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Physicochemical Characteristics of Pork Liver Pâtés Containing Nonthermal Air Plasma-Treated Egg White as an Alternative Source of Nitrite

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Featured Application: The practical application of plasma-treated egg whites in the production of liver pâtés is to introduce nitrite ions to the product. Nitrite is an important ingredient in the production of meat products because it improves color, taste, and safety by inhibiting lipid oxidation, for example. The use of plasma-activated egg whites in the production of liver pâtés could be of industrial importance, as it has the potential to reduce the ingredient list, production time, and cost, and thus could make liver pâtés more competitive in the market.

Abstract: The use of nonthermal air plasma is rapidly becoming a novel technology as an alternative source of nitrites in the meat industry. As egg white is a versatile and cost-effective ingredient commonly used to improve the texture of meat products, the effect of its addition after plasma treatment (PTEW) on the yield, pH, residual nitrite, nitrosyl hemochrome, TBARS, color, texture parameters, and aroma profile of pork liver pâtés was studied. The nitrite ion content of plasma-activated egg whites was adjusted to the positive controls containing 60 ppm (PC1) and 120 ppm (PC2) sodium nitrite by modifying the duration of their plasma treatment (PTEW1 and PTEW2, respectively). A group without the addition of nitrites was also manufactured (NC). Each treatment (NC, PC1, PC2, PTEW1, PTEW2) was analyzed on days 1, 3, 5, and 7 of storage at 4 °C. The results showed that liver pâtés containing plasma-treated egg whites had a similar nitrite and nitrosyl hemochrome content compared to samples containing the same amount of nitrite ions derived from sodium nitrite ($p \geq 0.05$). In addition, 40 ppm nitrite ions, regardless of the source, was sufficient to achieve the desired reddish-pink color of the product over the entire storage period. Both nitrites from sodium nitrite and plasma-treated egg whites also significantly reduced lipid oxidation compared to the NC group (between 10% and 23% reduction on the last day), but had no significant effect on yield, pH, and texture parameters of the products. Based on the principal component analysis (PCA), the aroma profile of pâtés differed significantly between the groups with and without nitrites, with the largest differences observed on the first day (approx. 88%). Importantly, PTEW1 and PTEW2 aroma after production was similar to group PC2. The results of our study suggest that plasma-activated egg whites can be used as a potential source of nitrite in liver pâté production without adversely affecting the technological properties and shelf life of the final product.

Keywords: pork liver pâté; curing; sodium nitrite; egg white; atmospheric non-thermal plasma; plasma treatment; residual nitrite; quality

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1. Introduction

The improvement and development of traditional food processes is mainly motivated by the improvement of food quality, as well as consumer demands for greater food variety.

Novel food technologies are being developed to enhance food safety, prolong shelf life, and optimize the preservation of critical quality features, in response to these challenges. The application of cold plasma as a nonthermal technology has great potential, and is therefore currently of great interest to the food industry [1–3].

Cold plasma, a gas that is partially ionized by applying energy to it at atmospheric or subatmospheric pressures, contains a mixture of ions, electrons, free radicals, and ultraviolet photons [4]. The food industry has extensively adopted this technology for direct or indirect food treatment, primarily as a nonthermal processing method for food preservation and decontamination [3]. This is because the reactive species present in plasma, including ozone, hydrogen peroxide, other free radicals, and UV radiation, can impair the cell walls, membranes, and DNA of microorganisms, leading to their destruction [5]. In recent years, many studies have indicated that nitrite ions produced by plasma can provide comparable functionality to sodium nitrites [6–11]. This is due to the fact that, during the discharge of a feed gas consisting of N_2 and O_2 molecules, collisions with electrons occur, leading to the formation of various nitrite oxides (such as NO_2, N_2O_3, and N_2O_5). These oxides then react with water in food matrices, creating nitric and nitrate acids, which finally decompose primarily into nitrites [9,12]. So far, the quality of conventional cured meat products (with sodium nitrite) has been compared with the quality of those subjected to direct nonthermal plasma treatment [11,13,14] or those containing ingredients produced using cold plasma, such as water [9,15–17], winter mushrooms [10], onion [18], milk [19,20], as well as soy and pea protein solutions [21]. The above studies have demonstrated promising results for alternative curing methods using nonthermal atmospheric plasma, taking into account both the physicochemical and microbiological properties of the finished products.

Liver pâtés are traditional meat products that are still popular in many countries, mainly in Europe [22,23]. Although they are characterized by numerous modifications of recipes (different types and proportions of raw materials, functional and seasoning additives) and technological process parameters that affect their quality and sensory characteristics, they are distinguished by the fact that their main ingredients are liver, fat, and meat [24]. Thanks to the use of appropriate technological processes, pâtés have good taste and a smooth texture [25]. Liver pâtés, in addition to proteins, could also contain minerals and vitamins such as calcium, copper, iron, zinc, magnesium, or vitamins B and A [26], making them both sensory acceptable and nutritious. The main advantage of this kind of product is the rich content of vitamin B_{12}, which, among other things, is involved in DNA synthesis, supports the nervous system, cardiovascular system, and energy metabolism [27]. The fact that they can be eaten both hot and cold has made liver pâtés a popular choice for consumers who are looking for convenient and ready-to-eat products [26].

Nevertheless, due to the high iron and fat content in the composition of liver pâtés, along with the high degree of processing involved in their production, they are extremely susceptible to lipid oxidation [28,29] which could degrade their sensory quality by producing off-flavors, as well as changing their color and texture [30]. Taking this into account, producers usually add chemical preservatives to liver pâtés, not only to prevent bacterial growth, but also to extend shelf life by delaying oxidative processes of these high-fat products during storage. Among these types of functional additives, sodium nitrite is the most common [29]. The use of nitrite ions, with proven antimicrobial and antioxidant properties, also leads to the creation of a characteristic aroma and pinkish color of heat-treated products as a result of the formation of nitrosyl derivatives of heme dyes [31–34]. All of this makes sodium nitrite difficult to replace with other substances, although the literature indicates that its excessive consumption may be associated with various health problems, including an increased risk of cancer and cardiovascular disease [34–37].

Other important ingredients in liver pâté production are emulsifiers and binders, which create a stable emulsion from the liver pâté stuffing, resulting in a product with a good texture. One of the most popular natural emulsifiers is lecithin, which is contained in egg yolk [38]. Egg white (EW) is also characterized by specific emulsifying properties, and in addition, it can form a gel, hold water, and create foam [39–41]. From a nutritional

standpoint, it is a good source of protein and low in fat [42]. Due to its essential amino acid content, high bioavailability, and diverse functional properties, EW is widely used in food research [43], and is also cost-effective [44]. However, as noted by Razi et al. [44], the properties of egg white can be influenced by various factors, including pH, ionic strength, and temperature. This study is motivated by the increasing restrictions on nitrite use and the need for alternative preservation methods in food processing. Based on our previous studies on the in situ production of nitrites in selected plant and animal protein solutions using nonthermal atmospheric plasma [19–21], the authors wanted to investigate whether plasma-treated egg white (PTEW) could be used as a substitute for sodium nitrite without losing functional properties or affecting the aroma of meat products, such as liver pork pâté, which is particularly susceptible to oxidation. So far, no similar studies have been conducted. Thus, two experimental groups, PTEW1 and PTEW2, were compared to a nitrite-free group (negative control—NC) and two groups cured with 60 ppm (PC1) and 120 ppm (PC2) sodium nitrite (positive controls) during a 7 day storage period at 4 °C. The comparison was made with consideration to the commonly used levels of nitrites in pâté processing and the maximum permissible amounts allowed for these types of products in Denmark, given the increasing restrictions on nitrite use [45].

2. Materials and Methods

2.1. Materials and Reagents

Pork liver, pork lard, shoulder, and seasonings were purchased locally, while analytical grade chemicals and reagents were obtained from Sigma-Aldrich Co., Ltd. (St. Louis, MO, USA).

2.2. Cold Plasma Treatment of Egg Whites

In a preliminary study, the nitrite content of plasma-activated egg whites (PTEW1 and PTEW2) was determined and adjusted to the positive controls (PC1 and PC2) by modifying the plasma treatment duration. A total of 160 g of egg whites was treated with an atmospheric pressure air plasma jet system with barrier discharge operating at 20 kHz (Plasma-beam; Diener Electronic, Baden-Württemberg, Germany). Each time, a stream of plasma with a flow rate of 2 m^3/h was placed 15 cm above the sample, which was mixed with a magnetic stirrer (350 rpm). After various durations of plasma treatment, and being made up with water to 160 g, the samples were analyzed for nitrite content using the AOAC method (no. 973.31) modified by Lee et al. [46]. Target plasma treatment times were selected to achieve nitrite ion concentrations of approximately 500 ppm (100 min—the average of three batches: 507 ± 30 ppm NO_2^-) and 1000 ppm (200 min—the average of three batches: 1018 ± 31 ppm NO_2^-) in egg whites, enabling the introduction of 40 mg and 80 mg of nitrite ions, respectively, to liver pâté with 8% egg whites per kg of stuffing (equivalent to 60 ppm and 120 ppm of sodium nitrite). The pH of the egg whites after plasma treatment remained above 6.

2.3. Pork Liver Pâté Preparation

Liver pâtés were produced in a laboratory of Department of Technique and Food Development (Institute of Human Nutrition Sciences, Warsaw University of Life Sciences) in three separate batches at weekly intervals at the turn of November and December 2022. Depending on the content and source of the nitrite used for the manufacture of pâtés, five different formulations were considered: NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 mg NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 mg NO_2^-.

Before processing the pâtés, the livers were soaked for 15 min in cold water, and the lard was scalded with hot water for 10 min. For the preparation of batters, pork shoulder, pork lard, and liver were cut into 3 cm cubes and homogenized for 3 min in a

bowl cutter (Robot Coupe R2A, Vincennes, France). The spices and other ingredients were then added and the process continued for 2 min. The formulations of individual groups are presented in Table 1. The obtained batters, weighing approximately 270 ± 10 g, were placed into aluminum molds and thermally treated at 180 °C in a convection oven (CPE 110 Küppersbuch, Gelsenkirchen, Germany) until the internal temperature of each sample reached 72 °C. The liver pâtés were then cooled in air for 30 min at about 10 °C. After reaching room temperature, each sample was covered with stretch film and stored at 4 °C. The samples were analyzed after 1 (24 h after production), 3, 5, and 7 days of storage.

Table 1. Experimental liver pâté recipes.

Ingredients (%)	Group [1]				
	NC	PC1	PTEW1	PC2	PTEW2
pork shoulder	40	40	40	40	40
pork lard	40	40	40	40	40
pork liver	20	20	20	20	20
egg white	8	8	-	8	-
egg white treated by air plasma for 100 min	-	-	8	-	-
egg white treated by air plasma for 200 min	-	-	-	-	8
egg yolk	4	4	4	4	4
salt	2	2	2	2	2
white pepper	0.2	0.2	0.2	0.2	0.2
garlic	0.03	0.03	0.03	0.03	0.03
thyme	0.03	0.03	0.03	0.03	0.03
nutmeg	0.03	0.03	0.03	0.03	0.03
sodium nitrite	-	0.006	-	0.012	-

[1] NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-.

2.4. Analytical Methods

2.4.1. Product Yield

The yield of the product was calculated by dividing the weight of the liver pâtés after heat treatment by their weight before heat treatment, and multiplying the result by 100:

$$PY = (W_{bht}/W_{aht}) \times 100\ (\%) \quad (1)$$

where: PY—product yield (%); W_{bht}—weight of the liver pâtés before heat treatment (g); W_{aht}—weight of the liver pâtés after heat treatment (g).

2.4.2. pH Measurement

The pH of the egg whites after plasma treatment was measured using a FiveEasyTM F20 benchtop pH meter (Mettler Toledo, Columbus, OH, USA), while the pH changes in the liver pâtés were measured using a Testo 205 pH/temperature measuring instrument (Testo, Lenzkirch, Germany). Prior to the measurements, calibration was conducted using standardized buffers with pH values of 4.01 and 7.00 at room temperature. For each sample, three measurements were taken.

2.4.3. Residual Nitrite Content

The modified method of Lee et al. [46] was used to measure the nitrite content in plasma-treated egg whites and liver pâtés. Samples weighing 10 g were mixed with hot water (150 mL, 80 °C), sodium hydroxide (10 mL, 0.5 M), and zinc sulfate (10 mL, 12%). Following heating in a shaking water bath at 80 °C for 20 min, cooling for 10 min in tap water, and thorough mixing with 20 mL of 10% ammonium acetate with a pH of 9.1 that had been adjusted using ammonia water, all solutions were filtered using Whatman no. 1 filter paper. The obtained filtrates (20 mL) were mixed with sulfanilamide in an acid solution (1 mL; 30 mmol/L) and N-(1-naphthyl)ethylenediamine dihydrochloride (1 mL, 5 mmol/L), and diluted to 25 mL with deionized water before being analyzed with a spectrophotometer

(SparkTM 10M, Tecan Group, Männedorf, Switzerland) at 540 nm. The residual nitrite content was calculated using a calibration curve prepared from the absorbance readings of sodium nitrite standard solutions, with three measurements taken for each sample.

2.4.4. Nitrosyl Hemochrome Content

To determine the nitrosyl hemochrome content in liver pâtés, a slightly modified method of Lee et al. [46] was used. Samples weighing 5 g were homogenized with water (1.5 mL) and acetone (20 mL) using a homogenizer (Ultra Turrax T18 basic, IKA Werke, Germany), and their absorbance, after being stored for 15 min in the dark, was measured at 540 nm to calculate the nitrosyl hemochrome concentration (ppm). Total pigment concentration (ppm) was calculated by measuring the absorbance at 640 nm of samples (5 g) after homogenization with water (1 mL), HCl (0.5 mL), acetone (20 mL), and storage for 1 h in the dark. The result was then multiplied by 680. The nitrosyl hemochrome content (%) was obtained by dividing the nitrosyl hemochrome concentration by the total pigment concentration, and multiplying by 100. Three replicates were conducted for each sample.

2.4.5. Instrumental Color Parameters

The color parameters of the liver pâtés were determined by using a Minolta chromometer (CR-400, Konica Minolta Inc., Tokyo, Japan) with a standardized light source (D65 illuminator), an observation angle of 2°, and a spot diameter of 8 mm. The samples were cut crosswise, and the color of their inner surface was immediately measured. Prior to measurements, the equipment was calibrated using the white standard calibration plate ($L^* = 98.45$, $a^* = -0.10$, $b^* = -0.13$). All samples were assessed for lightness (L*), redness (a*), and yellowness (b*) values, with three measurements taken from random places on each sample.

2.4.6. Lipid Oxidation

TBARS in liver pâtés were analyzed by modifying the method of Pikul et al. [47], as described by Marcinkowska-Lesiak et al. [21]. Samples weighing 5 g from each group were homogenized with 50 mL of trichloroacetic acid (20% by volume, acidified with 1.6% concentrated phosphoric acid) and 2.5 mL of an antioxidant solution. After filtering with Whatman no. 1 filter paper and diluting with an ethanol:water mixture, 5 mL of TBA solution was added to the filtrate, heated, cooled, and centrifuged. Absorbances at 532 nm were measured with a microplate reader (SparkTM 10M, Tecan Group, Switzerland), and TBARS values (mg malonaldehyde equivalent/kg sample) were calculated using a standard curve prepared from 1,1,3,3-tetramethoxypropane. Samples were analyzed in triplicate.

2.4.7. Instrumental Texture Parameters

A universal testing machine (Instron 5965, Norwood, MA, USA) with a cylindrical probe with a diameter of 40 mm was used to perform the texture profile analysis (TPA). Cube-shaped samples (2 cm × 2 cm × 2 cm) from each group were subjected to two cycles of 50% compression (head speed—200 mm/min and cell capacity—500 N). The texture properties of the samples were determined, including hardness (N), adhesiveness (J/cm^2), cohesiveness (−), springiness (−), and gumminess (N). Three replicates were performed for each sample.

2.4.8. Analysis of Volatile Compounds

An electronic nose (Heracles II, Alpha M.O.S., Toulouse, France) was used to perform the aroma analysis of liver pâtés. Samples weighing 2 g were placed in 20 mL headspace vials and capped with Teflon-faced silicon rubber, following the method of Wojtasik-Kalinowska et al. [48]. The analysis was performed in triplicate. Specific volatile compounds were identified with reference to database of compounds for aroma and chemical analysis (AroChemBase, Alpha MOS Co., Toulouse, France).

2.5. Statistical Analysis

Statistica 13.3 software (StatSoft Inc., Tulsa, OK, USA) was used to analyze the obtained data using a general linear model with treatment and storage times as fixed effects and replications as random effects. Product yield results were subjected to one-way ANOVA, while data on pH, residual nitrite and nitrosyl hemochrome, instrumental color, texture parameters, and TBARS values were analyzed using two-way ANOVA. To determine the differences between the means, Tukey's test, with a 0.05 level of significance, was used. All results were expressed as means with standard errors. In the case of the aroma profile, the differentiation of the analyzed samples was carried out by principal component analysis (PCA).

3. Results and Discussion

3.1. Product Yield and pH

Product yield is an important factor in the production of liver pâté, as it affects both the quality and profitability of the product. It refers to the amount of final product obtained from a certain amount of batter. Egg whites have been claimed to have a positive effect on yield because they contain proteins that can help emulsify the fat in the meat batter and increase the water holding capacity of the final product [49,50]. The percentage yield of liver pâtés showed no significant differences ($p \geq 0.05$) between treatments, as shown in Figure 1, with an average range of 83.91 ± 0.55% to 84.99 ± 0.65%. According to the literature, mild oxidation via plasma can improve the solubility, foaming, and emulsifying properties of proteins. However, excessive oxidation can result in a decrease in protein functionality [51]. The obtained results may suggest that the technological properties of egg whites were not adversely affected by the duration of plasma treatment used to produce nitrite ions. Additionally, Jung et al. [13] demonstrated that direct infusion of nitrites into meat batter through cold plasma did not significantly influence cooking loss of the product.

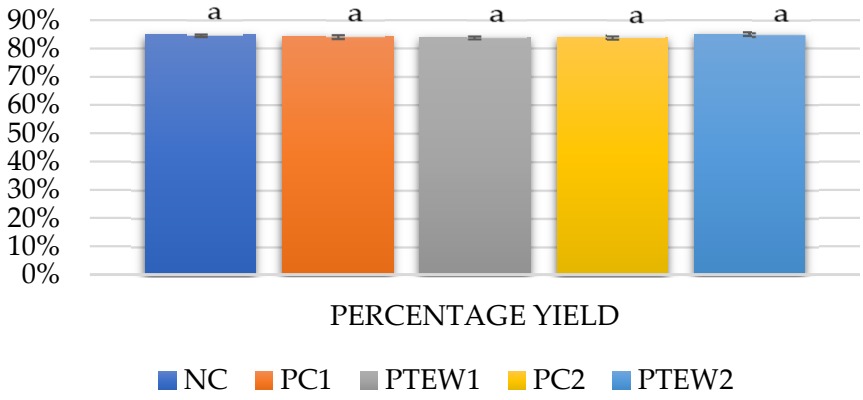


Figure 1. The effect of plasma-treated egg whites on percentage yield of liver pâtés (mean ± SE); NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-; the mean values with different letters differ statistically significantly ($p < 0.05$).

In the case of meat products, pH can also affect their texture, flavor, safety, and shelf life. The results concerning the pH of the analyzed liver pâtés are shown in Table 2. The average pH values observed in the above study, which ranged from 6.32 ± 0.04 to 6.42 ± 0.01, were consistent with typical pH values reported for this type of product [52,53]. Although Dolega et al. [29] found that the pH values of the liver pâtés varied slightly depending on the dosage of sodium nitrite used, Vossen et al. [54] reported that mean pH values of pâtés, before and after display for 48 h, ranged from 6.56 ± 0.04, regardless of the sodium nitrite dose. Our results also indicated that not only the quantity, but also the origin of

the nitrite, had no impact on the mean pH values among the analyzed treatments. This could be attributed to the strong buffering capacity of egg whites, whose pH remained stable even after plasma treatment. Additionally, Jung et al. [13] reported that the natural buffering capacity of meat batters treated with cold plasma resulted in slight fluctuations in their pH values. Considering the storage time, the pH values of liver pâtés stored for 7 days at 4 °C did not show any significant differences ($p \geq 0.05$). Similarly to our results, Martín-Sánchez [53] also found no significant differences in the mean pH values of pork liver pâtés stored under similar conditions for 4 days.

Table 2. The effect of plasma-treated egg white on pH (mean ± SE [1]) of liver pâtés during storage.

Parameters	Group [2]	1 Day	3 Day	5 Day	7 Day
pH [−]	NC	6.33 ± 0.02	6.36 ± 0.01	6.39 ± 0.01	6.42 ± 0.02
	PC1	6.32 ± 0.04	6.34 ± 0.02	6.39 ± 0.01	6.42 ± 0.01
	PC2	6.33 ± 0.03	6.36 ± 0.01	6.41 ± 0.01	6.41 ± 0.01
	PTEW1	6.35 ± 0.04	6.34 ± 0.03	6.40 ± 0.01	6.40 ± 0.02
	PTEW2	6.33 ± 0.04	6.33 ± 0.02	6.41 ± 0.01	6.40 ± 0.02

[1] SE—standard error; [2] NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-.

3.2. Residual Nitrite Content and Percent Cured Meat Pigment

The amount of residual nitrite in cured meat products depends on several factors, including the amount of nitrite added in the curing process, the type of meat used, curing time and temperature, and the presence of other ingredients that may influence the direction of the nitrite reaction in the final product [55]. Table 3 shows residual nitrite levels in liver pâtés cured with nitrites from various sources and stored for 7 days. The NC group had the lowest nitrite concentration during the storage period ($p < 0.05$). This was probably due to inadvertent contamination of the product with nitrites, e.g., from the nitrogen metabolism of the animal and feed [56]. The calculated amount of added nitrite ions for groups PC1 and PTEW1 was 40 ppm, while for groups PC2 and PTEW2 it was 80 ppm. As expected, liver pâtés from groups PC1 and PTEW1 showed significantly lower ($p < 0.05$) nitrite content from day 1 than pâtés from groups PC2 and PTEW2. This was due to the lower amount of nitrite ions added to the batters during production. Importantly, in terms of residual nitrite throughout the entire storage period, groups with plasma-activated egg whites did not differ from groups that contained the same amount of nitrite ions derived from sodium nitrite ($p \geq 0.05$). Although Jung et al. [9] showed that the residual nitrite content in emulsion-type sausages containing plasma-treated water decreases more rapidly during storage, our study found no significant differences between the residual nitrite content of the PC1 and PTEW1 groups and that of the PC2 and PTEW2 groups on individual days of storage. The obtained results might provide support for the effectiveness of using plasma-treated egg whites as a potential replacement for traditional nitrite-based additives in meat preservation.

Merino et al. [55] reported that although the nitrite content of the liver pâtés decreased the most after the first 24 h compared to the initial level due to heat treatment, it continued to decline gradually during storage. Similarly in our research, in all cured samples (PC1, PTEW1, PC2, PTEW2) a significant decrease in nitrite content ($p < 0.05$) was observed with the extension of storage time, which was consistent with the literature data for pâtés containing nitrites [54], and may be related to the reactivity of nitrites with meat ingredients, as well as oxidation to nitrates [31].

During the curing process of meat, nitrite reacts with myoglobin to form nitrosylmyoglobin. As a result of heat treatment, unstable nitrosylmyoglobin reacts further with nitric oxide to form nitrosyl hemochrome, which is responsible for the characteristic pink color of cured meat products [57]. As expected, throughout 7 days of storage, liver pâtés from the NC group were characterized by significantly lower nitrosyl hemochrome content ($p < 0.05$)

than cured liver pâtés, regardless of the amount and form of the nitrite ions introduced into the product (Table 3, $p < 0.05$). Although a decrease in the content of nitrosyl hemochrome was observed in all cured samples during storage, the PC2 and PTEW2 groups were characterized by higher mean values of the analyzed parameter than the PC1 and PTEW1 groups throughout the storage period ($p < 0.05$). Furthermore, there were no significant differences in nitrosyl hemochrome content between PC1 and PTEW1 groups, and PC2 and PTEW2 groups, regardless of the storage time ($p \geq 0.05$). Yu et al. [57] found that the nitrosyl hemochrome content in cured meat products is affected by, among others, their pH. Considering the above, at the end of storage, probably due to the lack of differences in average pH values, the decrease in nitrosyl hemochrome content in all cured groups was similar, and amounted to about 10% compared to 1 day after production. In addition, on each day of the analysis, regardless of the curing method, the groups with 80 ppm nitrite ions (PC2 and PTEW2) were characterized by nitrosyl hemochrome content only about 10% higher compare to the groups with 40 ppm nitrite ions (PC1 and PTEW1). Similarly, Jung et al. [10] demonstrated that the nitrosyl hemochrome content of ground ham was no different for groups with sodium nitrite and groups with plasma-treated winter mushroom powder after 0 and 30 days of storage.

Table 3. The effect of plasma-treated egg white on residual nitrite and nitrosyl hemochrome content (mean ± SE [1]) of liver pâtés during storage.

Parameters	Group [2,3]	1 Day	3 Day	5 Day	7 Day
Residual nitrite content [mg/kg]	NC	$0.37^{aA} \pm 0.00$	$0.35^{aA} \pm 0.00$	$0.38^{aA} \pm 0.05$	$0.33^{aA} \pm 0.00$
	PC1	$22.01^{bD} \pm 0.15$	$18.65^{bC} \pm 0.25$	$16.27^{bB} \pm 0.26$	$13.85^{bA} \pm 0.22$
	PTEW1	$21.72^{bD} \pm 0.14$	$17.38^{bC} \pm 0.24$	$16.11^{bB} \pm 0.22$	$14.16^{bA} \pm 0.24$
	PC2	$35.03^{cC} \pm 0.45$	$31.11^{cB} \pm 0.20$	$28.05^{cA} \pm 0.19$	$27.33^{cA} \pm 0.11$
	PTEW2	$34.06^{cD} \pm 0.52$	$31.24^{cC} \pm 0.27$	$28.77^{cB} \pm 0.27$	$27.39^{cA} \pm 0.17$
Nitrosyl hemochrome content [%]	NC	$7.07^{aA} \pm 0.40$	$6.99^{aA} \pm 0.32$	$7.23^{aA} \pm 0.17$	$6.70^{aA} \pm 0.26$
	PC1	$50.12^{bC} \pm 0.57$	$48.27^{bB} \pm 0.48$	$47.18^{bB} \pm 0.25$	$45.07^{bA} \pm 0.51$
	PTEW1	$49.01^{bB} \pm 0.42$	$47.73^{bB} \pm 0.54$	$45.07^{bA} \pm 0.38$	$45.47^{bA} \pm 0.30$
	PC2	$58.23^{cD} \pm 0.61$	$56.45^{cC} \pm 0.65$	$54.19^{cB} \pm 0.33$	$52.40^{cA} \pm 0.50$
	PTEW2	$59.45^{cD} \pm 0.61$	$57.23^{cC} \pm 0.59$	$55.31^{cB} \pm 0.57$	$53.13^{cA} \pm 0.49$

[1] SE—standard error; [2] NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-; [3] different superscript lowercase letters within columns (a–c) and within rows (A–D) indicate statistical differences ($p < 0.05$).

3.3. Instrumental Color Parameters

During storage, the color of cured meat products may change due to factors such as fat oxidation or microbial growth. Considering the above, instrumental measurement of the color of liver pâtés can provide objective and consistent data that can be used in their quality control processes. Starting from day 1, the samples from the NC group were lighter ($p < 0.05$) than the samples from the cured groups (Table 4), regardless of the curing method used. In our previous studies, similar results regarding the effect of nitrites from various sources on the lightness of meat products were obtained. These findings suggest that the nitrites used in meat processing may significantly reduce the L* values of the final products [19,21]. In addition, although the PC2 group was darker 1 day after manufacture ($p < 0.05$) than the PC1 and PTEW1 groups, starting from the 3rd day of storage, all cured pâtés did not differ in terms of average L* values ($p \geq 0.05$). Overall, the lightness increased significantly ($p < 0.05$) during storage, regardless of treatment, which is consistent with the work of Estèvez and Cava [24], who compared the quality of Iberian and white pig liver pâtés during storage, which may be due to retrogradation of heme pigments [58].

As expected, in the present study, the redness of the cured samples decreased with increasing storage time ($p < 0.05$) due to nitrosyl hemochrome degradation [59]. Nevertheless, on each analyzed day, uncured pâtés were characterized by significantly lower average a* values ($p < 0.05$) than those from groups PC1, PTEW1, PC2, and PTEW2 (Figure 2, Table 4). Although some differences were observed in the mean a* values ($p < 0.05$) during the first 3 days of storage, when comparing cured liver pâtés to which 40 and 80 ppm nitrite

ions were added, there was no significant difference ($p \geq 0.05$) between liver pâtés to which the same amount of nitrite ions from different sources had been added. Moreover, starting from the fifth day of storage, the redness of all cured groups was not significantly different ($p \geq 0.05$). Similarly, Kim et al. [18] showed that sausages with onions subjected to atmospheric treatment in the presence of 30% egg white had similar or higher a* values compared to sausages with sodium nitrite, throughout the entire storage period. Sebranek et al. [11] suggested that ingoing nitrite levels of 40–50 ppm is typically adequate to obtain a cured color in most meat products. The obtained results indicate that the content of ingoing nitrite ions in the liver pâtés, already at the level of 40 ppm (corresponding to 60 ppm of sodium nitrite), is sufficient to obtain a proper color formation and is quite effective in maintaining the redness of the stored products, both in the case of the PC1 as well as PTEW1 group. Finally, the NC group showed the highest level of yellowness ($p < 0.05$) among all treatments, regardless of the day of storage. In addition, samples from individual treatments did not show significant differences in the average b* values throughout the storage period ($p \geq 0.05$), and thus the observed differences between the NC group and the cured groups were unlikely to be related to the oxidation process. Based on the nitrosyl hemochrome results and the TBARS values, the NC samples may appear more yellow due to the lack of nitrite-induced color change.

Table 4. The effect of plasma-treated egg whites on color parameters (mean ± SE [1]) of liver pâtés during storage.

Parameters	Group [2,3]	1 Day	3 Day	5 Day	7 Day
L* [−]	NC	62.30 ^{cA} ± 0.13	64.06 ^{bB} ± 0.32	64.01 ^{bB} ± 0.28	64.73 ^{bB} ± 0.28
	PC1	60.91 ^{bA} ± 0.16	61.89 ^{aAB} ± 0.27	62.32 ^{aB} ± 0.27	62.57 ^{aB} ± 0.25
	PTEW1	60.63 ^{bA} ± 0.28	61.68 ^{aAB} ± 0.29	62.56 ^{aB} ± 0.14	62.04 ^{aB} ± 0.28
	PC2	59.15 ^{aA} ± 0.26	61.86 ^{aB} ± 0.22	62.52 ^{aB} ± 0.45	62.20 ^{aB} ± 0.34
	PTEW2	60.00 ^{abA} ± 0.39	61.57 ^{aB} ± 0.26	63.09 ^{aC} ± 0.19	63.32 ^{aC} ± 0.18
a* [−]	NC	5.90 ^{aC} ± 0.10	5.52 ^{aBC} ± 0.29	4.83 ^{aAB} ± 0.18	4.66 ^{aA} ± 0.14
	PC1	12.69 ^{bB} ± 0.12	11.90 ^{bA} ± 0.16	11.97 ^{bA} ± 0.09	11.90 ^{bA} ± 0.11
	PTEW1	13.10 ^{bB} ± 0.12	12.45 ^{bcAB} ± 0.16	12.28 ^{bA} ± 0.14	12.32 ^{bAB} ± 0.13
	PC2	13.92 ^{cB} ± 0.16	12.59 ^{bcA} ± 0.13	12.16 ^{bA} ± 0.11	12.42 ^{bA} ± 0.14
	PTEW2	13.41 ^{bcC} ± 0.14	13.06 ^{cBC} ± 0.07	11.90 ^{bA} ± 0.11	12.46 ^{bAB} ± 0.12
b* [−]	NC	13.34 ^{b} ± 0.12	13.48 ^{b} ± 0.15	13.85 ^{b} ± 0.11	13.71 ^{b} ± 0.15
	PC1	11.76 ^{a} ± 0.11	11.35 ^{a} ± 0.13	11.87 ^{a} ± 0.16	11.40 ^{a} ± 0.18
	PTEW1	11.66 ^{a} ± 0.12	11.39 ^{a} ± 0.15	11.42 ^{a} ± 0.15	11.69 ^{a} ± 0.15
	PC2	12.15 ^{a} ± 0.12	11.75 ^{a} ± 0.12	11.45 ^{a} ± 0.15	11.72 ^{a} ± 0.10
	PTEW2	12.06 ^{a} ± 0.14	11.47 ^{a} ± 0.06	11.99 ^{a} ± 0.17	11.99 ^{a} ± 0.10

[1] SE—standard error; [2] NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-; [3] different superscript lowercase letters within columns (a–e) and within rows (A–D) indicate statistical differences ($p < 0.05$).

3.4. Lipid Oxidation

Fat oxidation can lead to loss of flavor, rancidity, and change in color and texture of meat products, ultimately reducing their overall quality and shelf life, and considering the high fat content in liver pâtés, it is one of the main factors affecting their quality during storage [54]. TBARS (thiobarbituric acid reactive substances) values are commonly used as an indicator of lipid oxidation, and represent the amount of malondialdehyde (MDA), one of the degradation products of lipid hydroperoxides and peroxides formed during the breakdown of polyunsaturated fatty acids [60]. In the above study, TBARS values (Table 5) were comparable ($p \geq 0.05$) 1 day after manufacture for all treatments, and significantly increased ($p < 0.05$) within 7 days of storage. Igene et al. [61] suggested that nitrites possess antioxidant properties by forming a complex with heme pigments that prevents the release of nonheme iron, which catalyzes lipid oxidation, through direct interaction with the released nonheme iron resulting from the denaturation of heme pigments, or by stabilizing unsaturated lipids within membranes. However, their effectiveness may vary depending

on the dose used, as well as processing and storage conditions. In our study, compared to uncured liver pâtés (NC group), groups with nitrite ions (PC1, PTEW1, PC2, PTEW2) were characterized by significantly lower lipid oxidation ($p < 0.05$) starting from the third day of storage. In addition, on day 7, the PC2 and PTEW2 groups had significantly lower TBARS values than the PC1 and PTEW1 groups. Additionally, Dineen et al. [62] found that cooked hams cured with a lower dose (25 ppm) of sodium nitrite showed significantly higher lipid oxidation after 10 days of storage than the control products cured with a higher dose (100 ppm) of sodium nitrite. Importantly, the groups to which the same amount of nitrite ions were added did not differ significantly ($p \geq 0.05$) on any of the analyzed days, regardless of the curing method.



Figure 2. Pork liver pâtés in porcelain bowls—top view; from the left: NC—negative control (liver pâtés without nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 NO_2^-; PC2—(liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 NO_2^-.

Table 5. The effect of plasma-treated egg white on TBARS values (mean ± SE [1]) of liver pâtés during storage.

Parameters	Group [2,3]	1 Day	3 Day	5 Day	7 Day
TBARS [mg MDA/kg]	NC	0.62 ± 0.05	1.34 ^{d} ± 0.03	1.87 ^{c} ± 0.03	2.06 ^{c} ± 0.04
	PC1	0.58 ± 0.04	1.12 ^{bc} ± 0.03	1.60 ^{b} ± 0.03	1.83 ^{b} ± 0.02
	PTEW1	0.56 ± 0.05	1.17 ^{cd} ± 0.02	1.67 ^{b} ± 0.06	1.86 ^{b} ± 0.04
	PC2	0.49 ± 0.04	0.88 ^{a} ± 0.05	1.36 ^{a} ± 0.03	1.62 ^{a} ± 0.03
	PTEW2	0.48 ± 0.01	0.94 ^{ab} ± 0.06	1.48 ^{ab} ± 0.02	1.59 ^{a} ± 0.04

[1] SE—standard error; [2] NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-; [3] different superscript lowercase letters within columns (a–d) indicate statistical differences ($p < 0.05$).

Based on our current and previous studies [19–21], it can be concluded that the use of indirect methods for nitrite production in aqueous, fat-free, or low-fat solutions containing natural buffers may be a more favorable approach than direct nitrite production in meat or meat batters through cold plasma. This is because direct plasma treatment of meat and meat products, as suggested by the studies conducted by Kim [63] or Jayasena [64], may lead to accelerated lipid oxidation due to the presence of reactive oxygen species in the plasma. Nevertheless, some studies have shown no negative effect of direct plasma treatment on the lipid oxidation of meat products compared to a group without sodium nitrite and plasma treatment [6,46]. These differences may result from the working gas used and the duration of plasma treatment [2], indicating that further research may be necessary to determine the optimal method for nitrite production in meat products.

3.5. Instrumental Texture Parameters

The texture of meat products, such as liver pâtés, refers to their physical properties that affect their sensory characteristics, including hardness (the force required to compress the pâté and the resistance it offers to deformation), adhesiveness (the degree to which the pâté sticks to the surface it comes into contact with), cohesiveness (the degree to which the pâté holds together after being deformed or compressed), springiness (the ability of the pâté to regain its original shape after deformation), and gumminess (the energy required to masticate the pâté until it is ready to swallow). The above parameters are important factors influencing the overall quality and consumer acceptance of meat products, and can be influenced by various factors, including meat product composition, processing and storage conditions, and the additives used. For example, egg white is used in low-cost emulsified meat products as a binder, positively contributing to their texture [50,65]. Texture parameters of the analyzed pâtés are presented in Table 6. The literature shows that the hardness of pâtés increases over time due to the separation of water and fat from the protein matrix and the drying of the products [22,52]. However, in our studies, mean hardness values did not differ between treatments ($p > 0.05$) during 7 days of storage at 4 °C, which proves the stability of all produced emulsions in the analyzed periods. The obtained values of adhesiveness in all groups also did not increase ($p \geq 0.05$), which proves that the functionality of the used egg whites was maintained until 7 days. Finally, the cohesiveness, springiness, and gumminess of liver were unaffected by treatment and storage time ($p \geq 0.05$). The obtained results may indicate that stable emulsions were obtained in all groups, even after adding plasma-treated egg white, and the storage time was probably too short to significantly reduce the moisture content of the analyzed pâtés and affect their texture parameters. Additionally, Meng et al. [8] showed that there were no significant differences in the values of hardness, springiness, and cohesiveness of smoked sausages prepared with the use of 10–90% nitrite and a phosphate solution treated with cold plasma. Regarding the effect of direct plasma treatment on the texture of the meat products, Chen [6] and Lee [46] obtained similar results.

3.6. Analysis of Volatile Compounds

During heat treatment of meat products containing nitrite ions, a number of complex chemical reactions occur, resulting in the formation of a variety of volatile compounds, including aldehydes, ketones, and other organic compounds, which are responsible for the specific cured flavor [66]. However, the above effect depends on many factors, including the amount of nitrite ions added, the composition of the product, and the processing conditions used. Volatile compounds analysis might help to optimize the recipe and production process to achieve a desired aroma profile.

Differences in the aroma profiles of the analyzed liver pâtés on different days of storage were demonstrated by principal component analysis (PCA) in Figures 3–6. In each figure, the samples were plotted on a two-dimensional plane based on the selected components, PC1 and PC2. The values on the vertical axis (88.034%—Figure 3; 78.557%—Figure 4; 35.587%—Figure 5; 29.764%—Figure 6) and on the horizontal axis (9.515%—Figure 3; 14.802%—Figure 4; 21.935%—Figure 5; 19.596%—Figure 6) explain the differences among samples along the respective axes, indicating that the differences are more significant on the vertical axis than on the horizontal axis in each figure. This indicates that on each analyzed day, there were significant differences in the aroma profile between the NC group and the groups containing nitrite ions. Meng et al. [8] found that the use of cold plasma can alter the volatile compounds in food products. In the case of smoked sausages, the application of a cold plasma-treated phosphate solution resulted in higher levels of ketones and esters compared to the group treated with nitrites. Although liver pâtés with plasma-activated egg whites had a slightly different flavor (less than 10%) on day 1 compared to the group containing 60 ppm of sodium nitrite (PC1), no discernible variations were observed in the aroma profile among those groups (PTEW1, PTEW2) and the group containing 120 ppm of sodium nitrite (PC2), as shown in Figure 3.

Table 6. The effect of plasma-treated egg whites on color parameters (mean ± SE [1]) of liver pâtés during storage.

Parameters	Group [2]	1 Day	3 Day	5 Day	7 Day
hardness [N]	NC	19.59 ± 0.38	19.15 ± 0.83	18.19 ± 0.80	18.38 ± 0.42
	PC1	18.99 ± 0.58	19.21 ± 0.77	18.31 ± 0.79	17.76 ± 0.75
	PTEW1	18.58 ± 0.70	17.68 ± 0.63	17.58 ± 0.44	17.96 ± 0.83
	PC2	18.48 ± 0.48	17.78 ± 0.61	18.66 ± 0.85	19.33 ± 0.61
	PTEW2	18.74 ± 0.42	17.85 ± 0.65	17.36 ± 0.69	17.93 ± 0.74
adhesiveness [J/cm^2]	NC	−0.015 ± 0.001	−0.014 ± 0.001	−0.015 ± 0.001	−0.014 ± 0.001
	PC1	−0.014 ± 0.001	−0.013 ± 0.001	−0.015 ± 0.001	−0.014 ± 0.001
	PTEW1	−0.012 ± 0.001	−0.011 ± 0.001	−0.013 ± 0.001	−0.015 ± 0.001
	PC2	−0.013 ± 0.001	−0.013 ± 0.001	−0.014 ± 0.001	−0.014 ± 0.001
	PTEW2	−0.012 ± 0.001	−0.012 ± 0.001	−0.013 ± 0.001	−0.013 ± 0.001
cohesiveness [−]	NC	0.18 ± 0.01	0.17 ± 0.00	0.18 ± 0.01	0.17 ± 0.01
	PC1	0.16 ± 0.01	0.18 ± 0.01	0.19 ± 0.01	0.19 ± 0.01
	PTEW1	0.16 ± 0.01	0.17 ± 0.01	0.17 ± 0.01	0.17 ± 0.00
	PC2	0.18 ± 0.01	0.16 ± 0.00	0.19 ± 0.01	0.18 ± 0.01
	PTEW2	0.18 ± 0.01	0.19 ± 0.01	0.17 ± 0.00	0.17 ± 0.01
springiness [−]	NC	0.14 ± 0.02	0.12 ± 0.01	0.14 ± 0.01	0.13 ± 0.01
	PC1	0.14 ± 0.01	0.13 ± 0.01	0.14 ± 0.00	0.15 ± 0.01
	PTEW1	0.13 ± 0.00	0.12 ± 0.00	0.13 ± 0.01	0.14 ± 0.00
	PC2	0.14 ± 0.01	0.13± 0.00	0.14 ± 0.00	0.14 ± 0.00
	PTEW2	0.14 ± 0.01	0.12 ± 0.01	0.12 ± 0.00	0.15 ± 0.00
gumminess [N]	NC	3.59 ± 0.21	3.29 ± 0.18	3.32 ± 0.14	3.24 ± 0.28
	PC1	3.05 ± 0.13	3.46 ± 0.09	3.56 ± 0.17	3.44 ± 0.14
	PTEW1	2.96 ± 0.19	3.06 ± 0.20	3.08 ± 0.24	3.12 ± 0.16
	PC2	3.44 ± 0.26	2.92 ± 0.13	3.50 ± 0.24	3.56 ± 0.21
	PTEW2	3.39 ± 0.14	3.34 ± 0.18	3.15 ± 0.19	3.05 ± 0.19

[1] SE—standard error; [2] NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-.

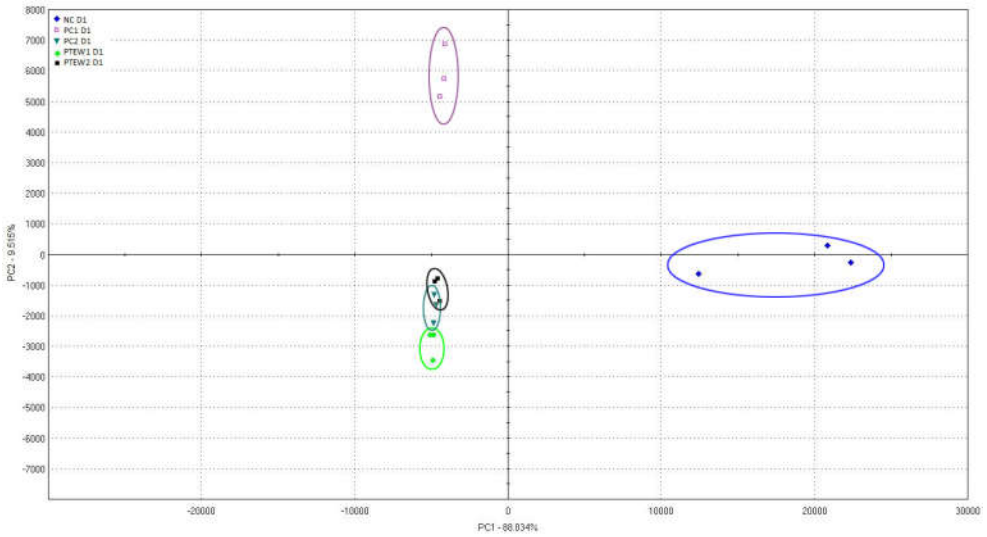


Figure 3. Principal component analysis of liver pâtés—day 1;NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^- .

Additionally, the study by Chen et al. (2022) found that the type and content of volatile compounds in roast lamb treated with plasma for 45 min were more similar to samples containing 0.005% sodium nitrite than to those without sodium nitrite. This is due to the fact that nitrite is known to be effective in preventing oxidative rancidity in heat-treated meat products, thereby inhibiting the formation of aldehydes, including hexanal, which, due to

the rapid formation by oxidation of omega-6 fatty acids, is a commonly used indicator of meat off-flavors [67].

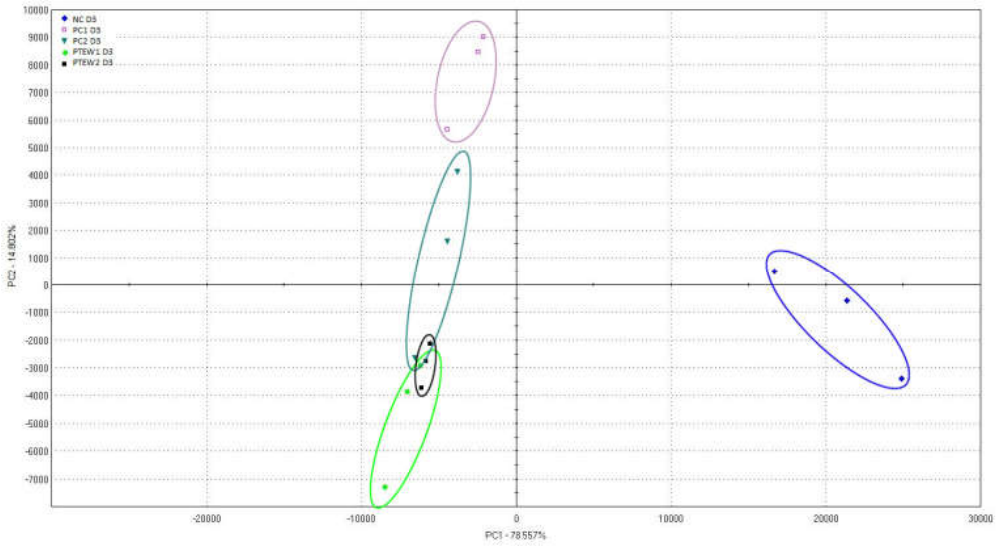


Figure 4. Principal component analysis of liver pâtés—day 3; NC—negative control (liver pâtés without a nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 ppm NO_2^-; PC2—positive control (liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 ppm NO_2^-.

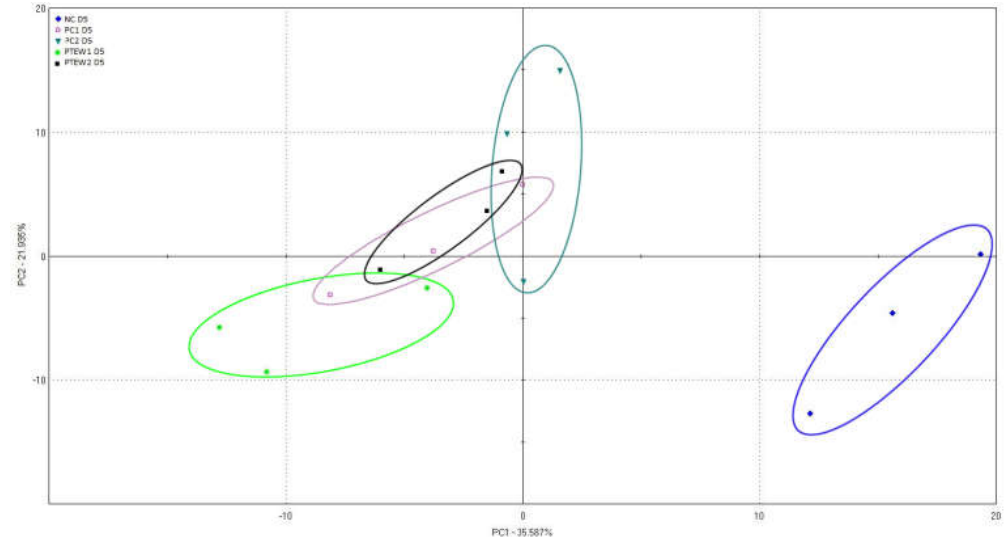


Figure 5. Principal component analysis of liver pâtés—day 5; NC—negative control (liver pâtés without nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 NO_2^-; PC2—(liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 NO_2^-.

In the Chen study [6], hexanal was not detected in the sodium nitrate-cured samples, and its concentrations in the plasma-treated samples were significantly lower compared to the uncured group. Nevertheless, in our work, based on AroChemBase (Alpha MOS Co., Toulouse, France), beginning from the first day of storage, hexanal was present in all liver pates, probably due to the intensive heat treatment. Therefore, to accurately identify differences in volatile compounds between groups, it would be necessary in the future to quantify all groups by gas chromatography-mass spectrometry.

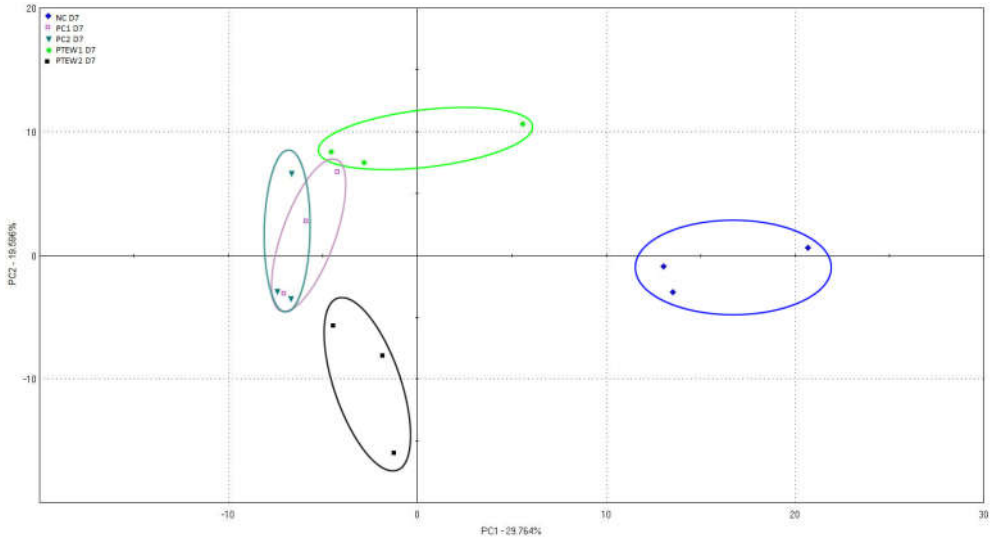


Figure 6. Principal component analysis of liver pâtés—day 7; NC—negative control (liver pâtés without nitrite source); PC1—positive control (liver pâtés with 60 ppm of sodium nitrite); PTEW1—liver pâtés with plasma-treated egg white containing 40 NO_2^-; PC2—(liver pâtés with 120 ppm of sodium nitrite); PTEW2—liver pâtés with plasma-treated egg white containing 80 NO_2^-.

During storage, the differences in the aroma profile among the groups containing nitrite ions slightly increased without a clear trend and did not exceed 22% on the last day. In contrast, the aroma profile of the NC group differed less from the groups containing nitrite ions over time, and by the seventh day of storage, the aroma profile of the NC group differed from that of PC1, PC2, PTEW1, and PTEW2 by less than 30% (Figure 6). Our previous studies [19,21] have also shown that storage time can affect the aroma profile of all groups, and that the differences in the aroma profile of meat products containing nitrite ions become less pronounced compared to those without nitrite, regardless of the source of the nitrite. The obtained results may be associated with a decrease in the content of residual nitrites in cured products subjected to storage.

4. Conclusions

In the present study, the unique nitrite ions produced by plasma treatment of egg whites was explored as potential synthetic nitrite replacers in liver pâtés. The use of PTEW as a source of nitrite ions in liver pâté showed no significant differences in the content of residual nitrites and nitrosyl hemochrome compared to liver pâtés containing the same nitrite ions content derived from sodium nitrite throughout the duration of storage. The addition of 40 and 80 ppm nitrite ions, from both sodium nitrite and plasma-activated egg white, effectively inhibited lipid oxidation in liver pâtés and provided a stable color characteristic of the cured meat products. The liver pâté samples treated with PTEW showed a significant change in the aroma profile (similar to conventionally cured products), but did not differ in pH and texture parameters compared to the NC group during 7 days of storage at 4 °C. Based on the obtained results, plasma-treated egg whites could be used as an alternative to sodium nitrite in meat products. Apart from improving the quality of the stored product, the use of plasma-treated egg white (PTEW) in pork liver pâtés could reduce the number of ingredients required in their production. Additionally, the use of plasma to generate nitrite ions results in a lower waste output than conventional sodium nitrite production, which generates byproducts such as water and sulfuric acid. Further research is needed to study the stability and shelf life during processing and storage, and particularly the sensory properties after the processing and evolution of microbiological properties during refrigerated storage of the selected treatments.

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