weight, sex, and diet to the fatty acid composition of differentiated pork. Canadian Journal of Animal Science 97:395-405. https://doi.org/10.1139/cjas-2016-0103

Latorre, M. A.; Pomar, C.; Faucitano, L.; Gariépy, C. and Méthot, S. 2008. The relationship within and between production performance and meat quality characteristics in pigs from three different genetic lines. Livestock Science 115:258-267. https://doi.org/10.1016/j.livsci.2007.08.013

Lindahl, G. 2005. Colour characteristics of fresh pork. Thesis (Ph.D.). Swedish University of Agricultural Sciences, Uppsala, Sweden. Acta Universitatis Agriculturae Sueciae 2005:43.

Lopez-Bote, C. J. 1998. Sustained utilization of the Iberian pig breed. Meat Science 49:S17-S27.

Lopez-Bote, C. J.; Toldrá, F.; Daza, A.; Ferrer, J. M.; Menoyo, D.; Silió, L. and Rodríguez, M. C. 2008. Effect of exercise on skeletal muscle proteolytic enzyme activity and meat quality characteristics in Iberian pigs. Meat Science 79:71-76. https://doi.org/10.1016/j.meatsci.2007.08.002

Marcos, B.; Gou, P.; Serra, X.; Guàrdia, M. D.; Zhen, Z. Y.; Hortós, M.; Mach, N.; Te Pas, M. F. W.; Keuning, E.; Kruijt, L.; Font i Furnols, M. and Arnau, J. 2013. Analysis of raw hams using SELDI-TOF-MS to predict the final quality of dry-cured hams. Meat Science 93:233-239. https://doi.org/10.1016/j.meatsci.2012.08.026

Meale, S. J.; Morgavi, D. P.; Cassar-Malek, I.; Anueza, D.; Ortigues-Marty, I.; Robins, R. J.; Schiphorst, A. M.; Laverroux, S.; Graulet, B.; Boudra, H. and Cantalapiedra-Hijar, G. 2017. Exploration of biological markers of feed efficiency in young bulls. Journal of Agricultural and Food Chemistry 65:9817-9827. https://doi.org/10.1021/acs.jafc.7b03503

Muñoz, M.; Sánchez-Esquiliche, F.; Caraballo, C.; Gómez, F.; Pariente, J. M.; Silió, L.; Rodríguez, C. and García-Casco, J. M. 2018. Animal breeding scheme applied to the quality of pure Iberian *montanera* pigs. Archives de Zootecnia 9-11.

Muriel, E.; Antequera, T. and Ruiz, J. 2002. Efecto del tipo de músculo sobre parámetros de calidad en carne fresca de cerdo ibérico. Ciencia y Tecnologia Alimentaria 3:241-247. https://doi.org/10.1080/11358120209487735

Nieto, R.; García-Casco, J.; Lara, L.; Palma-Granados, P.; Izquierdo, M.; Hernandez, F.; Dieguez, E.; Duarte, J. L. and Batorek-Lukač, N. 2019. Ibérico (Iberian) pig. In: European Local Pig Breeds – Diversity and Performance. A Study of Project TREASURE. Čandek-Potokar, M. and Nieto, R., eds. IntechOpen. https://doi.org/10.5772/intechopen.83765

Niñoles, L.; Clemente, G.; Ventanas, S. and Benedito, J. 2007. Quality assessment of Iberian pigs through backfat ultrasound characterization and fatty acid composition. Meat Science 76:102-111. https://doi.org/10.1016/j.meatsci.2006.10.018

Olsson, V. and Pickova, J. 2005. The influence of production systems on meat quality, with emphasis on pork. Ambio 34:338-343. https://doi.org/10.1579/0044-7447-34.4.338

Paganoni, B.; Rose, G.; Macleay, C.; Jones, C.; Brown, D. J.; Kearney, G.; Ferguson, M. and Thompson A. N. 2017. More feed efficient sheep produce less methane and carbon dioxide when eating high-quality pellets. Journal of Animal Science 95:3839-3850. https://doi.org/10.2527/jas.2017.1499

Patience, J. F.; Rossoni-Serão, M. C. and Gutiérrez, N. A. 2015. A review of feed efficiency in swine: biology and application. Journal of Animal Science and Biotechnology 6:33. https://doi.org/10.1186/s40104-015-0031-2

Pathare, P. B.; Opara, U. L. and Al-Said, F. A. 2013. Colour measurement and analysis in fresh and processed foods: a review. Food and Bioprocess Technology 6:36-60. https://doi.org/10.1007/s11947-012-0867-9

Prendiville, R.; Lewis, E.; Pierce, K. M. and Buckley, F. 2010. Comparative grazing behavior of lactating Holstein-Friesian, Jersey, and Jersey × Holstein-Friesian dairy cows and its association with intake capacity and production efficiency. Journal of Dairy Science 93:764-774. https://doi.org/10.3168/jds.2009-2659

Rauw, W. M. 2012. Feed efficiency and animal robustness. p.105-122. In: Feed efficiency in the Beef Industry. Hill, R. A., ed. John Wiley & Sons, Inc., New York, USA.

Rauw, W. M. and Gomez-Raya, L. 2015. Genotype by environment interaction and breeding for robustness in livestock. Frontiers in Genetics 6:310. https://doi.org/10.3389/fgene.2015.00310

Rauw, W. M.; Soler, J.; Tibau, J.; Reixach, J. and Gomez-Raya, L. 2006. The relationship between residual feed intake and feed intake behavior in group-housed Duroc barrows. Journal of Animal Science 84:956-962. https://doi.org/10.2527/2006.844956x

Rodrigáñez, J.; Silió, L. and Rilio, S. M. 1993. El cerdo Iberico y su sistema de producción. Animal Genetic Resources Information 12:89-96. https://doi.org/10.1017/S1014233900003436

Rodríguez Estévez, V.; García, A.; Peña, F. and Gómez, A. G. 2009. Foraging of Iberian fattening pigs grazing natural pasture in the dehesa. Livestock Science 120:135-143. https://doi.org/10.1016/j.livsci.2008.05.006

Rodríguez-Estévez, V.; Sánchez-Rodríguez, M.; Arce, C.; García, A. R.; Perea, J. M. and Gómez-Castro, A. G. 2012. Consumption of acorns by finishing Iberian pigs and their function in the conservation of the Dehesa agroecosystem. In: Agroforestry for Biodiversity and Ecosystem Services – Science and Practice. Kaonga, M., ed. InTech. https://doi.org/10.5772/34877

Ruiz, J.; Cava, R.; Antequera, T.; Martín, L.; Ventanas, J. and López-Bote, C. J. 1998. Prediction of the feeding background of Iberian pigs using the fatty acid profile of subcutaneous, muscle, and hepatic fat. Meat Science 49:155-163. https://doi.org/10.1016/S0309-1740(97)00136-8

Ruiz-Carrascal, J.; Ventanas, J.; Cava, R.; Andrés, A. I. and García, C. 2000. Texture and appearance of dry cured ham as affected by fat content and fatty acid composition. Food Research International 33:91-95. https://doi.org/10.1016/S0963-9969(99)00153-2

Schinckel, A. P. and de Lange, C. F. M. 1996. Characterization of growth parameters needed as inputs for pig growth models. Journal of Animal Science 74:2021-2036. https://doi.org/10.2527/1996.7482021x

Schivazappa, C.; Degni, M.; Nanni Costa, L.; Russo, V.; Buttazzoni, L. and Virgili, R. 2002. Analysis of raw meat to predict proteolysis in Parma ham. Meat Science 60:77-83. https://doi.org/10.1016/S0309-1740(01)00109-7

Sodini, S. M.; Kemper, K. E.; Wray, N. R. and Trzaskowski, M. 2018. Comparison of genotypic and phenotypic correlations: Cheverud's conjecture in humans. Genetics 209:941-948. https://doi.org/10.1534/genetics.117.300630

Solís, M.; De Pedro, E.; Garrido, A.; García, J.; Silió, L.; Rodríguez, C. and Rodrigáñez, J. 2001. Evaluación de la composición del lomo de cerdo ibérico mediante la tecnología NIRS. Información Técnica Económica Agraria 22:613-615.

Tejerina, D.; García-Torres, S. and Cava, R. 2012. Water-holding capacity and instrumental texture properties of m. *Longissimus dorsi* and m. *Serratus ventralis* from Iberian pigs as affected by the production system. Livestock Science 148:46-51. https://doi.org/10.1016/j.livsci.2012.05.005

van Son, M.; Gjerlaug Enger, E.; Grove, H.; Ros-Freixedes, R.; Kent, M. P.; Lien, S. and Grindflek, E. 2017. Genome-wide association study confirm major QTL for backfat fatty acid composition on SSC14 in Duroc pigs. BMC Genomics 18:369. https://doi.org/10.1186/s12864-017-3752-0

Ventanas, S.; Ventanas, J.; Ruiz, J. and Estévez, M. 2005. Iberian pigs for the development of high-quality cured products. p.27-53. In: Recent Research Developments in Agricultural & Food Chemistry. Pandalai, S., ed. v.6. Research Signpost.

Vestergaard, M.; Oksbjerg, N. and Henckel, P. 2000. Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of *semitendinosus*, *longissimus dorsi* and *supraspinatus* muscles of young bulls. Meat Science 54:177-185. https://doi.org/10.1016/S0309-1740(99)00097-2

Warner, R. D. 2017. The eating quality of meat – IV Water-holding capacity and juiciness. p.419-459. In: Lawrie's meat science. 8th ed. Toldrá, F., ed. Woodhead Publishing. Elsevier Ltd, Duxford, UK. https://doi.org/10.1016/B978-0-08-100694-8.00014-5

Wellock, I. J.; Emmans, G. C. and Kyriazakis, I. 2004. Describing and predicting potential growth in the pig. Animal Science 78:379-388. https://doi.org/10.1017/S1357729800058781