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Effects of Field Pea Diet and Immunocastration in Heavy Pigs on Fresh Pork and Dry-Cured Ham

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Abstract: Peas are an alternative to soybeans to supply protein in livestock feeds. Immunocastration avoids surgical castration of male pigs and increases fat deposition in female pigs. This work aimed to assess the effects of pea inclusion on the amount of fat and fatty acid profile of loins and on weight losses of dry-cured hams in different sexes of pigs; in addition, growth performance and feeding behavior in immunocastrated female pigs were evaluated. Two experiments were conducted with crossbred immunocastrated female (IF) and immunocastrated (IM) or surgically castrated (CM) male pigs from Duroc dams sired by Berkshire, which were assigned to one of two diets (soybean vs. pea-based). The effect of castration type on the afore-mentioned variables was evaluated in male pigs, and the growth performance, and feeding behavior in female pigs. The pea-based diet in IF had no effect on average daily gain nor on carcass traits; although, it increased feeding time ($p < 0.001$) and reduced n-3 polyunsaturated fatty acid (PUFA) content ($p < 0.05$). In male pigs, the pea-based diet did not change carcass fatness either but reduced the n-3 PUFA levels ($p < 0.05$). Likewise, IM had lower ($p < 0.001$) monounsaturated fatty acid (MUFA) and higher ($p < 0.05$) n-6 PUFA than CM. Diet did not affect dry-cured ham weight losses during the process, while IM showed greater ($p < 0.001$) losses than CM. Pigs fed a pea-based diet complied with the requirements of cured ham production, while immunocastration in male pigs increased weight losses, partly explained by lower fat content and higher fatty acid unsaturation.

Keywords: feeding behavior; feedstuff; pulse crops; meat quality; castration

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1. Introduction

Consumers' purchasing intentions are determined by various quality aspects, such as animal welfare [1], health aspects (no antibiotics and hormone residues), and marbled boneless pork loin [2]. However, consumers in the Mediterranean region perceive traditional foods, such as dry-cured ham, as high-quality products [3]. Furthermore, most of the environmental impacts of pork production arise from feed production [4]. Still, to remain competitive in the globalized world, the sector must implement sustainable and viable solutions to their sourcing. Soybean meal is the most important protein source to feed farm animals worldwide [5]. Currently, there is a growing need to find regional alternative sources of protein for livestock diets, such as peas, which have been considered potentially useful feedstuffs for pig feeding [6]. However, their dietary inclusion requires complete knowledge to enable animals to maximize performance.

In heavy pig production, immunocastration is a good strategy to improve the fatness of female pigs destined for dry-cured ham elaboration [7]. Likewise, male pigs are surgically castrated to avoid boar taint (androstenone and skatole) in their meat and meat products. However, due to the foreseen ban on surgical castration without pain relief in the European

Union, raising uncastrated male pigs may become a predominant practice. An alternative to surgical castration is immunization against endogenous gonadotropin-releasing hormone (GnRH). GnRH antibody production causes suppression of the testicular function in male pigs and the ovarian cycle in female pigs. The impact of immunocastration on productive performance has been inconsistent. Studies have shown that immunocastrated male pigs have higher growth rates and better feed efficiency than surgically castrated male pigs during the entire fattening period [8]. Moreover, enhancing feed efficiency is an effective approach to minimizing the environmental impact of pork production [9]. On the other hand, impaired pork chemical composition was observed in IM from Duroc paternal lines compared to surgical castration [10], while similar carcass and meat quality were observed in IM and CM from Pietrain paternal lines [11]. In immunocastrated female pigs (IF), Daza et al. [12] did not note any differences in backfat thickness. However, in other studies, increased backfat thickness modified fatty acid (FA) profile [10] and reduced aggressive interaction compared to surgically castrated female pigs [13].

Some countries raise heavy pigs on a restricted feeding pattern. Their performance and feeding patterns may differ from those of immunocastrated on ad libitum feeding basis, which is the most common feeding system in Spain. Scientific knowledge on optimal management of immunocastrated heavy pigs from alternative fatty crossbreds (as those from Berkshire sires) is still limited. The effects of partial or complete replacement of all the soybean meal with field peas in diets of IF and IM on carcass performance, carcass quality, and pork FA composition, as well as the potential alteration of feeding patterns, have not been studied. In a companion paper, on-farm performances and feeding behavior were evaluated in male pigs but not in female pigs [14]. Hence, it would also be reasonable to study how feeding strategies would affect the performances and behavior of IF in order to disentangle potential explanatory variables of their fatness content and composition. Pea fiber has been shown to improve gastrointestinal function by regulating lipid and amino acid metabolism, microbiota, and short-chain FA production [15].

Therefore, the present study is divided into two trials, one with IF and the other with male pigs (CM and IM), from a crossbred of Duroc dams by Berkshire sire. All of them were fed ad libitum and sacrificed at heavyweight (140 kg), as were intended for dry-cured ham and cured sausages production. The main aim of these experiments was to evaluate the effect of dietary pea inclusion on FA content and composition of loins and weight losses of dry-cured hams in three sexual types (IF, IM, and CM). In addition, the effect of castration type in male pigs (surgical vs. immunocastration) on the afore-mentioned variables was evaluated.

2. Materials and Methods

Animal procedures followed Spanish regulations RD 53/2013 and EU Directive 2010/63. Protocols were supervised by the University of Lleida's Animal Experimentation Committee (CEE 05-06/21).

2.1. Experimental Designs

Two experiments were conducted: one with female pigs and another with male pigs. In experiment 1 (Exp. 1), the replacement of soybean meal with field peas during the growing-finishing period of immunocastrated heavy female pigs (IF) was assessed. Growth performances, animal behavior, carcass quality, amount of fat and FA composition of loins, and weight losses of dry-cured hams were evaluated. In experiment 2 (Exp. 2), in addition to dietary pea inclusion, the effect of castration type in male pigs (surgical, CM vs. immunocastration, IM) was evaluated during the same fattening period. In this case, as mentioned, the growth performances were shown in an earlier manuscript [14], and herein, only the amount of fat and FA composition of loins and weight losses of dry-cured hams are shown.

Not all measurements were conducted on all animals in the two experiments, Exp. 1 and Exp. 2. An overview of the number of animals used per measurement is given in Table 1.

Table 1. Overview of number of pigs or number of pens used per measurement.

	Experiment 1		**Experiment 2**			
	Immunocastrated Female (IF)		**Castrated Male (CM)**		**Immunocastrated Male (IM)**	
Item	**SBM**	**PS-L**	**SBM**	**PS-L**	**SBM**	**PS-L**
Pens (n)						
Pig performance	4	4	NA	NA	NA	NA
Behavior	4	4	NA	NA	NA	NA
Pigs (n)						
Carcass quality	15	15	41	41	41	41
Fat amount and quality	12	12	24	24	24	24
Weight losses of dry-cured hams	12	12	15	14	15	13

SBM: soybean meal; PS-L: field pea seeds-local; NA = not applicable.

2.2. Pig Husbandry and Diets (Exp. 1 and Exp. 2)

In Exp. 1, crossbreed female pigs (Duroc dam line × Berkshire sire line) were weighed individually at the start of the experiment, at 15 weeks of age, and with an average body weight (BW) of 46.3 ± 1.7 kg. Female pigs were immunocastrated with two subcutaneous injections (2 × 2 mL) of Vacsincel® (Zoetis, Zaventem, Belgium) at 20 and 24 weeks of age. They were randomly allocated in eight pens of 12.5 m^2 size, fully slatted floor, with 12 pigs per pen, according to weight and dietary treatments, until the slaughter weight was 140 kg. The pens were identical, and all presented a ball and a rope as enrichment material. The pens were divided by plastic panel fences, which did not allow the pigs to see each other. The environment inside the room was controlled by an automatic control system that regulated both temperature and ventilation. Each pen had two drinking bowls inside an automatic feed hopper.

In Exp. 2, the male pigs were of the same genetic type and housed in identical pens near female pigs. They were provided with the same amount of space but were fed individually through automatic stations. The CM pigs were surgically castrated during the first week of age, whereas the IM pigs were kept as entire male pigs until they reached 20 weeks of age. At this point, they were vaccinated with the first dose of the anti-GnRH vaccine, followed by another dose at 24 weeks of age, using the same procedures as described in Argemí-Armengol et al. [14].

In both experiments, two dietary treatments were formulated for each phase: grower (40–80 kg), early finisher (80–110 kg), and late finisher (110–140 kg), involving the control (outsourced soybean meal as the main amino acid source, SBM) and experimental diet (field pea seeds, Pisum sativum-locally grown, PS-L). The control and experimental diets used different proportions of commercial maize, barley, soybean meal, wheat and wheat bran, soybean oil, and dehydrated alfalfa pellets. Field white-flowering peas were grown close to the fattening farm (9 km away). The control diets (SBM) did not contain any peas and had soybean meal at 19%, 13%, and 11% for the grower, early finisher, and late finisher, respectively. These diets had the same nutritional profile as the commercial farm of this pig industry for this type of pig crossbred. The experimental diets (PS-L) gradually included peas at 25%, 30%, and 40% (grower, early finisher, and late-finisher), partially to completely replacing soybean meal. The level of inclusion of field peas was gradually increased to adapt to the pig digestive tract capacity to stand with potential dietary anti-nutritional factors. Accordingly, the trypsin inhibitor activity was previously analyzed and kept within safety limits [14]. Diets were formulated to be isonitrogenous, isoenergetic, and isoamino acidic for the first limiting indispensable amino acids (AA). Inclusions of crystalline Lys, Met, Thr, and Trp were used to balance the dietary AA profile. The determinations of gross

energy, dry matter, ash, starch, ether extract, neutral detergent fiber, crude protein (CP), and total AA of the diets are detailed in Argemí-Armengol et al. [14]. The FA's composition of the tested diets in the late finisher period (SBM and PS-L) was analyzed and quantified following the one-step procedure described by Sukhija & Palmquist [16] (Table 2).

Table 2. Fatty acid (FA) composition of the tested diets (%, as-fed basis) in both experiments (1 & 2).

FA, % Total	**Late Finisher (110–140 kg)**	
Field Peas:	**0% (SBM)**	**40%(PS-L)**
C10:0 capric	4.09	4.05
C12:0 lauric	2.77	2.43
C14:0 miristic	0.47	0.60
C14:1 miristoleic	0.10	0.11
C16:0 palmitic	19.43	19.62
C17:0 margaric	1.02	0.98
C18:0 stearic	3.29	3.26
C20:0 arachidic	1.38	1.36
C16:1n-9 palmitoleic	0.21	0.22
C16:1n-7 hexadecenoic	0.03	0.05
C17:1 heptadecanoic	0.92	1.08
C18:1n-9 oleic	23.17	23.12
C18:1n-7 vaccenic	1.11	1.16
C20:1n-9 eicosenoic	0.99	1.05
C18:2n-6 linoleic	37.73	37.61
C18:3n-6 γ-linolenic	0.05	0.06
C18:3n-3 α-linolenic	3.01	2.97
C18:4n-3 stearidonic	0.23	0.28

SBM: soybean meal; PS-L: field pea seeds-local.

2.3. Performance, Carcass Quality, and Behavioral Time-Budget of Immunocastrated Female Pigs (Exp. 1)

Female pigs were individually weighed at 16, 21, 26, and 31 weeks of age, which corresponded to the initial time of grower diet, early finisher, diet, late finisher diet, and prior to slaughter (after 20 h of fasting), respectively. These BW were used to calculate the average daily gain (ADG) in each phase, and the final BW and carcass weight were used to calculate the killing-out proportion at the slaughterhouse. The slaughtering process was carried out in a commercial abattoir located near the farm, which was about 9 km away. The pigs were transported to the abattoir between 7:00–8:00 AM using a truck that had a relatively flat loading ramp. Upon arrival, the animals were allowed to rest for about 4–5 h with full access to water but not to feed. The pigs were stunned by CO_2 at a concentration of 87%. After stunning, they were exsanguinated, scalded, skinned, eviscerated, and split down the midline according to standard commercial procedures. The hot carcass weight was recorded individually before the carcasses were cooled and refrigerated at 2 °C. The carcasses were graded based on their lean content with an automated image analysis system (VCS 2000, E + V Technology GmbH, Oranienburg, Germany). The backfat thickness was measured at the 3rd–4th last rib and over the Gluteus medius muscle at its thinnest point.

Behavioral activity patterns, social interactions, and abnormal behaviors were recorded on a farm using instantaneous scan sampling. This was done to observe the effect of dietary treatment [17–19]. Two trained observers did direct observations on four pens from the middle corridor (a total of eight pens) once a week. The observers stood outside the pen and scanned each pen for about four hours at ten-minute intervals. Before starting the observations, the observers entered the room and walked around for thirty minutes to let the pigs get used to their presence and to ensure that the animals did not pay attention to the observers. During each scan, the observers counted the number of pigs engaged in each activity and behavior based on a previously defined ethogram (Table 3). Thus, each observation day provided a total of 12 scans per pen. The pen observations were performed daily in the same recording order sequence. The behavioral data from the scan

samples was analyzed on a pen basis as a mean percentage of the scans in each category (activity or behavior) in relation to the total number of scans [19] per day. The experiment lasted for about three months, from early February to mid-May, ending when the outside temperature had reached 25 °C.

Table 3. Ethogram used in scan sampling recordings (adapted from Casal-plana et al. [17], Argemí-Armengol et al. [18] and Fàbrega et al. [19]).

Category	Definition
Behaviors	
Negative social interaction	Head or snout in aggressive contact with another pig, negative social behavior
Positive social interactions	Head or snout in mild contact with another pig, positive social behavior
Eat concentrate or drinking	Head or snout over a bowl or feed hopper
Interaction with the pen fixtures	Licking, chewing, nosing, or sniffing unanimated objects from the pen, excluding enrichment material
Inactive	The pig remains immobile, showing no other behavior
Activity	
Lying	The pig is recumbent on its belly or side
Sitting inactive	The pig is upright on two front legs and hindquarters (sitting in a dog position)
Standing inactive	The pig is upright on all four legs, neither moving forward nor backward
Walking	The pig is upright on all four legs and moves in the pen

2.4. Fat and Fatty Acid Analyses of Loin (Exp. 1 and Exp. 2)

At a 2-h post-mortem, the loins were removed from the carcass using standard abattoir procedures. The external fat was partially trimmed by a skilled staff to meet commercial requirements. Then, a 10-cm section of the caudal *Longissimus lumborum* was taken from each individual (approximately 500 g). Subsequently, samples were vacuum-packaged in plastic bags and ultra-frozen at a temperature of −80 °C until analysis of intramuscular fat (IMF) content and FA composition.

The number of meat samples of each treatment and sex is detailed in Table 1, which were chosen randomly. Meat samples were allowed to thaw for 24 h (at 4 °C) and subsequently were freeze-dried (Freeze-dryer gamma 2-16 LSCplus, Martin Christ, Osterode am Harz, Germany) to determine the IMF content and FA fatty acid profile. The thawed losses were calculated as 100× (pre-frozen chop weight − thawed chop weight)/pre-frozen chop weight. Meat moisture was determined by the difference between the post-frozen and freeze-dried weight. The total lipids were extracted and then analyzed for FA profile determination. A solvent mixture of dichloromethane-methanol 8:2 was added to lyophilized weighted samples (Lyoquest, Telstar, Terrassa, Spain) and after homogenization in a mixer mill (MM400, Retsch technology, Haan, Germany) and centrifugation (8 min at 10,000 rpm), the upper layer containing lipids were collected. The lipid content was quantified gravimetrically after evaporation of the solvent in a nitrogen stream. The FA methyl esters (FAMEs) were obtained by heating the lipids (80 °C for 1 h) in the presence of methanol:toluene: H_2SO_4 (88:10:2 by volume). After esterification, FAMEs were extracted with hexane and separated in a gas chromatograph (HP 6890 Series GC System; Hewlett Packard, Avondale, PA, USA) after direct injection of the sample. The gas chromatograph was provided with an automatic injector (held at 170 °C), a flame ionization detector (held at 250 °C), and a capillary column (HP-Innowax polyethylene glycol, 30 m × 0.316 mm × 0.25 m). After injection, the oven temperature was increased to 210 °C at a rate of 3.5 °C/min, then to 250 °C at a rate of 7 °C/min. Identification and quantification of the FAMEs were made by comparing the retention times with those of authentic standards (Sigma–Aldrich, Alcobendas, Spain). The percentages of total saturated FA (SFA), monounsaturated FA (MUFA), polyunsaturated FA (PUFA), the PUFA/SFA ratio, total n-3 and n-6 percentages, and the n-6/n-3 ratio were calculated from individual FA proportions.

2.5. Weight Losses of Dry-Cured Hams (Exp. 1 and Exp. 2)

A group of hams were randomly chosen as samples from IC, IM, and IF (Table 1). Weight losses of dry-cured hams from all treatments and sexes were calculated with weight at different time points of the curing process. At the slaughterhouse, the left hind leg was taken from each carcass. Upon arrival at the ham-curing facility (AUSA's factory, Prats de Lluçanès, Spain), hams were individually weighed. Next, the femoral artery of the hams was manually pressed to purge the blood residues and reduce the risk of spoilage later on. Afterwards, they were chilled for 24 h and then trimmed for 6 days. The phases of the dry-curing process were the following: (i) Salting: hams were manually rubbed with a mixture containing KNO3, NaNO2, sodium ascorbate, and NaCl, and then they were pile-salted at 3–5 °C and 80–90% relative humidity for 15 days. (ii) After salting: hams were washed with cold water to remove the excess salt before being stored, which were re-weighed. Mean ham weight loss after salting was then calculated. (iii) Curing: hams were hung in racks with hangers and stored at 14 °C and 75–80% relative humidity for around 16 months. The individual weight of each piece was recorded at the end of the process (around 17 months later).

2.6. Statistical Analysis

The data were analyzed with the JMP Pro 16 version, statistical software (SAS Institute, Cary, NC, USA). The pen was the experimental unit for the analyses of the growth performance and behavior of female pigs, whereas the pig was the experimental unit for the analyses of carcass, FA composition of loins, and drip-losses of dry-cured hams. In Exp. 1 dealing with IF, all the data were analyzed with a standard least square model, including a fixed effect of dietary treatment (except the behavioral data, which were analyzed with a non-parametric Wilcoxon test with the same fixed effect). In Exp. 2, dealing with male pigs, the data were analyzed with a standard model, including fixed effects, feeding strategy, methods of castration, and single interactions. The interaction between feeding strategy and methods of castration is not reported in the text as they were non-significant ($p > 0.05$) in any variable. Values are presented as least square means and standard error of the mean. The level of significance was set at 0.05.

3. Results and Discussion

Results are detailed and discussed conjointly for both experiments (1 & 2). However, in Exp. 1 involving female pigs run commercially, only the feeding strategy was compared, whereas in Exp. 2 involving male pigs, a comparison between feeding and sexual types was conducted.

3.1. Growth Performances and Animal Behavior in Immunocastrated Female Pigs (Exp. 1)

3.1.1. Growth and Carcass Performances in Female Pigs

The growth performance and the carcass quality of heavy IF are presented in Table 4. Reasonably, no significant differences ($p > 0.05$) were found in BW and ADG when IF pigs were fed with a pea-based diet (PS-L) as an alternative protein source of soy meal (SBM). Thereby, the performance data indicates that grower and finisher pigs can tolerate field peas at 40% inclusion, greater than the current feeding recommendations [20], which could reduce costs for the energy use of the feed processing industry [21]. In agreement with previous studies reported in other pig sexes [22–24], no differences may be expected if diets are balanced for NE and indispensable for AA (especially lysine, methionine, threonine, and tryptophan). In contrast, IM-heavy pigs that received the PS-L diet (40% pea), from 110 kg of BW onwards, had lower ADG than those receiving SBM (0% pea) [14]. The digestibility of peas and differences in the voluntary feed intake between sexes may have contributed to this variation in efficiency in the feed conversion rate. Measuring feed efficiency traits at several time points becomes important, particularly when differences in nutrient digestion could affect it. Thus, based on their metabolic features, differential nutrition programs may be suggested for IM and IF in this rustic genotype [25].

Table 4. Performance1 traits and carcass1 quality of immunocastrated female pigs according to feeding strategy.

	Feeding Strategy (F)		SEM	*p*-Value [1]
Parameter	**SBM**	**PS-L**		**F**
Body weight (BW), kg				
Initial, day (d) 0	45.5	47.1	1.70	ns
Grower diet (40–80 kg), d 49	78.0	78.3	2.76	ns
Early finisher diet (80–110 kg), d 80	103.5	99.0	1.97	ns
Late finisher diet (110–140 kg), d 116	137.0	140.0	3.06	ns
Average daily gain (ADG), g/day				
Grower diet (40–80 kg)	723	693	39.3	ns
Early finisher diet (80–110 kg)	807	762	21.0	ns
Late finisher diet (110–140 kg)	914	951	41.3	ns
Carcass quality				
Carcass weight (kg)	105.7	106.0	2.24	ns
Killing-out proportion (%)	72.5	74.5	0.95	ns
Subcutaneous fat of ham (mm)	24.4	23.3	1.88	ns
Back fat thickness (mm)	36.3	34.8	1.97	ns
Lean meat %	52.4	53.8	0.89	ns

[1] Values are presented as least square means and standard error of the mean (SEM). The level of significance was set at 0.05, but tendencies were commented on if the level of significance was below 0.10. ns = not significant ($p > 0.05$). SBM: soybean meal; PS-L: field pea seeds-local.

Likewise, the PS-L diet in IF did not affect carcass weight and killing-out proportion, which agrees with a range of studies [24,26]. Similarly, replacing 100% of soybean with pea did not lead to significant differences in the lean, subcutaneous fat thickness (mm), and backfat depth of the Gluteus medius muscle, in line with other works evaluating alternative protein sources [27,28]. Therefore, the PS-L diet ensured equal carcass traits and fatness in IF than the SBM-based diet, which evidenced that eventual anti-nutritional factors in field peas did not impair the female growth and fatness accretion.

3.1.2. Behavior and Activity in Female Pigs

The effects of dietary treatment on feeding behavior and activities are shown in Figure 1, where some of the parameters studied differed significantly. Firstly, IFs that ate the experimental diet (PS-L) were more time lying ($p < 0.05$) than their counterparts who received the control diet (SBM). However, we did not observe any other differences in their time-budget activities, such as walking, sitting inactive, or standing inactive. Considering the activity behaviors of pigs, they spent a great part of the day resting, which ensured their comfort [29]. It was also shown that the presence of peas in the feed had a significant effect on the eating behavior of fattening IF pigs, whose time spent eating was longer than those fed with soybean ($p < 0.001$), as corroborated by previous studies [30] also in male pigs experiment [14]. Furthermore, the negative social interaction between female pigs was lower in PS-L than in the SBM diet ($p < 0.001$), which would suggest that the more frequent and longer the time spent eating, the less aggressive behavior among IF. In this sense, pigs fed a high-fiber diet took longer to consume their daily feed, were less active, and engaged in less negative social interaction behavior [31]. The inclusion of field peas increased dietary fiber fractions in the feed (reported in Argemí-Armengol et al. [14]), which partly would explain the greater time devoted to eating and subsequent lying idling by these female pigs.

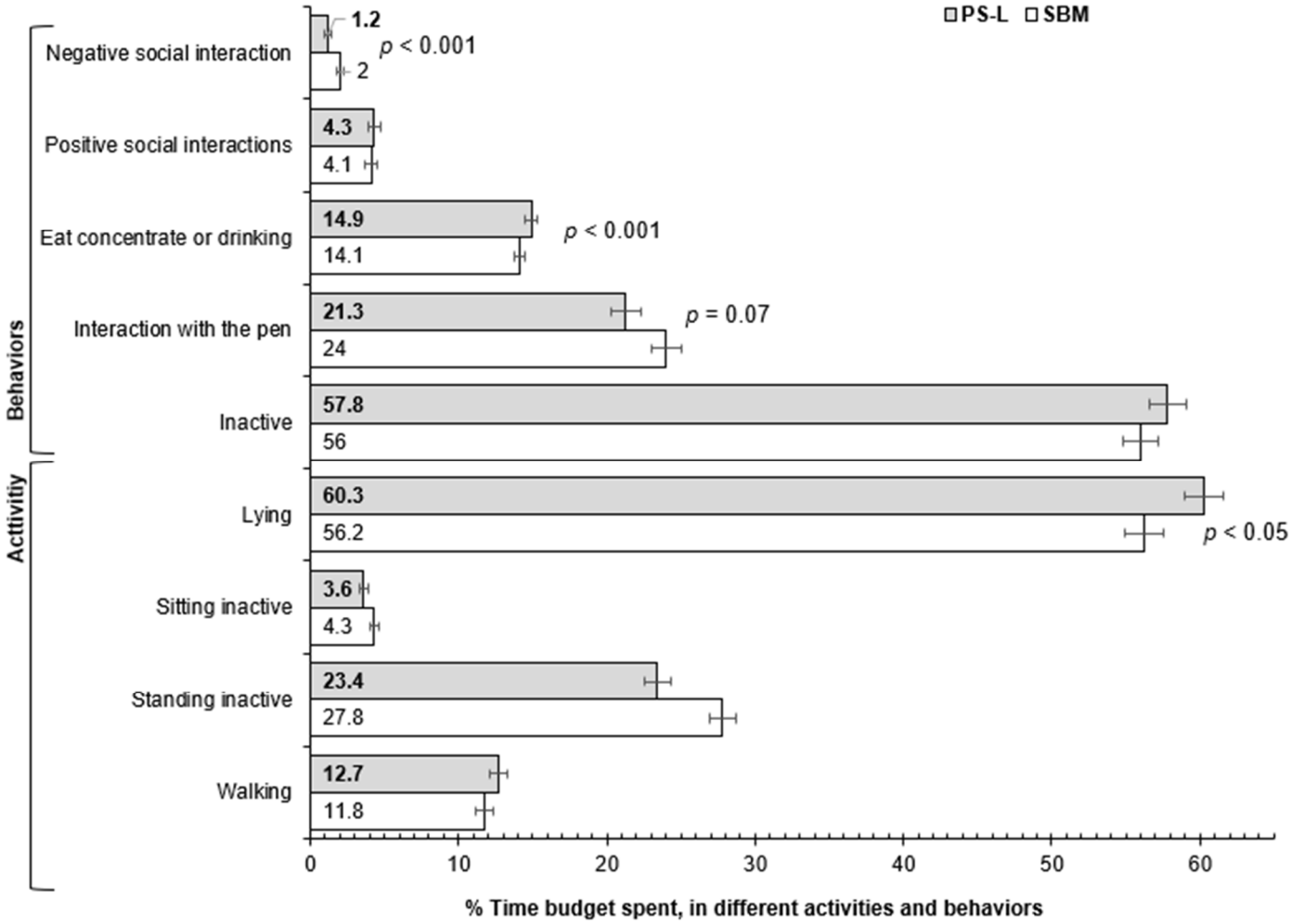

Figure 1. Time budget (%, proportion out of the 4-h recording period) in different activities and behaviors by scan sampling as affected by feeding treatment in immunocastrated females.

3.2. Fat and Fatty Acid of L. lumborum, and Dry-Cured Weight Processing Losses of IF (Exp. 1)

3.2.1. Fat Amount and Fatty Acids of *L. lumborum* in Immunocastrated Female Pigs

Table 5 presents the fat amount and the FA profile in *Longissimus lumborum* obtained from IF (Berkshire × Duroc). Regarding IMF, the feeding strategy (SBM vs. PS-L) did not contribute to its modification ($p > 0.05$). The resulting high IMF values in both treatments (between 5.2% and 5.4%) are attributed to genetic features of this sire line for adiposity [32]. Moreover, the Duroc breed and its crossbreds in the maternal line are also characterized by their high carcass and IMF content [33,34]. This leads to favorable outcomes in terms of consumer acceptance since the higher the IMF content (often referred to as marbling fat), the greater the tenderness and juiciness of the cooked meat [35]. Moreover, considering the subcutaneous backfat resulted in around 36 mm thickness, and the fat depot in the Gluteus medius muscle was above 25 mm thickness, these IFs would have a good potential to be processed for a long time dry-cured meat and ham [11,36].

Table 5. Effect of diet on amount fat and fatty acid profile (%) of intramuscular fat (IMF) from Longissimus lumborum of heavy female pigs.

	Feeding Strategy (F)		SEM	*p*-Value †
Item	**SBM**	**PS-L**		**F**
IMF (%)	5.4	5.2	0.3	ns
Fatty acid profile				
C14:0 myristic	1.54	1.54	0.030	ns
C15:0 pentadecanoic	0.03	0.02	0.001	ns
C16:0 palmitic	25.69	25.85	0.220	ns
C17:0 margaric	0.15	0.17	0.010	ns
C18:0 stearic	13.75	13.83	0.280	ns
C20:0 arachidic	0.17	0.19	0.004	**
C14:1n-5 myristoleic	0.09	0.09	0.010	ns
C16:1n-9 palmitoleic	0.08	0.11	0.005	***
C16:1n-7 hexadecenoic	3.32	3.3	0.100	ns
C17:1 heptadecanoic	0.17	0.23	0.030	ns
C18:1n-7 vaccenic	3.46	3.4	0.100	ns
C18:1n-9 oleic	41.9	42.2	0.310	ns
C20:1n-9 eicosenoic	0.63	0.68	0.020	ns
C24:1n-9 nervonic	0.03	0.05	0.004	**
C18:2n-6 linoleic	6.74	6.26	0.270	ns
C18:3n-3 α-linolenic	0.25	0.23	0.010	ns
C18:3n-6 γ-linolenic	0.02	0.02	0.001	ns
C18:4n-3 stearidonic	0.049	0.045	0.001	*
C20:2n-6 eicosadienoic	0.26	0.25	0.010	ns
C20:3n-6 dihomo- γ-linolenic	0.14	0.13	0.006	ns
C20:4n-6 arachidonic	1.04	0.99	0.070	ns
C20:5n-3 eicosapentaenoic	0.05	0.06	0.003	ns
C22:4n-6 adrenic	0.05	0.14	0.009	***
C22:5n-3 docosapentaenoic	0.17	0.16	0.009	ns
C22:6n-3 docosahexaenoic	0.16	0.05	0.010	***
ΣSFA	41.3	41.6	0.480	ns
ΣMUFA	49.7	50.1	0.400	ns
ΣPUFA	8.95	8.33	0.350	ns
Σn-6	8.11	7.66	0.320	ns
Σn-3	0.69	0.54	0.030	***
Σn-6/Σn-3	11.7	14.18	0.290	***

† Values are presented as least square means and standard error (SEM). The level of significance was set at 0.05. SBM: soybean meal; PS-L: field pea seeds local. ns = not significant ($p > 0.05$), * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. ∑SFA = C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0. ∑MUFA = C14:1n-5 + C16:1n-9 + C16:1n-7 + C17:1 + C18:1n-7 + C18:1n-9 + C20:1n-9 + C24:1n-9. ∑PUFA = C18:2n-6 + C18:3n-3 + C18:3n-6 + C18:4n-3 + C20:2n-6 + C20:3n-6 + C20:4n-6 + C20:5n-3 + C22:4n-6 + C22:5n-3 + C22:6n-3.

Furthermore, the larger the fat deposits, the higher the proportion of the novo synthesis acids (SFA and MUFA), and the lower the percentage of PUFA (provided only by dietary lipids) stored in adipose tissue [37]. Logically, in this trial, where these animals were slaughtered at heavy BW (140 kg), there was an increasing role for de novo tissue synthesis of SFA and MUFA and a relatively declining role for the direct incorporation of PUFA [38]. As expected, the isoamino acidic diets, with the same energy content and the diet FA profile (Table 2) (ΣPUFA, 41%; ΣSFA, 32%; and ΣMUFA; 27%), did not modify the concentration of total main FA groups in L. lumborum (Table 5) (ΣMUFA, 49,9%; ΣSFA, 41.5%; and ΣPUFA, 8.64%). Nonetheless, the type of diet affected the sum of n-3, n-6/n-3 ratio, and some individual FA proportions. Palmitic and stearic were found to be the major SFA (roughly 26% and 14% of total FA, respectively). Only a minor SFA was affected by the diet, with arachidic acid content being higher ($p < 0.01$) in pigs that consumed the PS-L diet compared to the SBM diet. Likewise, two n-9 PUFA, palmitoleic acid and nervonic acid, resulted in higher ($p < 0.01$) IF pigs that received PS-L diet, although they are not classed as essential FA. In contrast, n-3 PUFA content resulted in higher ($p < 0.05$) in the SBM diet than the PS-L

diet, owing to the greater docosahexaenoic acid (DHA) and stearidonic acid (SDA) content in IMF tissue. Long-chain n-3 is recommended in the human diet. DHA is a key component of cellular membranes and is essential for maintaining the structure and function of the brain, exerting mostly anti-inflammatory effects [39]. On the other hand, adrenic acid, which belongs to the n-6 family and is a very minor component in animal tissues [40], was lower ($p < 0.001$) in the SBM diet than in the PS-L diet. Consequently, the n-6/n-3 ratio was higher in the PS-L diet than in the SBM diet, which would result in less favorable for human nutritional reasons [41]. A lower ratio of n-6/n-3 is more desirable for reducing the risk of chronic diseases and heart diseases [42].

3.2.2. Dry-Cured Weight Processing Losses of Iminoacetate Female Pigs

Finally, the weight losses of hams during the dry and cured process of heavy IF are shown in Table 6. The initial weight of ham was very homogenous ($p > 0.05$) between female pigs that ate PS-L and SBM diets (range 12.8–12.5 kg). Regarding the weight loss at the end of salting, it was almost 4.2% in both diets ($p > 0.05$). The rate of weight loss is greater during salting, when the osmotic and hygroscopic effects of salt cover the entire thigh and remove water more easily from tissue [43]. During ripening, ham undergoes weight loss according to different humidity and temperature conditions. Large ham dry losses during dry-curing lead to a loss of marketable products, affecting ham quality [44], and from an economic point of view, both situations are undesired. In this trial, neither the final weight of ham (average of 8.8 kg) nor the dry losses (average 30.3%) in IF differed ($p > 0.05$) between diets. It was demonstrated that the whole of the hams from the experimental diet (PL-S) complied with dry-cured ham requirements due to good fatness and moderate weight loss. This agrees with the findings of Mordenti et al. [45], who concluded that dietary feeds without soybean may be used for heavy pig production for dry curing of hams. On average, total weight losses at the end of the curing process were below those observed in IF from the Protected Designated Origin "Teruel ham" (32.6%), reaching a similar final ham weight (8.91 kg) to the present study [36].

Table 6. Weights of hams after slaughtering and during the dry curing process of heavy female pigs.

	Feeding Strategy (F)		SEM	*p*-Value [1]
	SBM	PS-L		F
Length of curing, days	512	508	4.7	ns
Weights, kg				
Initial, cold ham before salting	12.8	12.5	0.19	ns
After salting (15 days)	12.3	11.9	0.19	ns
End of dry curing (17 months)	8.9	8.7	0.19	ns
Weight losses, %				
After salting [2]	4.1	4.5	0.33	ns
End of dry curing [2]	30.2	30.3	0.6	ns

[1] Values are presented as least square means and standard error (SEM). The level of significance was set at 0.05. ns = not significant ($p > 0.05$). SBM: soybean meal; PS: field pea seeds local. [2] Progressive weight losses as a percentage of ham cold weight.

3.3. Fat Amount and Fatty Acid of L. lumborum, and Dry-Cured Weight Processing Losses of Male Pigs (Exp. 2)

3.3.1. Effect of Feeding Strategy on Male Pigs

The only significant interaction between the type of castration and diet was observed for a minor PUFA n-6. In this case, IM fed the PS-L diet had higher adrenic acid than CM fed the same diet ($p < 0.05$, 0.2 vs. 0.15, respectively). This was in line with Exp. 1, in which the same experimental diet (PS-L) also increased the presence of this FA in pork in IF.

The backfat thickness and the subcutaneous fat of ham did not differ significantly between both diets (Table 7). The type of diet had no significant impact ($p > 0.05$) on the IMF content of *L. lumborum* either. This suggests that the fatty crossbred used (Duroc ×

Berkshire) could have mitigated the effect of diets on carcass and IMF content, as observed in other genetic types [7]. When comparing the results with those from Exp. 1, IF presented higher IMF, and the carcass fatness was thicker than IM in Exp. 2. Similarly, Seiquer et al. [46] concluded in Iberian pigs that IM had lower IMF content than those of CM and IF.

Table 7. Effect of diet and castration on amount fat on carcass and *L. lumborum* muscle of heavy male pigs.

	Feeding Strategy (F)		Method of Castration (C)		SEM	*p*-Value †		
	SBM	PS-L	IM	CM		F	C	FxC
Carcass								
Subcutaneous fat of ham, mm	23.8	21.7	21.2	24.3	0.93	ns	*	ns
Backfat thickness, mm	32.3	34.2	32.2	34.3	0.85	ns	ns	ns
L. lumborum								
Intramuscular fat, %	5.7	5.0	4.9	5.8	0.34	ns	ns	ns

† Values are presented as least square means and standard error of the mean (SEM). The level of significance was set at 0.05, but tendencies were commented if the level of significance was below 0.10. ns = not significant ($p > 0.05$), * = $p < 0.05$. SBM: soybean meal; PS-L: field pea seeds-local. IM = immunocastrated male, CM = surgically castrated male.

The feeding strategy in male pigs had no significant influence ($p > 0.05$) on total SFA and MUFA proportion in *L. lumborum* (Table 8). However, the loin from male pigs fed the SBM diet had higher PUFA and n-3 PUFA ($p < 0.001$), as well as a lower ratio of n-6/n-3 ($p < 0.001$) than pigs fed the PS-L diet. Opposite results were obtained in the study of Prandini et al. [26], where pigs were slaughtered at 127.5 and 158.5 kg BW and fed a diet containing peas, which had a higher n-3 content and lower n-6/n-3 ratio than the control diet with soybean. In that case, they used a lean crossbred and a diet with higher dietary energy (2550–2600 kcal NE/kg of feed) than the current commercial diets (2325 kcal NE/kg of feed), which may have provided higher dietary PUFA than in the current study. Most of the short and medium-chain SFA and MUFA are endogenously synthesized in pig adipocytes, which supports the finding that they were not affected by diet, whereas most of the PUFA are essential and must be supplied by diet [47]. In addition, the study by Prandini et al. [30] supplied a decreasing pea level (33% at 40–80 kg BW to 20% at 120–160 kg BW), which would decrease the eventual challenge of anti-nutritional factors because of using this ingredient. In both treatments, the main SFA produced from de novo synthesis were the palmitic (25.5%) and stearic (14%), which were hardly affected by dietary concentrations [35]. However, male pigs that ate the PS-L diet had greater ($p < 0.001$) myristoleic and nervonic acid proportion than those fed the control diet (SBM), which would confirm some MUFA increased as the percentage of SBM replacement increased, in line with the review by Parrini et al. [27].

PUFA resulted higher in pigs fed the SBM diet due to the higher linoleic (C18:2n-6) content and also minor unsaturated γ-linolenic acid ($p < 0.05$), α-linolenic acid ($p < 0.05$), eicosadienoic acid ($p < 0.05$), eicosapentaenoic acid (EPA, $p < 0.05$), and DHA ($p < 0.001$). Linoleic acid is a major feed ingredient in all species (in this experiment, around 37.5%), which passes through the pig's stomach unchanged and then is absorbed and incorporated into tissues [48]. Its proportion in pig adipose tissue and muscle is greater than other PUFA, which declines as fat deposition increases [35], resulting in an index of fatness. In a previous study dealing with performance traits in male pigs, IM consumed more feed daily at the late finisher period than CM [14] and could have increased the amount of fat amenable to change in the FA composition of muscle. As mentioned previously (in female pigs' trials), clinical human studies indicate that the ingested n-3 to n-6 FA ratio is important for maintaining cardiovascular health; nevertheless, they had to be consumed in a balanced proportion [42]. Consequently, the results show that the fresh loin IMF obtained from male pigs fed the PS-L diet has a worse FA composition compared with pigs fed the SBM diet.

Table 8. Effect of diet and type of castration on fatty acid profile (%) of intramuscular fat from *L. lumborum* of heavy male pigs.

	Feeding Strategy (F)		Method of Castration (C)		SEM	*p*-Value [1]		
	SBM	PS-L	IM	CM		F	C	FxC
Fatty acid profile								
C14:0 myristic	1.48	1.54	1.49	1.53	0.030	ns	ns	ns
C15:0 pentadecanoic	0.03	0.03	0.03	0.03	0.001	ns	ns	ns
C16:0 palmitic	25.35	25.50	25.35	25.50	0.200	ns	ns	ns
C17:0 margaric	0.18	0.20	0.19	0.19	0.008	ns	ns	ns
C18:0 stearic	13.79	13.84	14.27	13.37	0.240	ns	**	ns
C20:0 arachidic	0.18	0.19	0.19	0.18	0.003	ns	ns	ns
C14:1n-5 myristoleic	0.06	0.11	0.08	0.10	0.010	***	ns	ns
C16:1n-9 palmitoleic	0.12	0.13	0.14	0.11	0.007	ns	**	ns
C16:1n-7 hexadecenoic	3.11	3.29	3.09	3.32	0.085	ns	ns	ns
C17:1 heptadecanoic	0.26	0.25	0.25	0.26	0.030	ns	ns	ns
C18:1n-7 vaccenic	5.13	3.55	5.34	3.34	1.380	ns	ns	ns
C18:1n-9 oleic	39.05	41.28	38.29	42.04	1.335	ns	ns	ns
C20:1n-9 eicosenoic	0.68	0.68	0.68	0.68	0.020	ns	ns	ns
C24:1n-9 nervonic	0.03	0.04	0.04	0.04	0.003	***	ns	ns
C18:2n-6 linoleic	8.10	7.09	8.12	7.07	0.290	*	*	ns
C18:3n-3 α-linolenic	0.02	0.02	0.02	0.02	0.001	*	ns	ns
C18:3n-6 γ-linolenic	0.32	0.27	0.32	0.26	0.010	*	**	ns
C18:4n-3 stearidonic	0.05	0.04	0.04	0.05	0.001	ns	**	ns
C20:2n-6 eicosadienoic	0.33	0.29	0.34	0.28	0.010	*	**	ns
C20:3n-6 dihomo- γ-linolenic	0.15	0.15	0.15	0.14	0.008	ns	ns	ns
C20:4n-6 arachidonic	1.11	1.09	1.11	1.08	0.060	ns	ns	ns
C20:5n-3 eicosapentaenoic	0.07	0.06	0.07	0.06	0.003	*	ns	ns
C22:4n-6 adrenic	0.06	0.18	0.13	0.10	0.008	***	ns	*
C22:5n-3 docosapentaenoic	0.18	0.17	0.18	0.17	0.010	ns	ns	ns
C22:6n-3 docosahexaenoic	0.17	0.02	0.09	0.10	0.398	***	*	ns
ΣSFA	41.01	41.29	41.52	40.78	0.398	ns	ns	ns
ΣMUFA	48.44	49.34	47.91	49.88	0.360	ns	***	ns
ΣPUFA	10.55	9.37	10.58	9.34	0.383	*	*	ns
Σn-6	9.62	8.66	9.72	8.56	0.355	ns	*	ns
Σn-3	0.77	0.56	0.70	0.64	0.020	***	ns	ns
Σn-6/Σn-3	12.41	15.20	13.95	13.65	0.130	***	ns	ns

[1] Values are presented as least square means and standard error (SEM). The level of significance was set at 0.05, but tendencies were noted if the level of significance was below 0.10. ns = not significant ($p > 0.05$), * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$. SBM: soybean meal; PS-L: field pea seed-local. IM = immunocastrated male, CM = surgically castrated male. ∑SFA = C14:0 + C15:0 + C16:0 + C17:0 + C18:0 + C20:0. ∑MUFA = C14:1n-5 + C16:1n-9 + C16:1n-7 + C17:1 + C18:1n-7 + C18:1n-9 + C20:1n-9 + C24:1n-9. ∑PUFA = C18:2n-6 + C18:3n-3 + C18:3n-6 + C18:4n-3 + C20:2n-6 + C20:3n-6 + C20:4n-6 + C20:5n-3 + C22:4n-6 + C22:5n-3 + C22:6n-3.

Concerning processing weight losses of male pig hams, no differences ($p > 0.05$) between feeding strategies (SBM vs. PS-L) were found (Table 9). Therefore, the final ham weight over a 17-month seasoning period was not affected ($p > 0.05$), with a final value of around 8.5 kg. Although the comparison of hams between sexes was not the main objective of the study, since they were in different trials, the weight loss of dry-cured ham from male pigs (32.3%) was higher than that of female pigs (30.2%), reaching a higher final weight (8.8 kg). Moreover, considering that the subcutaneous fat of ham from pigs eating the experimental diet containing peas was like the amount in those from the control diet with soybean meal (21.7 vs. 23.8 mm, respectively), this alternative feeding strategy would guarantee an equivalent fat amount for the curing process.

Table 9. Weights of ham after slaughtering and during the dry curing process of heavy male pigs.

	Feeding Strategy (F)		Method of Castration (C)		SEM	*p*-Value [1]		
	SBM	PS-L	IM	CM		F	C	FxC
Length of curing, days	493	492	495	491	3.40	ns	ns	ns
Weights, kg								
Initial, cold ham before salting	12.2	12.6	12.6	12.3	0.20	ns	ns	ns
After salting (15 days)	11.7	12	12	11.7	0.19	ns	ns	ns
End of dry curing (17 months)	8.3	8.6	8.4	8.4	0.16	ns	ns	ns
Weight losses, %								
After salting [2]	4.8	4.7	5.0	4.5	0.13	ns	**	ns
End of dry curing [2]	32.5	32.1	33.6	31	0.5	ns	***	ns

[1] Values are presented as least square means and standard error (SEM). The level of significance was set at 0.05, but tendencies were noted if the level of significance was below 0.10. ns = not significant ($p > 0.05$), ** = $p < 0.01$, *** = $p < 0.001$. SBM: soybean meal; PS-L: field pea seeds-local. IM = immunocastrated male, CM = surgically castrated male. [2] Progressive weight losses as a percentage of ham cold weight.

3.3.2. Effect of Castration Method in Male Pigs

This study observed lower carcass fatness in IM than in CM, but the differences were attenuated in IMF, which was similar across groups (Table 7). The type of castration influenced the male growth rate since IM grew faster than CM [14]. However, Font-i-Furnols et al. [34] did not find differences in fat coverage over the Gluteus medius muscle among sexes in purebred Duroc sacrificed at 137 kg of BW. According to Bosi & Russo [49], backfat thickness must be sufficient to obtain retailed fresh hams, with fat cover ranging from 20 to 30 mm for a correct dry-curing process because it prevents an excessive drying of the pieces and improves organoleptic characteristics, which would be met in both groups of the current study. Also, in our study, IMF from IM seemed to have lower content only numerically (not significantly) than CM. Considering that Ruiz-Carrascal et al. [50] observed that IMF content has a stronger influence on some texture and appearance traits, such as positively affecting oiliness, brightness, juiciness, and marbling, and negatively related to dryness, fibrousness, and hardness, a reduction of IMF content due to male immunocastration would not be desirable. As this crossbred resulted in a high marbled meat (range 4.9–5.8% IMF in *L. lumborum*), it is expected that it would have a similar score for tenderness and juiciness in pork, without differences due to the method of castration.

Regarding fat composition, the method of castration succeeded in modifying the total MUFA ($p < 0.001$) and PUFA ($p < 0.05$), lower and higher in IM, respectively, than in CM (Table 8). Although castration did not affect total SFA, the content of stearic acid resulted in higher ($p < 0.01$) in the IM than CM, whose concentration is closely related to firmness/hardness [51]. Whilst the FA may influence tenderness and juiciness, these are more likely to be affected by the total amount of FA rather than individual proportions [51]. In this work, fat from IM had lower oleic acid content only numerically (not significantly) than from CM. It is worth noting that the lower total MUFA ($p < 0.001$) in IM could be partly attributed to the reduction of oleic acid (the major fatty acid), in agreement with earlier works of Font-i-Furnols et al. [52]. Oleic acid is formed from stearic acid by the enzyme stearoyl Co-A desaturase (a major lipogenic enzyme) and is a major component of neutral lipids and an important nutrient in human nutrition [5]. Moreover, this experiment confirms previous results by Gandemer [53] and Pérez-Ciria et al. [10], who observed the less developed the subcutaneous fat, the less the proportion of MUFA stored in the adipose tissue arising from novo synthesis. Accordingly, the subcutaneous fat of Gluteus medius resulted in thinner ($p < 0.05$), and the total MUFA content was lower ($p < 0.001$) in IM than in CM. Consequently, since the performance of IM pigs seems to differ from CM [14], their nutrient requirements could vary, and it has been proposed that IM may require higher dietary lysine levels than CM pigs to improve their cutting yields [54].

In this trial, the IMF of IM had greater ($p < 0.05$) total PUFA content and also n-6 content than CM, although n-3 content did not differ between the castration methods.

However, IM had a similar ($p > 0.05$) n-6/n-3 ratio to CM, in agreement with the findings of other authors [12,34,55]. This is probably because, after the second vaccination (week 26 of age), the average daily dietary intake in IM increased ($p = 0.06$) compared to CM [14] and, consequently, increased PUFA content, which is known to be directly related to feed intake. Differences in the level of PUFA are also related to changes in the rate of subcutaneous fat deposition [48], and our results confirm that IM had lower ($p < 0.05$) subcutaneous fat and higher PUFA content ($p < 0.05$) than CM. However, it is known that as the unsaturation level increases, the melting point declines [56]. Concomitantly, the susceptibility to faster lipid oxidation in dry-cured meat might be compromised [57]. Therefore, pork quality can be pursued by favoring high oleic acid content rather than PUFA content. In this study, the major PUFA in IMF was linoleic acid, which showed a higher concentration in IM than CM ($p < 0.05$) and also was the major dietary FA.

Regarding processing weight losses of male hams (Table 9), significant differences ($p < 0.01$) were found between the castration methods after salting and at the end of dry curing, which were higher in IM than CM, in agreement with the study by Pinna et al. [58]. In another study, no effects of the male castration method on ham weight losses were observed during the salting and curing process (on average, 32.0–33.6%, yielding a dry-cured ham of 9.2–9.4 kg after 19 months) [36]. Weight loss and related problems are well-recognized factors in the ham industry, with higher weight losses resulting in higher financial losses. This result can be attributed to the subcutaneous layer of fat covering the ham surface, which hinders the evaporation of water from the hams, which were thicker in CM than in IM [59]. Furthermore, FA composition can affect water migration and, consequently, the drying period, with a high level of linoleic acid being undesirable [60], which was higher in IM. According to Čandek-Potokar et al. [38], reduced subcutaneous backfat thickness has an impact on sensory quality defects in dry-cured ham. Thus, hams from CM were the most suitable raw hams for processing into traditional dry-cured products unless the ripening time is adapted to hams yielded from IM.

4. Conclusions

A pea-based diet would be a good alternative to soybean meal in IF, IM, and CM pigs, as it did not influence the ham processing weight losses. Furthermore, the present study indicates that the PS-L diet in female pigs had no effects on performance and carcass characteristics and improved their idling behavior and time devoted to eating. Nevertheless, both male and female pigs fed the diets with peas had less n-3 content in meat than those fed a SBM diet.

Immunocastration in male pigs modifies the FA composition of *L. lumborum* and increases the weight losses in dry-cured hams. Albeit SFA did not differ between castration methods, the MUFA was higher, and the PUFA was lower in CM. Even though the requirements of backfat thickness were fulfilled, overall weight losses of hams and FA composition of meat would suggest a better technological attitude for dry-curing pork of CM compared with IM.

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Data Availability Statement: Data are presented in tables and available upon reasonable request to the corresponding author.

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