

Research Article

Physicochemical and Sensory Properties of Broiler Chicken Breast Meat Stored Frozen and Thawed Using Various Methods

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The paper presents an analysis of the impact of freezing storage duration (1, 3, 5, and 7 months) and thawing methods, namely, in atmospheric air, water, and using microwave oven on the quality properties of broiler chicken breast meat. The physicochemical indicators of raw breast meat after thawing and after being subjected to heat treatment were evaluated. The sensory evaluation was also conducted. The findings indicate that the duration of storage has effects on the quality of meat stored frozen at -20°C . Unfavourable changes ($p < 0.05$) were observed between the first and seventh months of freezing storage in respect of such areas as increased drip loss, increased thermal loss, colour changes, and reduced ash content in thawed breast meat as well as in those subjected to heat treatment. Unfavourable changes in the sensory properties, namely, diminished intensity of flavour and aroma, were also observed. The analysis revealed significant ($p < 0.05$) impacts of thawing methods on the meat's quality properties, depending on the duration of freezing storage. The application of microwave oven method of thawing meat enabled the retention of better physicochemical properties (reduction of drip and thermal losses and increased ash content) as well as sensory properties such as the desirability of the flavor and juiciness of meat stored for one-month period. A longer period of freezing storage (5 and 7 months) revealed higher degrees of colour saturation towards red (a^*) in raw breast meat as well as reduced brittleness of breast meat thawed using microwave oven method prior to and after the heat treatment in comparison to those thawed using atmospheric air and water. *Practical Applications.* The duration of freezing storage and thawing methods has impacts on the meat's quality, including its processing value. The current study has its practical implications due to the immense consumption of broiler chicken meat, the high proportion of deep frozen meat products in commerce, and the acceptability and popularity of frozen stored meat in households. The current study enables one to ascertain how the physicochemical and sensory properties of broiler chicken breast meat change over the period of freezing storage (for 1, 3, 5, and 7 months) and which of the applied thawing methods (in atmospheric air, water, or microwave method) is most favourable for retaining meat's best quality.

1. Introduction

Poultry meat is a valuable constituent of human diet. Poultry meat, especially broiler chicken production has, over the last decades become one of the fastest growing segments of global meat market. The global broiler chicken production has between 2000 and 2016 grown by 80.5%, compared with pork and beef which in the period grew by 35.0% and 20.7%, respectively [1]. This has ultimately altered patterns of meat production. Overall meat production has observed increased proportion of meat obtained from broiler chickens by 7.1%,

while that of pork and beef decreased by 2.7% and 4.4%, respectively [2].

A specific feature of meat is its short shelf life [3]. A significant part of the poultry meat in commercial circulation is offered as chilled meat. Freezing is a commonly applied method of managing surplus production outputs. An accruing benefit of freezing is its possibility of prolonged storage compared to chilled meat offered for trade. Freezing results in changes in meat's quality properties, which are directly related to both the freezing process and the prevailing conditions in freezing storage [4]. Leygonie et al. [5]

emphasize that the freezing stage does not entirely inhibit bio-physicochemical processes that take place in meat, but merely inhibit or alter their trend. Consequently, only raw meat of highest quality with good processing and technological sensory properties and in good hygienic state ought to be designated for freezing. The quality and the technological suitability of meat during freezing and subsequent freezing storage process depends on several factors, including the freezing parameters, freezing storage conditions, temperature stability, storage duration, and methods of thawing [6–9].

Thawing which is the last lap of the chill technology is aimed at restoring the meat's features to as close to that of fresh meat. The run of the thawing process is significantly affected by such factors as temperature and the actual duration of the thaw process. Any impropriety in course of the thaw process could result in the deterioration of meat quality [4, 10]. Thawing in atmospheric air and in water are two commonly applied methods of thawing meat. The increased significance of deep frozen meat products in commercial scale has led to the application of modern, but quick methods of thawing meat. This requirement is fulfilled by microwave oven thawing, which has become increasingly applied both in households and in industry. A key advantage of the microwave oven method of thawing is its speediness [11] as well as microbiological safety [12].

The objective of the study was to ascertain the impact of freezing storage duration (1, 3, 5, and 7 months), while giving consideration to the method of thawing (using atmospheric air, water, and microwave oven) on the quality properties of broiler chicken breast meat. The scope of the study covered the assessment of the physicochemical properties of raw and thermally treated meat. Laboratory tests of meat quality were complemented with sensory evaluation.

2. Research Materials

The study material (*musculus pectoralis*) was sourced from 35-day old ROSS 308 broiler chickens held together in one production cycle on liter with unlimited access to standard feed mixtures dedicated for broiler chickens. Slaughtering and dissection of the chickens was undertaken according to industry standards set for poultry slaughterhouses. The birds were mechanically slaughtered after they had been subjected to vet tests and a combined water-electricity stunning treatment. The level of the current applied for the stunning comply with Regulations of the Council of Europe (EC) No 1099/2009 of 24 September 2009 [13], concerning the protections of animals meant for slaughter. The birds were, soon after the blood-letting and scalding ($56 \pm 2^\circ\text{C}$) plucked and mechanically gutted. The carcasses were chilled in two stages, namely, in water with temperatures of up to 16°C , followed by air-jet method to achieve in-meat temperature of 2°C . The chilled carcasses were mechanically dismembered and the skinless breast meat were manually cut out [14]. The experiments were carried out on fresh breast meat. An initial quality assessment criterion was set at pH15, which was measured in meat within 15–20 minutes of its

slaughter, using the HI 99163 pH meter (Hanna, Germany) fitted with a dagger electrode. Only meat with pH15 values ranging between 5.9 and 6.2 was accepted for further experimentation after eliminating those with PSE and DFD defects. Breast meat samples ($n = 360$, with average weight of 200 ± 50 g) were transported in isothermal containers to the laboratory and stored in a refrigerator at 4°C for 24 hours. They were later weighed to an accuracy of 0.01 g, labelled, and packed separately in polyethylene bags and frozen. The freezing process was conducted at a temperature of -20°C , with no air-flow regulation in the drawer freezers (GN 3056 from Liebherr, Germany). The frozen meat was stored in freezing conditions with constant parameters (temperature $-20 \pm 1^\circ\text{C}$ and humidity of 40%) for 1 month ($n = 90$), 3 months ($n = 90$), 5 months ($n = 90$), and 7 months ($n = 90$). Following the completion of the set storage period, 30 pieces from each category were thawed using atmospheric air (A), in water (W), and in microwave oven (M). Both thawing in atmospheric air and thawing in water were carried out in a refrigerated cabinet (FKV 36110, Liebherr, Germany) at 4°C without removing them from the bags to achieve the in-sample temperature of $4^\circ\text{C} \pm 1^\circ\text{C}$. The thaw process using a microwave oven involved placing the samples in a microwave oven (29Z013 model, 800 W, Zelmer, Poland) and subjected to electromagnetic wave treatment for 5 minutes. The sample's internal temperature at the end of the process was $0^\circ\text{C} \pm 1^\circ\text{C}$, while on its external layer, it was $5^\circ\text{C} \pm 1^\circ\text{C}$. The sample's internal temperature was subsequently stabilized at $4^\circ\text{C} \pm 1^\circ\text{C}$.

2.1. Quality Assessment of Breast Meat. Laboratory assessment of the raw breast meat was undertaken after they have been thawed to ascertain the following: namely, volume of drip loss, pH, water holding capacity, colour, and its chemical composition (protein content, fat, and mineral salt content). The volume of drip loss was determined by placing the sample in a cuvette, fitted with a 5 mm thick grid spacer to avoid any contact between the leakage and sample. The amount of leakage was ascertained based on the weight difference between prefreezing and after thawing using the formula:

$$W_r (\%) = \left(\frac{M_1 - M_2}{M_1} \right) \times 100\%, \quad (1)$$

where W_r = amount of drip loss (%), M_1 = weight of sample prior to freezing (g), and M_2 = sample weight after thawing (g). pH measurements were achieved using a dagger electrode, fitted with a (HI 99163 from Hanna) pH meter. The sample's water holding capacity (WHC) determined using the Grau and Hamm [15] method was based on the amount of juice squeezed from it. The colour assessment of the meat's cross-sectional surface was determined based on the reflection method using the Chroma Meter colorimeter (Konica Minolta Osaka, Japan) with the CR 400 head, with settings for illuminations compatible with the D_{65} illuminator. The reading of the measurement results was achieved in a CIE LAB colorimetric system CIE LAB [16], with L^* (lightness), a^* (redness), and b^* (yellowness). Three repeats

were undertaken for each sample. Brittleness was measured based on the cutting force (F_{max}), using a Zwick/Roell testing machine BT1-FR1.OTH.D14 (from Zwick GmbH & Co., KG., Ulm, Germany), applying a wide-width Warner-Bratzler (V-blade) with a head speed of 100 mm·min⁻¹ and a 0.2 N pre-cut force. The cutting was carried out on meat cubes with a cross section of 100 mm² and length of 50 mm. Nitrogen content was determined using the Kjeldahl method (the units from Foss Tecator, Höganäs, Sweden) and converted into protein, multiplying it with a factor of 6.25. The fat content was determined using the Soxhlet method (Büchi Extraction System B-811 apparatus, Flawil, Switzerland). The samples (5 g ± 0.001 g) were, having been dried at 105°C, subjected to extraction using n-hexane as the solvent. The fat content was determined by weight after removing the solvent. Total ash content was determined after the complete mineralization of 5 g of the meat sample at 550–650°C in a muffle Carbolite oven type AAF1100, Hope Valley, UK. To assess the post-heat treatment leakage, 30 g of meat samples were weighed, placed, and kneaded in 150 cm³ beakers and weighed (accuracy of 0.01 g). The samples, thus prepared, were covered with polyethylene foil and heated in a water bath at 72 ± 2°C for 30 minutes and subsequently cooled [17]. The amount of post-thermal treatment leakage is expressed based on the formula:

$$W = [(m_1 - m_2) : (m_1 - m_0)] \times 100\%, \quad (2)$$

where W = amount of post-thermal leakage (%), m_0 = mass of empty beaker (g), m_1 = mass of beaker with meat before thermal treatment (g), and m_2 = mass of beaker with meat after pouring out the leaked meat juice (g).

The samples were, for the purpose of thermal treatment, subjected to boiling in water containing 0.6% sodium chloride at a ratio of 1:2 (meat/water) until the attainment of sample's internal temperature of 82°C ± 2°C. Following the thermal treatment, the colour, brittleness, and chemical composition were determined as was done with the raw samples immediately after thawing.

2.2. Sensory Assessment. The sensory assessment of the quality of thawed breast meat was conducted using the scaling method in accordance with the Barylko-Pikielna and Matuszewska [18] methodology. A five-point scale assessment was applied, covering such quality indicators as the meat's aroma and flavour (especially its desirability and intensity), juiciness, brittleness, and general appearance (1 point being the lowest score and 5 points being the highest). In order to conduct the sensory assessment, the thermally treated samples were cooled to 20°C ± 2°C, cut into 1.5 cm thick slices perpendicular to the run of meat fibers, and then placed in plastic containers. The samples were randomly assessed after they had been encoded. The sensory assessment process was conducted, in two repetitions, by a 6-member assessment team with proven sensory sensitivity, trained in accordance with ISO 8586-2:2008 [19] and ISO 8587:2006 [20] standards.

2.3. Statistical Analysis. The results were statistically analyzed using the Statistica 13.1 software package [21]. The values set out in the tables determined the arithmetic mean (\bar{x}) and standard deviation (SD). The collected data were checked for normality with the Kolmogorov-Smirnov test with Lilliefors correction. The homogeneity of variances was checked with the Brown-Forsythe test. The model included the impact of the main factors (freezing storage duration and thawing method) and the interaction between them. To indicate the significance of differences between means, the Tukey's post hoc test with a level of significance $P < 0.05$ was applied. The statistical model was as follows:

$$y_{ijk} = \mu + FSD_i + TM_j + (FSD \times TM)_{ij} + e_{ijk}, \quad (3)$$

where y_{ijk} = value of the dependent variable, μ = general average, FSD_i = the main effect of freezing storage duration (1 month, 3 months, 5 months, and 7 months), TM_j = the main effect of thawing method (j = air condition, water, and microwave oven), $(FSD \times TM)_{ij}$ = interaction effect of freezing storage and thawing method, and e_{ijk} = the random experimental error.

3. Results and Discussions

Drip loss is an important quality indicator for meat subjected to freezing storage [4]. The current study indicated a significant ($p < 0.05$) impact of freezing storage duration and thawing methods on the amount of drip loss (Table 1). The amount of drip loss increased with the duration of freezing storage. Significant ($p < 0.05$) increase in leakage was observed between the 1st and 5th and 7th months as well as between the 3rd and 5th and 7th months of storage. Wei et al. [22] indicated lower values of this indicator, although with similar growth trends for the amount of drip loss from breast meat of broiler chickens stored frozen over a period of 8 months. A similar trend was observed with lamb meat stored frozen for 21 months [23]. Ali et al. [7] posted higher drip loss for broiler chickens breast meat thawed first in atmospheric air and then refrozen. It is assumed that the amount of meat leakage while it is being thawed could serve as pointer to the degree of damage to meat tissues during freezing as well as an indirect evaluation of various thawing methods [5]. The current study has shown that the amount of drip loss from breast meat thawed using microwave ovens after 1 and 3 months of storage was less ($p < 0.05$) compared with that from meat thawed using atmospheric air and in water methods. Short-lived microwave thawing resulted in less damage to meat tissues thereby leading to less water loss [24]. Higher drip losses from broiler chicken breast meat thawed using the microwave method was observed by Oliveira et al. [9] as against other thawing methods. Similar values of drip loss in samples thawed using microwave and atmospheric methods were observed by Chwastowska-Siwiecka et al. [25] in rabbit meat, as well as by Kim et al. [26] in beef and by Kondratowicz et al. [27] in pork. Yu et al. [28] demonstrated that the amount of thawing leakage is determined by the thawing temperature and increases with rising temperatures.

TABLE 1: Measurements for pH, thawing loss, water holding capacity, and thermal leakage in breast meat with regard to the duration of freezing storage and thawing methods.

Traits	Thawing method	Frozen storage duration			
		1 month	3 months	5 months	7 months
<i>After thawing</i>					
Thawing loss (%)	a	^x 3.56 ^b ± 0.30	^x 4.05 ^b ± 0.46	5.11 ^a ± 0.30	5.04 ^a ± 0.40
	w	^x 3.82 ^b ± 0.28	^x 3.89 ^b ± 0.61	4.96 ^a ± 0.81	4.94 ^a ± 0.34
	m	^y 2.46 ^b ± 0.48	^y 3.02 ^b ± 0.40	4.38 ^a ± 0.52	4.59 ^a ± 0.50
pH	a	5.96 ± 0.16	5.96 ± 0.14	5.86 ± 0.10	5.99 ± 0.12
	w	6.01 ± 0.08	5.95 ± 0.11	5.89 ± 0.14	5.90 ± 0.11
	m	5.91 ± 0.10	5.90 ± 0.13	5.86 ± 0.12	5.89 ± 0.09
WHC (%)	a	15.60 ^b ± 1.30	15.95 ^b ± 0.98	16.60 ± 1.08	18.02 ^a ± 1.31
	w	15.21 ^b ± 1.36	15.62 ^b ± 1.48	16.21 ± 1.51	17.92 ^a ± 1.40
	m	16.45 ^b ± 1.30	16.52 ^b ± 1.23	16.81 ± 1.10	17.80 ^a ± 1.43
<i>After cooking</i>					
Thermal leakage (%)	a	^x 25.03 ^b ± 3.05	^x 26.12 ^b ± 2.98	26.04 ± 2.52	28.03 ^a ± 2.95
	w	^x 25.92 ^b ± 2.32	^x 26.10 ^b ± 3.38	26.10 ± 3.14	28.52 ^a ± 3.05
	m	^y 23.81 ^b ± 3.29	^y 24.47 ^b ± 3.20	25.80 ± 4.29	27.19 ^a ± 3.52

Note. $\bar{x} \pm s$: arithmetic mean ± standard deviation; a: atmospheric air ($n = 10$); w: water ($n = 10$); m: microwave oven ($n = 10$). ^{a,b}Values in rows with different letters differ significantly $p < 0.05$. ^{x,y}Values in columns with different letters differ highly significantly $p < 0.05$.

Meat acidity is one of the most objective features that inform about the rate of postslaughter glycolysis, which is the primary cause of meat quality diversity. As a result of the various phases of water transformation during the freezing process, increased concentration of hydrogen ions, ionic strength, and pH changes can be observed [29]. Leygonie et al. [5] argue that given the proper freezing storage conditions, the pH of broiler chicken breast meat decreases with increasing storage duration, which is attributable to the loss of water with its associated soluble substances, the progressing process of glycogenolysis, and the accumulation of acidic products of ongoing transformational processes that are usually intensified during thaw processes [6]. Additionally, the process of protein denaturation may bring about the freeing of hydrogen ions [30]. The current study (Table 1) did not, however, indicate any impact of freezing storage duration on the pH of breast meat ($p > 0.05$). The results obtained in this regard are comparable to those obtained by Wei et al. [22]. Studies conducted by Ali et al. [29] and Chen et al. [8] on broiler chicken breast meat as well as by Muela et al. [23] on lamb demonstrated declines in pH values in subsequent weeks of freezing storage. Santosh Kumar et al. [31], on the other hand, observed pH increases in broiler chicken breast meat obtained from varied sources. Ongoing proteolytic processes in course of prolonged storage and inappropriate thawing do, in Akhtar et al. [6] and Leygonie et al.'s [5] opinion, lead to increased pH values in thawed tissues. The current study did not indicate significant ($p > 0.05$) impact of thawing methods on pH values. Similar results for these same methods of thawing were obtained by Kim et al. [32] for broiler chicken breast meat, by Chwastowska-Siwiecka et al. [25] for rabbit meat, and by Chwastowska and Kondratowicz [33] for pork.

Increased water holding capacity of breast meat determined using the forced leakage method between the first and seventh months as well as between the third and seventh months of freezing storage was observed in the current study. Greater water loss during the freezing storage period

reduced the amount of forced leakage from the meat, which can be considered a sign of a better water holding capacity of meat held in freezing storage over a longer period (Table 1). Similar trends in changes relating to water holding capacity during their freezing storage were revealed in studies conducted on pork by Chwastowska and Kondratowicz [33] and Kondratowicz et al. [27].

The amount of thermal leakage impacts lots of influence on the quality properties of meat for culinary purposes [9]. The current study has also demonstrated that the amount of thermal leakage increased with increasing length of freezing storage. Significant differences ($p < 0.05$) were observed between the first and seventh months as well as between the third and seventh months of storage, which can be attributed to the increased drip loss. Increased levels of thermal leakage in the eighth month of freezing storage were demonstrated by Wei et al. [22] on broiler chicken meat thawed in atmospheric air and also by Muela et al. [23] on lamb. The current study also indicated significant ($p < 0.05$) impact of thawing methods on the volume of thermal leakage. Less amount of thermal leakage was more associated with meat thawed using microwave oven methods as against those thawed using air and in water, having been stored frozen for 1 and 3 months. Differences in the amount of thermal leakage between the different methods become less significant ($p > 0.05$) as the freezing storage period got prolonged. Benli [34] also demonstrated the impact of thawing methods on the volume of thermal leakage, but obtained lower thermal leakage in using microwave thawing and deep freeze processes, while obtaining higher leakage using tap water, warm water, and kitchen counter. Yu et al. [28] confirmed that the volume of thermal leakage in frozen breast meat varied depending on the temperature while thawing. Zhuang and Savage [35] reported that cooked broiler breast fillets prepared directly from their frozen state or prepared after thawing exhibited significantly different thermal leakage. Chen et al. [8] observed less thermal leakage in subsequent thawing and freezing cycles.

Meat colour is an important assessment criterion. The extent of colour change of frozen meat is determined, mainly by prevailing conditions in freezing storage and access to oxygen [5, 6]. The current study demonstrated the existence of direct relationship between the duration of freezing storage and colour change (reduced brightness L^* but increased yellowness b^*) of breast meat soon after thawing (Table 2). Significant ($p < 0.05$) differences regarding these parameters were observed between the 1st and 7th months of freezing storage for samples thawed in atmospheric air and in water, whilst in samples thawed using the microwave method, the differences were between the 1st and 5th months of storage. Decreases in L^* value could be caused by declining water holding capacity, which leads to a lower surface light reflectivity [36]. The accumulation of metmyoglobin (MetMb) at the surface of meat during storage contributes significantly to its discoloration [37]. The increasing lipid oxidation and the formation of MetMb are the main factors contributing to changes in b^* value [38]. Similar trend in colour change regarding L^* and b^* parameters of breast meat frozen stored for 8 months were demonstrated in studies by Wei et al. [22]. Galobart and Moran [39] also indicated that thawing reduced the L^* value in pale-coloured fillets but increased it in dark-coloured ones. Lee and Park [40] reported that pork meat thawed by the microwave had yellowness compared with 4°C refrigerator thawing. Significant ($p < 0.05$) impacts of thawing methods on the red colour (a^*) parameter were observed in raw breast meat after their 5th and 7th months of freezing storage (Table 3). Microwave thawed breast meat was characterized by higher saturation of red colour (a^*) compared to those thawed in atmospheric air and in water. Kim et al. [32] provide that these combined results indicate that microwave thawing causes less meat protein denaturation and minimizes damage to the quality of frozen foods. In addition, increases in the microwave power minimized the formation of metmyoglobin, which ultimately affected the redness of the thawed chicken breast. Changes in post-thermally treated meat colour depend on the degree of myoglobin denaturation and also on the type and temperature of the thermal treatment [35]. The study demonstrated that freezing storage had no significant ($p > 0.05$) changes on the brightness L^* parameter of thawed meat subjected to thermal treatment (Table 2). After the 7th month of freezing storage, however, the meat was characterized by more intense yellow colour (b^*) saturation than after the 1st month, irrespective of the thawing method applied. Studies conducted by Benli [34] on meat thawed using domestic methods and subjected to thermal treatment did not confirm changes in L^* parameter of breast meat as well. Galobart and Moran [39] demonstrated that cooking thawed breast meat further increased L^* value and reduced the differences in L^* , a^* , and b^* parameters.

The results of analyses for brittleness measured by the cutting force are contained in Table 3. It was demonstrated that prolonged freezing storage increased the brittleness of breast meat soon after its thawing as well as after it has been subjected to thermal treatment. Significant ($p < 0.05$) differences were observed between the 1st and 7th months of

the freezing storage. The observed changes regarding brittleness could be the consequence of the fact that muscular cells were deteriorated because of intracellular ice forming during freezing which led to the lowering of the shear force in frozen and thawed samples [4]. Freezing storage, according to Shanks et al. [41] and Farouk et al. [42], improves the meat's brittleness. Observed changes in the meat's brittleness during its freezing storage could be triggered by protein changes in meat tissues [43]. It has also been found that the increase in brittleness is correlated to the length of freezing storage and the degree to which the meat was aged prior to freezing. The tenderising effect of freezing seems to be negated when the meat was sufficiently aged prior to freezing [44]. Gambuteanu et al. [4] postulates that the brittleness of poultry meat depended on the applied thawing method. The current studies have demonstrated the impact of thawing methods on the brittleness of both raw breast meat as well as those subjected to thermal treatment. A significantly ($p < 0.05$) lower cutting force was characteristic of breast meat thawed in atmospheric air and in water in comparison to those thawed using the microwave method (Table 3). Similar observations were noted regarding meat soon after thawing (after their 5th and 7th months of storage) and also after thermal treatment (for meat after 7 months of freezing storage). Similar results were reached by Oliveira et al. [9] in their trials on the brittleness of breast meat thawed using variety of methods. In Yu et al.'s [28] opinion, the thawing temperature impacts on the brittleness of chicken breast meat as they demonstrated that a lower cutting force was characteristic of samples thawed at lower temperatures. The brittleness of meat previously subjected to thermal treatment relied on the quality of the exit raw material, the type of thermal treatment, and the duration and temperature of heating [6]. In contrast, Lee et al. [43] observed that increased toughness was characteristic of breast meat stored frozen and boiled.

Table 4 provides an illustration of the chemical composition of meat in differing duration of freezing storage and thawing methods. The current studies did not show any significant ($p > 0.05$) impact of the duration of freezing storage and thawing methods on the total protein and fat content of raw meat soon after being thawed and subjected to thermal treatment. Protein transformations taking place in normal conditions in the process of thawing are, according to Akhtar et al. [6] and Gambuteanu et al. [4], insignificant and are often limited to trivial losses in protein and amino acids due to drip loss. Freezing storage has been shown to induce protein carbonylation, carboxylation, and the formation of schiff bases in chicken meat [45]. Freezing storage and thawing both have impacts on the activities of endogenous proteolytic enzymes responsible for the degradation of meat protein as well as the relaxation of meat tissue structures [42]. Studies conducted by Śmiecińska et al. [46] revealed increased content of both total and soluble protein in turkey breast meat after 6 weeks of freezing storage. Chan et al. [47], on the other hand, observed heightened content of soluble protein in frozen vacuum-packed turkey meat stored for 3 weeks before being thawed in atmospheric air at 4°C. Kim et al. [32] did not, however,

TABLE 2: Measurements of instrumental colour assessment (Konica Minolta, L^* , a^* , and b^*) of breast meat with regard to the duration of freezing storage and methods of thawing.

Traits	Thawing method	Frozen storage duration			
		1 month	3 months	5 months	7 months
<i>After thawing</i>					
Colour: L^* , lightness	a	53.30 ^a ± 6.80	51.81 ± 4.50	51.05 ± 4.10	50.42 ^b ± 5.12
	w	52.98 ^a ± 3.28	52.98 ± 3.08	52.03 ± 3.56	51.00 ^b ± 4.60
	m	53.12 ^a ± 4.48	51.10 ± 5.10	50.56 ^b ± 4.50	50.01 ^b ± 3.80
a^* , redness	a	1.64 ± 0.30	1.58 ± 0.50	^y 1.86 ± 0.50	^y 1.97 ± 0.50
	w	1.34 ± 0.48	1.28 ± 0.42	^y 1.78 ± 0.49	^y 1.90 ± 0.42
	m	1.96 ^a ± 0.58	2.10 ± 0.58	^x 3.10 ^b ± 0.58	^x 3.16 ^b ± 0.58
b^* , yellowness	a	6.42 ^a ± 0.98	6.32 ± 1.35	7.12 ± 0.86	8.12 ^b ± 0.86
	w	6.02 ^a ± 0.79	6.09 ± 1.20	7.08 ± 1.21	8.01 ^b ± 1.21
	m	6.06 ^a ± 0.88	5.89 ^a ± 1.04	8.09 ^b ± 1.08	9.12 ^b ± 1.08
<i>After cooking</i>					
Colour: L^* , lightness	a	82.83 ± 5.70	80.81 ± 4.80	81.31 ± 6.00	80.83 ± 4.70
	w	81.21 ± 5.00	81.98 ± 6.08	81.52 ± 5.10	80.21 ± 6.00
	m	82.86 ± 4.28	81.12 ± 5.10	80.14 ± 4.50	81.86 ± 7.28
a^* , redness	a	1.42 ± 0.46	1.58 ± 0.51	1.60 ± 0.48	1.59 ± 0.50
	w	1.34 ± 0.48	1.28 ± 0.40	1.38 ± 0.40	1.48 ± 0.42
	m	1.46 ^a ± 0.52	1.62 ± 0.36	1.78 ± 0.35	1.86 ^b ± 0.58
b^* , yellowness	a	11.04 ^a ± 0.98	12.30 ± 1.25	12.86 ± 2.10	13.12 ^b ± 1.86
	w	10.56 ^a ± 1.10	11.56 ± 1.41	12.03 ± 1.30	12.86 ^b ± 1.20
	m	10.92 ^a ± 1.20	11.80 ± 2.50	11.95 ± 1.08	12.08 ^b ± 2.00

Note. $\bar{x} \pm s$: arithmetic mean ± standard deviation; a: atmospheric air ($n = 10$); w: water ($n = 10$); m: microwave oven ($n = 10$). ^{a,b}Values in rows with different letters differ significantly $p < 0.05$. ^{x,y}Values in columns with different letters differ highly significantly $p < 0.05$.

TABLE 3: Measurements of instrumental assessment of texture (Warner-Bratzler, shear force N) of breast meat with regard to duration of freezing storage and methods of thawing.

Traits	Thawing method	Frozen storage duration			
		1 month	3 months	5 months	7 months
<i>After thawing</i>					
	a	13.98 ^a ± 1.86	13.05 ± 1.12	^y 12.04 ± 1.48	^y 11.84 ^b ± 2.10
	w	14.06 ^a ± 1.80	14.09 ^a ± 1.09	^y 13.00 ± 1.56	^y 12.01 ^b ± 1.62
	m	14.24 ^a ± 2.20	14.09 ± 2.47	^x 14.82 ± 2.20	^x 12.18 ^b ± 2.00
<i>After cooking</i>					
	a	18.12 ^a ± 2.86	18.05 ± 1.48	17.85 ± 1.87	^y 15.02 ^b ± 1.80
	w	18.25 ^a ± 1.89	18.32 ± 2.20	18.44 ± 3.50	^y 15.12 ^b ± 1.58
	m	19.18 ^a ± 2.56	19.00 ± 2.46	18.62 ± 2.56	^x 17.02 ^b ± 2.00

Note. $\bar{x} \pm s$: average value ± standard deviation; a: atmospheric air ($n = 10$); w: water ($n = 10$); m: microwave oven ($n = 10$). ^{a,b}Values in rows with different letters differ significantly $p < 0.05$. ^{x,y}Values in columns with different letters differ highly significantly $p < 0.05$.

demonstrate impacts of microwave thawing method on protein content of raw broiler chicken breast meat. Bustamante-Vargas et al. [48] noted that less protein losses were observed while applying the microwave method, in contrast to atmospheric and in water thawing methods. As the thawing temperature increased, so did the level of protein loss. Prolonged duration of the freezing storage resulted in reduced ash content (Table 4). Significant ($p < 0.05$) disparities were observed between the 1st and 7th months of storage in raw breast meat soon after the thawing process. Similar trends were, in contrast, observed between the 1st and 5th, as well as between the 1st and 7th months in meat previously thawed and subjected to thermal treatment. The observed reduction in ash content was probably due to increased meat leakage during the thawing process, hence the subsequent increased loss of mineral salts. Chwastowska and Kondratowicz [33] also demonstrated the impact of thawing (in atmospheric air and microwave) methods on the

ash content of pork meat. The significant ($p < 0.05$) impact of the thawing method on the ash content was, in the current study, demonstrated in thawed meat as well as that subjected to thermal treatment after a short, one-month interval of freezing storage. Higher ash contents were, however, observed in microwave thawed meat, in contrast with those thawed using atmospheric air and in water.

Freezing storage is capable of impacting influence on the sensory properties of meat. The extent of such transformations depend on the duration and freezing temperature as well as on the prevailing conditions of storage [4, 6]. The sensory properties of breast meat subjected to thermal treatment following its thawing, taking into consideration the duration of freezing storage and thawing methods are presented in Table 5. The current study demonstrates that meat after its 7th month of freezing storage was characterized by significantly ($p < 0.05$) lower intensity of flavor and poor juiciness. This decrease in juiciness might be due to

TABLE 4: Chemical composition of breast meat with regard to duration of freezing storage and methods of thawing.

Traits	Thawing method	Frozen storage duration			
		1 month	3 months	5 months	7 months
<i>After thawing</i>					
Crude protein (%)	a	23.85 ± 1.21	23.95 ± 1.56	23.94 ± 1.28	24.06 ± 1.32
	w	23.80 ± 1.26	23.82 ± 1.20	23.86 ± 1.50	23.89 ± 1.41
	m	23.74 ± 1.48	23.73 ± 1.82	23.88 ± 1.55	23.90 ± 1.35
Fat (%)	a	1.16 ± 0.20	1.16 ± 0.20	1.18 ± 0.28	1.19 ± 0.15
	w	1.14 ± 0.18	1.15 ± 0.15	1.16 ± 0.14	1.16 ± 0.12
	m	1.19 ± 0.28	1.19 ± 0.23	1.18 ± 0.25	1.17 ± 0.10
Ash (%)	a	^y 1.16 ^a ± 0.18	1.15 ± 0.28	1.16 ± 0.16	1.13 ^b ± 0.26
	w	^y 1.16 ^a ± 0.19	1.15 ± 0.30	1.15 ± 0.24	1.12 ^b ± 0.19
	m	^y 1.20 ^a ± 0.38	1.18 ± 0.38	1.18 ± 0.30	1.16 ^b ± 0.38
<i>After cooking</i>					
Crude protein (%)	a	30.98 ± 3.60	30.95 ± 2.56	30.94 ± 1.28	31.03 ± 2.32
	w	30.56 ± 3.00	30.82 ± 3.10	30.86 ± 2.50	30.95 ± 3.05
	m	29.56 ± 2.48	29.73 ± 2.82	30.88 ± 3.55	30.64 ± 2.54
Fat (%)	a	1.26 ± 0.20	1.26 ± 0.22	1.25 ± 0.18	1.24 ± 0.19
	w	1.24 ± 0.12	1.23 ± 0.19	1.23 ± 0.12	1.22 ± 0.12
	m	1.25 ± 0.16	1.24 ± 0.30	1.24 ± 0.21	1.23 ± 0.16
Ash (%)	a	^y 1.28 ^a ± 0.12	1.26 ± 0.27	1.23 ± 0.16	1.23 ^b ± 0.21
	w	^y 1.26 ^a ± 0.30	1.25 ± 0.32	1.23 ^b ± 0.21	1.22 ^b ± 0.18
	m	^x 1.31 ^a ± 0.33	1.29 ± 0.36	1.26 ± 0.22	1.25 ^b ± 0.30

Note. $\bar{x} \pm s$: arithmetic mean ± standard deviation; a: atmospheric air ($n = 10$); w: water ($n = 10$); m: microwave oven ($n = 10$). ^{a,b}Values in rows with different letters differ significantly $p < 0.05$. ^{x,y}Values in columns with different letters differ highly significantly $p < 0.05$.

TABLE 5: Results of sensory assessment of breast meat with regard to the duration of freezing storage and methods of thawing.

Traits	Thawing method	Frozen storage duration			
		1 month	3 months	5 months	7 months
<i>Odour intensity</i>					
Odour intensity	a	4.48 ± 0.30	4.32 ± 0.45	4.12 ± 0.31	3.88 ± 0.40
	w	4.40 ± 0.32	4.00 ± 0.51	3.82 ± 0.30	3.78 ± 0.32
	m	4.56 ± 0.50	4.40 ± 0.42	4.00 ± 0.52	4.10 ± 0.44
<i>Flavour intensity</i>					
Flavour intensity	a	4.44 ^b ± 0.30	4.40 ± 0.40	4.20 ± 0.28	3.82 ^a ± 0.28
	w	^y 4.18 ^b ± 0.30	4.12 ± 0.35	3.86 ± 0.30	3.42 ^a ± 0.30
	m	^x 4.86 ^b ± 0.45	4.48 ± 0.38	4.10 ± 0.52	4.02 ^a ± 0.38
<i>Odour desirability</i>					
Odour desirability	a	4.58 ± 0.40	4.15 ± 0.50	3.90 ± 0.50	3.68 ± 0.48
	w	4.50 ± 0.48	4.10 ± 0.42	3.88 ± 0.41	4.00 ± 0.31
	m	4.68 ± 0.30	4.12 ± 0.38	3.68 ± 0.38	3.95 ± 0.41
<i>Flavour desirability</i>					
Flavour desirability	a	4.16 ± 0.28	4.18 ± 0.40	4.04 ± 0.48	4.10 ± 0.42
	w	4.08 ± 0.32	4.00 ± 0.38	3.68 ± 0.54	3.81 ± 0.38
	m	4.80 ± 0.42	4.56 ± 0.46	4.10 ± 0.42	4.05 ± 0.40
<i>Juiciness</i>					
Juiciness	a	^y 4.20 ^b ± 0.40	4.40 ± 0.30	3.86 ± 0.51	3.12 ^a ± 0.40
	w	^y 4.18 ^b ± 0.31	4.06 ± 0.28	3.66 ± 0.46	3.10 ^a ± 0.31
	m	^x 4.92 ^b ± 0.49	4.42 ± 0.35	4.10 ± 0.50	3.62 ^a ± 0.32
<i>Tenderness</i>					
Tenderness	a	3.90 ± 0.32	3.83 ± 0.50	4.10 ± 0.40	4.22 ± 0.31
	w	3.62 ± 0.30	3.60 ± 0.32	3.66 ± 0.38	3.83 ± 0.30
	m	3.82 ± 0.38	4.00 ± 0.30	4.00 ± 0.51	4.10 ± 0.35

Note. $\bar{x} \pm s$: arithmetic mean ± standard deviation; a: atmospheric air ($n = 10$); w: water ($n = 10$); m: microwave oven ($n = 10$). ^{a,b}Values in rows with different letters differ significantly $p < 0.05$. ^{x,y}Values in columns with different letters differ highly significantly $p < 0.05$. Sensory scale: *odour-flavour intensity*: 1 = negatively changed, 2 = moderately changed, 3 = typical, weak, 4 = typical, strong, 5 = typical, very strong; *odour-flavour desirability*: 1 = not desirable, 2 = fairly desirable, 3 = desirable, 4 = very desirable, 5 = highly desirable; *juiciness*: 1 = very dry, 2 = dry, 3 = slightly juicy, 4 = juicy, 5 = very juicy; *tenderness*: 1 = very hard, 2 = hard, 3 = slightly tender, 4 = tender, 5 = very tender.

slight dehydration (loss of moisture) of the samples during the long period of storage. Similarly, sensory changes were observed in studies by Santosh Kumar et al. [31], who demonstrated that prolonging the freezing storage duration resulted in deteriorated juiciness of broiler chicken breast

meat. The sensory assessment conducted using a 5-point hedonic scale indicated that a 5-month duration of freezing storage did not produce significant deterioration to the quality of broiler chicken breast meat. This is in agreement with the observations of Abu-Ruwaida et al. [49] and Anand

et al. [50] who reported acceptability of chicken meat after 6–9 months of storage at -18°C as well as Śmiecińska et al. [46] after a short, 6-month long freezing storage. The current study has demonstrated a significantly ($p < 0.05$) better suitability of the microwave method of thawing meat stored for a month in order to retain the juiciness of broiler chicken breast meat than for those thawed using atmospheric air and in water. The intensity of flavour is also more, compared with that of meat thawed in water.

Data Availability

The research data used to support the findings of this study are included within the article.

Additional Points

Summary. The physicochemical and sensory properties of frozen stored breast meat were changeable depending on the duration of freezing storage. The storage of breast meat in frozen state for 5 months resulted in increased drip loss, but did not impact on other parameters of meat quality. Longer periods of storage (7 months) led to increased drip loss and thermal leakage, colour change (due to reductions in brightness L^* parameter and increased saturation of yellow b^*), and reduced ash content in breast meat thawed earlier as well as after the thermal treatment. The study also noted deteriorating sensory qualities such as in the intensity of flavor and aroma. Although the meat's brittleness, measured in terms of its cutting force, improved after the 7th month of storage, it was however not proven in manual oral flavor assessments. The application of microwave methods of thawing meat enabled the retention of better physicochemical (reduced drip and thermal leakage, and increased ash content) and sensory (desirable flavor and juiciness) properties of meat stored for a month. Prolonged duration of freezing storage (for 5 and 7 months) resulted in the breast meat thawed in atmospheric air and in water being characterized by a lower degree of colour saturation towards red (a^*) and less cutting force (better brittleness) than for meat thawed using the microwave method.

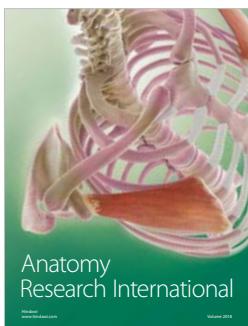
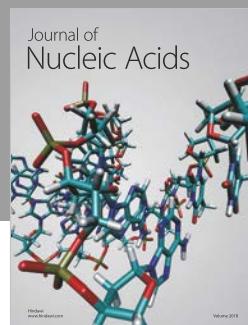
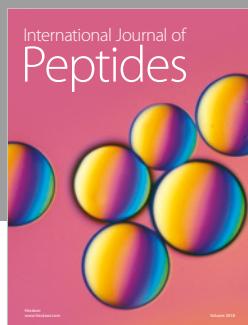
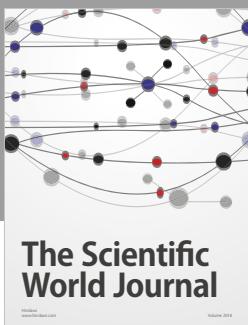
Conflicts of Interest

The authors declare that there are no conflicts of interest.

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