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Finishing season and feeding resources influence the quality of products from extensive-system Gascon pigs. Part 1: Carcass traits and quality of fresh loin

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ABSTRACT

Consumers perceive pork products from local breeds reared in extensive systems positively because of their specific quality properties and regional identity. The sensory, nutritional and technological qualities of these products depend, among other things, on pig production, especially its climatic conditions and the availability of feed resources, which can influence traits of muscle and fat tissue. The present study (part 1) 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 of age and ca. 170 kg live weight. Three finishing seasons were considered as follows: Winter ($n = 18$), Spring ($n = 22$) and Autumn ($n = 23$). To estimate specific effects of season on productive and 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. The finishing season did not influence growth rate. Compared to Winter pigs, Spring and Autumn pigs had slightly lower carcass fatness ($P < 0.05$), higher ultimate pH and redder and darker color of the *Longissimus* muscle (**LM**) ($P < 0.01$). Loin drip loss was low overall, but was higher for Spring pigs, whereas cooking loss and shear force were similar among seasons. Spring pigs tended to have the lowest LM lipid content, whereas LM myoglobin content remained unaffected. Autumn pigs had lower potential of lipid oxidation in LM than Winter and Spring pigs ($P < 0.01$), but muscle metabolic traits assessed via glycolytic and oxidative enzyme activities did not differ among seasons. The finishing season modified the backfat fatty acid (**FA**) profile, with a lower polyunsaturated FA percentage in Autumn pigs than Winter or Spring pigs ($P < 0.001$), even though the saturated and monounsaturated FA percentages did not differ. In particular, Spring pigs had the lowest *n*-6:*n*-3 and C18:2:C18:3 ratios ($P < 0.001$), as a result of grazing. Overall, Spring and Autumn finishing seasons seem more favorable to technological and sensory pork attributes, with an additional positive effect of Spring finishing on pork nutritional value.

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Implications

The quality of pork and products from local breeds in extensive systems can vary according to the availability of feeding resources and pig environmental conditions. Improving characterization of these effects on the intrinsic (sensory, nutritional, technological) quality will help actors in local pork chains control product quality better. Pig production or the factors that influence it, such as feeding resources associated to finishing season, can be considered as ways to improve the quality of products with common specifications, such as geographical origin labels, and thus further differentiate the products provided to consumers.

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Introduction

Pork chains that promote local pig breeds reared in extensive systems specific to a geographic area are developing in Europe and specifically in France. These slow-growing, fat breeds were progressively abandoned in the second half of the 20th century in favor of breeds selected to improve the efficiency of lean meat production. Since the 1980s, conservation programs for local breeds, combined with the strong willingness of local stakeholders (e.g. breeders, slaughterers, processors) to promote traditional breeding and processing practices, encouraged the renewal of these breeds and the development of chains to produce typical, high-quality pork and processed products (Lebret, 2008; Čandek-Potokar et al., 2019a). These products and chains meet consumers' increasing demand for food products with a regional identity (Guerrero et al., 2010; Prache et al., 2020). Some local chains have obtained official recognition of quality and origin (Protected Designation of Origin, **PDO**) for their products, such as the "Noir de Bigorre" (**NB**) chain for fresh loin and dry-cured ham. Local pig breeds are adapted to their local agro-climatic conditions, value local feed resources in extensive production systems and help maintain biodiversity (Edwards, 2005), all of which are issues that correspond to major concerns of the European Commission in its Farm to Fork Strategy (EU, 2020).

In terms of product quality, local breeds in extensive production systems associated with slaughter generally at a high age and weight promote the expression of muscle properties that contribute to sensory quality (Labroue et al., 2000; Bonneau and Lebret, 2010; Pugliese and Sirtori, 2012; Lebret et al., 2015). However, feeding management and variations in climatic conditions and physical activity associated with extensive systems influence pig growth, the metabolism and composition of muscle and fat tissue, and ultimately the quality of pork and processed products (Lebret, 2008). Better knowledge of the influence of farming practices and pig environmental conditions on the quality of pork and products would help sustain the development of pork chains that promote local breeds in extensive systems. Farming practices, especially the finishing season and availability of feeding resources, can be considered as ways to further differentiate the quality of products with common specifications. The objective of this study was to determine the influence of pig finishing season and local feed resources on carcass composition, properties of muscle and fat tissue, and the quality of PDO loin and dry-cured ham from the local Gascon breed produced in the extensive agroforestry system of the NB chain. This article focuses on carcass traits, muscle and fat tissue traits, and the quality of fresh meat (loin). A companion article (Lebret et al., 2021) (part 2) shows the quality traits of fresh ham and the sensory quality of PDO dry-cured hams from the same animals.

Material and methods

Animals and experimental design

Pure Gascon castrated male pigs were reared according to the PDO specifications of the NB chain (Mercat et al., 2019) in south-western France. Briefly, these specifications include that pure Gascon pigs must be born, reared and killed in a specified geographical area. They are born indoor or outdoor in open huts, weaned at minimum 33 days, and kept indoor on straw or on rangelands with a shelter, until maximum 6 months of age. They then are placed until slaughter on natural or cultivated grasslands (maximum of 20 pigs/ha), providing various grass species or leguminous plants, with possible access to a forest plot (e.g. acorns and chesnuts). In addition to natural feeding resources, pigs are fed with complementary food based of a minimum of 70% cereals (wheat, oat, barley, rye, triticale) produced on the geographical area, with potential protein resources (faba beans, peas, rapeseed or sunflower meal), minerals and vitamins. Maize, sorghum and sunflower are not allowed. Pigs are slaughtered at minimum 12 and maximum 24 months of age, with minimum hot carcass weight of 100 kg. In the present study, pigs were reared following these specifications and placed on rangelands which included a grassland (mostly orchard grass and some rescue and white and red clover) and a forest area (mostly oak trees) from 5 to 6 months of age until slaughter at around 170 kg BW. Three finishing seasons, with the following main characteristics, were considered: Winter: outdoor farming from July to slaughter in March, with supplementary feed distributed mainly during finishing (few natural resources available); Spring: outdoor farming from October to slaughter in June, supplementary feed and grazing mainly at the end of finishing; Autumn: outdoor farming from April to slaughter in December, supplementary feed and consumption of natural resources (mostly acorns, and grass). For each season, pigs were produced on two NB farms (**F1** and **F2**, located in the Hautes-Pyrénées department) following PDO specifications and harmonizing practices on the two farms as much as possible. A total of 63 Gascon pigs were included in the study, with $n = 18$ for Winter (F1: $n = 6$ issued from four litters, F2: $n = 12$ issued from five litters), $n = 22$ for Spring (F1: $n = 6$ from five litters; F2: $n = 16$ from seven litters) and $n = 23$ for Autumn (F1: $n = 8$ from five litters; F2: $n = 15$ from nine litters). The same sires (one sire on F1; three sires on F2, one of which had only one offspring) were used on each farm throughout the experiment.

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 (F1: 12.1% CP, 1.24% crude fat, 9.88 MJ NE/kg; F2: 12.8% CP, 1.33% crude fat, 9.87 MJ NE/kg; see Supplementary Table S1 for detailed compositions). Mean amounts distributed per pig were 3.71 (F1) and 2.74 (F2) kg/d in Winter, 4.23 (F1) and 2.65 (F2) kg/d in Spring and 3.89 (F1) and 2.40 (F2) kg/d in Autumn. In F1, the feed distribution practice (on the ground, in a dedicated area of the rangeland) resulted in waste and likely led to differences between the amount of feed distributed and that actually consumed. All pigs had permanent free access to water. Pigs were weighed individually at the start of the experiment (i.e. upon arrival on rangelands), during the growing and finishing periods at around 8 and 11 months of age to check for their regular growth, and the day before slaughter. Individual average daily gain during the whole growing-finishing period was calculated.

Handling, slaughtering and blood sampling

Pigs were slaughtered at a mean BW of 171 ± 17.7 kg. In each season, pigs from both farms were slaughtered on the same day in a commercial slaughterhouse (Arcadie, Tarbes, France). Preslaughter handling conditions were similar among seasons and between farms. On both farms, experimental pigs were grouped the evening before transport in an open-air pen without feed. The next day they were weighed, transported (maximum duration of 1.25 h) to the slaughterhouse and placed in lairage without mixing with unfamiliar pigs but with free access to water. The next morning, pigs were slaughtered by electrical stunning and exsanguination.

All carcass and tissue measurements, sampling and analyses described below were conducted on all experimental pigs. At slaughter, blood was collected in tubes that contained EDTA or heparin; one of each was rapidly centrifuged, and the plasma was stored at −20 °C. Another EDTA-tube blood sample was rapidly frozen at −20 °C for subsequent genotyping analyses. Plasma cortisol was determined from EDTA-collected samples using ELISA kits (ST AIA-Pack CORT, ST AIA-Pack hsE2; Tosoh Corporation, Tokyo, Japan) developed for an automatic analyzer (AIA 1800; Tosoh Corporation). The detection limit was 5 ng/ml. Intra-assay CVs were 4% and 2% at 6 and 175 ng/ml, respectively. Samples from all three seasons were analyzed within single assay. From heparin-collected samples, plasma concentrations of glucose (Glucose GOD, Thermo Fisher Scientific, Waltham, MA, USA) and lactate (lactate oxidase, Trinity Biotech, Jamestown, NY, USA), as well as creatine kinase (CK) activity (CK IFCC, Thermo Fisher Scientific), were determined using a spectro-photometric analyzer (Konelab20, Thermo Scientific). Samples from each season were analyzed within single assays for plasma glucose, lactate and CK; their intra-assay CVs were 1.4%, 1.4% and 1.9%, respectively, while their inter-assay CVs were 1.8%, 4.5% and 6.6%, respectively.

Carcass traits

On the day of slaughter, the hot carcass was weighed, and carcass dressing (hot carcass weight/final BW) was calculated. *Longissimus* muscle (**LM**) depth and backfat thickness (rind included) were measured with a ruler according to the ZP method (minimal distance between vertebral channel and cranial end of *gluteus* muscle for LM; minimal fat thickness over the *gluteus* muscle for backfat; Font-i-Furnols et al., 2016). Backfat thickness was also measured at the level of the last rib. The number of skin lesions (≥2 cm) on each carcass was counted. The same operator determined these traits throughout the experiment. After 24 h of chilling at 4 °C, the right carcass side was cut, and the ham, loin, shoulder, belly and backfat were weighed.

Biochemical and metabolic properties of Longissimus muscle and meat quality traits

During 40 min *postmortem,* LM samples were taken (right carcass side, last rib level), cut into small pieces and immediately frozen in liquid nitrogen. Samples were stored at −76 °C until determination of glycolytic potential (**GP**), initial pH (pHi; after muscle homogenization in sodium iodoacetate) and thiobarbituric acid reactive substances (**TBARSs**) content after forced chemical oxidation for 0, 60, 120, 180 and 240 min to assess oxidative stability, as detailed by Lebret et al. (2018). Activities of the metabolic enzymes lactate dehydrogenase, citrate synthase and β-hydroxyacyl-CoA dehydrogenase were determined as markers of glycolytic metabolism, oxidative capacity (tricarboxylic acid cycle) and lipid β-oxidation potential, respectively, as described by Lefaucheur and Lebret (2020).

The day after slaughter, ultimate pH (**pHu**) was measured at 24 h directly in the LM (between the 13th and 14th ribs). A transverse section of LM (second-to-last rib) was taken and bloomed (15 min, 4 °C, artificial light) before measuring CIE color coordinates L* (lightness), a* (redness), b* (yellowness), C* (saturation (chroma)) and h° (hue) (chromameter, Minolta CR300, Osaka, Japan). The section was then trimmed of external fat and minced, and a sub-sample was freeze-dried and pulverized before determining protein and water contents. The remaining portion was vacuum-packed and stored at −20 °C before determining intramuscular fat (IMF) and myoglobin contents. A second, consecutive transverse section of LM (100 ± 10 g) was taken (cranial side) to determine drip loss at 3 days *postmortem* (plastic-bag method). These measurements were performed as detailed by Lebret et al. (2018). A third, consecutive transverse section of LM (cranial side, at least 10 cm long) was taken, aged for 3 days at 4 °C, vacuum-packed and stored at −20 °C. After 24 h thawing at 4 °C, standardized LM samples (8 × 4 × 5 cm) were weighed, vacuum-packed, heated in a steam oven (70 °C, 50 min), cooled at 4 °C and weighed to calculate cooking loss. From each sample, 15 meat sections were taken with a punch (12 mm internal diameter) parallel to the fiber axis to determine shear force (Warner-Bratzler cell, Instron testing machine, Instron, Guyancourt, France). Data were averaged, and shear force was expressed in N.

Backfat traits and fatty acid composition

The day after slaughter, a sample of backfat (whole-tissue thickness) was taken at carcass splitting (ham level), vacuum-packed and stored at −20 °C before determining total lipid content (methanol/chloroform extraction), as described by Lebret et al. (2018). The fatty acid (**FA**) composition of backfat lipids was determined by gas chromatography after methylation of FA as detailed in Supplementary Material S1.

Sequencing and genotyping analyses

Four genes known for their influence on productive traits, fatness and pork quality, i.e. ryanodine receptor 1 (**RYR1**), protein kinase AMP activated γ3-subunit (**PRKAG3**), melanocortin-4 receptor (**MC4R**) and leptin receptor (**LEPR**) were sequenced or genotyped in all pigs (as detailed in Supplementary Material S1). Indeed, polymorphisms in these genes are in segregation in the Gascon breed (Muñoz et al., 2018). 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 productive, fatness and quality traits. In total, 21 single nucleotide polymorphisms (**SNPs**) (Supplementary Tables S2 and S3) were considered: one each in RYR1 and MC4R, two in LEPR and 17 in PRKAG3. The RYR1 mutation is known for its major influence on many traits, including carcass lean percentage, meat color and pHi (Ciobanu et al., 2011). A low frequency (3%) of the mutant allele was observed in an independent set of Gascon pigs (Muñoz et al., 2018). The PRKAG3 p.R200Q mutation, and to a lesser extent other SNPs in the gene, have a distinct influence on muscle glycogen content, pHu and other meat quality traits (Ciobanu et al., 2011). The MC4R D298N polymorphism was considered due to its influence on backfat thickness and meat color (Switonski et al., 2013). Polymorphisms in the LEPR gene that influence growth, fatness and meat quality traits have been identified (Muñoz et al., 2011). From the 21 markers, successive filters (detailed in Supplementary Material S1) were applied to keep only the informative and nonredundant markers. Ultimately, 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 Table S3).

Statistical analyses

Statistical Analysis System software (version 9.4; SAS Institute, Cary, NC, USA) was used to analyze the data. The pig was considered as 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 were analyzed via the PROC MIXED procedure with season, farm and genotype at SNPs as fixed effects (Supplementary material S1). Slaughter BW and time from exsanguination to muscle sampling were included in the model as a covariate for data analysis of carcass traits and pHi, respectively. Least-square means were calculated by season from raw data and were compared using a Tukey test. 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 finishing season had a distinct influence on many carcass and tissue characteristics and meat quality traits. The farm and the genotype at SNP markers also influenced some of these traits; however, since the influence of the season was the main objective of the study, only results by finishing season are detailed in the tables.

Effects of single nucleotide polymorphisms

The genotype of pigs for 21 SNPs in four genes were considered in our analysis. The design did not allow the estimation of the allelic substitution effects, but taking into account the genotypes of the individuals at the polymorphisms allowed a better estimation of the effects of season on growth, carcass, muscle, backfat and meat quality traits. All pigs were free of the RYR1 R615C (halothane) and PRKAG3 R200Q (RN^-) mutated alleles. This confirms the low frequency of the halothane mutation and the absence of segregation of the RN^- allele found by Muñoz et al. (2018) in another sample of pure Gascon pigs. Most of the significant effects of the SNPs tested that were observed on growth, carcass fatness and muscle and meat traits in the present study have already been reported, with PRKAG3 influencing backfat thickness and meat pHu, color and lipid oxidation (Škrlep et al., 2012; Galve et al., 2013); LEPR influencing growth, fatness and meat color (Muñoz et al., 2011); and MC4R influencing backfat thickness and meat color (Switonski et al., 2013).

Growth performance and carcass traits

The growth performance and carcass traits of Gascon pigs in extensive farming varied by season (Table 1). At slaughter, with high BW (> 170 kg) and age (> 400 d, i.e. 13 months), Autumn pigs tended to have higher BW than Winter and Spring pigs, and were slightly older than Spring pigs, which may be related to the higher BW and age of Autumn pigs at start of the experiment when animals were placed on rangelands. Average daily gain of Gascon pigs did not differ among seasons, and was generally low (mean of 465 g/d). Growth performance differed between farms, with F1 pigs having lower initial BW and age than F2 pigs, but higher average daily gain, most likely due to the larger mean amount of feed distributed on F1. It was not possible to harmonize these parameters better on the farms, which illustrates the diversity of practices within the NB chain. Autumn pigs tended to have a higher slaughter BW than Winter and Spring pigs but hot carcass weight did not differ among seasons. Autumn pigs had lower carcass dressing, which helps explain why their carcass weight was similar to those of the other groups, and indicates that their organs (e.g. gastrointestinal tract, liver, heart) weighed more. However, we were unable to record the weight of organs in our study. ZP muscle depth and backfat thickness did not differ among seasons, but Winter pigs had thicker backfat at the last rib level than Spring or Autumn pigs. The finishing season influenced carcass composition slightly, with a lower percentage of ham in Winter pigs than Spring or Autumn pigs, and a higher percentage of shoulder at the expense of belly in Autumn pigs than Winter or Spring pigs. Differences among groups remained small, however, with no more than one percentage point of difference among groups for each of these primary cuts. The percentages of backfat and loin did not differ among seasons.

Present data confirm the low growth performance and high carcass fatness of pigs from the pure Gascon breed produced in extensive conditions in the NB chain, in agreement with the literature (Sans et al., 1996; Labroue et al., 2000). Indeed, in the literature, average daily gain during the growing-finishing period ranges from 342 to 537 g/d, and mean ZP backfat thickness at slaughter (≥ 155 kg BW) ranges from 45 to 49 mm (review by Mercat et al., 2019). Low growth rate and high potential for fat deposition are generally observed in local pig breeds, such as the Gascon, that have not been selected for growth efficiency or carcass leanness (Bonneau and Lebret, 2010; Čandek-Potokar et al., 2019b). The significant, albeit moderate, effect of finishing season on carcass composition, with higher last rib backfat thickness and lower ham percentage for Winter pigs than Spring or Autumn pigs, is consistent with changes in body fat distribution towards external fat generally observed in finishing pigs as the ambient temperature decreases (Lebret, 2008).

Indicators of preslaughter handling and meat quality traits

At slaughter, the finishing season had no influence on plasma concentrations of cortisol (an indicator of preslaughter stress) or glucose, or the number of skin lesions (an indicator of aggressive behavior) (Table 2). In contrast, Autumn pigs had higher plasma concentrations of lactate (an indicator of anaerobic metabolism) and CK activity (an indicator of physical activity) than Winter or Spring pigs. Most of the meat quality traits assessed in the LM were influenced by the finishing season (Table 3). Autumn pigs had a lower pHi than Winter pigs, while Spring pigs had an intermediate pHi. LM pHu was lower in Winter pigs than Spring or Autumn pigs, although GP did not vary among them. Winter pigs had higher values of all color parameters than Spring or Autumn pigs. Spring pigs had slightly higher drip loss than Winter or Autumn pigs, but season did not influence loin cooking loss or shear force.

Despite the fasting duration of around 36 h, the levels of metabolic indicators such as plasma glucose concentration and GP in LM assessed in the present study were in the same range of values as found in pigs fastened for 21–23 h before slaughter (e.g. average values of 5.97 μmol/ml for plasma glucose and 140 μmol eq. lactate/g for GP of LM, assessed by the same methods, were reported by Lebret et al., 2011). This suggests that the quite long fasting duration in the present study should not have markedly influence results on meat quality traits. Overall, the results for cortisol and skin lesions indicate that the Gascon pigs in our study had similarly low levels of preslaughter stress. Autumn pigs' higher plasma lactate, higher CK and consistently lower pHi suggest that they had moderately higher preslaughter physical activity or stress than Winter or Spring pigs (Terlouw et al., 2008). The pHi remained high, however, which indicated no pale, soft and exsudative meat defect in the Gascon pigs, in agreement with the literature (Mercat et al., 2019). Accordingly, drip loss, which increases with the rate of decrease in *postmortem* pH in pork (Schäfer et al., 2002), remained low (less than 1.7%, on average). The lower LM pHu of Winter pigs, also found in the ham semimembranosus and *gluteus medius* muscles (Lebret et al., 2021), was not associated with higher GP, confirming that other muscle properties are involved in determining pHu, in agreement with similar findings in the LM of pigs of the local Basque breed (Lefaucheur and Lebret, 2020). The slightly lighter and less red (i.e. higher h°) color of loin from Winter pigs than Spring or Autumn pigs is in agreement with their lower pHu (Warriss, 2000). Most mean values of color parameters observed in our study confirm literature data (Sans et al., 1996; Labroue et al., 2000) and attest to the darker red color of Gascon pig meat, like that of many other local breeds, than that of selected breeds (Čandek-Potokar et al., 2019b). Despite a few differences in the rate and extent of the decrease in

Table 1
Growth performance and carcass traits of pigs by pig finishing season: Winter, Spring or Autumn.

	Finishing season[1]				
	Winter	Spring	Autumn	RMSE	*P*-value[2]
N	18	22	23		
Growth performance					
Initial live weight (kg)[3]	56.6[a]	55.1[a]	77.2[b]	10.49	S*** F***
Initial age (days)[3]	165[b]	157[a]	172[b]	10.38	S*** F*** M4* M5† M8*
Final live weight (kg)	171.6	171.4	183.1	17.05	S† M4†
Final age (days)	410[b]	401[a]	413[b]	11.74	S* F*** M4* M5* M8**
Average daily gain (g/day)	472	479	440	63.07	F*** M4** M7† M8†
Carcass traits					
Hot carcass weight (kg)	137.3	138.3	144.7	13.92	M4*
Dressing (%)	80.0[b]	80.7[b]	78.9[a]	1.42	S** M5*
Muscle depth (mm)[4]	70.8	73.8	70.2	5.42	HCW**
Backfat thickness (mm)[5]	46.1	44.6	44.8	5.92	HCW** M7*
Backfat thickness, last rib level (mm)	44.7[b]	39.8[a]	40.0[a]	5.03	S* HCW*** M4** M6* M7† M8†
Composition (%)[6]					
Ham	23.7[a]	24.3[b]	24.5[b]	0.78	S* HCW ** M4†
Loin	19.4	18.9	19.2	0.96	F† HCW ** M7* M8†
Shoulder	20.9[a]	21.3[a]	21.9[b]	0.71	S**
Belly	20.0[b]	19.8[b]	19.1[a]	0.82	S**
Backfat	14.4	14.1	13.8	1.48	HCW ** M4† M7* M8†

[a,b]Values within a row with different superscripts differ significantly at $P < 0.05$.
[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 all carcass traits), and RMSE obtained from the PROC MIXED procedure. ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.
[3] At the start of the growing-finishing period, upon arrival on rangelands.
[4] Minimal distance between vertebral channel and cranial end of *gluteus* muscle.
[5] Minimal fat thickness over the *gluteus* muscle.
[6] Percentage of right side.

Table 2
Plasma components and skin lesions at slaughter by pig finishing season: Winter, Spring or Autumn.

	Finishing season[1]				
	Winter	Spring	Autumn	RMSE	*P*-value[2]
N	18	22	23		
Plasma concentrations					
Cortisol (ng/ml)	86.5	87.0	97.9	29.83	F*
Glucose (μmol/ml)	5.53	5.74	6.09	0.06	F* M4† M8*
Lactate (μmol/ml)	8.63[a]	7.65[a]	14.71[b]	0.22	S***
Creatine kinase (U/ml)	1.24[a]	1.51[a]	2.57[b]	0.20	S*** M2* M3†
Skin lesions (n)	2.13	2.52	2.94	0.26	M6† M8*

[1] Least-square means estimated from raw data
[2] *P*-values of effects of finishing season (S), farm (F) and genetic markers (M1 to M8), and RMSE obtained from the PROC MIXED procedure applied to raw data (cortisol) or to log values to fit a normal distribution (glucose, lactate, creatine kinase, skin lesions). ***: $P < 0.001$, *: $P < 0.05$, †: $P < 0.10$.
[a,b] Values within a row with different superscripts differ significantly at $P < 0.05$.

Table 3
Meat quality traits of the *Longissimus* muscle by pig finishing season: Winter, Spring or Autumn.

	Finishing season[1]				
	Winter	Spring	Autumn	RMSE	*P*-value[2]
N	18	22	23		
pHi[3]	6.71[b]	6.57[ab]	6.48[a]	0.11	S*** F* M8†
pHu	5.53[a]	5.62[b]	5.65[b]	0.10	S** F** M1* M4**
Glycolytic potential (μmol eq. lactate/g)	147.0	142.5	150.2	20.73	F** M4*
Color					
Lightness (L*)	47.08[b]	44.13[a]	42.94[a]	2.06	S*** F** M4** M6** M8†
Redness (a*)	10.98[b]	9.69[a]	9.47[a]	1.39	S**
Yellowness (b*)	4.45[b]	3.72[a]	3.37[a]	0.69	S*** M1† M4**
Chroma (C*)	11.84[b]	10.39[a]	10.06[a]	1.50	S**
Hue angle (h°)	22.16[b]	21.05[a]	19.38[a]	2.26	S** F** M4** M6** M7**
Drip loss at 3 d p.m. (%)	1.40[a]	2.03[b]	1.60[a]	0.17	S** M4†
Cooking loss (%)	13.95	15.09	14.53	2.82	M4*
Shear force (N)[4]	24.36	22.94	25.62	8.00	F** M2* M3† M7†

[a,b]Values within a row with different superscripts differ significantly at $P < 0.05$.
[1] Least-square means estimated from raw data
[2] *P*-values of effects of finishing season (S), farm (F) and genetic markers (M1 to M8), and RMSE obtained from the PROC MIXED procedure applied to raw data (all parameters except drip loss) or to log values to fit a normal distribution (drip loss). ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.
[3] Time between exsanguination and muscle sampling was included as a covariate in the PROC MIXED procedure.
[4] Assessed on 1.13 cm^2 meat sections.

postmortem pH, which is known to influence mechanical tenderness (Warriss, 2000), meat shear force did not differ among seasons. Shear force remained moderate overall, with values closer to those found in the local Basque than in the selected Large White breed (Lebret et al., 2015), suggesting that meat from Gascon pigs had satisfactory tenderness. In addition to the influence of season, several differences were found between farms, with F1 pigs displaying lower plasma cortisol concentrations and lower pHu, associated with higher GP, L* and h° of meat, than F2 pigs. F2 pigs had lower meat shear force, which was contrary to the positive association often observed between tenderness and pHu when the latter ranges from 5.55 to 5.65. This result could be explained by other biochemical or structural muscle properties, such as myofiber diameter (reviewed by Listrat et al., 2016).

Muscle biochemical and metabolic properties

The finishing season influenced LM composition, with higher water content and slightly lower protein content in Autumn pigs than Winter pigs, while Spring pigs had intermediate values (Table 4). The season did not influence the myoglobin content, but Spring pigs tended to have lower IMF content than Winter or Autumn pigs. These slight variations in IMF content were independent of variations in carcass fatness among seasons. The mean IMF content in LM is in agreement with the IMF content of 2.6% found in Gascon pigs with the same BW and rearing conditions (Sans et al., 2004), while Labroue et al. (2000) reported an IMF content of 3.2% for 100 kg BW Gascon pigs reared indoors. Overall, the IMF content of Gascon pigs is higher than that of selected breeds, but lower than that of other local European breeds, which have IMF contents up to ca. 6.0% or even above e.g. in Nustrale, Alentejano, Iberico and Mangalica pigs (Pugliese and Sirtori, 2012; Čandek-Potokar et al., 2019b). The myoglobin content found in the LM agrees with 1.3 mg/g observed in this muscle by Sans et al. (2004). Red color differences among seasons were likely too small to be associated with significant differences in myoglobin content.

Metabolic enzyme activities in the LM showed only a trend for higher lactate dehydrogenase activity in Spring pigs than Autumn or Winter pigs, whereas β-hydroxy-acyl-CoA dehydrogenase and citrate synthase activities did not vary by season. These results, associated with the similar GP and myoglobin content in the three groups, indicate that finishing season had little influence on LM metabolic traits, despite the distinct differences in mean ambient temperature and its fluctuations. Since literature data show stimulated LM metabolism in pigs exposed to cold ambient temperature (12 °C vs. 23 °C), with higher GP and activities of glycolytic and oxidative enzymes (Faure et al., 2013), one could have expected greater differences in muscle metabolic traits among seasons. However, the literature reports smaller or even no significant effects of smaller temperature differences on LM metabolism (Lebret, 2008). In addition, the metabolism of the LM is less sensitive to variations in ambient temperature and/or physical activity than that of ham muscles involved in movement (Bee et al., 2004), which helps explain results of the present study.

The TBARS content in the LM at slaughter (i.e. $t = 0$ min) was similar in the three groups, but differed after induced chemical oxidation, with lower values for Autumn pigs than Spring or Winter pigs from 60 or 120 min onwards, respectively, with the Spring and Winter pigs having similar values. This suggests that the natural feeding resources available in autumn for Gascon pigs in an extensive system improves muscle antioxidant capacity (Ventanas et al., 2008; Pugliese and Sirtori, 2012), which is highly important for controlling lipid and protein oxidation processes during the ripening of pork products, especially dry-cured ham (Petrova et al., 2015). Overall, TBARS contents before (T0) and after induced chemical oxidation (T60 to T240 min) were lower in the LM of Gascon pigs than those determined in the LM of conventional Pietrain crossbreeds in the same laboratory using exactly the same technique (Lebret et al., 2018). This result suggests a low lipid oxidation potential of the muscles of Gascon pigs, which is favorable to their long processing time.

Fatty acid composition of backfat

The finishing season influenced the composition of backfat (Table 5 and Supplementary Table S4). Total lipid content was higher in Winter and Spring pigs than Autumn pigs. The percentages of saturated and monounsaturated FA (**MUFA**) were not influenced by the

Table 4
Biochemical and metabolic traits of the *Longissimus* muscle by pig finishing season: Winter, Spring or Autumn.

	Finishing season[1]				
	Winter	Spring	Autumn	RMSE	*P*-value[2]
N	18	22	23		
Biochemical composition (%)					
Water	73.14^{a}	73.56^{ab}	73.93^{b}	0.63	S** F*
Crude protein	23.63^{b}	22.80^{a}	22.78^{a}	0.58	S***
Myoglobin	0.12	0.12	0.12	0.02	
Lipids	2.68	2.31	2.66	0.53	S†
Metabolic enzyme activities (µmol substrate/min and per g)					
LDH[3]	2 026	2 163	2 017	192.84	S†
HAD[3]	4.03	3.55	3.76	0.85	
CS[3]	6.02	5.66	5.91	1.17	
Lipid oxidation: TBARS (µg MDA/g) as a function of incubation time[4]					
0 min	3.76	3.96	3.43	0.11	F* M2** M3**
60 min	6.37^{ab}	7.30^{b}	4.95^{a}	0.13	S** M2** M3**
120 min	12.18^{b}	15.03^{b}	8.44^{a}	0.19	S** M2†
180 min	19.56^{b}	21.04^{b}	12.89^{a}	0.15	S***
240 min	22.56^{b}	22.31^{b}	17.88^{a}	0.08	S** F† M5*

[a,b]Values within a row with different superscripts differ significantly at $P < 0.05$.
[1] Least-square means estimated from raw data
[2] *P*-values of effects of finishing season (S), farm (F) and genetic markers (M1 to M8), and RMSE obtained from the PROC MIXED procedure applied to raw data (water, crude protein, myoglobin, lipids, glycolytic potential, LDH, HAD, CS) or to log values to fit a normal distribution (TBARS at 0, 60, 120, 180, 240 min). ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.
[3] LDH: lactate dehydrogenase, HAD: β-hydroxy-acyl-Co-A dehydrogenase, CS: citrate synthase.
[4] TBARSs: thiobarbituric acid reactive substances

Table 5
Lipid content and fatty acid (FA) composition of backfat by pig finishing season: Winter, Spring or Autumn.

	Finishing season[1]				
	Winter	Spring	Autumn	RMSE	*P*-value[2]
N	18	22	23		
Lipid (%)	80.2[b]	80.4[b]	77.5[a]	2.55	S** F* M7** M8*
FA composition (% of identified FA)					
SFA[3]	39.3	39.5	40.0	1.14	M1* M2†
MUFA[3]	53.7	53.6	53.9	1.13	M1† M2* M3†
PUFA[3]	7.1[b]	6.8[b]	6.0[a]	0.50	S***
n-6	5.8[b]	5.5[b]	5.0[a]	0.42	S***
n-3	0.92[b]	0.96[b]	0.75[a]	0.09	S***
n-6:*n*-3	6.3[b]	5.8[a]	6.7[b]	0.49	S***
C18:2 *n*-6:C18:3 *n*-3	9.3[b]	8.4[a]	9.9[c]	0.50	S*** F† M1† M5† M6†

[a,b,c]Values within a row with different superscripts differ significantly at $P < 0.05$.
[1] Least-square means estimated from raw data
[2] *P*-values of effects of finishing season (S), farm (F) and genetic markers (M1 to M8), and RMSE obtained from the PROC MIXED procedure applied to raw data (lipid, SFA, MUFA, PUFA, *n*-6, *n*-6:*n*-3, C18:2 *n*-6:C18:3 *n*-3) or to log values to fit a normal distribution (*n*-3 FA). ***: $P < 0.001$, **: $P < 0.01$, *: $P < 0.05$, †: $P < 0.10$.
[3] SFA: Saturated, MUFA: Monounsaturated, PUFA: Polyunsaturated FA (detailed in Supplementary Material S1).

finishing season, while the percentages of total, *n*-6 and especially *n*-3 polyunsaturated fatty acid (**PUFA**) were higher for Winter and Spring pigs than Autumn pigs. Spring pigs had lower *n*-6:*n*-3 and C18:2:C18:3 ratios than Winter pigs and especially Autumn pigs. The overall results show that MUFAs, especially oleic acid C18:1 *n*-9 (Supplementary Table S4), are the predominant FA in the backfat of Gascon pigs, with a mean of 53.7% MUFA and 45.7% C18:1 *n*-9, and that PUFAs are in the minority (6.0–7.1%), which confirms previous data for this breed (Sans et al., 1996; Labroue et al., 2000). This also agrees with general findings that show high MUFA and low PUFA percentages in local fat pig breeds than in leaner selected breeds due to the well-documented increase in MUFA synthesis and deposition at the expense of exogenous PUFA as carcass fatness increases (Wood et al., 2008), as observed in the Iberian breed (Rey et al., 2006). The finishing season and associated differences in the availability of feeding resources in the extensive system influenced mainly the PUFA composition. The lower *n*-6:*n*-3 and C18:2:C18:3 ratios found in backfat and the *gluteus medius* muscle (Lebret et al., 2021) of Spring pigs confirm the positive influence of grassland, which is preferred during this season, on the lipid profile of backfat due to the high C18:3 *n*-3 content in grass (Rey et al., 2006; Pugliese and Sirtori, 2012). Analyses of grass samples collected in the grasslands during the three finishing seasons showed a high C18:3 *n*-3 percentage (i.e. 46.7–62.7% of identified FA, analyzed as described in Supplementary Material S1, detailed data not shown) and a low *n*-6:*n*-3 ratio (0.2–0.4). These results for backfat FA composition are favorable for the nutritional value of pork products, given the nutritional recommendations to increase *n*-3 FA intake (with C18:3 *n*-3 representing up to 1% of energy intake) and decrease the C18:2:C18:3 ratio to less than five in human diets (ANSES, 2011).

In contrast, one could have expected an increase in the backfat MUFA percentage, especially C18:1 *n*-9, in Autumn pigs, due to their consumption of acorns on rangelands. This assumption is based on the high C18:1 *n*-9 percentage in acorn lipids (up to 60% reported by Rey et al. (2006)) and even more on the high potential for FA synthesis from carbohydrates in the fat Gascon breed, since de novo lipogenesis leads mainly to accumulation of C18:1 in pigs (Wood et al., 2008). This was not the case in the present study, however, which differed from observations of Iberian pigs finished in a Montanera system and fed exclusively acorns and grass (Rey et al., 2006; Pugliese and Sirtori, 2012). This suggests that pigs in our experiment consumed few acorns, which can be explained by the low acorn production in the year the study was conducted, which highlights the impact of agro-climatic conditions on physiological responses and tissue properties of animals in extensive production systems.

Conclusion

Finishing season and feeding resources did not influence growth performance and had limited impacts on carcass composition of Gascon pigs in an extensive system. However, finishing pigs in this system during Spring or Autumn, compared to Winter, seem more favorable for certain pork quality traits (pHu, color). Besides, compared to Winter and especially Autumn, Spring finishing season and the associated feeding resources are favorable for the nutritional value of pork due to reduced *n*-6:*n*-3 PUFA ratio in backfat. However, this was associated to a greater LM oxidation potential in Spring and Winter pigs than Autumn pigs. Growth, carcass and meat quality traits of Gascon pigs also depended on the farm, but to a lesser extent than the finishing season. These results, associated with the influence of the finishing season and feeding resources on ham muscle properties and the sensory quality of dry-cured hams described in a companion article, provide useful information to actors in local pork chains (breeders, farmers) to optimize the quality of their products by modulating production and especially feeding practices.

Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2021.100240.

Ethics approval

Not applicable.

Data and model availability statement

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

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Declaration of interest

None.

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