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Wpływ utrzymywania tuczników w warunkach podwyższonego dobrostanu na zawartość kwasów tłuszczowych w mięsie wieprzowym

The effect of increased welfare conditions of fattening pigs on fatty acids content in pork meat

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Streszczenie

Powierzchnia chowu jest jednym z najważniejszych czynników wpływających na dobrostan tuczników. Celem niniejszego badania była ocena wpływu zwiększenia powierzchni przypadającej na tucznika na profil kwasów tłuszczowych w mięsie wieprzowym. W tym celu przeprowadzono trzy eksperymenty, w których wykorzystano odpowiednio 103, 78 i 78 świń. Każdy eksperyment obejmował trzy grupy o różnej powierzchni: grupę kontrolną z powierzchnią 1,0 m^2/świnię, która jest obecnie minimalną powierzchnią wymaganą przez Unię Europejską dla świń na tym etapie wzrostu, pierwszą grupę eksperymentalną z powierzchnią zwiększoną do 1,5 m^2/świnię oraz drugą grupę eksperymentalną z powierzchnią dwukrotnie większą, wynoszącą 2,0 m^2/świnię. Wszystkie świnie były hodowane w systemie wewnętrznym, intensywnym, na ściółce (pierwszy i trzeci eksperyment) lub na podłodze rusztowej (drugi eksperyment). Wszystkie świnie były karmione *ad libitum* mieszanką paszową na bazie zbóż. Z każdej grupy kontrolnej i eksperymentalnej (ze wszystkich eksperymentów) losowo wybrano czternaście tuczników (7 samic i 7 samców), co dało łącznie 42 osobniki na eksperyment. Skład kwasów tłuszczowych analizowano na podstawie próbek pobranych z mięśnia najdłuższego (*Musculus longissimus*) każdego wybranego osobnika. Wyniki wykazały, że zwiększenie powierzchni nie miało istotnego wpływu na skład kwasów tłuszczowych w mięsie wieprzowym. Tylko dwa parametry (C21:0 i C20:5n-3) z drugiego eksperymentu różniły się istotnie między grupą kontrolną a grupą eksperymentalną 2. Czynniki związane z płcią wydawały się mieć większy wpływ na profil kwasów tłuszczowych, dla kilku parametrów wykazano istotne statystycznie różnice między loszkami a wykastrowanymi samcami we wszystkich trzech eksperymentach. Analiza głównych składowych (PCA) wykazała, że na skład kwasów tłuszczowych może mieć większy wpływ czynnik genetyczny niż powierzchnia, płeć lub warunki środowiskowe. Wyliczenia przeprowadzone w celu oceny opłacalności ekonomicznej wskazały na spadek dochodów wraz ze wzrostem powierzchni przypadającej na zwierzę, ze względu na ograniczoną liczbę świń w kojcu. Dalsze badania powinny być przeprowadzone w celu zbadania możliwości wprowadzenia zmian mających na celu poprawę warunków dobrostanu świń przy jednoczesnym zachowaniu opłacalności produkcji.

Słowa kluczowe: kwasy tłuszczowe, poprawa warunków dobrostanu, gęstość obsady, świnie, praktyki hodowlane

Abstract

Space allowance is one of the most important factors while considering the welfare of fattening pigs. This study aimed to evaluate the effect of increased space allocation of fattening pigs on fatty acids profile in pork meat. In order to perform that, three experiments were conducted, using 103, 78 and 78 pigs, respectively. Each experiment involved three groups with different space allowances: the control group with 1.0 m^2/pig, which is the current minimum according to European Union space requirements for pigs at this growth stage, the first experimental group with space increased to 1.5 m^2/pig and the second experimental group with doubled space allowance, equalling 2.0 m^2/pig. The housing system of all pigs was indoor, intensive on litter (the first and third experiment) or slatted floor (the second experiment). All pigs were fed *ad libitum* with grain-based feed mixture. Fourteen fattening pigs (7 females and 7 males) were randomly selected from each control and experimental group (from all experiments), which resulted in a total of 42 individuals per experiment. Fatty acids composition was analysed using samples from *Musculus longissimus* taken from each selected individual. Results demonstrated that increasing space allocation had no significant effect on the fatty acid composition of pork. Only two parameters (C21:0 and C20:5n-3) from the second experiment differed significantly between control group and experimental group 2. Sex-related factors appeared to have a greater influence on the fatty acid profile, with several parameters differing significantly between gilts and castrated males in all three experiments. The Principal Component Analysis revealed there might be genetic-related component affecting fatty acid composition more that space allowance, gender or housing conditions itself. Calculations carried out to assess economic viability indicated a decrease in income as the space per animal increases, due to the limited number of pigs per pen. Further research should be conducted in order to examine the possibilities of implementing changes aimed at improving the welfare conditions of pigs, while maintaining the profitability of production.

Keywords: fatty acids, increased welfare conditions, stocking density, pigs, husbandry practices

Contents

1. Introduction

Meat is an important component in the human diet, but its consumption depends on current consumer preferences, which are constantly changing (Mustapa et al., 2025). At the moment, the second most often consumed type of meat in the world is pork, thus socio-economic changes are having a significant impact on its production. An increasing number of people are paying attention not only to the quantity and price of available meat, but also to its quality, including taste and sensory qualities and nutritional value (de Araújo et al., 2022). The above-mentioned characteristics can be influenced by many, often interacting factors (Olsson and Pickova, 2005). Among them, factors related to animal welfare can play an important role, which is also another element of livestock production that has received increasing attention recently. More and more consumers are preferring not to buy meat from intensive farms in favour of meat from more extensive, organic conditions (Millet et al., 2005). Furthermore, also on the scientific side, more and more positive aspects of keeping animals under improved welfare conditions are noted, which, in addition to directly improving the quality of their life, also affect fattening and slaughter traits.

One of the key components in the diet of animals, including pigs, are lipids. They are an important source of energy, as well as of fatty acids, which are necessary for the regulation of many physiological processes, gene expression or the maintenance of cell structure (Fanalli et al., 2022). The content and proportion of fatty acids in the pig's body play an important role in, among other things, the functioning of the digestive and immune systems. They influence inflammatory reactions, oxidative stress or epithelial barrier functions (Lauridsen, 2020). Certain fatty acids such as docosahexaenoic acid (DHA), oleic acid (OA), linoleic acid (LA) and eicosapentaenoic acid (EPA) are important factors in the regulation of transcription in many tissues, including brain, muscle and adipose tissue.

The fatty acid content of the pig's diet translates into its content in the meat (Fanalli et al., 2022). This, therefore, is of great importance in terms of the health benefits of pork for humans. In humans, as in other animals, fatty acids play an important role and are essential for the proper functioning of the body. Many of them cannot be synthesised by the human body on its own, so it must ingest them with food. This is why a balanced, complete diet containing all essential fatty acids is so important. Deficiencies of these acids, particularly n-6 linoleic acid and n-3 alpha-linolenic acid, can lead to many health problems. The proportions of consumption of the different fatty acid groups are also very important.

A diet rich in monounsaturated (MUFA) and polyunsaturated (PUFA) fatty acids supports, among other things, the prevention of cardiovascular diseases, whereas eating a lot of foods containing saturated fatty acids (SFA) or trans fatty acids may contribute to increasing the risk of such diseases. (Moghadasian and Shahidi, 2016).

For the reasons mentioned above, there are attempts to modify the fat content and fatty acid composition of food products, including pork. Efforts are being made to obtain animal products that meet the recommendations for a healthy diet in terms of reducing dietary fat intake, including saturated fatty acids, while increasing the intake of monounsaturated and polyunsaturated fatty acids (Jakobsen, 2000). There are many factors that influence the fat and fatty acid content of pork. Beside such factors as diet, there is an increasing amount of research on the effect of increased welfare on the fatty acid content of pork. Among others, the influence of factors such as housing conditions, environmental enrichments or foraging and pasture availability has been demonstrated (Ludwiczak et al., 2023). So far, no conclusive results have been obtained demonstrating the influence of space allowance, and this may also prove to be an important factor and, in addition, increase the comfort of the fattening pigs. Therefore, there is an indication for more research in this field.

2. Hypothesis of the study

It is hypothesized that increased welfare conditions, i.e. lower stocking density, of fattening pigs will affect the fatty acid profile in pork meat.

3. Aim of the study

This study aimed to evaluate the effect of increased welfare conditions of fattening pigs (lower stocking density) on fatty acids profile in pork meat. In order to perform that, the data on 126 fattening pigs from three breeds were collected in three experiments and analyzed.

4. Materials and methods

4.1. Animals

Three experiments were conducted in wielkopolska region in Poland to investigate whether the space allowance in fattening pigs has an effect on the fatty acid profile in pork meat. The three experiments were part of the *mEATquality* project, which aims to study the impact of increased welfare on animal production and promotes more sustainable meat production.

The first experiment included 103 commercial hybrid DanBred pigs, 42 gilts and 61 castrated male. Animals were randomly assigned to three groups - a control group with 47 (initially 48, one died during fattening) individuals and two experimental groups with 32 and 24 individuals. Their initial body weight was approximately 30 kg, fattening lasted 80 days from March to May (Spring). The pigs were slaughtered at approximately 123 kg. All animals received a cereal-based feed mixture, balanced according to their needs in two growing periods: the grower and the finisher. All pigs were fed *ad libitum*. The housing system for all groups was an intensive litter (straw) system. The area per fattening pig in the control group was 1.0 m^2 and in the experimental groups 1.5 m^2 and 2.0 m^2, respectively.

The second experiment included 78 crossbred (Polish Large White x Polish Landrace) x (Duroc x Pietrain) pigs, 34 gilts and 44 castrated male, randomly assigned to three groups. The control group (1.0 m^2/pig) included 30 individuals and groups with increased space per pig included 20 (1.5 m^2/pig) and 28 (initially 30, one died during fattening, one was lame therefore wasn't slaughtered) (2.0 m^2/pig) individuals. Their initial body weight was approximately 25 kg. They were slaughtered at approximately 108 kg, after 97 days of fattening from August to December (Autumn). The housing system for all groups was intensive on slatted floor. All animals were fed *ad libitum*, with grain-based feed mixture, which were balanced according to their needs in two growing periods: the grower and the finisher.

The third experiment included 78 Pulawska breed pigs, 39 gilts and 39 castrated males. They were randomly assigned to three groups – a control group (1.0 m^2/pig) included 23 individuals, and experimental groups included 28 (1.5 m^2/pig) and 27 (initially 28, one was isolated, therefore wasn't slaughtered) (2.0 m^2/pig) individuals. The fattening lasted 101 days from September to January (Autumn / Winter). The initial body weight of animals was approximately 35 kg, they were slaughtered at approximately 125 kg. The housing system for all groups was intensive on litter. All animals received grain-based feed mixture, divided into two growing periods: the grower and the finisher. The mixture was balanced according to animals' needs. In each period pigs were fed *ad libitum*.

Table 1. Breed, housing system and number of individuals in each experiment

	Breed	Housing system	N	N control group (1.0 m^2/pig)	N experimental group 1. (1.5 m^2/pig)	N experimental group 2. (2.0 m^2/pig)
Experiment 1	DanBred commercial hybrid	intensive on litter	103	47	32	24
Experiment 2	crossbred (Polish Large White x Polish Landrace) x (Duroc x Pietrain)	intensive on slatted floor	78	30	20	28
Experiment 3	Pulawska breed	intensive on litter	78	23	28	27

4.2. Slaughter

Fourteen fattening pigs (7 females and 7 males) were randomly selected from each control and experimental group (from all experiments), which resulted in a total of 42 individuals per experiment. The selected animals were slaughtered at a local professional slaughterhouse in Ptaszkowo, where they were stunned by electric shock and killed by exsanguination. Loins (*Musculus longissimus*) were taken from each individual and subjected to laboratory analysis.

The animals from experiment 1. were slaughtered on 22.05.2023, from experiment 2. on 04.12.2023 and from experiment 3. on 08.01.2024.

4.3. Laboratory analysis of fatty acid profile in meat

At the end of the experiment, data were collected on the content of individual fatty acids in the pork from three experiments. To prepare the Longissimus thoracis muscle samples for analysis, 450 mg of the muscle tissue was homogenized and transferred to a crew-cap Tefl on-stoppered tubes (Pyrex, 15 ml). Next, 1 ml of 2 M KOH (prepared in water) and 1 ml of 1 M KOH (prepared in methanol) were added to the sample. The samples were heated up to 95°C for 10 minutes, then allowed to cool at room temperature for another 10 minutes before a 10-minute sonication was applied. These treated samples in tubes were protected from light and stored overnight under nitrogen at 23°C. For further processing, hydrolyzed muscle samples underwent incubation in a block heater set to 90°C for 40 minutes. Afterward, the solution was vortexed and acidified with 4 M HCl until the pH dropped below 2.0. Fatty acids were extracted from the samples with diethyl ether in four cycles. Following extraction, the fatty acids were esterified with 0.5 M NaOH in methanol, then converted into fatty acid methyl esters (FAMEs) using boron trifluoride. For analysis, the samples were processed through a gas chromatograph (Varian Star CP 3800) fitted with a flame ionization detector and a 100-m fused silica capillary column (with an internal diameter of 0.25 mm and coated with 0.2 µm of CP-Sil 88). Hydrogen served as the carrier gas at a flow rate of 1.3 mL/min, while the injector and detector were maintained at 200°C and 250°C, respectively. The oven temperature started at 120°C for 7 minutes, then was raised to 140°C at a rate of 7°C per minute, held for 10 minutes, and finally increased to 240°C at a rate of 4°C per minute. Peaks were identified by comparing retention times with fatty acid methyl ester standards, and the final quantities of fatty acids were determined with an internal standard (tridecanoic acid) and calculated based on IS concentration and peak area, the results were expressed as mg/100 g of meat. Indices of thrombogenicity and atherogenicity were computed using specified fatty acid ratios, with the thrombogenicity index formula as:

$$IT = (C14:0 + C16:0 + C18:0)/[(0.5 \times \Sigma MUFA) + (0.5 \times \Sigma n-6\ PUFA) + (3 \times \Sigma n-3\ PUFA) + (n-3/n-6)]$$

and the atherogenicity index formula as:

$$AI = [C12:0 + (4 \times C14:0) + C16:0]/\Sigma UFA$$

The Δ-9 desaturation index was calculated as the ratio of total oleic to stearic acid.

4.4. Statistical analysis

The results obtained from the above experiments were statistically analyzed using R Studio. For this purpose, the analysis of variance (ANOVA) with interaction between sex and group of the animal (control, G1, G2) was used. ANOVA is a statistical test used to compare the means of three or more groups to determine if at least one differs significantly, showing whether observed differences occurred due to real effects or just random variation. Each of the three experiments was evaluated separately.

To visualize and further analyze obtained results, the Principal Component Analysis (PCA) was done, using PCA calculator from statskingdom.com. Principal Component Analysis (PCA) is a statistical method that reduces data dimensionality by transforming many variables into fewer principal components (PC) that capture the most variance. This simplifies complex data, highlighting key patterns and relationships while reducing noise and redundancy.

5. Results

5.1. Experiment 1.

Table 2 presents the statistical analysis of the effect of different space allowance and sex on the fatty acids content in pork meat of fattening pigs from the first experiment. In the first experiment, no statistically significant differences were observed between the groups. However, statistically significant differences were noted in 15 parameters between the sexes. For all of these parameters, the values were higher for gilts. These parameters were: C18:2c9c12 (linoleic acid), C20:0 (eicosanoic acid), C18:3c9c12c15 (alpha-linolenic acid), C20:1t, C21:0 (heneicosanoic acid), C20:2 (eicosadienoic acid), C20:4n-6 (arachidonic acid), C23:0 (tricosanoic acid), C22:2 (docosadienoic acid), C22:5n-3 (docosapentaenoic acid [DPA]), PUFA (polyunsaturated fatty acids), n-6 (omega-6 fatty acids), n-3 (omega-3 fatty acids), n-6PUFA, n-3PUFA.

Table 2. Mean and (SD) of fatty acid profile in experiment 1 with statistical analysis of the effect of experimental group (different space allowance) and sex of pigs.

Parameter	Experimental group				Sex			Group*Sex
	Exp1.G1	Exp1.G2	Exp1.CON	p-value	Gilts	Castrated males	p-value	p-value
C12:0	2.06 (1.13)	2.55 (1.71)	3.00 (2.84)	ns	2.65 (2.14)	2.39 (1.83)	ns	ns
C14:0	16.05 (4.75)	17.71 (4.90)	19.13 (8.56)	ns	17.50 (6.93)	17.70 (5.45)	ns	ns
C14:1	0.74 (0.43)	0.77 (0.40)	1.03 (0.97)	ns	0.83 (0.66)	0.85 (0.63)	ns	ns
C15:0	1.16 (0.29)	1.19 (0.69)	1.42 (0.98)	ns	1.36 (0.77)	1.13 (0.59)	ns	ns
C15:1	13.31 (3.70)	11.83 (6.71)	9.66 (3.20)	ns	12.72 (5.24)	10.48 (4.55)	ns	0.036
C16:0	321.23 (64.14)	363.50 (85.84)	311.01 (77.04)	ns	343.75 (80.25)	321.51 (75.96)	ns	ns
C16:1	36.84 (11.89)	38.95 (11.76)	33.41 (9.87)	ns	35.46 (10.49)	37.71 (12.13)	ns	ns
C17:1	8.48 (2.67)	7.34 (4.26)	5.91 (2.68)	ns	7.83 (3.68)	6.66 (3.07)	ns	ns
C18:0	173.69 (32.20)	206.12 (65.55)	168.49 (56.05)	ns	197.96 (62.30)	167.93 (41.24)	ns	ns
C18:1c9	461.46 (119.84)	519.41 (138.07)	436.79 (121.23)	ns	485.49 (124.79)	462.45 (135.43)	ns	ns
C18:1c11	47.50 (11.50)	49.68 (10.46)	43.32 (11.14)	ns	48.07 (10.81)	45.78 (11.51)	ns	ns
C18:2c9c12	177.71 (28.37)	170.89 (61.96)	143.93 (40.28)	ns	181.60 (46.53)	146.36 (42.15)	0.009	ns
C20:0	1.68 (0.54)	1.79 (0.99)	1.24 (0.46)	ns	1.86 (0.82)	1.28 (0.49)	0.006	ns
C18:3c9c12c15	9.78 (3.14)	10.00 (5.04)	8.84 (2.43)	ns	11.02 (4.42)	7.96 (1.72)	0.008	ns
C20:1t	2.05 (0.55)	2.70 (1.31)	2.57 (1.51)	ns	2.79 (1.51)	2.06 (0.51)	0.047	ns
C18:3n-6	7.74 (2.44)	7.97 (2.54)	7.04 (2.79)	ns	7.69 (2.63)	7.51 (2.53)	ns	ns
C21:0	4.29 (0.78)	4.05 (1.08)	3.64 (1.39)	ns	4.37 (1.19)	3.60 (0.87)	0.023	ns
C20:2	1.61 (0.61)	1.60 (0.83)	1.66 (0.86)	ns	1.88 (0.86)	1.34 (0.50)	0.025	ns

Table 2 cont. Mean and (SD) of fatty acid profile in experiment 1 with statistical analysis of the effect of experimental group (different space allowance) and sex of pigs.

Parameter	Experimental group				Sex			Group*Sex
	Exp1.G1	Exp1.G2	Exp1.CON	p-value	Gilts	Castrated males	p-value	p-value
C22:0	5.34 (1.35)	5.06 (2.35)	4.02 (1.59)	ns	5.33 (2.04)	4.28 (1.54)	ns	ns
C20:3n-6	41.73 (12.63)	38.40 (19.60)	29.38 (14.29)	ns	40.93 (18.29)	32.08 (12.88)	ns	ns
C22:1n-9	1.39 (0.42)	1.61 (0.84)	3.08 (5.99)	ns	2.69 (4.58)	1.22 (0.31)	ns	ns
C20:4n-6	0.64 (0.24)	0.53 (0.21)	0.57 (0.32)	ns	0.65 (0.26)	0.50 (0.24)	0.043	ns
C23:0	2.73 (0.86)	2.45 (1.24)	2.03 (0.73)	ns	2.71 (1.12)	2.09 (0.75)	0.035	ns
C22:2	0.66 (0.27)	0.67 (0.41)	0.61 (0.37)	ns	0.76 (0.41)	0.53 (0.21)	0.031	ns
C24:0	0.25 (0.29)	0.24 (0.17)	0.46 (0.48)	ns	0.35 (0.37)	0.26 (0.29)	ns	ns
C20:5n-3	5.21 (1.60)	5.18 (2.74)	3.88 (1.75)	ns	5.35 (2.49)	4.17 (1.56)	ns	ns
C24:1	0.61 (0.89)	0.49 (0.50)	1.15 (1.34)	ns	0.77 (1.04)	0.70 (0.92)	ns	ns
C22:5n-3	7.55 (2.24)	7.28 (3.78)	5.70 (2.17)	ns	7.72 (3.30)	5.96 (2.16)	0.041	ns
C22:6n-3	0.28 (0.26)	0.51 (0.41)	0.30 (0.26)	ns	0.40 (0.37)	0.34 (0.29)	ns	ns
SFA	532.06 (98.62)	608.38 (155.78)	517.83 (139.30)	ns	581.76 (149.18)	525.38 (118.42)	ns	ns
UFA	825.27 (143.56)	875.82 (178.81)	738.82 (168.04)	ns	854.66 (157.66)	774.66 (177.36)	ns	ns
MUFA	572.36 (140.31)	632.78 (157.42)	536.91 (141.02)	ns	596.66 (143.66)	567.91 (156.57)	ns	ns
PUFA	252.91 (44.70)	243.04 (89.66)	201.91 (57.65)	ns	258.00 (69.38)	206.76 (60.44)	0.01	ns
n-6	228.47 (40.24)	218.46 (79.90)	181.52 (53.04)	ns	231.62 (62.33)	186.98 (55.30)	0.012	ns
n-3	22.82 (4.46)	22.97 (9.26)	18.73 (4.70)	ns	24.49 (7.08)	18.44 (4.83)	0.002	ns
n-6/n-3	10.06 (0.83)	9.64 (0.73)	9.64 (1.02)	ns	9.53 (0.85)	10.06 (0.81)	ns	ns
n-6PUFA	228.47 (40.24)	218.46 (79.90)	181.52 (53.04)	ns	231.62 (62.33)	186.98 (55.30)	0.012	ns
n-3PUFA	22.82 (4.46)	22.97 (9.26)	18.73 (4.70)	ns	24.49 (7.08)	18.44 (4.83)	0.002	ns
LNA/LA	0.06 (0.02)	0.06 (0.02)	0.06 (0.02)	ns	0.06 (0.02)	0.06 (0.02)	ns	ns
Thrombogenicity index	1.09 (0.11)	1.18 (0.17)	1.21 (0.21)	ns	1.14 (0.21)	1.18 (0.11)	ns	ns
Atherogenicity index	0.68 (0.06)	0.73 (0.12)	0.76 (0.17)	ns	0.72 (0.15)	0.73 (0.09)	ns	ns

c – cis; t – trans; n – group position; FA – fatty acids; SFA – saturated fatty acids; UFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids

5.2. Experiment 2.

In table 3., the statistical outcomes of the second experiment are presented, showing the effects of different space allowance and sex on the fatty acids content in pork meat. The results of the second experiment indicated statistically significant differences between the groups for the two parameters analysed. The first of these is C21:0 (heneicosanoic acid), for which the level of statistical significance was 0.038. The mean value for the control group for this parameter was 0.62 (standard deviation = 0.47), for experimental group 1. it was 2.5 (SD = 3.15), and for experimental group 2. it was 4.19 (SD = 5.24). The post-hoc test (Tukey's test) indicated a statistically significant difference between the control group (1.0 m^2/pig) and experimental group 2. (2.0 m^2/pig), where the adjusted p-value between these groups was 0.029. Analysis of variance with interaction did not reveal any statistically significant differences for this parameter between sexes or for the interaction between group and sex.

The second parameter for which the analysis of variance showed a statistically significant difference between the groups was C20:5n-3, which is eicosapentaenoic acid (EPA), a long-chain omega-3 fatty acid. The level of statistical significance for this variable obtained in ANOVA was 0.028. The mean values for the groups were as follows: 4.33 for the control group (standard deviation = 0.56), 4.01 for experimental group 1. (SD = 0.44) and 3.74 for experimental group 2. (SD = 0.65). The post-hoc test result indicated a statistically significant difference between the control group (1.0 m^2/pig) and experimental group 2. (2.0 m^2/pig). The adjusted p-value was 0.021. The results of the analysis of variance with interaction did not show a statistically significant difference between the sexes, however for the interaction between the group and sex, the p-value was 0.04.

Figure 1. presents the results of Tukey’s test for parameters with a statistically significant difference between groups. The results are presented separately for each parameter. The columns indicate the differences in means between individual groups. Confidence intervals are marked, and comparisons between groups with statistically significant differences are marked with an asterisk (*).

In addition to results presented above, the analysis of variance with interaction showed statistically significant differences between sexes for the three parameters analysed. For all of them, the mean values were higher in males. These were: C14:1(myristoleic acid), Thrombogenicity index (a value that indicates the tendency to form clots in the blood vessels, based on the fatty acid composition) and Atherogenicity index (a biomarker that reflects the ratio of triglycerides and high density lipoprotein [HDL]).

Table 3. Mean and (SD) of fatty acid profile in experiment 2 with statistical analysis of the effect of experimental group (different space allowance) and sex of pigs.

Parameter	Experimental group				Sex			Group*Sex
	Exp.2 G1	Exp.2 G2	Exp.2 CON	p-value	Gilts	Castrated males	p-value	p-value
C12:0	2.93 (1.62)	3.22 (1.64)	3.42 (4.24)	ns	3.23 (3.65)	3.15 (1.38)	ns	ns
C14:0	25.45 (9.79)	25.58 (8.80)	27.44 (11.98)	ns	23.37 (6.42)	28.95 (12.25)	ns	ns
C14:1	0.71 (0.18)	0.79 (0.25)	0.67 (0.20)	ns	0.63 (0.13)	0.81 (0.24)	0.005	ns
C15:0	1.06 (0.18)	1.24 (0.29)	1.10 (0.23)	ns	1.07 (0.20)	1.19 (0.28)	ns	ns
C15:1	6.58 (1.03)	6.02 (2.25)	6.73 (1.85)	ns	6.46 (1.40)	6.42 (2.11)	ns	ns
C16:0	506.56 (193.03)	487.93 (159.25)	501.73 (185.19)	ns	457.55 (115.52)	539.92 (214.99)	ns	ns
C16:1	64.01 (23.96)	59.03 (20.66)	68.24 (27.81)	ns	58.98 (16.17)	68.55 (29.56)	ns	ns
C17:1	3.14 (0.77)	3.27 (1.31)	3.05 (0.69)	ns	3.19 (0.94)	3.11 (0.97)	ns	ns
C18:0	280.92 (104.10)	279.66 (87.18)	270.91 (83.70)	ns	255.18 (62.38)	299.15 (108.04)	ns	ns
C18:1c9	837.43 (365.20)	771.61 (301.64)	807.00 (331.27)	ns	760.84 (241.25)	849.85 (395.38)	ns	ns
C18:1c11	70.83 (22.75)	64.30 (19.48)	72.75 (20.43)	ns	68.21 (17.34)	70.38 (24.05)	ns	ns
C18:2c9c12	136.67 (36.01)	133.79 (35.16)	129.43 (27.54)	ns	132.00 (26.61)	134.60 (38.03)	ns	0.009
C20:0	1.23 (0.16)	1.15 (0.25)	1.67 (0.99)	ns	1.50 (0.81)	1.20 (0.30)	ns	ns
C18:3c9c12c15	10.09 (3.98)	9.91 (3.23)	9.67 (3.15)	ns	9.41 (2.96)	10.37 (3.79)	ns	ns
C20:1	4.42 (1.33)	4.61 (1.31)	4.34 (1.25)	ns	4.20 (1.13)	4.72 (1.37)	ns	ns
C18:3n-6	13.23 (5.90)	12.19 (4.65)	12.42 (4.87)	ns	11.73 (3.71)	13.50 (6.09)	ns	ns
C21:0	2.50 (3.15)A	4.19 (5.24)A	0.62 (0.47)B	0.038	1.72 (3.68)	3.16 (3.78)	ns	ns
C20:2	4.02 (1.75)	3.87 (1.45)	3.89 (1.14)	ns	3.91 (1.16)	3.94 (1.69)	ns	ns
C22:0	4.00 (0.59)	3.77 (0.78)	4.22 (0.47)	ns	4.05 (0.49)	3.93 (0.76)	ns	ns
C20:3n-6	24.81 (2.52)	23.63 (4.71)	26.05 (2.91)	ns	25.52 (3.09)	24.14 (3.94)	ns	ns
C22:1n-9	1.70 (0.69)	1.65 (0.50)	1.84 (1.14)	ns	1.60 (0.44)	1.86 (1.05)	ns	ns
C20:3n-3	1.88 (1.86)	1.6 (0.50)	1.87 (1.29)	ns	1.87 (1.61)	1.70 (0.96)	ns	ns
C20:4n-6	0.82 (0.52)	0.93 (0.49)	0.91 (0.70)	ns	0.81 (0.54)	0.96 (0.59)	ns	ns
C23:0	1.36 (0.27)	1.35 (0.32)	1.38 (0.29)	ns	1.36 (0.29)	1.37 (0.29)	ns	ns
C22:2	0.57 (0.18)	0.66 (0.20)	0.71 (0.38)	ns	0.59 (0.18)	0.70 (0.33)	ns	ns
C24:0	0.73 (0.25)	0.70 (0.17)	0.79 (0.35)	ns	0.70 (0.21)	0.78 (0.31)	ns	ns
C20:5n-3	4.01 (0.44)A	3.74 (0.65)A	4.33 (0.56)B	0.028	4.07 (0.39)	3.98 (0.75)	ns	0.04
C24:1	0.78 (0.29)	0.88 (0.13)	0.78 (0.31)	ns	0.74 (0.20)	0.89 (0.28)	ns	ns
C22:5n-3	4.18 (0.55)	4.10 (0.77)	4.51 (0.67)	ns	4.32 (0.52)	4.21 (0.81)	ns	ns
C22:6n-3	1.78 (0.98)	1.81 (0.87)	1.82 (1.05)	ns	1.80 (0.71)	1.80 (1.15)	ns	0.046
SFA	834.40 (309.71)	816.43 (255.07)	822.00 (281.59)	ns	757.25 (183.03)	891.31 (336.69)	ns	ns
UFA	1191.66 (453.01)	1108.39 (379.88)	1160.99 (412.37)	ns	1100.88 (300.06)	1206.49 (494.28)	ns	ns
MUFA	989.59 (411.97)	912.17 (340.79)	965.39 (378.69)	ns	904.85 (272.96)	1006.58 (448.64)	ns	ns
PUFA	202.07 (48.28)	196.22 (47.86)	195.61 (37.52)	ns	196.03 (34.98)	199.91 (52.01)	ns	0.01
n-6	176.10 (42.62)	171.19 (42.03)	169.52 (32.72)	ns	170.65 (30.73)	173.9 (45.73)	ns	0.01
n-3	21.95 (4.73)	21.16 (4.65)	22.20 (4.90)	ns	21.47 (3.82)	22.07 (5.46)	ns	0.039
n-6/n-3	8.04 (0.93)	8.06 (0.56)	7.74 (0.93)	ns	7.99 (0.78)	7.91 (0.87)	ns	ns
n-6PUFA	175.54 (42.65)	170.53 (41.99)	168.81 (32.70)	ns	170.05 (30.73)	173.2 (45.73)	ns	0.01
n-3PUFA	21.95 (4.73)	21.16 (4.65)	22.20 (4.90)	ns	21.47 (3.82)	22.07 (5.46)	ns	0.039

Table 3 cont. Mean and (SD) of fatty acid profile in experiment 2 with statistical analysis of the effect of experimental group (different space allowance) and sex of pigs.

Parameter	Experimental group				Sex			Group*Sex
	Exp1.G1	Exp1.G2	Exp1.CON	p-value	Gilts	Castrated males	p-value	p-value
LNA/LA	0.07 (0.01)	0.07 (0.01)	0.07 (0.01)	ns	0.07 (0.01)	0.08 (0.01)	ns	ns
Thrombogenicity index	1.26 (0.10)	1.32 (0.14)	1.26 (0.10)	ns	1.23 (0.10)	1.33 (0.11)	0.006	ns
Atherogenicity index	0.76 (0.07)	0.80 (0.08)	0.77 (0.06)	ns	0.74 (0.07)	0.8 (0.06)	0.007	ns

c – cis; t – trans; n – group position; FA – fatty acids; SFA – saturated fatty acids; UFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids

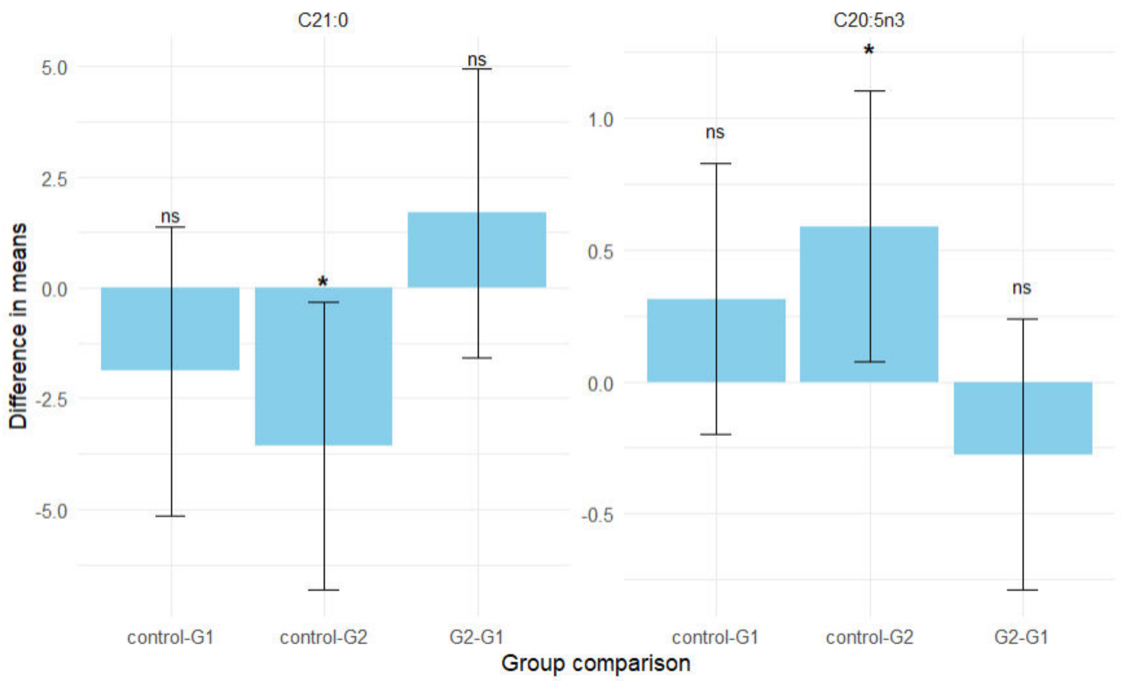

Figure 1. Post-hoc test (Tukey's test) results for parameters with statistically significant difference between the groups from the second experiment.

5.3. Experiment 3.

Table 4. shows the results of statistical analysis conducted in the third experiment, presenting the effect of varying space allowance and sex on the fatty acids content in pork meat. In the third experiment, no statistically significant differences between the groups were observed for any of the analysed parameters. However, the results of the analysis of variance

with interaction indicate the presence of statistically significant differences between the sexes for 6 parameters. For four of them, the mean values were higher for gilts. These were: C20:0 (eicosanoic acid), C22:2 (docosadienoic acid), C24:0 (lignoceric acid), C20:5n3 (eicosapentaenoic acid [EPA]). For two of them the mean values were higher for castrated males, and these parameters were: C16:1 (palmitoleic acid) and n6/n3.

Table 4. Mean and (SD) of fatty acid profile in experiment 3 with statistical analysis of the effect of experimental group (different space allowance) and sex of pigs.

Parameter	Experimental group				Sex			Group*Sex
	Exp.3 G1	**Exp.3 G2**	**Exp.3 CON**	**p-value**	**Gilts**	**Castrated males**	**p-value**	**p-value**
C12:0	3.72 (2.74)	8.66 (19.62)	2.50 (0.61)	ns	3.80 (2.24)	5.99 (15.99)	ns	ns
C14:0	18.02 (2.96)	21.41 (10.40)	19.90 (5.32)	ns	18.51 (4.55)	21.02 (8.52)	ns	0.031
C14:1	0.84 (0.37)	0.68 (0.18)	0.71 (0.27)	ns	0.79 (0.27)	0.70 (0.31)	ns	ns
C15:0	1.27 (0.65)	0.99 (0.39)	1.08 (0.52)	ns	1.26 (0.49)	0.96 (0.55)	ns	ns
C15:1	11.7 (2.01)	9.38 (2.93)	9.86 (3.52)	ns	10.78 (3.24)	9.88 (2.70)	ns	ns
C16:0	350.81 (47.13)	362.46 (97.57)	363.89 (85.98)	ns	344.05 (74.24)	374.63 (79.75)	ns	ns
C16:1	46.62 (8.40)	47.63 (18.21)	51.21 (11.45)	ns	44.60 (13.03)	52.61 (11.94)	0.045	ns
C17:1	2.68 (0.69)	2.86 (0.97)	2.95 (1.32)	ns	2.80 (1.03)	2.86 (1.02)	ns	ns
C18:0	203.50 (42.28)	201.53 (49.58)	203.01 (50.15)	ns	199.10 (44.65)	206.50 (48.68)	ns	ns
C18:1c9	590.11 (177.01)	619.34 (239.15)	549.68 (239.70)	ns	527.53 (221.13)	646.51 (198.78)	ns	ns
C18:2c9c12	125.58 (28.29)	118.33 (31.13)	111.99 (33.08)	ns	126.18 (33.11)	110.73 (26.35)	ns	ns
C20:0	1.41 (0.41)	1.14 (0.48)	1.32 (0.64)	ns	1.46 (0.62)	1.12 (0.32)	0.027	ns
C18:3c9c12c15	17.88 (13.50)	15.97 (14.31)	13.02 (3.51)	ns	18.26 (14.76)	12.84 (5.10)	ns	ns
C20:1t	4.09 (1.58)	4.21 (1.86)	3.39 (0.97)	ns	4.18 (1.71)	3.59 (1.24)	ns	ns
C18:3n-6	12.86 (8.42)	11.37 (4.74)	9.92 (2.19)	ns	11.43 (7.19)	11.34 (3.83)	ns	ns
C21:0	5.11 (5.50)	7.23 (11.37)	6.79 (8.30)	ns	6.21 (9.04)	6.51 (8.08)	ns	ns
C20:2	2.84 (1.10)	2.51 (0.73)	2.23 (0.58)	ns	2.65 (0.99)	2.41 (0.67)	ns	ns
C22:0	4.13 (0.84)	3.42 (1.34)	3.82 (1.28)	ns	4.13 (1.21)	3.45 (1.06)	ns	ns
C20:3n-6	26.19 (3.98)	21.25 (7.58)	23.79 (7.66)	ns	25.32 (7.24)	22.21 (5.96)	ns	ns
C22:1n-9	0.93 (0.87)	0.63 (0.37)	0.73 (0.31)	ns	0.76 (0.75)	0.78 (0.34)	ns	ns
C20:3n3	0.65 (0.55)	0.48 (0.43)	0.57 (0.43)	ns	0.58 (0.50)	0.56 (0.45)	ns	ns
C20:4n6	1.45 (1.83)	1.22 (1.24)	0.69 (0.27)	ns	1.31 (1.69)	0.92 (0.67)	ns	ns
C23:0	0.97 (0.29)	0.73 (0.24)	0.85 (0.28)	ns	0.92 (0.32)	0.78 (0.22)	ns	ns
C22:2	0.96 (0.82)	0.71 (0.35)	0.71 (0.33)	ns	1.00 (0.66)	0.58 (0.29)	0.01	ns
C24:0	0.41 (0.48)	0.25 (0.13)	0.17 (0.10)	ns	0.37 (0.40)	0.18 (0.08)	0.029	ns
C20:5n-3	5.17 (0.74)	4.75 (1.21)	5.16 (2.39)	ns	5.65 (1.78)	4.39 (1.05)	0.01	ns
C24:1	0.98 (0.54)	1.04 (0.69)	0.70 (0.25)	ns	1.05 (0.57)	0.75 (0.45)	ns	ns
C22:5n-3	3.83 (0.84)	3.06 (1.14)	3.72 (1.57)	ns	3.83 (1.47)	3.25 (0.89)	ns	ns
C22:6n-3	3.02 (3.02)	1.36 (0.70)	2.24 (3.17)	ns	2.59 (3.15)	1.85 (1.91)	ns	ns
SFA	721.74 (115.76)	753.11 (147.24)	729.97 (169.34)	ns	733.03 (140.26)	736.04 (148.79)	ns	ns

Table 4 cont. Mean and (SD) of fatty acid profile in experiment 3 with statistical analysis of the effect of experimental group (different space allowance) and sex of pigs.

Parameter	Experimental group				Sex			Group*Sex
	Exp.3 G1	Exp.3 G2	Exp.3 CON	p-value	Gilts	Castrated males	p-value	p-value
UFA	815.95 (192.59)	833.22 (239.72)	759.98 (240.00)	ns	750.02 (220.80)	857.22 (213.73)	ns	ns
MUFA	656.42 (177.83)	683.43 (249.06)	618.69 (240.45)	ns	590.91 (218.97)	716.35 (207.18)	ns	ns
PUFA	159.53 (38.61)	149.80 (45.04)	141.28 (35.81)	ns	159.12 (46.03)	140.87 (29.85)	ns	ns
n-6	133.00 (28.59)	127.18 (38.52)	120.53 (31.80)	ns	134.44 (37.20)	118.97 (25.70)	ns	ns
n-3	30.56 (17.12)	25.61 (14.21)	24.70 (8.52)	ns	30.90 (16.95)	22.89 (7.43)	ns	ns
n-6/n-3	4.89 (1.29)	5.30 (0.75)	5.01 (0.77)	ns	4.75 (0.94)	5.38 (0.91)	0.038	ns
n-6PUFA	133.00 (28.59)	127.18 (38.52)	120.53 (31.80)	ns	134.44 (37.20)	118.97 (25.70)	ns	ns
n-3PUFA	9.54 (6.15)	7.83 (3.87)	7.02 (3.47)	ns	9.12 (5.52)	7.11 (3.43)	ns	ns
LNA/LA	0.03 (0.01)	0.04 (0.01)	0.03 (0.01)	ns	0.03 (0.01)	0.03 (0.01)	ns	ns
Thrombogenicity index	1.48 (0.73)	1.46 (0.63)	1.73 (1.08)	ns	1.68 (1.06)	1.44 (0.49)	ns	ns
Atherogenicity index	0.87 (0.47)	0.86 (0.40)	1.02 (0.70)	ns	1 (0.68)	0.83 (0.32)	ns	ns

c – cis; t – trans; n – group position; FA – fatty acids; SFA – saturated fatty acids; UFA – unsaturated fatty acids; MUFA – monounsaturated fatty acids; PUFA – polyunsaturated fatty acids

5.4. Principal Component Analysis

Principal Component Analysis visualized obtained results and allowed further analysis.

Figures 2, 3, and 4 present the differences between the groups from experiments 1, 2, and 3, respectively. All charts show that the data overlap and do not form clearly separated groups. This indicates that there are no clear differences between the individual groups.

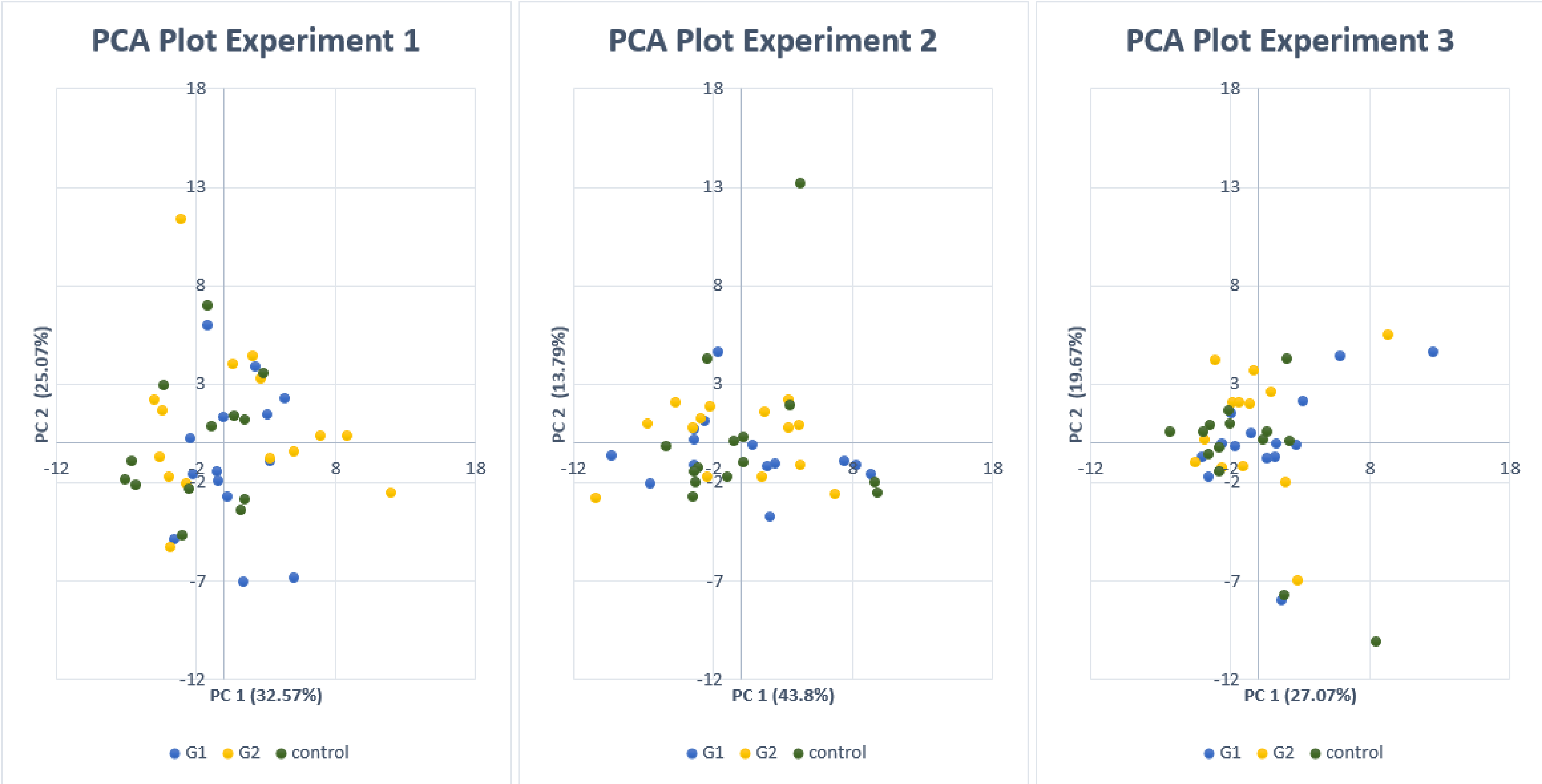

Figure 2. PCA plot showing the differences in FA profile between experimental groups in three studied experiments.

Figures 5, 6, and 7 contain compiled data from all three experiments. The first plot presents a general comparison of all data from the three experiments. This chart shows the relatively largest differences between the three data groups presented, suggesting differences between the experiments. The second plot presents a comparison of data between experimental groups. As in the plots comparing data between groups for individual experiments, here too, overlapping data can be observed, indicating no significant differences between groups. The third plot shows a comparison of data for gender from all experiments combined. Some of the data in this chart diverges slightly, but most of it is concentrated in one place, which may suggest slight differences between sexes.

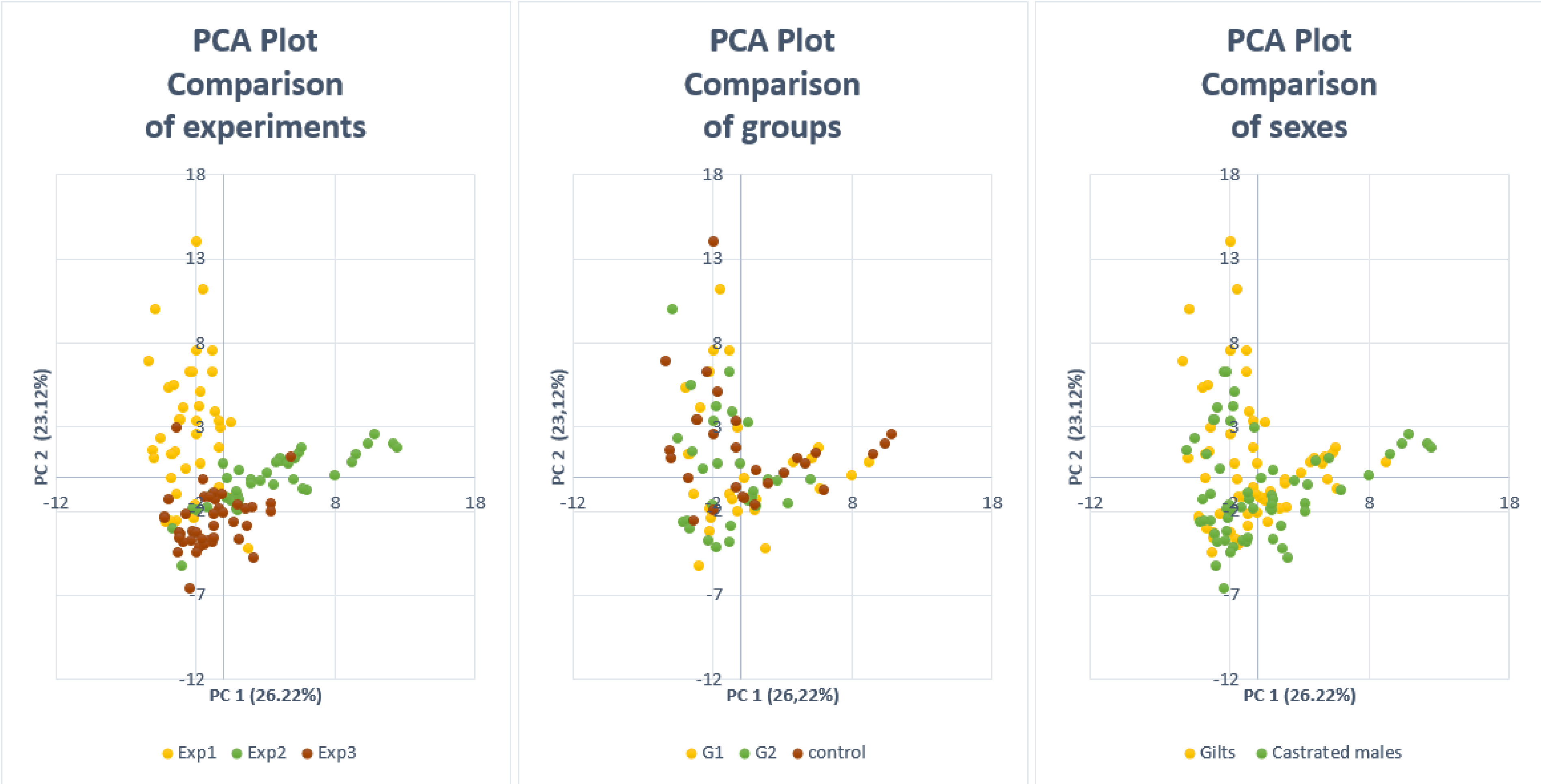

Figure 3. PCA plot showing the differences in FA profile within full dataset (all three experiments jointly) between: 1) experiments, 2) experimental groups, 3) sexes.

6. Discussion

6.1. Fatty acids profile

The fatty acid content of meat is an important factor in human and animal nutrition. In humans, dietary fatty acids influence lipid metabolism, cardiovascular health, and the risk of chronic diseases (Jakobsen, 2000; Micha et al., 2010). In pigs as well, they're one of the key components of diet, affecting the regulation of many physiological processes, directly influencing animals' health (Fanalli et al., 2022). In addition, fatty acid profile determine the technological quality and nutritional value of pork (Wood et al., 2008). Consequently, fatty acid composition is a very important parameter in studies evaluating the impact of various factors on meat quality. Among these factors, diet is consistently reported as the most important determinant of the fatty acid profile, with housing conditions and space allowance playing a more limited role (Jørgensen et al., 2000; Ludwiczak et al., 2023).

In the present thesis, three independent experiments were conducted to investigate whether increased space allocation (1.0 m^2, 1.5 m^2 or 2.0 m^2 per pig) affects the fatty acid composition of pork. The experiments differed in breed and housing system: first experiment involved DanBred commercial hybrid with housing system intensive on litter (N = 103), second experiment included crossbred (Polish Large White × Polish Landrace) × (Duroc × Pietrain) with housing system intensive on slatted floor (N = 78), while in the third experiment was Pulawska breed with housing system intensive on litter (N = 78). All animals were fed *ad libitum* with grain-based feed mixture. Across the three experiments, no significant differences were observed between space allowance groups, except for two fatty acids (C21:0 and C20:5n-3) in experiment 2, where a difference between the control and the 2.0 m^2 group (G2) was confirmed by post-hoc test (Tukey's test). In contrast, several sex-related differences were found: 15 parameters in experiment 1 (higher in gilts), 3 in experiment 2 (higher in castrated males), and 6 in experiment 3 (mixed direction). PCA analysis within each experiment showed no clear differences between experimental groups, but comparisons across experiments revealed larger variation, suggesting that breed and housing system exerted a stronger influence than space allowance. Interestingly, variability was highest in experiments 1 and 2, whereas the local Pulawska breed in experiment 3 showed more homogeneity. This may suggest that genetic-related factors have a greater effect than environmental conditions in this case. Taken together, these results indicate that space allocation had little effect on the fatty acid composition of pork under the tested conditions, whereas sex, genotype, and environment were more influential.

These findings are consistent with previous studies. Nannoni et al. (2019), who evaluated the growth parameters, carcass and meat quality, as well as the behaviour of heavy pigs, found that increasing space allowance (1.3 m^2 compared to 1.0 m^2 per pig) improved animal welfare and sensory evaluation of ham but did not alter the composition of fatty acids or other main meat quality features and carcass traits. Similarly, Serrano et al. (2013), who investigated the effect of space allocation (0.84 and 0.76 m^2/pig), gender and their interaction on growth performance and carcass and meat quality of pigs, found no significant differences between individuals kept on different space allowance, except for MUFA and SFA. However, in the same study, the results indicated differences in several parameters (linoleic acid, SFA, MUFA) between the sexes. This observation is consistent with the results obtained by Razmaitė et al. (2021) and Xia et al. (2023), who indicate a significant influence of sex on the fatty acid profile. Besides that, several studies have indicated differences in fatty acid content depending on breed, emphasizing the role of genetics. Ludwiczak et al. (2023) suggests that local breeds differ from commercial breeds in terms of PUFA, MUFA and SFA content. This is supported by studies conducted, among others, by Aboagye et al. (2020), Franco et al. (2014), Serra et al. (1998). Finally, diet remains the single most influential factor shaping fatty acid composition in pork. Ludwiczak et al. (2023) suggest that the fatty acid profile is influenced to a greater extent by diet or the interaction of nutritional factors and the housing system than by the housing system itself, including the space allowance per pig. Jørgensen et al. (2000) points out that the diet of fattening pigs is one of the most important factors modifying the fatty acid profile in meat. Coates and Ayerza's (2009) study shows that enriching the pigs' diet with different types of oils significantly affects the fatty acid content in pork. Given the number of various factors influencing the fatty acids profile of pork, it is necessary to take into account not only each of them individually, but also the interactions between them (Olsson and Pickova, 2005), which shape the final effect.

6.2. Space allowance and increased welfare

Space allowance is the least investigated factor affecting the meat quality in pigs, according to Ludwiczak et al. (2023). As mentioned above, previous studies, as well as this study, have shown that space allowance per pig on its own has no significant effect on the fatty acid profile. However, analysing the aspect of housing conditions and taking into account not only the increased space but also free-range farming, significant differences between pigs kept indoors and outdoors can be observed. Andres et al. (2001) observed that the fatty acid content of meat was strongly affected by the rearing system. Galian (2008) showed that despite the lack of statistically significant differences in many meat quality characteristics, such as intramuscular fat content, pH and colour, the housing system had an impact on mineral and fatty acid composition. In addition, animals kept outdoors showed a better growing rate, final live weight in relation to age, and higher carcass yields (both warm and cold), as well as superior weights for the most valuable meat cuts. Parunović et al. (2020) also observed significant differences in the heaviness of cold and warm carcasses, depending on the housing system. In addition, cholesterol levels and the PUFA/SFA ratio in backfat differed significantly. Free-range pigs had higher n-3 PUFA and lower n-6 PUFA levels, as well as a lower MUFA/SFA ratio. Nilzen (2001) also noted that despite the limited influence of the housing system on some meat parameters, pigs kept outdoors had higher levels of PUFA in intramuscular fat, as well as elevated levels of vitamin E, compared to animals kept indoors. The observed differences are likely related to differences in diet, associated with access to pastures and roughage (Ludwiczak et al. 2023), but also other factors such as exposure to sunlight and the resulting increased synthesis of vitamin D3, also affecting meat quality (Duffy et al., 2018), as well as increased physical activity, resulting from the availability of even more space. In addition to affecting meat production parameters, free-range also allows pigs to display species-specific behaviour, while reducing the occurrence of abnormal behaviour (Millet et al., 2005). Nannoni et al. (2019) observed differences in the behavior of animals kept in increased space allowance. The ability to exhibit natural behaviour is one of the key factors in reducing stress responses, positively affecting health, among other things by limiting harmful stereotypical behaviour such as tail biting, as well as improving immunity. Gimsa et al. (2018) emphasises that psychosocial stress, which can be caused by various factors, including overcrowding, can weaken immune functions and trigger the development of pathologies. It can affect various innate and acquired immune responses, such as leukocyte distribution, cytokine secretion, lymphocyte proliferation and antibody production, as well as immune responses to viral infections or vaccinations. In addition, stress can cause or promote gastrointestinal diseases through inflammatory disorders. Considering this, it can be concluded that providing animals with high welfare conditions, including increased space, has positive effects not only in terms of animal well-being, but also for financial reasons, possibly reducing veterinary treatment costs. On the other hand, whilst some aspects of animal health may be improved by extensive conditions, free-range increases the exposure to parasites and contact with wildlife, which may lead to higher risk of zoonotic infections (Edwards, 2005). Therefore, when considering the validity of introducing a free-range system, both its positive aspects and possible negative implications should be taken into account. Nevertheless, there are many available options to enrich the environment and improve welfare conditions, which can also be applied to indoor maintenance. The enrichment ensured and overall quality of the environment can impact pigs' well-being equally, and sometimes more than the amount of space provided itself (Chidgey, 2024). Li et al. (2020) observed that aggressive and harmful behaviour was significantly reduced with enrichment provision, regardless of space allowance. Beattie et al. (1996) concluded, that enrichment, such as substrates peat and straw, played a greater role than space allocation in decreasing the frequency of harmful social behaviour and aggression. With that being said, considering how cognitively complex and intelligent animals pigs are (Marino and Colvin, 2015), providing them with high welfare conditions and reducing stress factors is of high importance, not only from the production profitability point of view, but also ethical aspects (Kasper et al., 2020).

6.3. Economic evaluation and customer preferences

Interventions aimed at introducing changes to improve farm animals' welfare are rarely tested for economic viability, which limits their implementation (Peden et al., 2021). Previous studies on the cost-effectiveness of increasing the space available to animals often point to a significant increase in production costs, which discourages many producers from improving animal welfare conditions. In order to verify economic profitability based on the experiments conducted within this thesis, a quick economic evaluation was carried out to determine the impact of changes in space allocation on profitability. The calculations included only the price and quantity of feed consumed per pen with different space allowances and the average price for the live fattener, which in Poland at the beginning of 2025 was ~1.46 €/kg live weight. In the first experiment, feed costs were ~472 €/ton, in the second experiment ~332 €/ton, and in the third experiment ~329 €/ton. This resulted in the following income per pen in Exp1: control - 3230 €, G1 - 2616 €, G2 - 1502 €, in Exp2: control – 2609 €, G1 - 2717 €, G2 - 1645 €, and in Exp3: control – 2261 €, G1 - 2501 €, G2 - 2501 €. Based on these values, it can be concluded that, on average, increasing the space allocation is associated with a decrease in income for the farmer.

This observation is consistent with several other studies, such as Jensen's et al. (2012), who state that the space allocation for farm animals is a controversial animal welfare issue for producers, policymakers and the society. Their research indicates a notable increase in costs, with no statistically significant improvement in productivity and pen hygiene in well-managed commercial pig systems. However, by applying appropriate strategies to optimise the production process, it is possible to improve welfare conditions while maximising profits. Lerner et al. (2020) conducted a study comparing different space allowances and marketing strategies, examining their impact on the growth performance of pigs. In groups where the space per animal decreased as the pigs grew and the animals were sold only once at the end of the fattening period, there was a decrease in average daily gain and average daily feed intake, while the gain to feed ratio (G:F) did not differ, regardless of the initial space allocation. Marketing pigs three or four times during fattening period, significantly improved G:F, compared with the groups in which pigs were marketed only once. The reduction in space in the first strategy limited feed intake, resulting in lower growth rate, as well as lower final body weight. Total weight gain per pen was maximised in the group with the lowest initial space allowance and multiple marketing events. Another approach involves free-range farming as a profitable and competitive system that also has a positive impact on welfare. Norgaard (1995) points to such positive aspects of outdoor farming as relatively low financial input, averaging about one-third compared to commercial indoor systems, as well as simple technical solutions that allow for easier adaptation to changing conditions, both environmental and socio-economic. He indicates easier gradual expansion as an additional advantage. Bütler and Gazzarin (2024) examined economic profitability of organic pig production. Six out of ten farms included in the study proved to be profitable. Even though organic farms have higher production costs than conventional farms, they can still remain economically competitive due to higher gross margins and better wages. The question is whether customers are willing to pay a higher price for meat from farms that maintain higher animal welfare standards. Gorton et al. (2023) reports that consumers increasingly consider ethical aspects of food production, to be important to them, but the higher prices of products labelled as coming from animals with enhanced welfare generally discourage them from buying them. However, he distinguished two almost equal groups of consumers, referred to as price-sensitive and concerned customers. Among the former, the willingness to pay more for an animal welfare label is very low. In the latter, however, consumers pay more attention to aspects of meat production such as environmental friendliness, animal welfare and fair trade, which results in them being much more willing to buy meat produced on farms with higher animal welfare standards. In a choice experiment conducted by Grunert et al. (2018) the importance of production characteristics in consumers' choice of pork was investigated. The characteristics taken into account related to animal welfare, health and safety, and environmental impact. The results indicated that consumers consider health and safety aspects, such as no microbial contamination or less use of antibiotics, as well as traceability, to be the most important, suggesting that factors related to individual benefits played the greatest role. Animal welfare characteristics were considered less important, and the environmental impact played the smallest role in meat selection. On the other hand, Dudinskaya et al. (2021) state that despite certain differences between consumers from different countries in terms of the characteristics of meat production that are most important to them and their willingness to pay for them, organic labels and national origin were highly valued in most countries. Giannetto et al. (2023) emphasise that 47% of respondents are willing to pay a higher price for pork produced using animal-friendly methods. Gross et al. (2021) also report that a significant part of customers are willing to pay more for products with animal welfare or organic label. This corresponds with the sensory consumer evaluation, in which products labelled as organic received the highest ratings, followed by animal welfare products, while conventionally produced meat received the lowest ratings. However, in a blind test, the sensory evaluation of the products was similar. It can be concluded that information about organic and animal-friendly products has a positive impact on sensory perception and liking, as well as willingness to pay. Therefore, modern, sustainable pig production must balance animal welfare and environmental impact with efficiency (Sossidou et al., 2025), while also taking into account socio-economic aspects and consumer preferences, which have a direct impact on the choice of products purchased and, consequently, on the profitability of production.

7. Conclusion

The results suggest that increasing space allowance has no significant effect on the fatty acids content in pork. On the other hand, the sex-related factors seemed to have a greater effect on fatty acids profile, with several parameters differing significantly between gilts and castrated males across all three experiments conducted. Furthermore, Principal Component Analysis indicated the largest differences between experiments, with the least variation within the experiment involving the local breed, compared to commercial crossbred pigs, suggesting that genetic-related factors, followed by environmental conditions, may play a more decisive role than space allocation. From an economic point of view, the provision of additional space did not prove to be profitable, as the decreased income due to the limited number of pigs per pen was not compensated by improved meat quality. Nevertheless, the absence of negative effects on the fatty acids composition can be considered a positive outcome, since higher welfare standards may be implemented without compromising pork quality. Considering both ethical aspects and consumer expectations, improving welfare conditions remains an important goal in pig production, although it poses economic challenges under current production systems.

8. Abbreviations

ANOVA – analysis of variance
DHA – docosahexaenoic acid
EPA – eicosapentaenoic acid
FA – fatty acids
HDL – high density lipoprotein
LA – linoleic acid
MUFA – monounsaturated fatty acids
ns – non significant
OA – oleic acid
PC – principal components
PCA – Principal Components Analysis
PUFA – polyunsaturated fatty acids
SD – standard deviation
SFA – saturated fatty acids
UFA – unsaturated fatty acids

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