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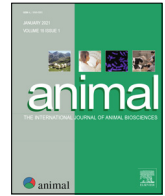
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Finishing season and feeding resources influence the quality of products from extensive-system Gascon pigs. Part 2: muscle traits and sensory quality of dry-cured ham

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ABSTRACT

The quality of pork products from local breeds in extensive systems depends, among other things, on pig production. In particular, the variability in climatic conditions and feeding resources may influence the properties of tissues at slaughter and the quality of pork and processed products. The present study (part 2) was part of a larger project that assessed the influence of the finishing season and feeding resources on carcass and tissue traits and the quality of meat and dry-cured ham from Gascon pigs in an extensive system. Following the specifications of the Protected Designation of Origin “Noir de Bigorre”, castrated Gascon males were reared on rangelands (grassland and forest areas) and received a supplementary diet from 5 to 6 months of age until slaughter at a minimum of 12 months and ca. 170 kg BW. Three finishing seasons were considered: Winter ($n = 18$), Spring ($n = 22$) and Autumn ($n = 23$). To estimate the specific effects of season on quality traits and avoid bias due to effects of genes known to influence these traits, polymorphisms in the RYR1, PRKAG3, MC4R and LEPR genes were included in the analysis models. Compared to Winter pigs, Spring and Autumn pigs had higher ultimate pH in the *semimembranosus* and *gluteus medius* (GM) muscles, lower meat lightness ($P < 0.05$) and tended to have higher GM intramuscular fat (IMF) content ($P < 0.10$). They also had higher GM contents of saturated, monounsaturated and polyunsaturated fatty acids (FAs) than Winter pigs ($P < 0.05$). Spring pigs had the lowest n-6:n-3 polyunsaturated FA ratio and the highest GM α -tocopherol content ($P < 0.001$), indicating pig grazing. The finishing season did not influence the processing yield of dry-cured hams (24-month process). Within each seasonal group, ten hams selected for genetic variability and IMF content were analyzed by a trained sensory panel. The season did not modify the appearance or odor, but influenced texture and taste. Hams from Winter and Spring pigs had higher tenderness and melting fat scores than hams from Autumn pigs ($P < 0.01$). Hams from Spring pigs had higher taste intensity and salty taste ($P < 0.01$) but lower positive tastes (e.g. fruits, forest) than hams from the other groups. Overall, finishing season had moderate effects on ham sensory traits. Furthermore, our results reveal high redness, tenderness, taste and odor intensity, and low rancid flavor of hams from Gascon pigs produced in an extensive system.

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Implications

In extensive pig production systems, the quantity and nature of feeding resources available in rangelands can influence tissue com-

position, especially its fatty acid profile, and the sensory properties of products. In pork chains focusing on high-quality products, pig feeding is a way to modulate their intrinsic (sensory, nutritional, technological) quality. Compared to Winter or Autumn, Spring finishing season for Gascon pigs has thus been associated to higher pork nutritional value and taste intensity of dry-cured ham. Tenderness also differs between seasons, indicating that sensory

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quality of dry-cured ham results from interactions of factors throughout the production and processing chain.

Introduction

The literature describes well how pork products from local pig breeds produced in extensive systems exhibit sensory properties that are better than those from the same breeds in conventional systems and much better than those from “conventional” breeds selected to improve growth efficiency and lean meat production (reviews by [Bonneau and Lebret 2010](#); [Čandek-Potokar and Škrlep, 2012](#); [Pugliese and Sirtori, 2012](#)). Indeed, pig genotype and production conditions interact to determine the properties of the raw material, which can interfere with the processing conditions that develop the intrinsic (sensory, nutritional, technological) properties of the final products ([Cava et al., 2000](#); [Virgili and Schivazappa, 2002](#); [Petrova et al., 2015](#)). Dry-cured ham, which is usually the main product in high-quality pork chains, is highly appreciated by consumers ([Diaz-Caro et al., 2019](#); [Vitale et al., 2020](#)). In addition to the well-known Iberian pigs and dry-cured ham, many other high-quality pork chains exist and continue to develop in Europe. One of them is the French “Noir de Bigorre” (NB) chain, which produces pork and dry-cured ham from pure Gascon pigs reared in an extensive system, and whose products have obtained a Protected Designation of Origin (PDO) quality label ([Mercat et al., 2019](#)). Pigs in this system are placed on rangelands, including grassland with a variety of grass and legume species (≤ 20 pigs/ha) and a forest area (e.g. acorns and chestnuts) and are fed supplementary food, from 5 to 6 months of age until slaughter at a minimum of 12 months of age and minimum 100 kg carcass weight. Thus, the type and amount of natural feeding resources available for pigs vary during the year depending on the season. The type of feeding regimen provided to finishing Iberian pigs influences the sensory quality of dry-cured hams, with lower firmness and higher flavor intensity of hams from pigs in the Montanera system (acorns and pasture as the only resources) than those from Iberian pigs fed a conventional diet. This difference is due to modifications in the fatty acid (FA) composition of pig tissues and the profile of volatile and non-volatile compounds that develop during ham processing ([Cava et al., 2000](#); [Pugliese and Sirtori, 2012](#)). Consumers can perceive these sensory differences ([Diaz-Caro et al., 2019](#)). These results indicate that in extensive systems, the natural feeding resources available for pigs in a given finishing season could influence the intrinsic quality of dry-cured hams, with potential improvement in texture and flavor traits if pigs consume local fruits (acorns, chestnuts, etc.) during autumn. The objective of our study was to determine the influence of pig finishing season and local feed resources on carcass composition, muscle and fat tissue properties, and the quality of PDO loin and dry-cured ham from the Gascon local breed produced in the extensive agro-forestry system of the NB chain. This article focuses on the quality traits of fresh hams and the sensory quality of dry-cured hams. A companion article ([Lebret et al., 2021](#)) describes the influence of pig finishing season and feeding resources on carcass, *longissimus* muscle (LM) and backfat traits, as well as on the quality of fresh loin from the same animals.

Material and methods

The companion article ([Lebret et al., 2021](#)) details the animals and experimental design, including sequencing and genotyping analyses, preslaughter handling and the methods used to assess the carcass, meat quality traits and muscle composition; thus, we present them only briefly below.

Animals and experimental design

Pure Gascon castrated male pigs were reared according to the PDO specifications of the NB chain ([Mercat et al., 2019](#), and briefly described in [Lebret et al., 2021](#)), in southwestern France. Animals were placed on rangelands, which included a grassland (mostly orchard grass and some rescue and white and red clover, ≤ 20 pigs/ha), a forest area (mostly oak trees) and a shelter, from 5 to 6 months of age until slaughter at around 170 kg BW. Three finishing seasons were considered: Winter: outdoor farming from July to March, with supplementary feed distributed mainly during finishing (few natural resources available); Spring: outdoor farming from October to June, supplementary feed and grazing mainly at the end of finishing; Autumn: outdoor farming from April to December, supplementary feed and consumption of natural resources (mostly acorns, and grass).

For each season, pigs were produced on two NB farms following PDO specifications, and practices were harmonized on the two farms as much as possible. A total of 63 Gascon pigs were included in the study (18, 22 and 23 for Winter, Spring and Autumn, respectively). Experimental pigs were included in a larger group of animals in order to represent actual NB production conditions. Whatever the season, all pigs received supplementary feed (meal) that was produced on each farm, based on triticale, faba beans and a mineral supplement, and had permanent free access to water. Experimental pigs were weighed individually throughout the experiment and the day before slaughter. Pigs were slaughtered at a mean BW of 171 ± 17.7 kg in one slaughter batch (including pigs from both farms) per season, following similar preslaughter handling conditions among seasons and between farms. Pigs were slaughtered in a commercial slaughterhouse by electrical stunning and exsanguination. Details of the number of litters and sires considered to produce the experimental pigs, the number of pigs per farm by season, the composition and quantity of supplementary feed distributed per pig per day for each season and farm, and preslaughter handling and slaughtering conditions are described in [Lebret et al. \(2021\)](#).

Carcass, muscle and meat quality traits

Carcass and muscle measurements, sampling and analyses were conducted on all animals. Just after slaughter, evisceration and removal of diaphragm and abdominal fat, the hot carcass was weighed, and backfat thickness and LM depth were measured at the level of the *gluteus medius* (GM) muscle (ZP (Zwei-Punkt Messverfahren) method, [Font-i-Furnols et al., 2016](#)). After 24 h at 4 °C, carcasses were cut, and ultimate pH (pHu) was measured in the *semimembranosus* muscle (SM) and GM of the right ham, using a Metrohm pH-meter with automatic temperature compensation (Berlin, Germany) and equipped with a dedicated electrode (Ingold Xerolyte). Right hams were then trimmed (a rounded cut including all of the bottom round, which remained covered in a layer of fat, retaining half of the aitchbone) and, after 15 min of blooming under artificial light at 4 °C, color coordinates L^* (lightness), a^* (redness), b^* (yellowness), C^* (chroma) and h° (hue) of the GM were determined (average values of three repetitive measurements at one site) using a chromameter Minolta CR300 (Osaka, Japan). From the trimmed part from each ham, a GM sample (ca. 50 g) was collected, trimmed of external fat, minced, vacuum-packed and stored at -20 °C before determining lipid (intramuscular fat, IMF) content from chloroform:methanol extraction ([Folch et al., 1957](#)), α -tocopherol content, and FA composition. FA composition of GM lipids was determined by gas chromatography after FA methylation with boron trifluoride methanol and was expressed in mg per 100 g of tissue by considering the GM lipid content ([Lebret et al., 2021](#)). Alpha-tocopherol was determined by HPLC

from lipid extracts, as described by [Lebret et al. \(2018\)](#), and was expressed in μg per g of tissue.

Dry-cured ham processing

Right hams from all experimental pigs were processed into dry-cured hams for 24 months, following the specifications of NB PDO dry-cured hams ([European Union, 2017](#); [Mercat et al., 2019](#)). PDO specifications require at least 20 months of processing, but actors in the NB chain plan to increase the duration to 24 months for at least some of the hams to increase their flavor ([Petrova et al., 2015](#)). Thus, the present study considered 24 months of processing for all hams. At carcass cutting, hams were individually identified with a numbered plastic collar for traceability until the end of processing, and just after pH and color measurements, they were transported (30 min) to the processing plant (Salaisons de l'Adour, Louey, France). Hams were weighed on arrival (i.e. initial weight before processing) and kept 24 h at 3 °C before salting for 10 days ('soft' salting technique, with hams covered twice: on the first and sixth day with dry mineral sodium chloride including 0.4% potassium nitrate; salting room temperature 1–3 °C). After salting, salt was removed by blowing and hams were hanged in a resting room (temperature 3–5 °C) under dynamic and then static ventilation for two and twelve weeks, respectively. They were quickly rinsed with water to remove excess salt and dried in a "steaming" room for one week (temperature progressively increased from 18 °C to 22 °C). After greasing the lean parts of the hams with pig fat to prevent excessive drying, hams were placed in a drying room (temperature 17–19 °C, 75% relative humidity) for 12 weeks, and then in a ripening room that connected with outside air (temperature 18–19 °C) for 17 months. Hams were weighed at the end of the 24 months of processing (final ham weight) to calculate processing yield.

Sensory quality of dry-cured hams

For each season, ten dry-cured hams were selected for sensory analysis based on the representativeness of the i) farm, ii) genetic diversity of animals (litters and sires) and iii) GM IMF content. Hams with an initial weight ≤ 11.2 kg were excluded to avoid those that were too light, which are less suitable for 24-month processing. However, we ensured that ham weight and their homogeneity among seasons were suitably representative. All selected hams were prepared at the same time during each season, by the same staff of the processing plant, who followed the same protocol strictly each season. At the end of ripening, hams were deboned and trimmed of the rind and some of the external fat to keep the fat depth similar on all hams. They were then molded into a paver shape and stiffened. The central part of each ham, including the SM, *biceps femoris* (BF), semitendinosus and rectus femoris muscles and backfat, was sliced (1.3 mm thick) with a slicing machine. Slices were vacuum-packed, stored at 4 °C and transported to the sensory analysis laboratory (Quali-Saveurs, Arzacq, France).

Sensory tests were conducted approximately four weeks after the end of ripening. Hams from each season were tasted in two sessions within the same week (five hams per session) by the same 11 panelists qualified and trained in sensory analysis of dry-cured ham (NF/EN ISO 8586) within and among seasons. In addition, one training session was conducted a few days before the first sensory session of each season. Before each session, packages of ham slices were placed at 19 °C for 1 h and then opened, and the slices were laid out on plates for 15 min at 19 °C before being given to the panelists. The tasting room was equipped with 12 individual sensory cabins at an ambient temperature of 20–22 °C. Each panelist determined the sensory profile of each product (monadic distribution) (NF/EN ISO 13299), which included descriptors of aspect, texture, flavor and odor on a discrete scale from 0 (absent) to 6 (high).

The panelists evaluated all the slices as a whole for the descriptors of aspect, and a transversal, middle section of the slice including *semimembranosus* and BF muscles and subcutaneous fat for the descriptors of texture, flavor and odor, because it is representative of how dry-cured hams are usually consumed. All the sensory traits considered in the study and the recommendations for their assessment by the panelists are described in [Table 1](#). During the session, panelists were served bread, water and an apple to neutralize taste between samples. The mean of individual panelist scores for each sample and descriptor was calculated and used for statistical analysis.

Sequencing and genotyping analyses

As described in the companion article ([Lebret et al., 2021](#)), four genes known for their effects on carcass fatness, tissue FA profile or pork quality (i.e. ryanodine receptor 1 (RYR1), protein kinase AMP activated γ 3-subunit (PRKAG3) ([Ciobanu et al., 2011](#)),

Table 1

Description of the sensory quality traits considered in the sensory analysis of 24-month dry-cured hams from Gascon pigs (assessed on a discrete scale from 0: absent to 6: high).¹

Traits	Description - recommendation
Appearance of the slice	Assessed on the whole slice, and on the side presented without turning the slice over
Quantity of fat	Quantity of intermuscular fat – not subcutaneous or intramuscular
Redness	Average red intensity over the whole slice
Marbling	Average marbling (intramuscular fat) intensity over the whole slice
Tyrosine	Number of tyrosine points (small white points in the lean) on the slice (1 point score = 1 tyrosine point; score 6: ≥ 6 tyrosine points)
Texture ²	Assessed on a transversal, middle section of the slice including <i>semimembranosus</i> and <i>biceps femoris</i> muscles and subcutaneous fat, and eating lean and fat together
Tenderness	Product which does not require much chewing to be ready to swallow
Dry	Average dryness (i.e. does not contain moisture) of the part tasted
Melting fat	Perception of fat melting when the product is in the mouth
Flavor ²	Assessed on the transversal section of the slice, eating lean and fat together
Taste intensity	Intensity of global taste
Salty taste	Intensity of salty taste
Rancid taste	Intensity of rancid taste
Other positive tastes	Intensity of other positive tastes, described as fruits, hazelnut, chestnut, dried fruits, forest by the panelists
Other negative tastes	Intensity of other negative tastes, described as plastic, chemical, animal, moldy, bitter by the panelists
Taste persistence	Olfactory-gustatory feeling similar to that perceived when the product was in the mouth
Odor intensity	Intensity of global odor
Odor of raw meat	Intensity of raw meat (metallic) odor
Rancid odor	Intensity of rancid: strong and pungent odor, specific of old butter
Other positive odors	Intensity of other positive odors described as forest, chestnut, hazelnut, butter, flower, dry fruits by the panelists
Other negative odors	Intensity of other negative odors described as chemical, pungent, animal, moldy by the panelists

¹ The sensory traits, their description and recommendations were proposed by the sensory laboratory Quali-Saveurs (Arzacq, France) expert in the evaluation of dry-cured hams, then discussed and validated by the participants in the study (actors of Noir de Bigorre Pork chain, INRAE and IFIP scientists).

² For assessment of texture and flavor traits, panelists were asked to cut and taste a transversal middle section including lean and fat, which is how dry-cured ham is usually consumed.

melanocortin-4 receptor (**MC4R**) (Hong et al., 2015) and leptin receptor (**LEPR**) (Henriquez-Rodriguez et al., 2016)) were sequenced or genotyped in all pigs. Our aim was to take into account this genetic information to avoid bias that could have resulted from unbalanced number of pigs per genotype at these loci, and therefore better estimate the specific effects of season and farm on ham muscle traits. In total, 21 single nucleotide polymorphisms (**SNPs**) (one each in RYR1 and MC4R, two in LEPR and 17 in PRKAG3) were initially considered. After filtering steps to avoid non-informative or redundant markers, eight SNPs – five in PRKAG3 (denoted M1 to M5), one in MC4R (M6) and two in LEPR (M7 and M8) – were retained and used in subsequent analyses (Supplementary Material S1 of Lebret et al., 2021).

Statistical analyses

Statistical Analysis System software (version 9.4; SAS Institute, Cary, NC, USA) was used to analyze the data. The pig was considered the statistical unit for all traits. First, data were analyzed using a PROC MIXED model with the season and farm as fixed effects to calculate residues. The normality of residues was checked (Kolmogorov-Smirnov, $P \geq 0.05$). When necessary, data were log-transformed and tested again to assess the normality of their residues. Then, raw or log-transformed data for GM and SM traits and processing yield of dry-cured hams were analyzed via the PROC MIXED procedure with season, farm and genotype at SNPs as fixed effects. Because residues of GM α -tocopherol content could not be normalized, non-parametric tests were used to determine the effect of season and differences among seasons (PROC NPAR1WAY, Kruskal-Wallis test, dscf option); medians were calculated by treatment. Raw or log-transformed data for sensory quality traits of dry-cured hams, as well as slaughter, carcass, fresh ham and GM traits of the corresponding pigs (i.e. $n = 10$ per season), were analyzed via the PROC MIXED procedure with season and farm as fixed effects. The genotype at SNP markers could not be included in the model because the analysis would have had more levels than individuals per season. Slaughter BW was included in the model as a covariate when analyzing carcass traits. Least-square means were calculated by season from raw data and compared using a Tukey test. Pearson's correlation coefficients (PROC CORR PEARSON) were calculated between carcass or muscle traits and processing yield of dry-cured hams (for $n = 63$ pigs), or between GM traits and sensory properties of dry-cured hams (for $n = 30$ hams). Fixed effects and differences between means were considered as significant for $P < 0.05$ and as a trend for $P < 0.10$.

Results and discussion

The pigs' finishing season had a distinct influence on muscle composition and quality traits of fresh hams and the sensory traits of dry-cured hams, as found for carcass and LM traits (Lebret et al., 2021). The farm and, when included in the model, the genotype at SNPs also influenced some of these traits. The design did not allow the estimation of the allelic substitution effects, but taking into account the genotypes of the individuals at these polymorphisms allowed a better estimation of the effects of season on muscle composition and meat quality traits. As detailed in Lebret et al. (2021), all pigs were free of the RYR1 R615C (halothane) and PRKAG3 R200Q (RN⁻) mutated alleles. Both mutations have major detrimental effects on pork quality and the technological and sensory properties of dry-cured hams (Ciobanu et al., 2011; Čandek-Potokar and Škrlep, 2012). Polymorphism at M4 (PRKAG3 gene) affected the pHu of SM (Table 2), in agreement with the literature on SNP polymorphisms in this gene on pHu of pork (Ciobanu et al., 2011). Significant effects of M6 (MC4R) and M8 (LEPR) SNP mark-

ers were found on the n-6 polyunsaturated FA (**PUFA**) content of the GM (Table 3), in accordance with effects of these markers on C18:2n-6 PUFA reported in the pig GM (Henriquez-Rodriguez et al., 2016) and LM (Hong et al., 2015). However, since the influence of season was the main objective of the study, only results by finishing season are detailed in the tables.

Quality traits of ham muscles

The finishing season influenced the pHu of the SM and GM muscles, with lower pHu for Winter pigs than Spring or Autumn pigs, which had similar mean values (Table 2). Winter pigs also had a GM lighter in color than Spring or Autumn pigs, while the other color parameters (i.e. redness, yellowness, chroma and hue angle) were similar among seasons. Similarly, the LM of Winter pigs was lighter in color and had lower pHu than that of Spring or Autumn pigs (Lebret et al., 2021). The lower pHu in the loin and ham muscles of Winter pigs agrees with results of a previous study (Lebret et al., 2011), in which pigs reared in an alternative system (i.e. access to an outdoor area) in Winter instead of Spring had lower pHu in the LM and SM. This effect of season is often, but not always, associated with higher muscle glycogen content as ambient temperature decreases. Indeed, we previously observed higher glycolytic potential in the SM, but not in the LM, of Winter pigs than Spring pigs in the alternative system (Lebret et al., 2011), which agrees with the present study for the LM (Lebret et al., 2021). This confirms differences in the metabolic responses of muscles to environmental conditions (Bee et al., 2004). As explained for the LM, the lighter color of the GM of Winter pigs than Spring or Autumn pigs can be attributed to their lower pHu, due to the well-known negative relationship between these two traits.

Winter pigs had lower initial and final ham weights than Spring or Autumn pigs (by a mean of -0.7 and -0.5 kg, respectively, Table 2), which agrees with the lower ham percentage in the carcass of the former (Lebret et al., 2021). The processing yield of dry-cured hams did not differ among seasons. This indicates that the moderately lower pHu and initial weight of hams from Winter pigs did not impair their processing yield, as confirmed by the lack of any trend in correlation ($P > 0.10$) between initial weight, GM pHu or SM pHu and processing yield. In contrast, processing yield was positively correlated with ZP backfat thickness ($r = 0.23$, $P = 0.049$). This correlation agrees with Čandek-Potokar and Škrlep (2012), who reported that backfat thickness has more influence on processing losses of dry-cured ham than the pHu or weight of fresh hams.

Lipids, fatty acids and α -tocopherol contents of the gluteus medius muscle

The finishing season influenced the lipid fraction of the GM, with a trend for higher IMF content ($P = 0.097$) in Spring and Autumn pigs than in Winter pigs (Table 3). The FA composition of GM was expressed as quantity per 100 g of fresh tissue to take into account variations in IMF content between seasonal groups, which is more accurate when considering the FA profile as an indicator of the nutritional value of pork. Compared to Winter pigs, Spring and Autumn pigs had significantly higher contents of saturated (**SFA**, +29%) and monounsaturated fatty acids (**MUFA**, +29%), and PUFA to a lesser extent (+13%), with no differences between Spring and Autumn pigs for these traits. The finishing season also influenced the type of PUFA, with higher n-6 content in the GM of Autumn pigs than Winter pigs, while Spring pigs had an intermediate value, and higher n-3 content for Spring and Autumn pigs than Winter pigs. This resulted in lower n-6:n-3 and C18:2:C18:3 ratios in the GM of Spring pigs than that of Winter or Autumn pigs,

Table 2

Meat quality traits of *semimembranosus* (SM) and *gluteus medius* (GM) muscles, and weight and processing yield of 24-month dry-cured ham by pig finishing season: Winter, Spring or Autumn.

	Finishing season ¹			RMSE	P-value ²
	Winter	Spring	Autumn		
N	18	22	23		
Ultimate pH (pHu), SM	5.48 ^a	5.56 ^b	5.58 ^b	0.10	S* F* M4* M5†
Ultimate pH (pHu), GM	5.39 ^a	5.46 ^b	5.46 ^b	0.06	S**
Color, GM					
Lightness (L*)	46.80 ^b	45.29 ^a	44.78 ^a	1.98	S* M5†
Redness (a*)	19.94	18.59	18.97	2.16	
Yellowness (b*)	10.37	10.12	9.97	1.23	
Chroma (C*)	22.48	21.17	21.44	2.41	
Hue angle (h°)	27.54	28.56	27.82	1.64	M2†
Initial ham weight (kg)	11.84 ^a	12.55 ^b	12.52 ^b	0.55	S** HCW***
Final ham weight (kg)	8.38 ^a	8.78 ^b	8.89 ^b	0.96	S** HCW***
Processing yield (%)	71.22	70.47	71.88	3.00	

¹ Least-square means

² P-values of effects of finishing season (S), farm (F), genetic markers (M1 to M8), and hot carcass weight (HCW) included as covariate for ham weights and processing yield, and RMSE obtained from the PROC MIXED procedure. ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.

^{a,b} Values within a row with different superscripts differ significantly at $P < 0.05$.

Table 3

Lipid and fatty acid (FA) content of the *gluteus medius* muscle by pig finishing season: Winter, Spring or Autumn.

	Finishing season ¹			RMSE	P-value ²
	Winter	Spring	Autumn		
N	18	22	23		
Lipid (%)	3.20	3.84	3.71	0.11	S†
FA content, mg/100 g					
SFA ³	908 ^a	1172 ^b	1198 ^b	0.13	S*
MUFA ³	1318 ^a	1701 ^b	1764 ^b	0.14	S*
PUFA ³	207 ^a	234 ^b	249 ^b	0.07	S** F* M1† M3† M6† M7† M8†
n-6	179 ^a	200 ^{ab}	218 ^b	31.37	S** F* M1† M6* M7† M8*
n-3	23.8 ^a	29.4 ^b	27.5 ^b	4.89	S**
n-6:n-3	7.7 ^b	6.9 ^a	8.0 ^b	0.68	S***
C18:2n-6:C18:3n-3	12.7 ^b	11.3 ^a	13.7 ^b	1.70	S*** M5†
α -tocopherol, $\mu\text{g/g}$ ⁴	0.33 ^b	4.48 ^a	0.12 ^c		S***

¹ Least-square means estimated from raw data, except for α -tocopherol (medians).

² P-values of effects of finishing season (S), farm (F), genetic markers (M1 to M8), and RMSE obtained from the PROC MIXED procedure applied to raw data (n-6, n-3, n-6:n-3, C18:2n-6:C18:3n-3) or to log-transformed values (lipid, SFA, MUFA, PUFA) to fit a normal distribution. ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.

³ SFA: Saturated, MUFA: Monounsaturated and PUFA: Polyunsaturated FA (detailed in Supplementary Table S1).

⁴ Non-parametric test.

^{a,b} Values within a row with different superscripts differ significantly at $P < 0.05$.

which had similar ratios. The GM α -tocopherol content was higher for Spring pigs than Winter pigs, while Autumn pigs had the lowest content.

While Winter pigs tended to have the lowest IMF content in the GM, Spring pigs tended to have the lowest IMF content in the LM (Lebret et al., 2021). Furthermore, the IMF content of the LM and GM was moderately correlated ($r = 0.46$, $P < 0.001$). Likewise, Font-i-Furnols et al. (2019) observed a similar correlation ($r = 0.62$) between LM and GM IMF content. This indicates that it would be challenging to estimate the IMF content of one of these muscles from that of the other one. Regarding the IMF content of ham muscles of Gascon and other local or selected pig breeds, the literature provides more data on the BF and SM than on the GM muscle. However, the GM was chosen for ease of sampling and to keep the ham whole for processing. Recent data showed higher IMF content in the GM of Iberian (7.4%) and Alentejano (9.0%) pigs slaughtered at 150–160 kg BW (Lebret et al., 2019) than in that of Gascon pigs in the present study. In the BF muscle of Gascon pigs slaughtered at 170 kg BW, IMF content of 2.8% was reported (Sans et al., 2004), while contents up to 10% were reported in the BF of Iberian pigs (Pugliese and Sirtori, 2012). Overall, these observations indicate that, as in the loin (Lebret et al., 2021), the IMF content in ham muscles of Gascon pigs is higher than that generally found in breeds selected for growth efficiency

and carcass leanness, but is moderate compared to that of other local pig breeds (Čandek-Potokar and Škrlep, 2012).

For FA, the observation that the GM contained the most MUFA, especially C18:1n-9 (Supplementary Table S1), agrees with the high MUFA and C18:1 percentages reported in the BF of Gascon pigs (Sans et al., 2004), as found in the LM of Iberian (Tejerina et al., 2012) and other local breeds (Čandek-Potokar et al., 2019). In contrast, the GM PUFA content was low, in accordance with the backfat FA profile of these pigs (Lebret et al., 2021) and the general observations of higher MUFA and lower PUFA percentages in muscle and fat tissues of local breeds than those of selected breeds (Mourot, 2009; Lebret et al., 2019; Čandek-Potokar et al., 2019). Besides variations in SFA, MUFA and PUFA contents in the GM, the finishing season and feeding resources influenced mainly its PUFA profile and α -tocopherol content. The lowest n-6:n-3 and C18:2:C18:3 ratios in the GM of Spring pigs, also found in backfat (Lebret et al., 2021), were due to higher contents of C18:3n-3 and its derivative C20:5n-3 (ecosapentaenoic acid) (Supplementary Table S1). Given the high C18:3n-3 content found in the grass species analyzed in our experiment (Lebret et al., 2021), which agrees with the literature (Rey et al., 2006) and the high α -tocopherol content of grass (Rey et al., 2006; Tejerina et al., 2012), results for GM composition demonstrate that pigs consumed more grass in grassland in the Spring than during the other finishing seasons.

These results agree with the literature on the positive influence of grazing on the contents of n-3 FA and antioxidant compounds in pig tissues (Tejerina et al., 2012; Pugliese and Sirtori, 2012), which provide co-benefits for the nutritional value of pork (Mourot, 2009). In contrast, the expected higher MUFA content, especially C18:1n-9, in the GM of Autumn pigs than in those of other finishing seasons occurred only when compared to Winter pigs, but not to Spring pigs. Moreover, differences between Autumn and Winter pigs may be partly ascribed to the trend for higher IMF content of the formers. No differences were found in the percentage of C18:1n-9 in backfat between seasonal groups, which was overall high (45–46%; Lebret et al., 2021). The higher percentages of MUFA and C18:1 in ham and loin muscles of Iberian pigs fed exclusively acorns and grass in the Montanera finishing system (Andres et al., 2001; Rey et al., 2006; Tejerina et al., 2012) and in backfat of Cinta Senese pigs fed acorns and pasture in an extensive system (Pugliese et al., 2009) have been described well. The GM muscle and backfat FA profiles observed in the present study suggest that Gascon pigs consumed few acorns, probably due to the low acorn production in the year of the experiment. This result highlights that the availability of feeding resources among seasons and years is a critical point in extensive pig production systems.

Slaughter, carcass traits and ham properties of pigs selected for sensory analysis of dry-cured hams

The main slaughter, carcass and ham traits of the ten pigs selected per finishing season for sensory analysis of dry-cured ham are presented in Table 4. Winter and Autumn pigs had heavier final BW than Spring pigs, but slaughter age did not differ among the three groups. In comparison, for all pigs in the experiment ($n = 63$), final BW did not differ significantly, but the slaughter age of Spring pigs was slightly lower than that of Winter or Autumn pigs (Lebret et al., 2021). Hot carcass weight and ZP muscle and fat thickness did not differ significantly among seasons for the selected pigs or when considering all pigs in the experiment. For the selected pigs, the influence of finishing season was not significant on SM or GM pHu, but for all pigs in the experiment, pHu was lower in the SM and GM of Winter pigs than those of Spring or Autumn pigs. Mean pHu of the SM and GM by season was ranked in the same order for the selected pigs and all pigs in the experiment, indicating that the selection procedure was appropriate.

GM IMF content did not differ significantly among seasons for the selected pigs ($P = 0.11$) or when considering all pigs in the experiment. Mean IMF contents were ranked in the same order among seasons for the 30 selected hams and all hams in the experiment. Initial and final ham weight did not differ significantly among seasons for the selected hams, whereas these weights were lowest for Winter pigs when considering all pigs in the experiment. In accordance with practices of the NB chain, overly light hams were excluded from this long duration of processing. The season had no influence on the processing yield. Overall, these results indicate that the subsample of pigs selected for sensory analysis of their dry-cured hams represented well all pigs in the experiment.

Sensory quality of dry-cured hams

The sensory quality traits of dry-cured hams by pig finishing season are shown in Table 5. Product appearance did not differ among seasons, as indicated by the quantity of fat and intensity of redness, marbling and tyrosine crystals resulting from proteolysis (Čandek-Potokar and Škrlep, 2012). In contrast, season influenced the texture of dry-cured hams, with greater tenderness and higher melting fat score, and a trend for higher dryness ($P = 0.082$) of hams from Winter and Spring pigs, which had similar scores, than hams from Autumn pigs. The flavor traits also differed among seasons, with higher taste intensity and salty taste scores and lower scores for other positive tastes (i.e. fruits, hazelnut, chestnut, and forest) for hams from Spring pigs than hams from Winter or Autumn pigs. Rancid taste tended to be higher ($P = 0.074$) for hams from Winter or Spring pigs but remained low overall. Other negative tastes (e.g. plastic, chemical, animal, moldy, bitter) did not differ among seasons and were low. Taste persistence had high scores that were similar among seasons. Season had no influence on any of the descriptors of odors: odor intensity, raw meat, rancid or other negative odors (e.g. chemical, pungent, animal, moldy) or positive odors (e.g. forest, chestnut, hazelnut, butter, flower, dried fruits). Scores were low for raw meat, rancid and negative odors (maximum mean of 0.26).

Season had no influence on the redness of dry-cured hams, which agrees with the similar hue and lightness observed in the fresh GM. The overall high redness scores of dry-cured hams from Gascon pigs confirm previous findings (Simon et al., 1997) and can

Table 4

Slaughter, carcass and ham traits of pigs selected for sensory analysis of dry-cured ham by pig finishing season: Winter, Spring or Autumn.

	Finishing season ¹			RMSE	P-value ²
	Winter	Spring	Autumn		
N	10	10	10		
Slaughter					
BW (kg)	183.4 ^b	173.1 ^a	183.8 ^b	9.82	S*
Age (days)	397	405	410	12.66	S† F***
Carcass traits					
Hot carcass weight (kg)	148.2	140.4	146.9	8.32	
Muscle depth (ZP_Muscle) (mm)	67.9	71.1	68.4	4.59	
Backfat thickness (ZP_Fat) (mm)	47.6	48.1	49.2	4.00	HCW***
Ham muscles					
Ultimate pH (pHu), <i>semimembranosus</i>	5.56	5.60	5.66	0.12	F†
Ultimate pH (pHu), <i>gluteus medius</i>	5.45	5.47	5.51	0.07	F*
Lipid (%), <i>gluteus medius</i>	2.96	3.71	3.49	0.11	F**
Processing of dry-cured hams					
Initial ham weight (kg)	12.65	13.00	12.95	0.55	F* HCW***
Final ham weight (kg)	9.10	9.39	9.46	0.37	F† HCW***
Processing yield (%)	72.4	71.5	73.2	1.97	

¹ Least-square means.

² P-values of effects of finishing season (S), farm (F), and hot carcass weight (HCW) (included as a covariate for carcass and ham traits), and RMSE obtained from the PROC MIXED procedure applied to raw data. ***, $P < 0.001$, **, $P < 0.01$, *, $P < 0.05$, †; $P < 0.10$.

^{a,b} Values within a row with different superscripts differ significantly at $P < 0.05$.

Table 5

Sensory quality traits of dry-cured hams (scored on a discrete scale from 0: absent to 6: high) by pig finishing season: Winter, Spring or Autumn.

	Finishing season ¹			RMSE	P-value ²
	Winter	Spring	Autumn		
N	10	10	10		
Appearance					
Quantity of fat	2.12	2.06	1.78	0.43	
Redness	3.82	3.89	4.07	0.33	
Marbling	1.96	2.06	2.03	0.35	F†
Tyrosine	2.15	3.04	2.31	1.19	
Texture					
Tenderness	4.77 ^b	4.57 ^b	4.18 ^a	0.29	S***
Dry	2.22	2.25	2.05	0.20	S†
Melting fat	3.78 ^b	3.65 ^b	3.30 ^a	0.33	S** F†
Flavor					
Taste intensity	3.44 ^a	3.66 ^b	3.45 ^a	0.14	S**
Salty taste	3.03 ^a	3.33 ^b	2.88 ^a	0.23	S***
Rancid taste	0.13 ^b	0.15 ^b	0.05 ^a	0.09	S†
Other positive tastes	0.95 ^b	0.65 ^a	0.90 ^b	0.24	S*
Other negative tastes	0.31	0.15	0.19	0.17	
Taste persistence	2.80	2.95	2.81	0.21	
Odor intensity	2.36	2.41	2.48	0.07	
Odor of raw meat	0.20	0.24	0.26	0.10	
Rancid odor	0.04	0.04	0.07	0.05	
Other positive odors	0.62	0.48	0.42	0.19	
Other negative odors	0.20	0.13	0.13	0.13	

¹ Least-square means.² P-values of effects of finishing season (S) and farm (F) and RMSE obtained from the PROC MIXED procedure applied to raw data (all parameters except odor intensity) or to log-transformed data (odor intensity) to fit a normal distribution. ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.^{a,b} Values within a row with different superscripts differ significantly at $P < 0.05$.

be explained by the redder meat of Gascon pigs than that of selected breeds (Čandek-Potokar et al., 2019), as well as the formation of nitrosomyoglobine from nitrites produced by the reduction of nitrates used during salting (Petrova et al., 2015). The similar marbling scores agree with the lack of seasonal effect on the IMF content of the GM, and unsurprisingly, the two traits were strongly correlated ($r = 0.59$, $P < 0.001$), in agreement with Ramos et al. (2007).

Overall, tenderness scores were high and dryness scores were moderate, which confirms the soft texture of dry-cured hams from Gascon pigs reported by Simon et al. (1997). These results are of great importance to the NB chain, since texture is one of the most important factors that influence consumer acceptability of the product (Morales et al., 2013). Tenderness of dry-cured hams depends on the degree of drying and proteolysis (Virgili and Schivazappa, 2002; Petrova et al., 2015). We expected that the long processing duration and relatively low pHu of ham muscles, which promote proteolysis (Virgili and Schivazappa, 2002), would lead to a high degree of proteolysis. Indeed, the tyrosine score was strongly and negatively correlated with the pHu of the SM and GM muscles ($r = -0.54$ and -0.57 , respectively, $P < 0.001$). Despite the long processing duration, mean dryness scores remained moderate, which also explains the high tenderness. Because the lean and fat portions of ham slices were tasted together, the high melting fat score likely also contributed to tenderness, as suggested by their strong correlation ($r = 0.77$, $P < 0.001$). In contrast, tenderness was not correlated with GM IMF content, in agreement with Ramos et al. (2007). According to Ruiz et al. (2000), IMF content seems to influence in particular the juiciness of dry-cured ham, which was not assessed in the present study. Therefore, the greater tenderness of hams from Winter and Spring pigs than Autumn pigs can be explained by the higher melting fat score of the former, which likely resulted from their higher PUFA percentage in the backfat (Lebret et al., 2021). Although non-significant, the lower muscle pHu of Winter and Spring pigs than Autumn pigs may also have contributed to the increased ham tenderness due to more proteolysis in the former, as previously explained. Indeed, a trend for a

negative correlation was observed between GM pHu and tenderness ($r = -0.34$, $P = 0.066$), in agreement with Ramos et al. (2007), who observed a positive relationship between muscle pHu and firmness of dry-cured ham.

The flavor of dry-cured hams includes the perception of salt and volatile and non-volatile compounds (e.g. acids, aldehydes, alcohols, ketones, esters, furans) that result from proteolysis, lipolysis of subcutaneous and intramuscular lipids, and oxidation of free FAs that occur during processing, especially the ripening phase (Toldra, 1998; Gandemer, 2002; Petrova et al., 2015). The types and contents of volatile compounds also determine the odor of dry-cured hams (Toldra, 1998; Pugliese et al., 2009). The overall high taste intensity and slightly lower salty taste, taste persistence and odor intensity scores observed in the present study agree with results of Simon et al. (1997). The scores of the other positive tastes and odors were low, but higher than those of rancid or other negative tastes or odors, indicating that the products in the present study had acceptable flavor properties.

The greater taste intensity of hams from Spring pigs than Winter or Autumn pigs can be explained in part by their saltier taste, since both traits were strongly correlated ($r = 0.73$, $P < 0.001$), but cannot be explained by the intensity of other positive tastes, which was higher in hams from Winter and Autumn pigs. Finishing season did not influence the intensity of positive odors, and overall, positive tastes and odors remained low. Thus, the expected increase in fruit (especially acorn) tastes and odors resulting from acorn consumption in Autumn remained low. This was due to the low consumption of acorns, as suggested by the FA profile of the backfat and GM. The types and contents of the volatile compounds, and thus the intensity of taste and odor of dry-cured hams, depend in part on the FA composition of pig tissues, which results mainly from the composition of the pig diet (Cava et al., 2000; Pugliese et al., 2009; Čandek-Potokar and Škrlep, 2012). No significant relations were observed in the present study between IMF or FA contents of the GM muscle and taste traits; however, these biochemical parameters were negatively correlated with positive odors ($r = -0.38$ to -0.44 , $P \leq 0.041$), which was unexpected

(Gandemer, 2002). These results and the very low intensities of rancid taste and odor suggest that products from lipolysis contributed little to the flavor of dry-cured hams. In contrast, products from proteolysis had a greater influence, as suggested by the positive correlation between the intensity of tyrosine crystals and taste persistence ($r = 0.51$, $P < 0.004$). Accordingly, Sans et al. (2004) suggested that amino-acid degradation exceeded lipid oxidation during the processing of dry-cured ham from Gascon pigs. Analysis of volatile compounds in the present study would have helped investigate the biochemical pathways that underlay the tastes and odors of dry-cured hams.

Conclusion

The finishing season and feeding resources available to Gascon pigs in an extensive system influenced the properties of fresh GM and SM muscles, which had lower pHu, lighter color and a trend for lower IMF content for Winter pigs than Spring or Autumn pigs. The lower n-6:n-3 FA ratio and higher GM α -tocopherol content of Spring pigs due to grazing increase the nutritional value of pork. However, the MUFA content in the GM of Autumn pigs did not differ greatly from those from the other seasons, suggesting that the pigs consumed few acorns. Finishing season had no influence on the appearance or odors of hams. However, it did influence their texture and taste, with greater tenderness and melting fat scores for hams from Winter and Spring pigs than Autumn pigs, as well as higher taste intensity and salty taste but lower positive tastes (e.g. fruits, forest) for hams from Spring pigs than those from the other groups. Overall, sensory differences of hams among seasons remained moderate. Our results, along with data on tissue lipid composition, suggest that increasing differences in pigs' feeding regimens among finishing seasons could increase differences in the intrinsic properties of pork products. This study highlights the overall high redness, tenderness, taste and odor intensity, and the low rancid and negative tastes and odors of dry-cured hams from Gascon pigs in an extensive system.

Supplementary material

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.animal.2021.100305>.

Ethics approval

Not applicable.

Data and model availability statement

None of the data have been deposited in an official repository. The data are available to reviewers.

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Declaration of interest

None.

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