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Featured Application: The work fits into the idea of sustainable development by utilizing by-products from the production of plant-based food. The obtained results prove the possibility of using 'raw' (i.e. unprocessed, only subjected to grinding) fruit pomace in the production of processed products from ground meat from the category of convenience food. However, the use of raw fruit pomace, which is a perishable raw material, requires very efficient cooperation between the supplier and the recipient of this by-product.

Abstract: This study aimed at evaluation the effect of addition of shredded black chokeberry (*Aronia melanocarpa*) pomace on the quality of heat-treated and vacuum-packed pork burgers stored for 14 days at +4°C. Four burger treatments: control (BC), and products with 2%, 3.5% and 5% of chokeberry pomace (B2, B3.5 and B5, respectively) were analysed for physicochemical and microbiological properties. The use of chokeberry pomace resulted in an increase ($p < 0.05$) in thermal loss and a decrease ($p < 0.05$) in the pH, and differentiated ($p < 0.05$) the contents of water, protein, fat and salt in burgers. The chokeberry pomace affected the colour of burgers; products B2, B3.5 and B5 were significantly ($p < 0.05$) darker, and were characterized by greater redness, and lesser yellowness than BC product. Moderate antimicrobial properties of chokeberry pomace were recorded on the last day of burgers storage, when lower ($p < 0.05$) numbers of LAB and *Pseudomonas* spp. bacteria were found in products B2–B5 than in the BC product. It seems advisable to continue research on the use of chokeberry pomace, but in a processed form, taking into account the sensory quality.

Keywords: chokeberry pomace; pork burgers; vacuum packaging; refrigerated storage; meat product quality

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1. Introduction

In modern food production, climate policy is becoming increasingly important, leading to growing interest in sustainable production and "less waste"/"zero waste" policies [1–3]. Changes in the consumption pattern driven by environment and health concerns are also clearly visible [4–8]. In response to the challenges of promoting a sustainable production and consumption strategy, including the concept of "less waste", research is being conducted on improving the management of waste products from the fruit and vegetable industry by incorporating them into meat products [9].

Waste products, which are the parts not utilized during the technological processes of producing juices, pulps, or jams, consist of pomace, peels, and fruit pits [9,10]. These by-products are estimated to constitute about 10% to 35% of the mass of the processed raw material, with the share of pomace during traditional fruit pressing averaging 20% to 25% of the raw material mass [10]. Strategies for utilizing fruit and vegetable pomace in meat processing include enhancing the health value of meat products and extending their shelf life [11–14]. However, raw fruit and vegetable pomace is relatively

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unstable due to its high water content. It should be valorised if immediate reuse or storage under conditions that prevent undesirable microbiological changes is not possible. 'Valorization' refers to enhancing the availability and functionality of specific components found in fruit pomace [14]. In research studies on the use of fruit and vegetable pomace as an ingredient in meat products, it is most commonly utilized in either its dried form or as aqueous or alcoholic extracts [12,15–18].

One of the fruits with significant health benefits is the black chokeberry (*Aronia melanocarpa*). Originally brought to Europe from North America, black chokeberry bushes are relatively easy to cultivate on the continent [19]. Poland is one of the top producers of black chokeberries in Europe [20]. The health benefits of consuming the fruits of *Aronia melanocarpa* are discussed in detail in the literature [21]. Due to their tart flavor, black chokeberry fruits are seldom eaten fresh and are primarily utilized for industrial processing [19,22,23]. When black chokeberry fruit is processed into juice, pomace is produced as a by-product. This pomace is a rich source of beneficial components, including fibre and polyphenols [19,21,23]. Comparative studies of fourteen chokeberry products—including fruits, dried fruits, juices, jams, syrups, and pomace—showed that pomace contained the highest total levels of phenols and anthocyanins [24]. Polyphenolic compounds present in chokeberry pomace have been shown to exhibit antioxidant and antibacterial effects in ground meat products [12]. The results of the research [23] indicate that chokeberry pomace should be regarded as a heterogeneous raw material. When processing chokeberry pomace, it is necessary to consider the separation of seeds, which are a valuable source of fat, protein and minerals. The valorization of chokeberry pomace, which may include methods such as drying and freeze-drying, requires additional energy expenditure [17]. Therefore, the use of 'raw', i.e. unprocessed, possibly cooled or frozen and crushed, black chokeberry pomace as an ingredient in meat products should not be ruled out. However, this approach would require direct and very efficient cooperation between the supplier and the recipient of this by-product. There is limited information in the literature regarding the potential application of fresh chokeberry pomace in meat products [25,26]. In laboratory conditions an attempt was made to optimize the amount of pomace from black chokeberry added to pork burgers [26]. The chokeberry pomace was incorporated into the meat batter as a shredded 'paste'. The results indicated that including chokeberry pomace as an ingredient did not present technological challenges. However, the quantity of the added plant component significantly impacted most physical, chemical, and sensory quality features of the burgers. It is important to note that these studies were preliminary; the burgers were not subjected to storage tests or microbiological quality assessments. The study results were promising, leading to the decision to continue the research.

Therefore, this study aimed to evaluate selected physical, chemical, organoleptic and microbiological quality characteristics of pork burgers that included pomace from black chokeberry (*Aronia melanocarpa*) as one of the ingredients. The pomace was added in a shredded 'paste' form in amounts ranging from 2.0% to 5.0% of the total weight. After thermal processing, the burgers were vacuum-packed and stored at a refrigerated temperature for 14 days.

2. Materials and Methods

2.1. Materials

The raw materials (pork ham and pork jowl) were purchased at the Makro Cash and Carry wholesale store on the day of burgers production. The pomace from black chokeberry (Aronia melanocarpa) of the Nero variety was prepared at the Department of Fruit, Vegetable and Cereal Technology of the Warsaw University of Life Sciences (WULS).

2.2. Preparation of Black Chokeberry Pomace

The fruits came from conventional cultivation with a high degree of fertilization and were harvested in mid-September 2024. Before production, fresh chokeberries were washed and then pressed in a laboratory hydraulic press (BUCHER Unipektin AG HPL 14; Bucher Unipektin AG, Niederweningen, Switzerland), equipped with a drainage filter recommended for pressing berries and pome fruits. Chokeberries weighing approx. 10 kg were subjected to a three-cycle juice pressing process at a pressure of 5 bar. After each cycle, the material was loosened to improve the pressing

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process yield and reduce the water content in the obtained pomace. The appearance of fresh black chokeberry pomace is shown in Figure S1. After production, the pomace was vacuum packed in 0.070 mm thick PA/PE bags using a Multivac C200 packaging machine (Multivac, Natalin, Poland) in two portions, each weighing approx. 0.5 kg, frozen and stored at (–60 ± 1)°C. On the day of burgers production, frozen chokeberry pomace in the amount necessary for a given experimental series was defrosted in a microwave oven (operating time 4 minutes, microwave power 900 W) and then shredded to a 'paste' consistency in a Thermomix® device (Vorwerk, Warsaw, Poland). The grinding process parameters were knife speed of 4000/min, operating time of 5 minutes, and maximum temperature of 37°C.

2.3. Pork Burgers Formulation and Production

The following basic recipe in burger production was used: 80% pork ham (skinless and boneless), 20% pork jowl (de-skinned), and 1.8% salt (to the weight of meat and fat raw materials). Based on this formulation, four burger treatments were prepared: control product—BC without the addition of black chokeberry pomace, and B2, B3.5 and B5 products with the addition of pomace at the level of 2.0%, 3.5% and 5.0% (to the weight of meat and fat raw materials), respectively. The amounts of added pomace were set at a maximum level that did not impair the organoleptic quality of the products [26].

Pork ham and pork jowl were ground separately in a laboratory grinder (Mesko WN40; Mesko AGD Sp. z o.o., Skarżysko-Kamienna, Poland) on a 4.5 mm hole diameter mesh. The meat batter was prepared in a laboratory mixer (Kenwood Major KM800; Kenwood Ltd., Havant, UK) by introducing the ingredients into the mixing bowl in the following order: first meat with table salt, then the pork jowl, and in the case of B2, B3.5 and B5 treatments shredded chokeberry pomace, and mixing until all ingredients were evenly distributed (approx. 10 minutes). Then, burgers weighing about 110 g were formed using a hand moulder (Hendi BV, Rhenen, The Netherlands) and baked in the air at 180°C (relative air humidity 10%) in a convection-steam oven (Rational SCC WE61; Rational AG, Landsberg am Lech, Germany). Thermal treatment was carried out until the temperature in the geometric centre of the hamburgers reached 80°C. The appearance of pork burgers after heat treatment is shown in Figure S2. After cooling, the burgers were vacuum packed in 0.070 mm thick PA/PE bags with a Multivac C200 packaging machine (Multivac, Natalin, Poland) and stored under cooling conditions (+4 ± 1)°C) in the absence of light for 1, 7 and 14 days. The experiment was repeated two times in two independent experimental series.

On the production day, the culinary quality characteristics of burgers were determined, i.e., thermal loss, 'shrinkage' (the change in the diameter of the burgers after baking), and basic chemical composition. The other quality characteristics of pork burgers, were assessed one day after production and after 7 and 14 days of storage under cooling conditions.

2.4. Methods

2.4.1. Culinary Quality Characteristics and Basic Chemical Composition of Pork Burgers – Production Day

Thermal Loss

The thermal loss of burgers was determined using the weight method. For this purpose, three randomly selected hamburgers of each variant were weighed with an accuracy of 0.01 g before and after baking (and cooling), and the result was expressed as a percentage of the weight of the product before baking.

Shrinkage

The change in diameter after baking ('shrinkage') was calculated by measuring the diameter of three randomly selected burgers of each variant before and after baking (and cooling). Measurements were taken using an electronic caliper with an accuracy of 0.01 mm, and the result was expressed as a percentage of the diameter of the product before baking.

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Basic Chemical Composition

The basic chemical composition of burgers (water, protein, fat and table salt content) was determined following the PN-A-82109:2010 standard [27] using a near-infrared spectrometer (FoodScan™2, Foss Analytical A/S, Hillerød, Denmark), operating in the wavelength range from 850 nm to 1500 nm and using calibration based on an artificial neural network model. Ground burgers were used for measurements. For this purpose, 300 g of each product variant was ground twice in a laboratory meat grinder (Diana 886.8, Zelmer, Rzeszów, Poland) on a 2 mm mesh and mixed thoroughly. The prepared samples were placed on a measuring cuvette and then in the device's measuring station. Once started, the measurement was performed automatically, and the results were read on the computer monitor. The measurement was performed in duplicate for each burger variant in a given experimental series. The mean values were taken as final results.

2.4.2. Quality Characteristics of Pork Burgers – After Storage

pH

The pH of burgers was measured using the Testo 206-pH2 pH-meter (Testo SE & Co. KGaA, Titisee-Neustadt, Germany). The measurement was performed by inserting the pH-meter electrode into a measurement sample. The measurement sample was prepared in a beaker by 10 g (± 0.01 g) of ground burger variant in a laboratory grinder (Diana 886.8, Zelmer, Rzeszów, Poland) equipped with a 2 mm mesh, and mixing with 30 mL of distilled water. The measurement was performed in duplicate for each hamburger variant in each series, and mean values were taken as final results.

L*, a* and b* Colour Parameters

L*, a* and b* colour parameters were measured on the surface of burgers in six repetitions for each burger treatment. The MINOLTA® CR-400 colourimeter (Minolta, Tokyo, Japan; light source D65, observer 10°, a measuring head hole of 8 mm) was used. Before the measurement, the device was calibrated on a white standard (Y: 95.2 x: 0.3159, y: 0.3326). In each experimental series for each product treatment, the colour measurement was performed in six repetitions by placing the measuring device head in different places on the burger surface. The mean values were taken as final results.

The total colour difference (ΔE) between the control product and burgers with added black chokeberry pomace (for each storage time individually) was calculated as follows - equation 1 [28]:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \qquad (1)$$

where ΔL*, Δa*, and Δb* are the differences between the colour parameters of control product (BC) and the burgers with added black chokeberry pomace (B2, B3.5 and B5).

2.4.2.3. Texture – Shear Force

For the shear force measurement, samples were cut from each burger treatment in a shape similar to a cuboid, i.e. approximately 10 cm long (product diameter), 3 cm wide and approximately 0.8 cm thick. The shear force of burgers was measured using a Zwicki 1120® universal testing machine (Zwick GmbH & Co., Ulm, Germany), and a measuring head equipped with a flat-blade knife was used. The speed of the movement of the measuring head was 50 mm/min, the initial force was 0.5 N, and the force deactivation threshold was set at 50% of the maximum force recorded during the test. The maximum shear force recorded when the knife cut through the samples was taken as the measurement result. In each series, the measurement was carried out in six repetitions for each burger treatment, and mean values were taken as final results.

Microbiological Analyses

On the days of analyses, packages with burgers were opened under sterile conditions. Samples were prepared according to Polish Standard PN-EN ISO 6887–2:2017 [29]. Microbiological analyses included the determination of the total count of aerobic mesophilic microorganisms [30], as well as the number of psychrotrophic bacteria [31], lactic acid bacteria – LAB [32], *Enterobacteriaceae* [33], *Pseudomonas spp*. [34], *Brochothrix thermosphacta* [35], and yeasts and moulds – YAM [36]. All the

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bacterial counts were expressed as colony forming units per g of product (cfu/g). Methods used for microbiological quality determination were described in detail by Chmiel et al. [37] and Cegiełka et al. [38]. Chokeberry pomace was also evaluated for microbiological quality regarding the same microbial groups.

2.4.3. Statistical Analysis

The data were presented as the means ± standard deviation (SD). For the statistical analysis of the results, Statistica® v. 13.0 software (StatSoft Inc., Tulsa, OK, USA) was used. To determine the effect of the black chokeberry pomace addition on culinary quality characteristics of burgers determined only at the production day (thermal loss, shrinkage and basic chemical composition), which were assessed only on day 1 of storage, One-Way Analysis of Variance (One-Way ANOVA) was used. The Tukey's HSD test was applied as a statistical test (at a significance level of $\alpha = 0.05$). Before the use of ANOVA, the normality of data was evaluated using the Shapiro–Wilk test. The homogeneity of variances for the datasets was confirmed using the Levene test.

The results for the other quality features (pH, shear force, L*, a* and b* colour parameters, microbiological quality) were analyzed using Two-Way Analysis of Variance (Two-Way ANOVA). Four different burger treatments (BC, B2, B3.5 and B5), three storage time intervals (1, 7, and 14 days) and their interaction (Treatment × Storage time) were included as fixed terms, while two experimental series were included as random term. Means were compared by Tukey's multiple range tests at an $\alpha = 0.05$ significance level to determine the significance of the effect of the addition of chokeberry pomace, storage time and their interaction.

3. Results and Discussion

3.1. Culinary Quality Characteristics of Pork Burgers

Thermal loss in burgers after baking ranged from 23.5% in the BC product to 30.8% the B5 product and varied significantly ($p < 0.05$) depending on the changes made to the raw material composition of the burgers (Table 1). Compared to the control product (BC), burgers with a lower concentration of chokeberry pomace, i.e. B2 and B3.5, exhibited a greater ($p < 0.05$) weight loss. Burgers with the highest amount of chokeberry pomace (B5) showed the highest ($p < 0.05$) thermal loss among all meat product treatments.

Table 1. Thermal loss, shrinkage, and the content of basic chemical components in pork burgers with added black chokeberry pomace (mean value ± standard deviation).

Feature	BC *	B2 *	B3.5 *	B5 *
Thermal loss [%]	23.5 a ± 1.58	27.4 b ± 0.85	27.7 b ± 1.52	30.8 c ± 0.80
Shrinkage [%]	16.9 a ± 1.92	17.5 a ± 2.07	18.7 a ± 1.68	21.1 a ± 0.90
Moisture content [%]	59.31 d ± 0.06	57.74 c ± 0.03	57.08 b ± 0.11	55.97 a ± 0.11
Protein content [%]	26.68 a ± 0.08	27.89 b ± 0.10	27.71 b ± 0.11	28.47 c ± 0.06
Fat content [%]	12.47 a ± 0.01	12.84 b ± 0.00	13.77 c ± 0.12	13.96 c ± 0.06
Sodium chloride content [%]	1.94 b ± 0.03	1.71 a ± 0.04	1.64 a ± 0.03	1.63 a ± 0.02

* Treatments: BC—pork burgers without chokeberry pomace; B2—pork burgers with 2.0% chokeberry pomace; B3.5—pork burgers with 3.5% chokeberry pomace; B5—pork burgers with 5.0% chokeberry pomace; a-d—mean values in the same row marked with different letters are significantly different at $p < 0.05$.

The change in the diameter of burgers after baking, referred to as 'shrinkage', ranged on average from 16.9% in the BC product to 21.1% in the B5 product and was the greater the higher the share of pomace in the raw material composition of the product (Table 1). However, the differences found between the burger treatments were insignificant ($p > 0.05$).

The results of the present study indicate that incorporating a plant-based ingredient into the raw material composition of a minced meat product can affect some characteristics of its culinary quality. Similarly, other researchers [39,40] found that the production yield of burgers after heat treatment - measured as the ratio of the finished product weight to meat batter weight - may depend on the inclusion of an ingredient of plant origin. However, the results obtained are not unambiguous. For

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example, the production yield of grilled mixed beef and pork burgers decreased significantly ($p < 0.05$) when 6.0% oat fibre preparation was added to the meat batter [40].

Limited information is available in the literature regarding using raw fruit pomace in minced meat products. Most of the research focused on the possible applications of dried fruit or vegetable pomace and fruit pomace extracts in meat processing [11,13,18,41,42].

Peiretti et al. [11] found that adding 1% or 2% of dried berry pomace resulted in a relatively small, insignificant ($p > 0.05$) increase in pork patties yield after heat treatment. According to the authors, dried fruit pomace is rich in dietary fibre, which helps retain moisture and fat within the food product matrix of the food product, preventing weight loss. However, in contrast to the present study, there was a tendency to decrease the degree of 'shrinkage' in the meat product containing fruit pomace, which was seen as a positive aspect in terms of culinary quality. The authors concluded that the dimensional changes occurring in the pork patties during baking were primarily due to the denaturation of meat proteins, which were the predominant ingredient in the product.

Tarasevičienė et al. [18] investigated the impact of berry pomace (from raspberries and blackberries) at levels of 1%, 3%, and 5% on changes in the quality of beef patties during a 9-day storage at 4°C. The highest weight loss was observed in the control patties (without added pomace) while adding pomace from both raspberries and blackberries resulted in a slight reduction in weight loss.

In the present study, the observed tendency of increasing thermal loss in the burgers with higher amounts of chokeberry pomace may have been due to the introduction of a low-acid ingredient. This observation aligns with findings by Tyburcy et al. [43], who added prunes to pork burgers.

3.2. Basic Chemical Composition of Pork Burgers

The use of chokeberry pomace in pork burgers resulted in relatively small but significant ($p < 0.05$) differences in the content of basic chemical components (Table 1). The water content ranged from 55.97% in the B5 product to 59.31% in the BC product, with a decrease ($p < 0.05$) noted as the concentration of chokeberry pomace increased. This reduction in water content in burgers containing chokeberry pomace can most likely be attributed to higher thermal loss (Table 1). In contrast to the water content, both protein and fat levels in the burgers increased with higher amounts of pomace. The B5 product had significantly ($p < 0.05$) the highest protein content (28.47%), while the BC product had the lowest (26.68%). The B2 and B3.5 products formed a homogeneous group, exhibiting lower ($p < 0.05$) protein levels than those in the B5 product but higher ($p < 0.05$) than in the BC product. Regarding fat content, the most significant difference ($p < 0.05$) was observed between the BC product (12.47%) and both the B5 and B3.5 products (19.96% and 13.77%, respectively). The sodium chloride content in pork burgers ranged from 1.63% in the B5 product to 1.94% in the BC product, being significantly higher ($p < 0.05$) in the burgers without chokeberry pomace (BC) compared to those containing added pomace (B2–B5). The obtained results allow us to assume that even a relatively small amount of fruit pomace added to meat batter may affect the nutritional value of a minced meat product, such as burgers.

Differences in the chemical composition of the pork burgers can be attributed to the varying chemical compositions of the raw materials used in production: the meat, fat, and chokeberry pomace. The pomace from chokeberry contains less water than pork ham, and its predominant nutrients are carbohydrates [10,19,22].

Based on the findings of other studies [39,40], it is clear that the basic chemical composition of burger-type meat products primarily depends on the type of meat used as raw material. However, adding plant ingredients to the meat batter can modify the chemical composition of the final meat product.

In studies on the use of valorised, i.e. dried fruit and vegetable pomace [13,41,44], no clear effect of these plant ingredients on the basic chemical composition of meat products was demonstrated. Skwarek and Karwowska [13], who examined the effect of freeze-dried tomato pomace (0.5%, 1% and 1.5%) on the quality of fermented sausages with reduced nitrite content, found significant differences ($p \leq 0.05$) in protein, fat and water content among the sausage treatments. Only the table salt content was similar in the experimental sausages. Dried tomato pomace was also used in beef frankfurters

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[41]. The study revealed that increasing the concentration of tomato pomace from 1 kg to 3, 5, and 7 kg per 100 kg of meat batter significantly ($p \leq 0.05$) influenced the fat, protein, ash, and water content in the sausages, depending, however, on the proportion of vegetable pomace in the recipe composition. With higher amounts of pomace, there was a tendency to increase the content of carbohydrates, protein, and ash in the sausages while decreasing the contents of water and fat. The observed differences in the chemical composition of sausages were attributed to the high protein and fibre content in dried tomato pomace, which likely contributed to the increase in protein and carbohydrate content in sausages containing the pomace. Another study [44] showed that the addition of 4% and 6% dried pomace from *Citrus reticulata* fruit, a hybrid variety of mandarin, resulted in a significant ($p < 0.05$) reduction in protein and fat content in ground pork products compared to the control product.

3.3. pH Value of Pork Burgers During Storage

The average pH value of the pork burgers varied from 6.73 in the B5 product on day 7 to 6.93 in the BC product on day 1 (Table 2). Product treatment (i.e. the addition level of black chokeberry pomace) and storage time affected ($p < 0.05$) the pH value of pork burgers. However, no interaction ($p > 0.05$) was observed between the treatment and storage time (Table 2).

Table 2. Changes in pH value in pork burgers with added black chokeberry pomace during storage (mean value ± standard deviation).

Storage time [days]	BC *	B2 *	B3.5 *	B5 *
1	6.93 e ± 0.02	6.82 d ± 0.01	6.77 abc ± 0.01	6.75 ab ± 0.01
7	6.91 e ± 0.01	6.80 cd ± 0.00	6.76 ab ± 0.01	6.73 a ± 0.00
14	6.90 e ± 0.01	6.79 bcd ± 0.01	6.76 ab ± 0.01	6.74 a ± 0.01
p-value	Treatment: p = 0.0000	Storage Time: p = 0.039	Treatment × Storage Time: p = 0.6872	

* Treatments: BC—pork burgers without chokeberry pomace; B2—pork burgers with 2.0% chokeberry pomace; B3.5—pork burgers with 3.5% chokeberry pomace; B5—pork burgers with 5.0% chokeberry pomace; a-e—mean values marked with different letters are significantly different at $p < 0.05$.

It was found that incorporating chokeberry pomace into the burgers resulted in a significant ($p < 0.05$) reduction in the pH value, regardless of the storage time. The product without chokeberry pomace (BC) had significantly the highest pH ($p < 0.05$), observed in all storage times, which was 6.93 on day 1 and 6.90 on day 14. Even the use of the smallest amount of pomace (B2) resulted in a relatively small but significant ($p < 0.05$) decrease in pH compared to the BC product. Increasing the addition of chokeberry pomace to 3.5% and 5% (products B3.5 and B5, respectively) resulted in a further reduction of the pH of the burgers. The lowest pH was measured in the B5 product, which varied from 6.75 on day 1 to 6.74 on day 14.

During the storage of burgers for each product treatment, pH decreased only slightly, and the observed changes were insignificant ($p > 0.05$).

The pH value of pork burgers differing in the level of added chokeberry pomace resulted from the active acidity of the raw materials used and their proportions in the recipe. The average pH values of the raw materials used to produce the burgers were 6.03 for pork ham, 6.08 for pork jowl and 3.36 for chokeberry pomace. Taking the above into account, it can be anticipated that adding chokeberry pomace to the meat batter will lower the pH of the final product. Moreover, the slight decrease in the pH of the burgers on day 14 of storage could have been caused by the growth of lactic acid bacteria, which will be discussed later in the article.

The results of this study are consistent with those of other researchers [12,18,42] who demonstrated that including a plant ingredient, even in a processed form, in the recipe composition of a meat product can reduce the active acidity in this product.

In contrast to our results, the findings reported by other researchers [15,41] indicate that the use of fruit or vegetable pomace in processed forms did not significantly change the pH of meat products.

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Raw pork burgers that contained an alcoholic extract from red grape pomace (0.06 g of extract per 100 g final product) and were packed under aerobic conditions did not show a significant difference ($p > 0.05$) in active acidity compared to the control product during 6-day storage [15]. Similarly, different levels of dried tomato pomace, ranging from 0% to 7% (w/w), did not affect ($p > 0.05$) the pH of beef sausages [41].

3.4. L, a* and b* Colour Components of Pork Burgers During Storage*

Table 3 presents the results of instrumental measurement of colour parameters (L*, a* and b*) of pork burgers differing in the amount of black chokeberry pomace added.

Table 3. Changes in colour parameters (L*, a* and b*) in pork burgers with added black chokeberry pomace during storage (mean value ± standard deviation).

Storage time [days]	BC *	B2 *	B3.5 *	B5 *
		L* (lightness)		
1	64.42 e ± 1.85	55.95 d ± 1.77	51.02 c ± 2.85	49.73 abc ± 1.83
7	63.13 e ± 1.87	55.23 d ± 2.46	50.23 bc ± 3.00	47 76 ab ± 2.25
14	62.07 e ± 1.55	54.38 d ± 2.02	49.28 abc ± 2.38	46.98 a ± 2.85
p-value	Treatment: p = 0.0000	Storage Time: p = 0.0001	Treatment × Storage Time: p = 0.9588	
		+a* (redness)		
1	+5.77 a ± 1.17	+7.30 b ± 1.05	+8.99 c ± 0.97	+9.44 c ± 0.77
7	+5.70 a ± 0.85	+6.48 ab ± 0.55	+9.00 c ± 0.60	+9.59 c ± 0.47
14	+5.44 a ± 1.42	+6.38 ab ± 0.61	+9.27 c ± 0.94	+9.61 c ± 0.76
p-value	Treatment: p = 0.0000	Storage Time: p = 0.4558	Treatment × Storage Time: p = 0.2024	
		+b*/−b* (yellowness/blueness)		
1	+8.08 f ± 0.80	+4.46 e ± 0.98	+0.85 cd ± 0.52	+0.44 c ± 0.65
7	+10.53 g ± 0.88	+3.47 e ± 0.85	−0.74 b ± 1.40	−2.00 a ± 0.62
14	+10.58 g ± 0.57	+1.87 d ± 0.45	−2.00 a ± 0.66	−2.77 a ± 0.74
p-value	Treatment: p = 0.0000	Storage Time: p = 0.0005	Treatment × Storage Time: p = 0.0005	

* Treatments: BC—pork burgers without chokeberry pomace; B2—pork burgers with 2.0 chokeberry pomace; B3.5—pork burgers with 3.5% chokeberry pomace; B5—pork burgers with 5.0% chokeberry pomace; a,-g—mean values regarding a given colour parameter marked with different letters are significantly different at $p < 0.05$.

A significant effect ($p < 0.05$) was observed for both burger processing and storage time on the colour parameter L*; however, there was no interaction ($p > 0.05$) between these two factors (Table 3). The L* colour parameter values varied from 46.98 in the B5 product on day 14 to 64.42 in the BC product on day 1. The BC product exhibited significantly the lightest ($p < 0.05$) colour regardless of the storage time. The addition of 2% black chokeberry pomace (product B2) resulted in a significant ($p < 0.05$) darkening of the burger colour. Increasing the chokeberry pomace addition to 3.5% and 5% (products B3.5 and B5, respectively) led to a further decrease ($p < 0.05$) in the L* value; however, the differences between the B3.5 and B5 products were not significant ($p > 0.05$).

All burger treatments, i.e. BC, B2, B3.5, B5, tended to darken during storage, as indicated by a slight decrease in the value of the colour parameter L*; however, these changes were not significant ($p > 0.05$; Table 3).

As for the colour parameter a*, a significant effect ($p < 0.05$) on this parameter was observed only for burger treatment, and not for storage time ($p > 0.05$) or interaction between treatment and storage time ($p > 0.05$; Table 3). The colour parameter a* value varied from +5.44 in the BC product on day 14 to +9.61 in the B5 product on the same day (Table 3). the redness of the burgers increased with the increase in the share of chokeberry pomace in the recipe composition. Regardless of the storage time, the product without chokeberry pomace (BC) exhibited significantly lower ($p < 0.05$) redness

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compared to products containing chokeberry pomace (B2%-B5%). The addition of 2% chokeberry pomace (B2) resulted in a higher a* value compared to the BC product; however, this difference was significant ($p < 0.05$) only on day 1. The B3.5 and B5 products demonstrated significantly ($p < 0.05$) higher a* values than the BC and B2 products, forming a distinct homogeneous group.

For all burger treatments, only insignificant ($p > 0.05$) changes in the value of the colour parameter a* during storage were observed (Table 3).

Yellowness was the colour parameter of pork burgers most affected by adding chokeberry pomace (Table 3). Both the treatment and storage time significantly influenced the colour parameter b* value in the pork burgers ($p < 0.05$), and an interaction between these two factors was also observed. The colour parameter b* value varied from -2.77 in the B5 product on day 14 to +10.58 in the BC product on the same day of storage. Regardless of the storage time, the BC product exhibited significantly ($p < 0.05$) the highest b* colour parameter value. As the addition level of pomace increased, there was a gradual decrease in the b* colour parameter value in pork burgers. On day 1, the b* parameter value was lower ($p < 0.05$) in the burgers with the smallest amount of chokeberry pomace (B2) when compared to the control product (BC). Increasing the chokeberry pomace addition level to 3.5% and 5% (B3.5 and B5 products, respectively) resulted in a further decrease ($p < 0.05$) in yellowness. On day 7, all burger treatments showed significant differences ($p < 0.05$) in the b* colour parameter value, with negative values recorded for the B3.5 and B5 burgers. Negative b* parameter values were also observed on day 14 for the B3.5 and B5 burgers, which differed significantly ($p < 0.05$) from the BC and B2 products. The negative values of the colour parameter b* caused by the plant ingredient indicated a predominance of blue over yellow in the overall colour tone of these products.

Significant changes ($p < 0.05$) in the b* colour parameter values were observed during the storage of all burger treatments. However, the trends in yellowness differed between the control burgers (BC) and those containing chokeberry pomace (B2–B5). For the BC burgers, the b* value increased over time. In contrast, the burgers with chokeberry pomace (B2–B5) showed a decrease in the b* parameter value over time.

Black chokeberry pomace is a rich source of water-soluble anthocyanin pigments, which gives this plant material its dark purple colour [19]. Thus, the color changes observed in the pork burgers were likely due to the anthocyanin pigments. The effect of black chokeberry pomace on pork burgers colour was confirmed by the total colour difference (ΔE) between the control product (BC) and the burgers with varying amounts of black chokeberry pomace during storage (Table S1). The ΔE values obtained were quite high, ranging from 9.42 (the difference between BC and B2 on day 1) to 20.57 (the difference between BC and B5 on day 14). This indicates that the pork burgers containing chokeberry pomace exhibited such distinct colour difference from the control product that an ordinary observer might perceive them as having two distinct colours [28].

The results of previous studies [11,12,15,42] indicate that the effect of adding fruit pomace on the colour of a meat product made from comminuted meat is ambiguous, depending, among other things, on the form of pomace used as an ingredient of the meat product.

Similarly to the present work, Tamkutė et al. [42] found that 2% addition of ethanol extract from defatted black chokeberry pomace to minced pork burgers caused a significant ($p < 0.05$) decrease in the value of the L* colour parameter and an increase ($p < 0.05$) in the value of the a* colour parameter compared to a similar product without pomace. Unlike in this study, the observed increase in the value of the burgers' colour parameter b* due to the influence of chokeberry pomace extract was insignificant ($p > 0.05$). At the same time, it was shown that the differences in the colour parameters of control burgers and those with the addition of chokeberry pomace extract were the greatest after production, while they decreased during the 16-day storage of burgers at refrigerated temperature.

3.5. Texture (Shear Force) of Pork Burgers During Storage

The shear force values for pork burgers ranged from 20.83 N in BC product on day 1 to 27.99 N in B5 product B5 on day 14 (Table 4). Both the treatment of the product and its storage time significantly affected ($p < 0.05$) the shear force of pork burgers, and an interaction was observed between these two factors. It was found that adding black chokeberry pomace to the recipe

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composition of pork burgers resulted in a gradual increase in shear force. Thus, the greatest differences were noted between the burgers without pomace (BC) and those with the highest amount of this ingredient (B5). On day 1, the shear force value in the BC and B5 products was 20.83 N and 24.43 N, respectively, although the difference between the burger treatments mentioned above was insignificant ($p > 0.05$). However, significant differences ($p < 0.05$) in shear force between BC and B5 products were observed on days 7 and 14. On day 14, the shear force values were the highest ranging from 24.17 N in BC product to 27.99 N in the B% product.

During the storage of burgers, regardless of the treatment applied, a tendency was observed for the burgers to become 'harder', which was reflected in progressively higher shear force values (Table 4).

Table 4. Changes in shear force value [N] in pork burgers with added black chokeberry pomace during storage (mean value ± standard deviation).

Storage time [days]	BC *	B2 *	B3.5 *	B5 *
1	20.83 a ± 3.40	21.01 ab ± 1.80	21.03 ab ± 3.77	24.43 abcde ± 2.52
7	21.55 abc ± 21.55	21.67 abc ± 1.64	23.28 abcd ± 2.04	25.88 de ± 3.41
14	24.17 abcd ± 2.04	24.64 bcde ± 2.48	24.82 cde ± 2.46	27.99 e ± 2.88
p-value	Treatment: p = 0.0000	Storage Time: p = 0.0000		Treatment × Storage Time: p = 0.9568

* Treatments: BC—pork burgers without chokeberry pomace; B2—pork burgers with 2.0% chokeberry pomace; B3.5pork burgers with 3.5% chokeberry pomace; B5—pork burgers with 5.0% chokeberry pomace; a-e—mean values marked with different letters are significantly different at $p < 0.05$.

The incorporation of shredded chokeberry pomace in pork burgers was expected to affect the textural properties of these meat products. Previous studies have demonstrated that the texture of burger-type meat products may be significantly influenced by the composition of the raw materials, especially when non-meat ingredients are added [39,40]. Changes in the texture parameters of a minced meat product due to the addition of a plant ingredient could be attributed to the influence of this ingredient on the meat batter matrix. It is also likely that the observed increase in 'hardness' of the pork burgers, as the amount of chokeberry pomace increased, is related to greater thermal loss and shrinkage compared to the control product (Table 1).

There is limited information in the literature regarding the impact of crushed fruit pomace on the textural properties of meat products. Therefore, this discussion will focus on how valorized forms of pomace influence the texture of meat products. Martín-Sánchez et al. [45] investigated the effect of fresh date palm by-products in the amount of 0, 5%, 10% and 15% on the texture of a campagne-type pork pâté using the texture profile analysis (TPA) test. According to the authors, date palm by-products are a good source of dietary fibre, which allowed the assumption that this component will affect the protein–water and protein–protein gel network and thus the pâté consistency. However, it was found that the hardness and gumminess of the pâtés were significantly ($p < 0.05$) higher only for the product with the lowest date paste addition. At the same time, based on the measurement results of such texture parameters as springiness, cohesiveness and resilience, it was shown that adding date 'paste' did not significantly differentiate the deformation properties of the pâtés and recovery after compression.

The instrumental texture parameters of meat products may be also influenced by the addition of dried fruit pomace and vegetable pomace [41,44]. The results of TPA test of pork patties, to which four different levels (0, 2%, 4%, 6%) of dried kinnow pomace powder were used to replace lean meat in the meat batter composition, showed that the hardness of these meat products increased significantly ($p < 0.05$) with the addition of 4% and 6% of the plant ingredient compared to the control product [44]. The increase in the hardness of pork patties with increasing the proportion of kinnow pomace powder was explained by the improvement of the binding properties of the meat batter after heat treatment, which could have been caused by the higher fiber content.

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3.6. Microbiological Analyses of Pork Burgers During Storage

The black chokeberry pomace used in the burgers showed good microbiological quality. In the pomace samples, only aerobic mesophilic microorganisms and bacteria from the *Enterobacteriaceae* family were detected, both at the level of 1 × 10² cfu/g. No lactic acid bacteria, yeasts, or moulds were detected in the pomace samples.

The results of the microbial quality of pork burgers are presented in Table 5.

The presence of aerobic mesophilic microorganisms was found in all burger treatments, and their number ranged from 1.1 × 10¹ cfu/g in the B3.5 product on day 1 to 4.2 × 10³ cfu/g in the same product on day 14 (Table 5).

It was found that only storage time affected ($p < 0.05$) the total number of mesophilic microorganisms in pork burgers. Product treatment had no effect ($p > 0.05$) on this microbiological quality characteristic of burgers. Moreover, no interaction was found between treatment and storage time ($p > 0.05$). Regardless of the amount of chokeberry pomace added, the lowest numbers of aerobic mesophilic microorganisms in pork burgers were found on day 1, and the highest – on day 14. BC, B2, B3.5 and B5 burgers did not differ significantly from each other ($p > 0.05$) in terms of the number of this group of microorganisms during the entire storage period. The obtained results indicate that aerobic mesophilic microorganisms introduced into the B2–B5 products together with chokeberry pomace did not cause a significant ($p > 0.05$) increase in the contamination of burgers with this group of microorganisms compared to the control product (BC). On the other hand, the addition of chokeberry pomace did not significantly reduce the growth of aerobic mesophilic microorganisms in pork burgers. The microbiological contamination of burgers was probably also influenced by heat treatment, which reduced the number of microflora in the meat product.

Regardless of the amount of chokeberry pomace added, the number of aerobic mesophilic microorganisms in burgers increased during storage (Table 5). However, compared to day 1, on day 14 a significant ($p < 0.05$) increase in the number of this group of microorganisms was recorded only for BC and B5 products.

It was found that psychrotrophic bacteria were present in burger treatment (Table 5). It was found that product treatment and storage time affected ($p < 0.05$) the number of psychrotrophic bacteria, and the interaction between these two factors was also observed. On day 1, psychrotrophic bacteria counts ranged from 1.0 × 10¹ cfu/g in products B3.5 and B5 products to 2.3 × 10¹ cfu/g in BC product. On days 1 and 7 of storage, there were no significant differences ($p > 0.05$) in the number of psychrotrophic bacteria between the control burger (BC) and burgers with the addition of chokeberry pomace (B2–B5).

Similarly to aerobic mesophilic microorganisms, the growth of the number of psychrotrophic bacteria in all burger treatments during the storage of pork burgers at refrigerated temperature was observed. Compared to day 1, on day 14 a significant ($p < 0.05$) increase in the number of these bacteria occurred in all burger treatments. Moreover, at the end of the storage period, the product B2 showed the lowest number of psychrotrophic bacteria (1.6 × 10² cfu/g), which was significantly ($p < 0.05$) lower than in the product BC (3.6 × 10² cfu/g), but not significantly different ($p > 0.05$) from the other burgers with added chokeberry pomace, i.e. B3.5 and B5.

Table 5. Changes in microbial quality [cfu/g] of pork burgers with added black chokeberry pomace during storage (mean value ± standard deviation).

Storage time [days]	BC *	B2 *	B3.5 *	B5 *
Total count of aerobic mesophilic microorganisms				
1	2.2 × 10¹ a ± 7.6 × 10⁰	1.2 × 10¹ a ± 5.8 × 10⁰	1.1 × 10¹ a ± 1.2 × 10⁰	3.5 × 10¹ a ± 5.0 × 10⁰
7	2.7 × 10² a ± 3.5 ×10²	3.2 × 10¹ a ± 2.6 × 10¹	1.0 × 10³ a ± 1.6 × 10³	4.5 × 10¹ a ± 5.0 × 10⁰
14	1.5 × 10³ b ± 2.2 × 10³	9.0 × 10² ab ± 7.0 × 10¹	4.2 × 10³ ab ± 9.5 × 10²	1.9 × 10³ b ± 2.0 × 10³

p-value	Treatment: p = 0.1049	Storage Time: p = 0.0000	Treatment × Storage Time: p = 0.0921	
Psychrothrophic bacteria				
1	2.3×10^{1} a ± 2.5×10^{0}	2.1×10^{1} a ± 2.0×10^{0}	1.0×10^{1} a ± 5.8×10^{0}	1.1×10^{1} a ± 2.0×10^{0}
7	1.4×10^{1} a ± 4.0×10^{0}	2.0×10^{1} a ± 1.0×10^{1}	6.0×10^{1} ab ± 1.7×10^{1}	2.2×10^{1} a ± 1.0×10^{1}
14	3.6×10^{2} d ± 4.0×10^{1}	1.6×10^{2} bc ± 5.3×10^{1}	2.7×10^{2} cd ± 7.6×10^{1}	2.0×10^{2} cd ± 1.5×10^{1}
p-value	Treatment: p = 0.0040	Storage Time: p = 0.0000	Treatment × Storage Time: p = 0.0027	
Lactic acid bacteria (LAB)				
1	1.2×10^{1} a ± 1.5×10^{0}	1.7×10^{1} a ± 6.0×10^{1}	1.7×10^{1} a ± 1.1×10^{1}	3.3×10^{1} a ± 2.1×10^{1}
7	2.9×10^{1} a ± 1.0×10^{1}	1.8×10^{1} a ± 4.4×10^{0}	3.6×10^{1} a ± 5.3×10^{0}	2.7×10^{1} a ± 2.1×10^{1}
14	9.1×10^{3} c ± 1.7×10^{2}	5.7×10^{3} b ± 1.9×10^{3}	5.2×10^{3} b ± 3.4×10^{3}	2.5×10^{3} ab ± 5.6×10^{2}
p-value	Treatment: p = 0.0040	Storage Time: p = 0.0000	Treatment × Storage Time: p = 0.0007	
Bacteria from the *Enterobacteriaceae* family				
1	ND**	ND**	ND**	ND**
7	ND**	ND**	ND**	ND**
14	ND**	ND**	ND**	ND**
***Pseudomonas* spp.**				
1	1.5×10^{2} a ± 5.0×10^{1}	1.5×10^{2} a ± 7.0×10^{1}	2.7×10^{2} a ± 2.1×10^{2}	1.1×10^{2} a ± 1.5×10^{1}
7	1.9×10^{2} a ± 6.0×10^{1}	1.4×10^{2} a ± 4.0×10^{1}	2.8×10^{2} a ± 1.9×10^{2}	5.3×10^{2} a ± 2.8×10^{2}
14	8.9×10^{3} c ± 6.3×10^{2}	2.5×10^{3} b ± 1.4×10^{3}	1.3×10^{3} ab ± 2.1×10^{2}	2.7×10^{3} b ± 1.2×10^{3}
p-value	Treatment: p = 0.0000	Storage Time: p = 0.0000	Treatment × Storage Time: p = 0.0000	
Brochothrix thermosphacta				
1	ND**	ND**	ND**	ND**
7	1.3×10^{2} a ± 5.8×10^{1}	1.1×10^{2} a ± 1.0×10^{1}	1.0×10^{2} a ± 6.0×10^{0}	1.6×10^{2} a ± 3.6×10^{1}
14	7.5×10^{3} b ± 1.3×10^{3}	5.7×10^{3} b ± 1.1×10^{3}	6.9×10^{3} b ± 2.5×10^{3}	5.2×10^{3} b ± 2.0×10^{3}
p-value	Treatment: p = 0.4225	Storage Time: p = 0.0000	Treatment × Storage Time: p = 0.4491	
Yeast and moulds				
1	ND**	ND**	ND**	ND**
7	ND**	ND**	ND**	ND**
14	ND**	ND**	ND**	ND**

* Treatments: BC—pork burgers without chokeberry pomace; B2—pork burgers with 2.0% chokeberry pomace; B3.5—pork burgers with 3.5% chokeberry pomace; B5—pork burgers with 5.0% chokeberry pomace; a-d—mean values regarding a given colour parameter marked with different letters are significantly different at p < 0.05. ** not detected in 0.1 g of sample.

Also, lactic acid bacteria (LAB) were detected in all pork burger treatments (Table 5). The LAB number varied from 1.2×10^{1} cfu/g in the BC product on day 1 to 9.1×10^{3} cfu/g in the same product variant on day 14. It was found that product treatment and storage time affected ($p < 0.05$) the LAB number, and the interaction between these two factors was also observed. On day 1 and day 7, no significant ($p > 0.05$) differences in the LAB between burgers assessed in this study were detected. However, on the last day of storage (day 14), it was noted that the number of LAB in burgers with chokeberry pomace (B2–B5) was significantly ($p < 0.05$) lower than in the control product (BC).

Regardless of the addition of chokeberry pomace, all burger treatments showed an increase in LAB levels between days 1 and 14. This increase was not significant ($p < 0.05$) only for the product B5, i.e. with the highest share of pomace in the recipe composition (Table 5).

The number of *Pseudomonas* bacteria in the pork burgers ranged from 1.5 × 10^2 cfu/g (product B5, day 1) to 8.9 × 10^3 cfu/g (product BC, day 14; Table 5). Similarly to LAB, on days 1 and 7 the pork burgers did not differ significantly ($p > 0.05$) in the number of *Pseudomonas* bacteria, regardless of the level of chokeberry pomace added. Only on day 14 the burgers containing chokeberry pomace (B2, B3.5 and B5) showed a significantly lower ($p < 0.05$) level of *Pseudomonas* levels compared to the control product (BC). Extending the storage time of the burgers to 14 days resulted in a significant ($p < 0.05$) increase in the number of *Pseudomonas* bacteria, except for the B3.5 product.

Over the storage time, the highest growth of *Pseudomonas* bacteria was recorded in the BC product, and it was significantly ($p < 0.05$) higher than in burgers with chokeberry pomace (B2–B5; Table 5).

After the burgers were produced (on day 1), no *Brochothrix thermosphacta* bacteria were detected in any pork burger treatments (Table 5). Still, their growth was observed as the storage time of the burgers increased. On day 7, the number of *Brochothrix thermosphacta* bacteria in pork burgers varied within small limits, i.e. from 1.0 × 10^2 cfu/g for the B3.5 product to 1.6 × 10^2 cfu/g for the B5 product, however without any differences ($p > 0.05$) between the burger treatments. On day 14, a significant ($p < 0.05$) increase in the number of *Brochothrix thermosphacta* bacteria was noted in all burger treatments, i.e. regardless of the use of chokeberry pomace. On the last day of storage, the BC product recorded the highest number of *Brochothrix thermosphacta* bacteria (7.5 × 10^3 cfu/g); however, the differences between the burger treatments were not significant ($p > 0.05$). Thus, our results indicate that adding chokeberry pomace did not significantly influence the count of *Brochothrix thermosphacta* bacteria in pork burgers.

One day after production, regardless of the amount of chokeberry pomace added, no *Enterobacteriaceae* or yeasts and moulds were found in any of the analysed burger treatments (Table 5). Moreover, bacteria from the *Enterobacteriaceae* family and yeasts and moulds were absent in 0.1 g of the product during the entire 14-day storage period of the burgers at refrigerated temperature.

The results obtained indicated that all variants of pork burgers evaluated in this study showed good microbiological quality, considering that bacteria from the *Enterobacteriaceae* family are considered indicators of the microbiological quality of food and the hygiene status of the production process [46]. During 14 days of storage, not only no the *Enterobacteriaceae* bacteria, but also no yeast or moulds were detected in any of the pork burger treatments. On days 1 and 7 of storage, it was observed that the addition of chokeberry pomace to pork burgers, regardless of the addition level of this ingredient, did not significantly reduce the growth of aerobic mesophilic microorganisms, Psychrothrophic bacteria, LAB, *Pseudomonas* spp. and *Brochothrix thermosphacta*. However, a beneficial, i.e. significant effect of chokeberry pomace on some aspects of the microbiological quality of pork burgers was noted on the last day of storage of these meat products at refrigerated temperature. Although with the passage of storage time an increase in the number of the mentioned groups of microorganisms was observed in all burger treatments, on day 14 the products containing chokeberry pomace, i.e. B2, B3.5 and B5 showed a significant lower number of LAB and *Pseudomonas* bacteria than control product–BC.

In the available literature, no information was found regarding the application possibilities of unprocessed fruit pomace for minced meat products. However, the research subject was the use of dried fruit or vegetable pomace or extracts obtained from pomace [12,13,15,42].

Black chokeberry fruits and pomace obtained from its fruits are a rich source of polyphenolic compounds, the dominant ones of which are anthocyanins [19,23,47]. This group of compounds is responsible for the antimicrobial activity of chokeberry fruits and its by-products [21].

Minced meat products such as burgers stored at refrigerated temperatures provide an excellent environment for the growth of many groups of microorganisms that contribute to the deterioration of their quality and shelf life. Although the maximum number of aerobic mesophilic bacteria is not regulated by law, it has been assumed that meat products are unfit for consumption when their number reaches 7–8 log cfu/g [48]. LAB, *Pseudomonas* and *Enterobacteriaceae* as well as *Brochothrix thermosphacta* can grow under refrigerated conditions [46,49,50].

Babaoğlu et al. [12] compared the antibacterial properties of water extracts from pomace from various fruits rich in polyphenolic compounds: black chokeberry, blackberry, red currant and

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blueberry (60 g/800 g of meat batter) as potential ingredients of minced beef patties, stored at refrigerated temperature for 9 days. On the first day after production, the total number of mesophilic aerobic bacteria was significantly ($p < 0.05$) lower in products containing added extract from pomace of chokeberry, blackberry and blueberry than in the control product. This trend continued until day 6 of beef patties storage. The observed reduction in antibacterial activity of water extracts from berries was explained by the gradual degradation of bioactive substances (including polyphenols) present in them. The gradual loss of antibacterial activity of water extracts from pomace was also confirmed in relation to the number of psychrotrophic bacteria, lactic acid and staphylococci (*Staphylococcus*). Unlike in the present study, it was shown that the use of any of the berry pomace extracts did not significantly inhibit the growth of LAB during 9 days of storage. The results obtained by the authors suggest that the water extract from black chokeberry pomace was the most promising natural preservative among the berry pomace extracts tested, improving the microbiological quality of beef patties.

Tamkutė et al. [42] assessed the impact of various concentrations of water and ethanol extracts obtained from defatted chokeberry pomace on the growth of selected pathogenic and food spoilage bacteria. Based on the results obtained in pork slurries, ethanol extract from chokeberry pomace was selected for further studies in pork meat products. One of the products were minced meat burgers, which, according to the authors, provide a particularly favorable growth environment for microorganisms due to significant cell damage, relatively high free water content and appropriate pH. The spoilage of this type of meat product stored at refrigerated temperature is attributed to the growth of, among others, *Brochothrix thermosphacta*, LAB, *Pseudomonas* spp., and *Enterobacteriaceae*. The heat treatment used may stabilize the microbiological quality of burgers, but on the other hand it may weaken the antimicrobial properties of plant extracts due to the degradation of temperature-sensitive bioactive compounds. It was found that a 2% addition of ethanol extract from chokeberry pomace inhibited the growth of *Brochothrix thermosphacta* in pork burgers during 16-day storage at refrigerated temperature: in samples without extract the number of these bacteria increased to 7 log cfu/g, while in samples with extract it reached only 3.87 log cfu/g. In our study, however, no significant effect of chokeberry pomace addition on the number of *Brochothrix thermosphacta* in pork burgers during 14-day storage was found. Moreover, it was observed that the chokeberry pomace extract effectively inhibited the growth of aerobic mesophilic bacteria, *Pseudomonas putida* and LAB during the storage of pork burgers, because in products with the extract the number of the above-mentioned microorganisms on the last day of storage (day 16) was significantly lower than in the control product. However, on the last day of storage of the pork burgers assessed in our study, a significant reduction in the growth of microorganisms resulting from the addition of chokeberry pomace was observed only for *Pseudomonas* spp. and LAB bacteria.

Garrido et al. [15] assessed the effect of two types of red grape pomace extracts on the microbiological quality of pork burgers packed in aerobic conditions and stored at +4°C for 6 days, i.e. simulating retail conditions. The authors did not find a significant effect of grape pomace extracts on total viable count, psychrophilic bacteria and coliforms. However, the factor that significantly differentiated the growth of the above-mentioned groups of microorganisms was the time of burger storage. Moreover, it was noticed that on the last day of storing the burgers (day 6), regardless of the modifications used in the raw material composition, the number of bacteria in the burgers exceeded the level considered as the spoilage limit (10^6–10^7 cfu/g). According to the authors, this was probably due to the relatively low dose of added extracts, i.e. 0.06 g per 100 g of final product.

The aim of the work by Skwarek and Karwowska [13] was to assess the effect of the addition of freeze-dried tomato pomace (0.5%, 1%, 1.5%) on the quality of dry fermented sausages with a reduced content of nitrites. The analysis of the obtained results showed a significant reduction in the population of *Enterobacteriaceae* with an increase in the amount of tomato pomace powder added, which, according to the authors, indicates the possibility of using this plant ingredient as an antimicrobial agent in this type of pork products.

Koskar et al. [51] compared the ability to inhibit the growth of microorganisms by powder preparations obtained from plants, including chokeberry pomace, in raw and cooked minced pork. The authors concluded that plant preparations showed great potential in the development of meat

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products of satisfactory microbiological quality, but the highest antimicrobial effectiveness was demonstrated by combinations of various plant powders, including: 3% apple + 1% onion + 2% blackcurrant berries; 3% apple + 1% garlic + 2% tomato, and 3% apple + 2% tomato + 1% rhubarb petioles, and not individual components.

5. Conclusions

The addition of a plant ingredient, which was chokeberry pomace, to the meat batter for pork burgers could have led to a reasonable expectation that this treatment would have an effect on the quality of the finished meat product. The results obtained in this work confirmed the above hypothesis. In summary, the use of black chokeberry pomace in a slightly processed raw form, i.e. ground to a 'paste' consistency, for a minced pork burger product does not pose any technological difficulties, but significantly affects many quality parameters of this meat product. Changes in the colour of the burgers, which was the quality feature most differentiated by the addition of chokeberry pomace, manifested by darkening, increased redness and decreased yellowness, were most probably caused by anthocyanin pigments present in this plant raw material.

Pork burgers with the recipe composition adopted in this study, after heat treatment and vacuum packaging, could be stored at refrigeration temperature for 14 days, because the observed changes in quality characteristics were not disqualifying. On the other hand, due to the significant effect of the chokeberry pomace 'paste' on slowing down the growth of only some of the tested groups of microorganisms in burgers, it can be assumed that the addition of this plant ingredient will not significantly improve the storage durability of burgers over a longer period of time. In order to comprehensively assess changes in the quality characteristics of pork burgers prepared with chokeberry pomace during storage, this research should be extended to include a sensory evaluation of finished meat products. If the sensory attributes of the burgers deteriorate, it would be worth considering continuing research on the use of chokeberry pomace, but in a refined form, e.g. freeze-dried. Processed fruit pomace is a raw material with a higher degree of preservation and usability than raw pomace, hence their use will not require close cooperation between the supplier and the recipient of the plant raw material.

6. Patents

Not applicable.

Supplementary Materials: Figure S1. Fresh black chokeberry pomace.; **Figure S2.** The appearance of pork burgers with various additions of chokeberry pomace after heat treatment.; **Table S1.** The total colour difference (ΔE) between the control product (BC) and pork burgers with added black chokeberry pomace during storage.

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