

## Article

# Comparison of Lipid Profile and Oxidative Stability of Vacuum-Packed and Longtime-Frozen Fallow Deer, Wild Boar, and Pig Meat

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**Abstract:** The present study aimed to evaluate the lipid content and oxidation of fallow deer (FD), wild boar (WB), and pig meat (PM) at  $-18^{\circ}\text{C}$  for a 360-day storage period. The lowest fat content was observed in thigh meat (TM) of FD (2.53%;  $p < 0.05$ ). The ratio of polyunsaturated/saturated fatty acids (PUFA/SFA),  $n-6/n-3$ , hypocholesterolemic/hypercholesterolemic index (h/H), and the lipid nutritional quality indexes were calculated. The PUFA/SFA ratio of each meat sample was compared with the required value of more than 0.4 while the optimal  $n-6/n-3$  ratio was determined only in shoulder meat (SM) of FD meat samples (3.94;  $p < 0.001$ ). An atherogenic index of lower than 1.0 was observed in each meat sample and a thrombogenic index of lower than 0.5 was observed only in TM of FD (0.53;  $p < 0.001$ ). During the storage period, the malondialdehyde (MDA) content of WB and PM samples showed a higher variability than the FD samples. On the initial day as well as on the 360th day of the storage period, the lowest MDA content in the loin of PM was measured. Long-term vacuum packaging resulted in lower lipid oxidation during meat storage ( $p < 0.01$ ); however, the duration of the storage period significantly affected the level of lipid oxidation ( $p < 0.001$ ).

**Keywords:** malondialdehyde; fatty acid profile; lipid nutritional quality indexes; quality



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## 1. Introduction

Lipids belong among one of the main qualitative meat variables responsible for qualitative and sensory characteristics, respectively. Sensory characteristics of meat such as softness and juiciness are very important in the evaluation of the flavor and aroma profile of meat [1].

From an evolutionary perspective, it has been determined that eating venison and other game meat is good for human health. As a result, the demand for and popularity of game meat and venison from deer species have recently increased [2]. Red meat has a long history of being recognized as a significant dietary source of key nutrients and proteins; however, new research suggests that consuming red meat may increase the chance of developing colon cancer and cardiovascular diseases [3].

The quality and origin of beef meat are now more widely known to the modern consumer. Meat from fallow deer can satisfy consumer demand which is mainly aimed at achieving and maintaining a healthy diet and lifestyle. Venison is a type of deer meat that is distinguished by having a high level of proteins and minerals whilst on the contrary, a low content of fat (which is typically not intramuscular fat) and a low content of cholesterol [4]. Game meat has a lower energetic value ranging from 90 to 110 kcal/100 g when compared

to beef, pork, mutton, or poultry meat which contain energetic values ranging from 114 to 231 kcal/100 g of muscle tissue [5]. In human nutrition, fallow deer meat has a beneficial fatty acid profile [6] with increased concentration of *n*-3 polyunsaturated fatty acids (PUFA) than venison from other deer species [7]. Meat from farm-raised fallow deer is also an excellent source of iron and copper, and because of this, it has the potential to be suggested as a component of a healthy diet [8].

During the last decades, pork has been the most popular type of meat consumed in western countries. However, there is a growing tendency to purchase meat from European wild boars (*Sus scrofa scrofa*) in addition to meat from domestic pigs (*Sus scrofa domesticus*) due to the general fact that game meat is leaner and, consequently, healthier than meat from domesticated animal species [9].

Wild boars have fatter carcasses, larger loin regions, more slow-twitch oxidative and fast-twitch oxidative glycolytic muscle fibers, fewer fast-twitch glycolytic muscle fibers and darker, less tender, and leaner meat when compared to domestic pigs. The nutrition of animals may have an impact on the quality of the meat produced from wild boars and domestic pigs which may be positively or negatively rated by consumers after cooking the meat. When a higher proportion of lipids undergo oxidation, the fatty acid content and overall meat shelf-life may be significantly impacted [10].

Due to the high number of unsaturated phospholipids and pro-oxidant iron ions in myoglobin, the lipids in game meat might have the tendency to oxidize faster. Therefore, game meat should be kept in an oxygen-deficient container [11]. The most common way to distribute venison is in vacuum packages. Vacuum packaging extends the shelf life of meat together with freezing. Additionally, the process of tenderization and flavor development also occurs within vacuum packages. Venison can be frozen to extend its shelf life and make it more accessible to nearby and far-off markets [12]. Since freezing causes only modest and acceptable changes in meat quality and, therefore, successfully preserves meat for long-term storage, it is a widely utilized method of meat preservation. The majority of meat manufacturing and distribution businesses utilize it, as do customers who frequently buy more meat than they can eat at once and store the extra in their freezers [11].

The color and preservation of meat during storage can be effectively enhanced by selecting the proper packaging and storage methods [13]. Fresh meat could be packaged using vacuum packing, modified atmosphere packaging (MAP), or air-permeable packaging [14]. Vacuum and modified conditions of packaging offer longer meat shelf life; however, air-permeable packaging is most frequently used for raw, cold red meat [15]. Vacuum packaging creates anaerobic conditions that increase the meat's oxidative and microbiological shelf life [16]. Packaging either with high levels of oxygen or low levels of oxygen are two different types of MAP, especially with oxygen combined with nitrogen or carbon dioxide. Compared to MAP with a high oxygen content (70–80%), vacuum packaging offers the advantages of less lipid oxidation and improved pigment stability [17].

MDA has been determined in meat samples of fallow deer [11,18], in minced products of fresh and frozen/thawed fallow deer meat [19], foal meat [20,21], pork [17,22], wild boar meat [21,23,24], and ground beef meat [13] in previously published studies. Numerous factors such as the rate of freezing, the storage temperature, and temperature fluctuations all affect the quality of frozen meat [25].

The present study was aimed to research the nutritional value of fallow deer meat, wild boar meat, and pork with special attention paid to the differences in the selected cuts of meat (loin, shoulder, and thigh meat) with the intention to evaluate the effect of long-term storage on the decomposition processes of lipids in samples packed under vacuum conditions.

## 2. Materials and Methods

### 2.1. Meat Samples

In this study, three animal species—fallow deer (FD), wild boars (WB), and pigs (PM)—were investigated. FD and WB originated from a breeding farm (Rozhanovce,

Slovak Republic), and PM from the university farm (Košice, Slovak Republic). Each experimental group (FD, WB, and PM) was composed of six selected animals. They were slaughtered during the autumn–winter season. From each group (FD, WB, and PM), selected cuts were taken of the loin (LM; *muscles longissimus dorsi*), taken from between the 13th and 14th rib; shoulder meat (SM; *muscles supraspinatus*, *muscles infraspinatus*, *muscles subscapularis*, *muscles triceps brachii*); and thigh meat (TM; *muscles semimembranosus*).

On the initial day of this experiment, the meat samples ( $n = 54$ ) were stored at a temperature of  $4 \pm 2$  °C until the meat quality analysis (fatty acid profile, physicochemical analysis and lipid oxidation determination) was made. Subsequently, the meat samples ( $n = 216$ ) with an approximate weight of 100 g were vacuum-packed for long-term storage. The samples were packed under vacuum conditions in plastic bags (polyethylene, thickness 70 µm, G-PACK, LLC., Slovak Republic) using the Boss Vacuum machine (NE 2746 N, Bad Homburg, Germany) and kept at freezing temperature of  $-18 \pm 2$  °C for 90, 180, 270, and 360 days until the determination of lipid oxidation.

## 2.2. Physicochemical Analysis

Meat samples were analyzed for their dry matter and lipid content according to standard methods [26]. The content of dry matter was determined by oven-drying to a constant weight at a temperature of 170 °C using the Universal Oven UN 110 (Mettler GmbH + Co. KG, Büchenbach, Germany). Lipids were isolated by petroleum ether in a Soxhlet apparatus (LTHS 500, Brněnská Druteva v.d., Brno, Czech Republic) and were determined gravimetrically. Triplicate measurements of the physicochemical analysis of each meat sample were performed.

## 2.3. Fatty Acid Analysis

In order to analyze the composition of fatty acids, they were turned into their methyl esters and separated via gas chromatography [27]. The parameters of gas chromatography analysis were set according to Gajdoš et al. [28]. The gas chromatograph (GC-6890 N, Agilent Technologies, Palo Alto, CA, USA) was equipped with a capillary column DB-23 (60 m × 0.25 mm, film thickness 0.25 µm, Agilent Technologies) and an FID detector (Agilent Technologies).

Identification and quantification were done according to Slaný et al. [29]. The ChemStation software B0103 (Agilent Technologies) was used to calculate the fatty acid concentration. The resulting values of each fatty acid in were presented as a mean of the triplicate measurements and were expressed as percentage of total fatty acid (%/total fatty acid).

## 2.4. Calculation of Lipid Nutritional Quality Indexes (IQN)

According to Ulbricht and Southgate [30], Fernandes et al. [31], Erickson et al. [32], and the Cardiovascular Review Group [33], the fatty acid profile was utilized to determine a number of nutritional variables regarding meat lipids. The polyunsaturated/saturated fatty acids ratio (PUFA/SFA; 1),  $n-6/n-3$  PUFA ratio ( $n-6/n-3$ ; 2), atherogenic index (AI; 3), thrombogenic index (TI; 4), peroxidability index (PI; 5), and hypocholesterolemic/hypercholesterolemic index (h/H; 6) were calculated according to the following formulas:

$$\text{PUFA/SFA} = (\text{C18:2n-6} + \text{C18:3n-3}) / (\text{C14:0} + \text{C16:0} + \text{C18:0}) \quad (1)$$

$$n-6/n-3 [(\sum n-6) / (\sum n-3)] \quad (2)$$

$$\text{AI} = (\text{C12:0} + 4 \times \text{C14:0} + \text{C16:0}) / (\sum \text{MUFA} + \sum \text{PUFA}) \quad (3)$$

$$\text{TI} = (\text{C14:0} + \text{C16:0} + \text{C18:0}) / (0.5 \times \sum \text{MUFA}) + (0.5 \times \sum n-6 \text{ PUFA}) + (3 \times \sum n-3 \text{ PUFA}) + (\sum n-3 \text{ PUFA} / \sum n-6 \text{ PUFA}) \quad (4)$$

$$\text{PI} = (\text{monoenoicacid} \times 0.025) + (\text{dienoicacid} \times 1) + (\text{trienoicacid} \times 2) + (\text{tetraenoicacid} \times 4) + (\text{pentaenoicacid} \times 6) + (\text{hexaenoicacid} \times 8) \quad (5)$$

$$h/H = [(C18:1n-9 + C18:1n-7 + C18:2n-6 + C18:3n-6 + C18:3n-3 + C20:3n-6 + C20:4n-6 + C20:5n-3 + C22:4n-6 + C22:5n-3 + C22:6n-3)] / ((C14:0 + C16:0)) \quad (6)$$

### 2.5. Determination of Lipid Oxidation

Lipid decomposition changes were determined in individual experimental groups at the beginning of storage on the initial day of the experiment and then on the 90th, 180th, 270th, and 360th day of storage. The lipid oxidation processes were measured based on the rate of secondary damage to fats, conditioned by the oxidation of unsaturated fatty acids according to Marcinčák et al. [34]. Malondialdehyde (MDA), as a main product of secondary lipid oxidation, was determined by the spectrophotometric method as a complex with 2-thiobarbituric acid (MDA-TBA) at a wavelength of 532 nm by the spectrophotometer (Helios γ, Thermo spectronic, Cambridge, United Kingdom). The results were expressed as mg/MDA/kg per sample as an average value of three measurements per sample.

### 2.6. Statistical Evaluation

The results of all determined parameters presented in this study were expressed as the mean and standard deviation (SD) of measurements that were each replicated six times. The GraphPad Prism 8.3 (GraphPad Software, San Diego, CA, USA) and R-statistics 4.0.3 software [35] with “FactomineR” [36] and “factoextra” packages [37] were used for the analysis of the obtained data according to Pagès [38] and Semjon et al. [39]. One-way and multiway analysis of variance (ANOVA) with Tukey’s post hoc tests were used to express the significant differences between sample groups. MDA content was statistically investigated in experimental samples on the initial day of the experiment and, subsequently, on the 90th, 180th, 270th, and 360th day of storage in vacuum conditions at a temperature of  $-18 \pm 2$  °C. The effect of meat cuts, meat type, and storage were set as the main aspects of the multiple factor analysis (MFA). A statistical significance level of  $p < 0.05$  was set prior to data analysis.

## 3. Results and Discussion

The results of the physicochemical determinations of loin, shoulder, and thigh meat samples are presented in Table 1. The loin and shoulder meat samples taken from FD, WB, and PM significantly differed in their fat content ( $p < 0.05$ ). The highest fat content was observed in WB loin and shoulder meat as well as in PM thigh samples. The lowest fat content was detected in all meat samples of FD compared to the other types of meat. The fat content significantly differed in shoulder samples from the other types of meat (Table 1,  $p < 0.001$ ). However, in this current study, the fat content of the FD loin and shoulder meat samples were higher than those reported by Švrčula et al. [6] in both stag and doe farm-raised FD. The body weight and fat reserves of the wild boar and generally in all wild animals, depend on the nutrient composition of their diet. When the so-called “energetic cost of maintenance” is less than food intake measured in energy units, production or body growth and fat deposition can take place in wild ungulates [40].

**Table 1.** The results of chemical measurements of loin, shoulder, and thigh muscles of meat samples.

Physicochemical Variables	Meat Sample	Fallow Deer	Wild Boar	Pig	<i>p</i> -Value
Dry matter, %	Loin meat	30.31 ± 0.70 <sup>b</sup>	32.57 ± 0.32 <sup>a</sup>	30.92 ± 0.37 <sup>b</sup>	0.004
Fat, %	Loin meat	3.69 ± 0.66 <sup>ab</sup>	4.69 ± 0.45 <sup>a</sup>	3.11 ± 0.03 <sup>b</sup>	0.016
Dry matter, %	Shoulder meat	27.90 ± 0.90 <sup>b</sup>	30.58 ± 1.25 <sup>a</sup>	32.15 ± 0.93 <sup>a</sup>	0.007
Fat, %	Shoulder meat	2.66 ± 0.51 <sup>b</sup>	6.87 ± 0.23 <sup>a</sup>	6.13 ± 0.52 <sup>a</sup>	<0.001
Dry matter, %	Thigh meat	28.74 ± 0.45 <sup>b</sup>	32.01 ± 0.37 <sup>a</sup>	32.33 ± 0.42 <sup>a</sup>	<0.001
Fat, %	Thigh meat	2.53 ± 0.33 <sup>b</sup>	4.10 ± 0.43 <sup>ab</sup>	5.87 ± 1.75 <sup>a</sup>	0.021

Means without a common superscript letter (<sup>a,b</sup>) in rows significantly differ (Tukey’s test,  $p < 0.05$ ).

Numerous studies have shown that the lipid composition of venison is related to the animal's diet just like the lipid composition of meat from other ruminants and that an intensive production system including feeding with grain-based feed mixtures has a negative impact on the desirable fatty acid profile [41]. In the wild, animals naturally grow slowly when there is enough forage which results in lighter carcasses but with the production of meat of a higher quality [42].

Table 2 shows the results of the fatty acid profiles of the LM samples in FD, WB, and PM. The major SFA in all samples of wild boar meat and pig meat was palmitic acid (PA, C16:0), whereas in the samples of fallow deer meat, it was stearic acid (SA, C18:0) ( $p < 0.001$ ). The predominant MUFA in all the analyzed samples of meat was oleic acid (OA, C18:1). FD samples had significantly lower OA and MUFA percentages compared to the other types of meat ( $p < 0.001$ ). From the PUFAs, linoleic acid (LA, C18:2,  $n-6$ ) was most represented in wild boar meat and pig meat, while in fallow deer meat, it was arachidonic acid (AA, C20:4,  $n-6$ ). The samples of WB and PM had a higher percentage of OA ( $p < 0.001$ ) and a lower percentage of AAs than FD meat ( $p < 0.001$ ).

**Table 2.** The composition of fatty acids of the loin samples (%/total fatty acid; mean  $\pm$  SD).

Fatty Acid (%)	Fallow Deer	Wild Boar	Pig	<i>p</i> -Value
C12:0	0.08 $\pm$ 0.06 <sup>b</sup>	0.04 $\pm$ 0.03 <sup>b</sup>	0.17 $\pm$ 0.02 <sup>a</sup>	0.012
C14:0	3.01 $\pm$ 1.59	0.75 $\pm$ 0.17	0.77 $\pm$ 0.07	0.038
C16:0	18.48 $\pm$ 3.05	16.55 $\pm$ 0.81	20.96 $\pm$ 0.18	0.067
C18:0	21.32 $\pm$ 0.78 <sup>a</sup>	10.77 $\pm$ 0.24 <sup>c</sup>	12.77 $\pm$ 0.15 <sup>b</sup>	<0.001
C20:0	0.49 $\pm$ 0.25	0.20 $\pm$ 0.02	0.16 $\pm$ 0.01	0.057
C22:0	0.33 $\pm$ 0.09	0.15 $\pm$ 0.02	0.11 $\pm$ 0.05	0.010
C16:1 <i>n</i> -9	0.60 $\pm$ 0.1	0.43 $\pm$ 0.07	0.38 $\pm$ 0.02	0.112
C16:1 <i>n</i> -7	1.25 $\pm$ 0.23 <sup>b</sup>	2.16 $\pm$ 0.40 <sup>a</sup>	1.81 $\pm$ 0.19 <sup>ab</sup>	0.024
C18:1 <i>n</i> -9	13.68 $\pm$ 1.48 <sup>b</sup>	29.75 $\pm$ 3.67 <sup>a</sup>	28.95 $\pm$ 0.75 <sup>a</sup>	<0.001
C18:1 <i>n</i> -7	1.59 $\pm$ 0.46 <sup>b</sup>	3.55 $\pm$ 0.14 <sup>a</sup>	3.16 $\pm$ 0.07 <sup>a</sup>	<0.001
C20:1 <i>n</i> -9	0.23 $\pm$ 0.01 <sup>c</sup>	1.17 $\pm$ 0.12 <sup>a</sup>	0.55 $\pm$ 0.01 <sup>b</sup>	<0.001
C18:2 <i>n</i> -6	20.15 $\pm$ 5.36	26.80 $\pm$ 2.85	22.43 $\pm$ 0.65	0.142
C18:3 <i>n</i> -6	0.07 $\pm$ 0.04 <sup>b</sup>	0.07 $\pm$ 0.03 <sup>b</sup>	0.17 $\pm$ 0.02 <sup>a</sup>	0.010
C18:3 <i>n</i> -3	2.07 $\pm$ 0.69 <sup>a</sup>	0.55 $\pm$ 0.08 <sup>b</sup>	0.78 $\pm$ 0.04 <sup>b</sup>	0.007
C18:4 <i>n</i> -3	0.09 $\pm$ 0.02 <sup>a</sup>	0.00 $\pm$ 0.00 <sup>b</sup>	0.00 $\pm$ 0.00 <sup>b</sup>	<0.001
C20:2 <i>n</i> -6	0.10 $\pm$ 0.03 <sup>c</sup>	0.49 $\pm$ 0.02 <sup>a</sup>	0.42 $\pm$ 0.02 <sup>b</sup>	<0.001
C20:3 <i>n</i> -6	0.26 $\pm$ 0.12 <sup>b</sup>	0.36 $\pm$ 0.09 <sup>b</sup>	0.65 $\pm$ 0.07 <sup>a</sup>	0.006
C20:3 <i>n</i> -3	0.10 $\pm$ 0.04	0.09 $\pm$ 0.02	0.12 $\pm$ 0.02	0.471
C20:4 <i>n</i> -6	11.92 $\pm$ 1.10 <sup>a</sup>	4.94 $\pm$ 1.76 <sup>b</sup>	4.51 $\pm$ 0.49 <sup>b</sup>	0.001
C20:5 <i>n</i> -3	0.74 $\pm$ 0.43	0.21 $\pm$ 0.08	0.21 $\pm$ 0.02	0.065
C22:5 <i>n</i> -3	3.13 $\pm$ 1.48 <sup>a</sup>	0.86 $\pm$ 0.25 <sup>b</sup>	0.78 $\pm$ 0.09 <sup>b</sup>	0.027
C22:6 <i>n</i> -3	0.31 $\pm$ 0.19	0.12 $\pm$ 0.04	0.14 $\pm$ 0.02	0.170
$\Sigma$ Saturated Fatty Acids	43.71 $\pm$ 5.82 <sup>a</sup>	28.46 $\pm$ 1.28 <sup>b</sup>	34.94 $\pm$ 0.48 <sup>b</sup>	0.005
$\Sigma$ Monounsaturated Fatty Acids	17.36 $\pm$ 2.36 <sup>b</sup>	37.05 $\pm$ 4.40 <sup>a</sup>	34.84 $\pm$ 1.04 <sup>a</sup>	<0.001
$\Sigma$ Polyunsaturated Fatty Acids	38.94 $\pm$ 9.48	34.49 $\pm$ 5.22	30.22 $\pm$ 1.43	0.315
$\Sigma$ Polyunsaturated Fatty Acids <i>n</i> -3	6.44 $\pm$ 2.84 <sup>a</sup>	1.84 $\pm$ 0.46 <sup>b</sup>	2.04 $\pm$ 0.19 <sup>b</sup>	0.026
$\Sigma$ Polyunsaturated Fatty Acids <i>n</i> -6	32.50 $\pm$ 6.64	32.66 $\pm$ 4.75	28.18 $\pm$ 1.24	0.473

Means without a common superscript letter (<sup>a-c</sup>) in row significantly differ (Tukey's test,  $p < 0.05$ ).

The highest  $n-3$  PUFA proportion (6.44%), mainly, ALA, DPA, EPA, and DHA were represented in LM meat samples of FD. Regarding human nutrition, the increase of DPA, EPA, and DHA acids which are significantly higher compared to other types of dishes is significant.

Table 3 shows the results of the fatty acid profiles of the shoulder meat (SM) samples in FD, WB, and PM. SA was mainly represented in the SM of FD (22.67%,  $p < 0.001$ ). Meat samples of SM from WB and PM had a higher proportion of OA ( $p < 0.01$ ) and also a higher proportion of  $\Sigma$  MUFA ( $p < 0.01$ ) compared to FD. SM of FD had a significantly higher  $\Sigma$  SFA compared to WB and PM ( $p < 0.05$ ) and a higher level of  $\Sigma$  PUFA ( $p < 0.05$ ) compared



to PM. SM of FD had the highest proportion of *n*-3 PUFA (ALA, DPA, EPA, and DHA) ( $p < 0.001$ ).

**Table 3.** The results of the fatty acid profile determination of the shoulder meat samples (%/total fatty acid; mean  $\pm$  SD).

Fatty Acid (%)	Fallow Deer	Wild Boar	Pig	<i>p</i> -Value
C12:0	0.03 $\pm$ 0.04 <sup>b</sup>	0.04 $\pm$ 0.03 <sup>b</sup>	0.11 $\pm$ 0.01 <sup>a</sup>	0.028
C14:0	2.04 $\pm$ 0.82 <sup>a</sup>	0.81 $\pm$ 0.21 <sup>b</sup>	0.92 $\pm$ 0.06 <sup>ab</sup>	0.040
C16:0	16.87 $\pm$ 1.65	18.34 $\pm$ 3.50	20.45 $\pm$ 0.50	0.229
C18:0	22.67 $\pm$ 2.04 <sup>a</sup>	11.70 $\pm$ 1.59 <sup>b</sup>	11.39 $\pm$ 0.27 <sup>b</sup>	0.000
C20:0	0.32 $\pm$ 0.13	0.21 $\pm$ 0.04	0.12 $\pm$ 0.01	0.056
C22:0	0.24 $\pm$ 0.03 <sup>a</sup>	0.16 $\pm$ 0.03 <sup>b</sup>	0.04 $\pm$ 0.00 <sup>c</sup>	<0.001
C16:1 <i>n</i> -9	0.49 $\pm$ 0.13	0.49 $\pm$ 0.09	0.44 $\pm$ 0.02	0.722
C16:1 <i>n</i> -7	1.56 $\pm$ 0.17	2.43 $\pm$ 0.85	2.44 $\pm$ 0.20	0.134
C18:1 <i>n</i> -9	15.97 $\pm$ 0.11 <sup>b</sup>	35.93 $\pm$ 8.07 <sup>a</sup>	33.90 $\pm$ 1.00 <sup>a</sup>	0.004
C18:1 <i>n</i> -7	2.21 $\pm$ 0.38 <sup>b</sup>	3.78 $\pm$ 0.93 <sup>a</sup>	3.90 $\pm$ 0.11 <sup>a</sup>	0.021
C20:1 <i>n</i> -9	0.22 $\pm$ 0.03 <sup>c</sup>	1.47 $\pm$ 0.23 <sup>a</sup>	0.61 $\pm$ 0.01 <sup>b</sup>	<0.001
C18:2 <i>n</i> -6	17.64 $\pm$ 0.88 <sup>b</sup>	30.05 $\pm$ 4.74 <sup>a</sup>	18.54 $\pm$ 1.44 <sup>b</sup>	0.003
C18:3 <i>n</i> -6	0.08 $\pm$ 0.02 <sup>b</sup>	0.06 $\pm$ 0.01 <sup>b</sup>	0.15 $\pm$ 0.01 <sup>a</sup>	0.002
C18:3 <i>n</i> -3	2.81 $\pm$ 0.46 <sup>a</sup>	0.64 $\pm$ 0.12 <sup>b</sup>	0.72 $\pm$ 0.08 <sup>b</sup>	<0.001
C20:2 <i>n</i> -6	0.15 $\pm$ 0.03 <sup>b</sup>	0.55 $\pm$ 0.09 <sup>a</sup>	0.45 $\pm$ 0.03 <sup>a</sup>	<0.001
C20:3 <i>n</i> -6	0.33 $\pm$ 0.07 <sup>b</sup>	0.37 $\pm$ 0.07 <sup>b</sup>	0.53 $\pm$ 0.03 <sup>a</sup>	0.013
C20:3 <i>n</i> -3	0.14 $\pm$ 0.03 <sup>a</sup>	0.09 $\pm$ 0.02 <sup>ab</sup>	0.13 $\pm$ 0.01 <sup>b</sup>	0.044
C20:4 <i>n</i> -6	11.79 $\pm$ 1.10 <sup>a</sup>	5.44 $\pm$ 1.18 <sup>b</sup>	4.13 $\pm$ 0.29 <sup>b</sup>	<0.001
C20:5 <i>n</i> -3	1.06 $\pm$ 0.24 <sup>a</sup>	0.25 $\pm$ 0.06 <sup>b</sup>	0.17 $\pm$ 0.01 <sup>b</sup>	<0.001
C22:5 <i>n</i> -3	3.37 $\pm$ 0.59 <sup>a</sup>	0.98 $\pm$ 0.18 <sup>b</sup>	0.72 $\pm$ 0.08 <sup>b</sup>	<0.001
C22:6 <i>n</i> -3	0.33 $\pm$ 0.08 <sup>a</sup>	0.14 $\pm$ 0.03 <sup>b</sup>	0.14 $\pm$ 0.02 <sup>b</sup>	0.005
$\Sigma$ Saturated Fatty Acids	42.17 $\pm$ 4.71 <sup>a</sup>	31.27 $\pm$ 5.40 <sup>b</sup>	33.04 $\pm$ 0.85 <sup>b</sup>	0.038
$\Sigma$ Monounsaturated Fatty Acids	20.46 $\pm$ 0.81 <sup>b</sup>	44.10 $\pm$ 10.17 <sup>a</sup>	41.28 $\pm$ 1.35 <sup>a</sup>	0.005
$\Sigma$ Polyunsaturated Fatty Acids	37.70 $\pm$ 3.50 <sup>a</sup>	38.55 $\pm$ 6.50 <sup>a</sup>	25.68 $\pm$ 2.00 <sup>b</sup>	0.020
$\Sigma$ Polyunsaturated Fatty Acids <i>n</i> -3	7.71 $\pm$ 1.40 <sup>a</sup>	2.08 $\pm$ 0.41 <sup>b</sup>	1.88 $\pm$ 0.20 <sup>b</sup>	<0.001
$\Sigma$ Polyunsaturated Fatty Acids <i>n</i> -6	29.99 $\pm$ 2.10 <sup>a</sup>	36.46 $\pm$ 6.09 <sup>a</sup>	23.35 $\pm$ 1.80 <sup>ab</sup>	0.020

Means without a common superscript letter (<sup>a-c</sup>) in row significantly differ (Tukey's test,  $p < 0.05$ ).

Table 4 shows the results of the fatty acid profile of the thigh meat samples of FD, WB, and PM. Out of all the SFAs, palmitic acid in PM ( $p < 0.001$ ) and stearic acid in FD meat samples ( $p < 0.001$ ) were determined as the highest. The lowest (oleic acid) was determined in the TM of FD while the TM of WB contained more than a 70% higher level of oleic acid ( $p < 0.001$ ). The TM meat samples of FD and WB had a comparable percentage of linoleic acid (C18:2, *n*-6) ( $p < 0.01$ ); however, the TM of FD had more than a 65% higher level of arachidonic acid (C20:4, *n*-6) compared to WB and PM samples ( $p < 0.001$ ). The TM of FD had the lowest  $\Sigma$  MUFA ( $p < 0.001$ ) and the highest  $\Sigma$  PUFA level ( $p < 0.001$ ) with a significantly higher level of *n*-3 PUFA ( $p < 0.001$ ).

The LM, SM, and TM of fallow deer are characterized by a high percentage of palmitic, stearic, linoleic, and arachidonic acid compared to the fatty acid composition stated in the literature regarding wild and farmed fallow deer [2,7,8,43]. Compared to the meat samples of wild boar and pork, fallow deer in this study showed 2-fold higher levels of stearic acid. Stearic acid is considered a healthier fatty acid compared to other SFAs and is associated with decreases in low- and high-density lipoprotein cholesterol concentrations when compared with palmitic acid [44]. Daszkiewicz et al. [11] determined that the percentage of stearic acid in fallow deer meat significantly differed between wild (17%) and farmed animals (25%) and their observations of stearic acid percentage are similar to our presented results.

**Table 4.** The results of the fatty acid profile determination of thigh meat samples (%/total fatty acid; mean  $\pm$  SD).

Fatty Acid (%)	Fallow Deer	Wild Boar	Pig	<i>p</i> -Value
C12:0	0.00 $\pm$ 0.00 <sup>c</sup>	0.05 $\pm$ 0.00 <sup>b</sup>	0.08 $\pm$ 0.01 <sup>a</sup>	<0.001
C14:0	0.74 $\pm$ 0.30	0.61 $\pm$ 0.11	0.88 $\pm$ 0.14	0.333
C16:0	12.72 $\pm$ 1.50 <sup>b</sup>	13.84 $\pm$ 0.34 <sup>b</sup>	21.05 $\pm$ 0.79 <sup>a</sup>	<0.001
C18:0	18.36 $\pm$ 0.87 <sup>a</sup>	11.17 $\pm$ 0.28 <sup>b</sup>	12.49 $\pm$ 0.12 <sup>b</sup>	<0.001
C20:0	0.19 $\pm$ 0.01 <sup>b</sup>	0.21 $\pm$ 0.01 <sup>a</sup>	0.14 $\pm$ 0.00 <sup>c</sup>	<0.001
C22:0	0.20 $\pm$ 0.01 <sup>a</sup>	0.22 $\pm$ 0.01 <sup>a</sup>	0.07 $\pm$ 0.02 <sup>b</sup>	<0.001
C16:1 <i>n</i> -9	0.34 $\pm$ 0.02 <sup>b</sup>	0.52 $\pm$ 0.05 <sup>a</sup>	0.28 $\pm$ 0.01 <sup>b</sup>	<0.001
C16:1 <i>n</i> -7	1.06 $\pm$ 0.15 <sup>c</sup>	1.60 $\pm$ 0.11 <sup>b</sup>	2.87 $\pm$ 0.33 <sup>a</sup>	<0.001
C18:1 <i>n</i> -9	10.12 $\pm$ 0.92 <sup>c</sup>	33.23 $\pm$ 1.17 <sup>a</sup>	28.44 $\pm$ 2.15 <sup>b</sup>	<0.001
C18:1 <i>n</i> -7	2.36 $\pm$ 0.13 <sup>c</sup>	3.02 $\pm$ 0.07 <sup>b</sup>	4.58 $\pm$ 0.08 <sup>a</sup>	<0.001
C20:1 <i>n</i> -9	0.18 $\pm$ 0.01 <sup>b</sup>	1.92 $\pm$ 0.19 <sup>a</sup>	0.50 $\pm$ 0.04 <sup>c</sup>	<0.001
C18:2 <i>n</i> -6	28.71 $\pm$ 1.72 <sup>a</sup>	25.81 $\pm$ 0.79 <sup>a</sup>	20.41 $\pm$ 2.58 <sup>b</sup>	0.004
C18:3 <i>n</i> -6	0.08 $\pm$ 0.01 <sup>b</sup>	0.06 $\pm$ 0.00 <sup>c</sup>	0.14 $\pm$ 0.01 <sup>a</sup>	<0.001
C18:3 <i>n</i> -3	3.96 $\pm$ 0.22 <sup>a</sup>	0.76 $\pm$ 0.07 <sup>b</sup>	0.58 $\pm$ 0.04 <sup>b</sup>	<0.001
C20:2 <i>n</i> -6	0.15 $\pm$ 0.02 <sup>c</sup>	0.57 $\pm$ 0.03 <sup>a</sup>	0.35 $\pm$ 0.03 <sup>b</sup>	<0.001
C20:3 <i>n</i> -6	0.38 $\pm$ 0.04 <sup>b</sup>	0.27 $\pm$ 0.07 <sup>b</sup>	0.74 $\pm$ 0.09 <sup>a</sup>	<0.001
C20:3 <i>n</i> -3	0.23 $\pm$ 0.03 <sup>a</sup>	0.08 $\pm$ 0.00 <sup>b</sup>	0.10 $\pm$ 0.01 <sup>b</sup>	<0.001
C20:4 <i>n</i> -6	14.21 $\pm$ 1.18 <sup>a</sup>	4.99 $\pm$ 0.98 <sup>b</sup>	4.98 $\pm$ 0.61 <sup>b</sup>	<0.001
C20:5 <i>n</i> -3	1.52 $\pm$ 0.15 <sup>a</sup>	0.17 $\pm$ 0.06 <sup>b</sup>	0.25 $\pm$ 0.04 <sup>b</sup>	<0.001
C22:5 <i>n</i> -3	4.03 $\pm$ 0.27 <sup>a</sup>	0.76 $\pm$ 0.12 <sup>b</sup>	0.93 $\pm$ 0.14 <sup>b</sup>	<0.001
C22:6 <i>n</i> -3	0.47 $\pm$ 0.02 <sup>a</sup>	0.14 $\pm$ 0.02 <sup>b</sup>	0.14 $\pm$ 0.04 <sup>b</sup>	<0.001
$\Sigma$ Saturated Fatty Acids	32.20 $\pm$ 2.70 <sup>a</sup>	26.10 $\pm$ 0.74 <sup>b</sup>	34.71 $\pm$ 1.08 <sup>a</sup>	0.002
$\Sigma$ Monounsaturated Fatty Acids	14.06 $\pm$ 1.24 <sup>b</sup>	40.30 $\pm$ 1.59 <sup>a</sup>	36.67 $\pm$ 2.60 <sup>a</sup>	<0.001
$\Sigma$ Polyunsaturated Fatty Acids	53.74 $\pm$ 3.67 <sup>a</sup>	33.60 $\pm$ 2.14 <sup>b</sup>	28.62 $\pm$ 3.60 <sup>b</sup>	<0.001
$\Sigma$ Polyunsaturated Fatty Acids <i>n</i> -3	10.21 $\pm$ 0.70 <sup>a</sup>	1.90 $\pm$ 0.27 <sup>b</sup>	2.01 $\pm$ 0.27 <sup>b</sup>	<0.001
$\Sigma$ Polyunsaturated Fatty Acids <i>n</i> -6	43.53 $\pm$ 2.97 <sup>a</sup>	31.70 $\pm$ 1.87 <sup>b</sup>	26.26 $\pm$ 3.33 <sup>b</sup>	0.001

Means without a common superscript letter (<sup>a–c</sup>) in row significantly differ (Tukey's test, *p* < 0.05).

Compared to wild boar and pig meat, fallow deer meat was characterized by a high representation of *n*-3 PUFA, especially EPA, DPA, and DHA. Practically all organisms need *n*-3 PUFAs for growth, development, and survival [45]. DHA is essential for the growth and operation of the brain and eyes. EPA and DHA have a variety of physiological activities that are connected to various health and clinical advantages, especially in relation to cardiovascular disease, cancer, inflammation, and neurocognitive function [46]. Most often, a person receives them in the diet by consuming fish (herrings, salmon, mackerels) and other marine products or by their use in the administration of medicinal formulations or dietary supplements [47]. Since the consumption of *n*-3 PUFA in human diets is low, the consumption of fallow deer meat could help to make up for this deficit.

Desaturation, chain elongation, and peroxisomal beta-oxidation, which are all mediated by the enzymes  $\delta$ -6 and  $\delta$ -5 desaturase, chain elongation enzymes (elongases), and oxidase, can also be used to convert ALA to DHA and produce EPA and DHA. However, only a very small percentage of ALA in humans is converted to DHA. DHA is also referred to as a conditionally necessary fatty acid since vegetarians convert DHA at a rate of 3–8%, whereas omnivores convert it at a rate of just 1–3% [48]. In our experiment, the proportion of ALA in fallow deer meat was several times higher than in wild boar meat and pig meat.

The similarity of the fatty acid composition in wild boar and pig meat can be explained by their species' similarity. To differentiate between domestic and wild pig muscle tissues in meals requires a distinction at the subspecies level which is more difficult. Due to the strong homology between the domestic and wild pig genomes, there are extremely few subspecies-specific bases [9].

The nutritional value of meat depends on animal species, sex, age, and feeding management as well as the anatomical site. For health reasons, the ratio of PUFA to SFA in

meat is more significant than the amount of total fat present [41]. Table 5 shows the lipid nutritional quality index for meat samples. All the meat samples analyzed have the ratio of PUFA to SFA in accordance with the recommended value ( $>0.4$ ). Because they may cause blood cholesterol levels to rise, foods with polyunsaturated and saturated fatty acid ratios below 0.45 have been deemed unsuitable for human consumption [31]. In the LM, P/S ratios ranged from 0.51 in fallow deer to 0.97 in wild boars; in the SM, from 0.49 in fallow deer to 0.99 in wild boars; and in the TM, from 0.61 in pork to 1.04 in wild boars.

**Table 5.** The results of lipid nutritional quality indexes (IQN).

Lipids Nutritional Quality Indexes	Meat Samples	Fallow Deer	Wild Boar	Pig	<i>p</i> -Value
Polyunsaturated Fatty Acids/Saturated Fatty Acids ratio	Loin	$0.51 \pm 0.08^b$	$0.97 \pm 0.06^a$	$0.67 \pm 0.02^c$	$<0.001$
<i>n</i> -6/ <i>n</i> -3		$5.58 \pm 1.59^c$	$18.10 \pm 2.04^a$	$13.86 \pm 0.70^b$	$<0.001$
Atherogenicity Index		$0.54 \pm 0.06^a$	$0.27 \pm 0.02^c$	$0.37 \pm 0.00^b$	$<0.001$
Thrombogenicity Index		$1.00 \pm 0.18^a$	$0.70 \pm 0.08^b$	$0.92 \pm 0.03^{ab}$	0.044
Peroxidability Index		$99.40 \pm 24.63^a$	$57.52 \pm 12.73^b$	$52.31 \pm 3.76^a$	0.022
Hypocholesterolemic/Hypercholesterolemic ratio		$2.51 \pm 0.02^b$	$3.87 \pm 0.30^a$	$2.74 \pm 0.07^b$	$<0.001$
Polyunsaturated Fatty Acids/Saturated Fatty Acids ratio	Shoulder meat	$0.49 \pm 0.03^c$	$0.99 \pm 0.02^a$	$0.59 \pm 0.03^b$	$<0.001$
<i>n</i> -6/ <i>n</i> -3		$3.94 \pm 0.45^c$	$17.57 \pm 0.54^a$	$12.46 \pm 0.42^b$	$<0.001$
Atherogenicity Index		$0.43 \pm 0.06^a$	$0.26 \pm 0.00^b$	$0.36 \pm 0.01^a$	$<0.001$
Thrombogenicity Index		$0.86 \pm 0.01^a$	$0.67 \pm 0.02^b$	$0.86 \pm 0.03^a$	$<0.001$
Peroxidability Index		$101.37 \pm 12.10^a$	$64.19 \pm 11.91^b$	$46.08 \pm 3.64^b$	0.001
Hypocholesterolemic/Hypercholesterolemic ratio		$2.95 \pm 0.18^b$	$4.05 \pm 0.05^a$	$2.94 \pm 0.07^b$	$<0.001$
Polyunsaturated Fatty Acids/Saturated Fatty Acids ratio	Thigh meat	$1.03 \pm 0.03^a$	$1.04 \pm 0.01^a$	$0.61 \pm 0.06^b$	$<0.001$
<i>n</i> -6/ <i>n</i> -3		$4.26 \pm 0.00^c$	$16.77 \pm 1.41^a$	$13.28 \pm 0.15^b$	$<0.001$
Atherogenicity Index		$0.23 \pm 0.02^b$	$0.22 \pm 0.00^b$	$0.38 \pm 0.02^a$	$<0.001$
Thrombogenicity Index		$0.53 \pm 0.01^b$	$0.61 \pm 0.02^b$	$0.92 \pm 0.07^a$	$<0.001$
Peroxidability Index		$132.40 \pm 9.81^a$	$56.36 \pm 6.28^b$	$52.96 \pm 6.86^b$	$<0.001$
Hypocholesterolemic/Hypercholesterolemic ratio		$4.92 \pm 0.32^a$	$4.79 \pm 0.09^a$	$2.79 \pm 0.15^a$	$<0.001$

Means without a common superscript letter (<sup>a-c</sup>) in row significantly differ (Tukey's test,  $p < 0.05$ ).

A risk factor for cancer and coronary heart disease, particularly the development of blood clots that result in heart attacks, is the ratio of *n*-6/*n*-3 PUFA. Again, certain meats have ratios higher than this, which is why less than 4.0 is advised [49]. The PUFA *n*-6/*n*-3 ratio in FD meat which ranges from 3.94 to 5.58 is close to the suggested values, indicating that these species may be considered good for promoting human health. With the exception of SM from fallow deer, which had an *n*-6/*n*-3 ratio of 3.94, all types of meat in the current investigation had a higher value than 4.0.

If the large proportion of  $\Sigma$  PUFA is out of balance with the  $\Sigma$  PUFA *n*-6/*n*-3 ratio, it may not necessarily be good. Meat from animals that have consumed grass and have high amounts of a C 18:3 *n*-3 has a favorable  $\Sigma$  PUFA *n*-6/*n*-3 ratio. The main fatty acids regulating the hypocholesterolemic index are the polyunsaturated fatty acids (PUFA) *n*-6 and *n*-3 and their ratio ( $\Sigma$  PUFA *n*-6/*n*-3). While *n*-6 predominates in the atherogenic ones, *n*-3 plays a significant function in controlling the thrombogenic index. Low AI and TI and a high *h*/*H* index are characteristics of a healthy animal product [50].

The link between the primary SFA (pro-atherogenic) and the main MUFA and PUFA is expressed by the atherogenicity index (AI) (anti-atherogenic). The ratio of pro-thrombogenic SFA to anti-thrombogenic MUFA and PUFA is known as the thrombogenicity index (TI) [28]. AI and TI that are less than 1.0 and 0.5 in the diet, respectively, are advised for human



health [29]. All the meat samples we analyzed had an AI within the acceptable range, unlike the TIs that were higher than the acceptable range.

The link between a tissue's fatty acid profile and its susceptibility to oxidation is represented by the peroxidizability index (PI) which identifies the technological quality of meat. However, the higher the PI value, the better the preventive potential for coronary artery disorders. The PI index is used to evaluate the stability of PUFA incorporated in food products and to protect them from potential oxidation processes. Due to their high vulnerability to lipid peroxidation, PUFA consumption in excess might have adverse effects such as oxidative stress. It has been proposed that oxidative stress, which is linked to the generation of lipid peroxides, contributes to the pathogenic processes in aging and numerous diseases including atherosclerosis [50]. Each sample of fallow deer meat had higher PI levels. The flesh of fallow deer may have a higher health value if it contains more *n*-3 PUFA and has a high PI value. Low PI values in wild boars and pigs indicate little oxidation of the meat's fatty acids and, therefore, long storage times. The *h*/*H* ratios showed a larger percentage of fatty acids with low cholesterol. The wild boar meat samples showed the highest *h*/*H* levels. Low AI and TI and a higher *h*/*H* index are characteristics of an animal product that is of good quality [50]—both of which are fulfilled by the fallow deer meat samples in our experiment.

According to the existence and/or composition of the variables, the tendency of meat to lipid peroxidation is affected by the species of animal, kind of muscle, and anatomical site [51]. Lipid oxidation is a spontaneous and unavoidable process taking place during postmortem aging [52] and does not stop during long-term freezer storage.

The results of malondialdehyde determination in samples while being stored in vacuum packages are shown in Table 6. On the first day of this experiment, the lowest MDA values in pig meat were measured in the LM samples. On the 180th day of storage, an increased content of MDA in PM samples was observed followed by a decrease until the 360th day of the experiment. In WB meat samples, a decrease in MDA content was detected up to the 270th day and a repeated increase on the 360th day of storage. In FD meat during storage, a gradual decrease of MDA was noted during the first 270 days of the experiment.

**Table 6.** The results of malondialdehyde determination in meat samples during storage at vacuum conditions (MDA mg/kg, mean  $\pm$  SD).

Meat Sample	Storage (Days)	Fallow Deer	Wild Boar	Pig	<i>p</i> -Value
Loin meat	0	0.115 $\pm$ 0.01 <sup>a</sup>	0.054 $\pm$ 0.01 <sup>b</sup>	0.025 $\pm$ 0.00 <sup>c</sup>	<0.001
	90	0.098 $\pm$ 0.02 <sup>a</sup>	0.054 $\pm$ 0.00 <sup>b</sup>	0.034 $\pm$ 0.01 <sup>b</sup>	<0.001
	180	0.086 $\pm$ 0.01 <sup>a</sup>	0.055 $\pm$ 0.01 <sup>b</sup>	0.063 $\pm$ 0.00 <sup>b</sup>	0.009
	270	0.082 $\pm$ 0.01 <sup>a</sup>	0.044 $\pm$ 0.01 <sup>b</sup>	0.055 $\pm$ 0.01 <sup>b</sup>	0.004
	360	0.084 $\pm$ 0.01 <sup>a</sup>	0.063 $\pm$ 0.01 <sup>ab</sup>	0.041 $\pm$ 0.01 <sup>b</sup>	0.008
Shoulder meat	0	0.060 $\pm$ 0.01 <sup>a</sup>	0.038 $\pm$ 0.00 <sup>b</sup>	0.034 $\pm$ 0.00 <sup>b</sup>	0.003
	90	0.139 $\pm$ 0.01 <sup>a</sup>	0.045 $\pm$ 0.00 <sup>b</sup>	0.055 $\pm$ 0.00 <sup>b</sup>	<0.001
	180	0.065 $\pm$ 0.02	0.062 $\pm$ 0.00	0.058 $\pm$ 0.01	0.781
	270	0.076 $\pm$ 0.02 <sup>a</sup>	0.050 $\pm$ 0.00 <sup>b</sup>	0.053 $\pm$ 0.00 <sup>b</sup>	0.024
	360	0.048 $\pm$ 0.00 <sup>b</sup>	0.075 $\pm$ 0.02 <sup>a</sup>	0.044 $\pm$ 0.01 <sup>b</sup>	0.021
Thigh meat	0	0.049 $\pm$ 0.00	0.045 $\pm$ 0.01	0.054 $\pm$ 0.01	0.237
	90	0.096 $\pm$ 0.02 <sup>a</sup>	0.056 $\pm$ 0.00 <sup>b</sup>	0.061 $\pm$ 0.01 <sup>ab</sup>	<0.001
	180	0.141 $\pm$ 0.02 <sup>a</sup>	0.074 $\pm$ 0.02 <sup>b</sup>	0.106 $\pm$ 0.02 <sup>ab</sup>	0.024
	270	0.089 $\pm$ 0.01 <sup>a</sup>	0.058 $\pm$ 0.00 <sup>b</sup>	0.102 $\pm$ 0.01 <sup>a</sup>	0.001
	360	0.068 $\pm$ 0.01	0.061 $\pm$ 0.01	0.054 $\pm$ 0.00	0.136

Means without a common superscript letter (<sup>a-c</sup>) in row significantly differ (Tukey's test, *p* < 0.05).

In the SM meat samples of PM and WB, there was a lower MDA content than in FD. The MDA values rose up to the 90th day of storage in the vacuum-packed samples. On the 360th day the lowest values were measured in FD of PM samples.

The lowest MDA content was recorded on the initial day of the trial in the TM samples of WB. During storage, the increase of MDA was up to the 180th day of storage. Subsequently, MDA content in meat samples decreased until the end stage of the trial. At the end of the trial, comparable MDA values were measured in all TM samples.

The increase in MDA values determined during storage and TBA in pig meat samples stored over 180 days are comparable to Huang et al. [53].

The rise of MDA values is a sign that the meat lipids have been oxidized [54]. The rise in MDA content up to the 180th day of storage can be explained by the gradual transformation of primary oxidation products (hydroperoxides) into secondary oxidation products (hydrocarbons, alcohols, aldehydes, and fatty acids) where MDA is the main secondary product that is produced in the largest amount during the oxidative degradation of lipids. The decrease in MDA can be explained by the effect of vacuum packaging when access to air is prevented and further oxidation processes do not occur. Substances reacting with TBA as well as MDA reached threshold levels, then started to break down and interact with other substances resulting in lower values when kept for a long time [55]. Meat samples were vacuum-packed before being frozen which, according to Daszkiewicz et al. [11], likely reduced the extent of oxidative alterations during storage. In addition to TBARS, Maqsood et al. [53] also determined the peroxide value in the packaged meat—the peroxide values first increased slightly and then increased significantly which is related to the accumulation of primary oxidation products and their more rapid decomposition into secondary oxidation products. This corresponds with lower TBARS values in the vacuum-packed meat which may have been due to the unavailability of oxygen at the stage of propagation of lipid oxidation.

Higher MDA values at the start of the trial may be influenced by slaughter conditions or slaughter stress. Cifuni et al. [21] described the effect of pre-slaughter stress on meat quality and stability of meat in farmed ungulates. Stress is directly related to the lipid oxidation in animal muscles. Physical activity before killing increases the concentration of oxygen-containing free radicals in tissues, accelerating lipid oxidation. Moreover, the increased level of lipid oxidation in wild boars and game may be caused by stress caused by the hunting methods.

The MDA content in our experiment varied from 0.025 to 0.141 mg·kg<sup>−1</sup>. The amount of MDA did not exceed the value of 2 mg of MDA/kg during freezer storage. Several authors [56–60] state that only MDA values above 2.0 mg·kg<sup>−1</sup> in meat and meat products causes a lack of acceptance of the flavor profile by consumers as oxidative deterioration of meat lipids has occurred.

Table 7 shows the results of the multiway ANOVA MDA determination. The factors of meat cuts, types, and storage significantly affected the lipid oxidation processes in meat samples ( $p < 0.001$ ).

**Table 7.** The results of multiway ANOVA analysis.

Factors	Multi-Way ANOVA Table			
	Sum Sq	Df	F Value	<i>p</i> -Value
Meat cuts	0.005	2	22.197	<0.001
Meat type	0.028	2	123.511	<0.001
Storage	0.011	4	24.793	<0.001
Meat cuts: Meat type	0.006	4	13.191	<0.001
Meat cuts: Storage	0.013	8	14.480	<0.001
Meat type: Storage	0.013	8	14.101	<0.001
Meat cuts: Meat type: Storage	0.013	16	6.677	<0.001

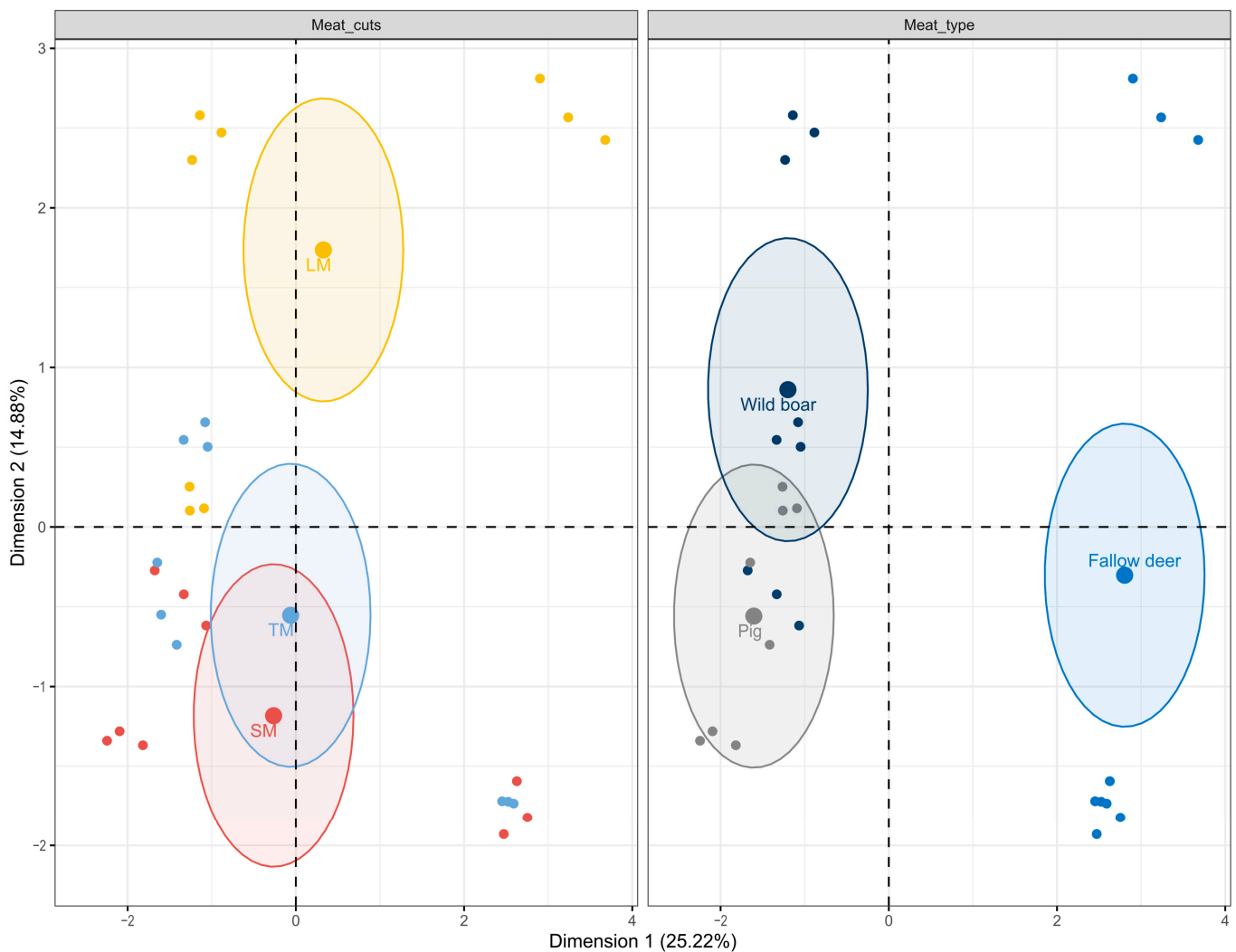
We used MFA statistical analysis to identify the number of final factors that were different from the first ones from the findings we acquired regarding physicochemical variables, lipid oxidation variables, and fatty acid variables identified on the first day of the experiment. The results of the MFA analysis revealed that four extracted components explain more than 67% of the total variation in the data set for distinct meat types (fallow deer, wild boar, and pig) and meat cuts (loin, shoulder, and thigh meat). The first dimension (Dim1) accounts for 25.22 percent, the second (Dim2) 14.88 percent, the third (Dim3) 14.22 percent, and the fourth (Dim4) 13.04 percent.

The results of Dim1 belonged mainly to the fatty acid variables (23.42%  $r = 0.98$ ) and physicochemical parameters of meat samples (16.42%  $r = 0.82$ ). The correlated variables in Dim1 included C12:0, lauric acid ( $r = -0.365$ ), C14:0, myristic acid ( $r = 0.638$ ), C16:0, palmitic acid ( $r = -0.380$ ), C18:0, stearic acid ( $r = 0.936$ ), C20:0 ( $r = 0.649$ ), C22:0 ( $r = 0.766$ ), C16:1  $n-9$ , palmitoleic acid ( $r = 0.292$ ), C16:1  $n-7$ , palmitoleic acid ( $r = -0.713$ ), C18:1  $n-9$ , oleic acid ( $r = -0.913$ ), C18:1  $n-7$ , vaccenic acid ( $r = -0.850$ ), C20:1  $n-9$  ( $r = -0.596$ ), C18:2  $n-6$ , linolenic acid ( $r = -0.124$ ), C18:3  $n-6$ , gamma-linolenic acid ( $r = -0.364$ ), C18:3  $n-3$ , alfa-linolenic acid ( $r = 0.862$ ), C18:4  $n-3$  ( $r = 0.862$ ), C20:2  $n-6$  ( $r = -0.892$ ), C20:3  $n-6$ , dihomogamma linolenic acid ( $r = -0.484$ ), C20:3  $n-3$  ( $r = 0.476$ ), C20:4  $n-6$ , arachidonic acid ( $r = 0.942$ ), C20:5  $n-3$ , eicosapentaenic acid ( $r = 0.839$ ), C22:5  $n-3$ , docosapentaenic acid ( $r = 0.916$ ), C22:6  $n-3$ , docosahexaenic acid ( $r = 0.812$ ),  $\Sigma$  saturated fatty acids ( $r = 0.614$ ),  $\Sigma$  monounsaturated fatty acids ( $r = -0.914$ ),  $\Sigma$  polyunsaturated fatty acids ( $r = 0.644$ ),  $\Sigma$   $n-3$  polyunsaturated fatty acids ( $r = 0.885$ ),  $\Sigma$   $n-6$  polyunsaturated fatty acids ( $r = 0.438$ ), water content ( $r = 0.780$ ), dry matter content ( $r = -0.780$ ), and fat content ( $r = -0.676$ ).

At a statistically significant level ( $p < 0.05$ ), each reported variable of Dim1 was correlated. The values of the MDA concentration of the meat samples (12.06%,  $r = 0.538$ ) were used to represent the lipid oxidation variable which made up the majority of Dim2's representation. In Dim1 and Dim2, a total variation of 40.10% was explained (Figure 1). Figure 2 shows the extracted factors of the meat samples that were associated in Dim1 and Dim2. With 35.42% ( $r = 0.90$ ) and 43.56% ( $r = 0.99$ ), respectively, the parameters of meat type and samples had a significant contribution to Dim3. Similarities of meat type (wild boar and pork) and meat cuts (SM and TM) in the analyzed variables was observed. SM with TM samples were not plotted closely to LM samples, meaning that these samples differed in analyzed variables and characteristics. Similarly, meat samples of fallow deer were plotted at a farther distance from the other analyzed meat types, meaning that the meat of fallow deer differed from the others in regards to the analyzed variables.

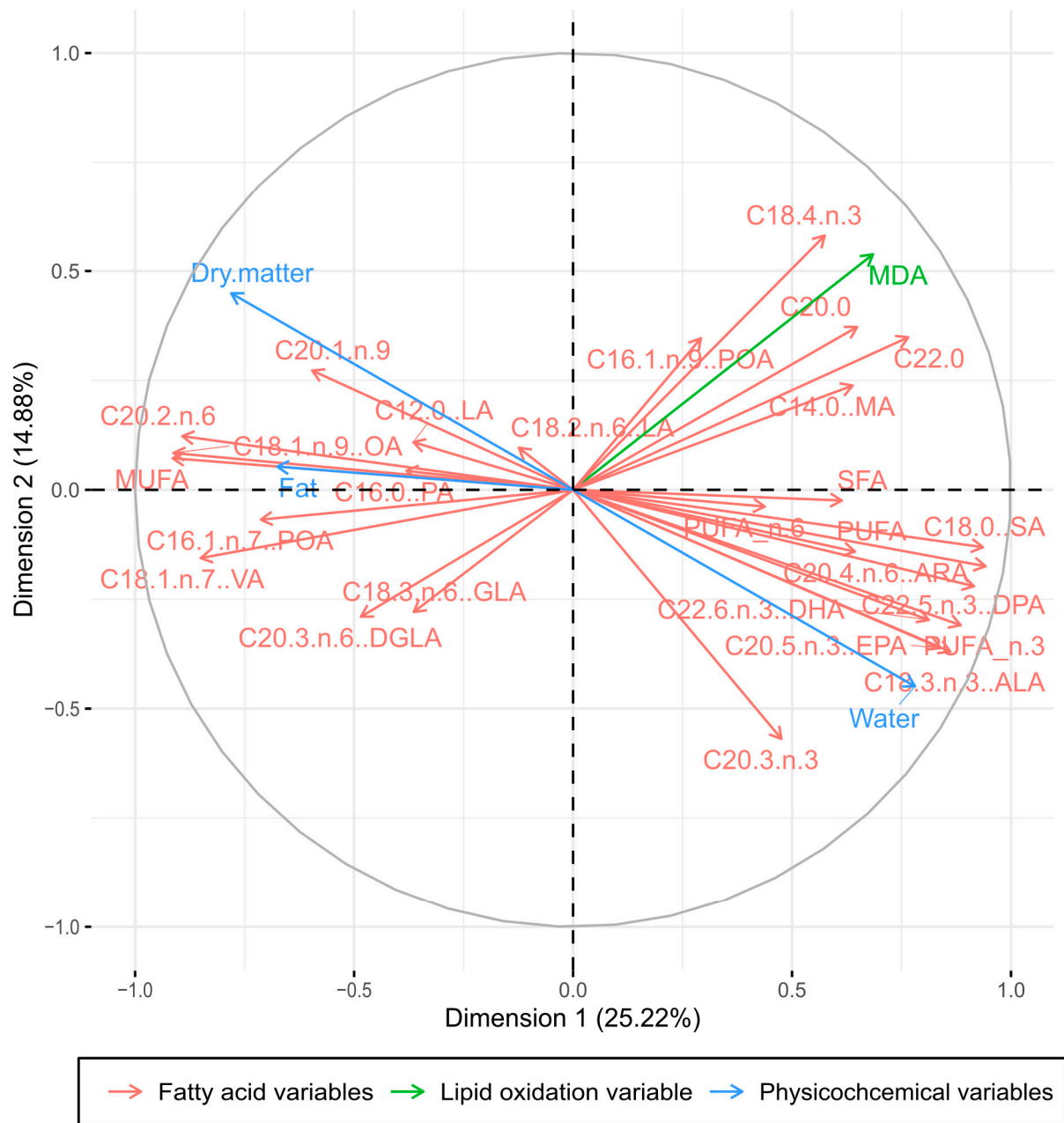
Due to the lower proportion of SFA and a three times higher proportion of PUFA in muscle lipids of deer species, they may provide meat that is more favorable for human consumption [2]. The feed, sex, age, fatness of the animal, the hunting season, the hunting system, and aspects in the slaughtering and carcass or meat conservation processes are only a few of the many variables that affect the quality of wild ungulate meat [61].

The availability of game meat is restricted by the hunting season and is far more time-consuming and skill-dependent than the preparation of pork [12]. Deer farms and the natural environment (deer are a game species) are the two sources of venison in Europe [62]. Compared to wild game, farmed meat has several advantages, in particular, the possibility of regular year-round deliveries of fresh products to the commercial network and a guarantee of a certain quality standard for slaughter and processing including requirements for tracing the origin of the animal. Due to the possibility of controlled nutrition and feeding with concentrated feeds, animals bred in this way grow faster and their meat usually contains a higher amount of intramuscular fat and often shows more favorable textural characteristics such as tenderness and juiciness [43,63].



**Figure 1.** The combined graph of individuals with visualized meat cuts and meat type factors. LM: loin meat; SM: shoulder meat; TM: thigh meat samples.

Due to the rising demand of consumers for free-range meat products, FD are enjoying new popularity and the number of deer farms is increasing all over the world. The increasing industrial meat production significantly affects the environment and also animal welfare. Additionally, industrially produced meat from deer bred on farms is advantageous for a constant production and supply of high quality meat [5]. Fallow deer is the most common cervid species farmed in Europe. Eating fallow deer meat can help increase the consumption of *n*-3 polyunsaturated fatty acids, particularly, EPA, DPA, and DHA fatty acids. The beneficial effects of *n*-3 PUFA are in the prevention, delay, and intervention of various diseases such as coronary artery diseases, hypertension, inflammatory and autoimmune disorders, neurodegenerative diseases, depression, and many other diseases [64].



**Figure 2.** The correlation circle of analyzed variables.

#### 4. Conclusions

The results of the presented study show that from the dietary point of view, the meat of fallow deer is the most suitable due to its low fat and high PUFA level (mainly LA (C18:2, *n*-6) and ALA (C18:3, *n*-3) but also EPA, DHA, DPA fatty acids). The most valuable and optimal PUFA/SFA, *n*-6/*n*-3 and h/H ratios and lipid nutritional quality indices (PI, AI, and TI) for human consumption were observed in samples of fallow deer. From the lipid oxidation point of view, the consumption of fresh meat is more suitable than long-term stored meat; however, vacuum packaging could ensure a lower level of lipid oxidation in stored meat.



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