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The Use of the Sous-Vide Method in the Preparation of Poultry at Home and in Catering—Protection of Nutrition Value Whether High Energy Consumption

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Abstract: Nowadays, the reduction of food waste, as well as protection of the nutritional value, are significant trends in domestic and catering food processing. Among the trends are innovations in food technology like sous-vide. The aim of this study was to evaluate the effect of sous vide cooking on the technological, nutritional, and microbiological quality of the chicken breast as well as to compare it to conventional methods (boiling and steaming). Meats after low-temperature sous-vide heat treatment were characterized by a significantly higher yield ($p \leq 0.05$) and water content than those prepared with conventional methods. The energy and time consumption of sous-vide preparation was 5–10 times higher than other methods. The examined heat treatments resulted in a good microbiological quality of samples. The nutritional value of sous-vide products depended on the process parameters. A higher temperature and sous-vide processing time resulted in a higher content of dry matter, protein, and fat in the meat and was close to that of conventional methods. Low parameters of the process resulted in the least changed profile of fatty acids in meat. The use of the sous-vide method protects the nutritional value and allows for the extension of the shelf life of the meat which ultimately reduces food waste. The sous-vide heat treatment method is more suitable for foodservice than use in home conditions because of high energy consumption, despite the protection of nutrition value.

Keywords: chicken meat; sous-vide; chemical composition; microbiological quality; energy consumption

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1. Introduction

According to FAO [1], more than one-third of food produced for human consumption is wasted, and the a significant share is ascribed to households. Many people around the world take action to limit food waste and to raise awareness about it. Interestingly, the level of food waste in the European Union reached approximately 88 million tons [2] and was created at various stages of the food supply chain [3]. Households (47 million tons, over 50%), processing (17 million tons, 19%), and food services (11 million tons, 12%) are major contributors of EU food waste [2]. The hospitality and food service sector has been identified as a branch of the food industry with great potential for food waste prevention [4]. According to several studies [5,6], the most common causes of food waste are food spoiling and expiration dates not noticed, as well as consumer difficulty in distinguishing between and properly understanding the terms "use by" and "best before" on the label. In food service, preparation waste was the largest fraction, followed by buffet leftovers and customer plate waste [4]. In households and food service, besides the trimming losses, a great share of initial weight is lost during heat treatment [7].

The sous-vide method could be a good solution for decreasing food waste in households and catering establishments [8]. Thermostable pouches and cooking under controlled conditions make it possible to extend shelf life, avoid overproduction, and therefore reduce food waste [9]. This is important in households, but also at foodservice facilities, where it is impossible to predict the demand for certain menu items.

Moreover, the use of the sous-vide method leads to obtaining meat products with a higher nutritional value than with conventional methods, as shown by various studies [10–15]. There are still too few scientific papers to unequivocally indicate a higher content of macronutrients in sous-vide meats. In light of previously published articles, however, it may be concluded that lower process parameters cause lower losses of B vitamins [10], amino acids [11,12] and lower HAA content [13,14]. Additionally, the retention of minerals [16,17] is similar to raw meat and higher than boiled samples. When using higher parameters of sous-vide (like conventional methods), this effect was not found [18,19].

There are very few original studies focused on the microbiological quality of products that have been exclusively treated with sous-vide low-temperature heat and without any special additives to extend durability. Based on a limited literature review [20–23], it appears that the use of the sous-vide method allows for obtaining a higher microbiological quality of stored samples than those made with traditional methods. The microbiological quality of the products depends on the type of raw material and its initial microbial count, the additives (e.g., marinate and brine composition) used and the heat treatment parameters applied.

In Europe, pork and poultry constitutes around 80% of the total consumed meat. During the last 20 years, a growth of poultry consumption, along with simultaneous high-level pork consumption and a drop of beef consumption, were noted [24]. The low price and health properties of poultry meat determine its important role in the diet of Poles. Poultry meat is characterized by a low-fat content and a relatively high content of polyunsaturated fatty acids. These parameters are beneficial for human health, mainly because of a reduction in the risk of weight gain or obesity, cardiovascular diseases, and type 2 diabetes [25–27].

Further, the production of chicken has a lower carbon footprint than pork, lamb, or beef [28,29]. Most of the carbon footprint studies are focused on the agricultural stage and ignore stages leading to food consumption (transportation, storage, cooking), even though the latter play a significant role in total energy use and greenhouse gas (GHG) emissions in food systems. The yield (moisture loss) and nutritional indicators e.g., food protein content may be useful life-cycle indicators [30]. GHG emissions vary depending on the cooking appliance. The cooking method and lengths have an important impact on post-farmgate emissions [28]. According to Pathare and Roskill [31], a low cooking temperature might reduce energy consumption with a beneficial effect for domestic and commercial catering operations; therefore, future research should include the energy requirement for different cooking methods of meat.

Taking into account the advantages of the sous-vide method and the nutritional value of poultry meat, it is important to determine to what extent this method could reduce food waste at home and in food service, as well as to what extent this method could be recommended for meat preparation as a the nutritionally sound option.

The aim of this study was to evaluate the effect of the temperature and time of sous vide cooking on the quality of chicken breast and compare it to conventional methods (boiling in a pot and steaming in a pot) in order to asses this method as a useful means for reducing food waste while protecting the nutritional value.

2. Materials and Methods

2.1. Sample Preparation

The material for the study was boneless, skinless chicken breasts *(musculus pectoralis major)* from ROSS 308 broiler chicken, which were slaughtered after 42 days of life and delivered by the producer (DROSED. S.A., Poland). The birds were fed a standard commercial diet (Cargill Poland, Warsaw). The average weight of the carcasses after the slaughter was 2.67 kg. The raw material was stored in conditions recommended by the producer (+4 ± 1 °C), washed, trimmed, and calibrated to 34–37 mm of thickness. One serving portion of the breast was 262 ± 10 g. Then the raw material was packed in vacuum pouches and subjected to thermal treatment.

Two traditional methods of heat treatment were used as a benchmark to evaluate the effect of sous-vide treatment on the quality of poultry meat: boiling and steaming. The selection of these heat treatment methods derived by the need to eliminate methods that allow for the creation of Maillard Reaction Products' (grilling, frying, roasting) and could, therefore, distort the assessment.

Boiling in a pot (BP_{100})—the process was carried out in a 14 cm—diameter stainless steel pot, on an induction (400 W) hob (Stalgast, Poland). The process was initiated with hot water (750 mL) and conducted under a lid until 70 °C was achieved [32,33] in the breast core (20 ± 2.5 min).

Steaming in a pot (SP_{100})—the chicken breast was cooked on a perforated insert in a steamer pot filled with boiling water, heated by induction with 400 W (No: 770351, Stalgast, Poland), and cooked until a temperature of 75 °C was reached [32,33] in the breast core (23 ± 2.25 min).

Sous-vide (SV_{64}, $SV_{66,}$ SV_{75})—the samples were vacuum-packaged in thermostable multi-layer polyethylene-polyamide pouches (Hendi, Poland) in a chamber-type vacuum packaging machine (Stalgast, Poland) and immersed in a sous-vide water bath (Hendi, Poland). The parameters of heat treatment were chosen during a panel discussion in a preliminary study:

- $\boldsymbol{SV_{64}}$ (64 °C, 60 min)—parameter according to sous-vide equipment manufacturer's guideline.
- $\boldsymbol{SV_{66}}$ (66 °C, 80 min*)*—parameter at a temperature of the water-bath lower than recommended to reach inside cooked poultry, but equivalent to the internationally accepted and generally conservative time-temperature combination (2 min, at 70 °C) [32,34].
- $\boldsymbol{SV_{75}}$ (75 °C, 35 min)—parameter at a temperature of the water-bath that is recommended to reach inside cooked poultry and equivalent to the 2 min at 70 °C combination [32,34].

2.2. Technological Parameters

The yield was calculated, as the weight before (raw) and after cooking, in accordance with the following equation:

$$Yield\ (\%) = \frac{cooked\ chicken\ breast\ weight\ (g)}{raw\ chicken\ breast\ weight\ (g)} \times 100 \quad (1)$$

The electric energy consumption of producing one portion was determined using an energy-monitoring socket (Energy Check 3000, Voltcraft®, CEI Conrad International (HK) Ltd., China). The total energy consumption was calculated by adding up the energy consumption for the cooking process and preheating the devices to a set temperature, while in the sous-vide method, the energy consumption of vacuum packaging was also added.

The total process duration was measured using a stopwatch and include the time of preparing the chicken breast, heating the device to a set temperature, processing the heat treatment, and vacuum packaging in the sous-vide method.

The pH of chicken breasts was measured in raw flesh and heat-treated samples by the use of WTW 340i pH meter (WTW, Weilheim, Germany) with an electrode (SenTix® SP Number 103645, WTW, Weilheim, Germany) for direct penetration measurements in the meat.

2.3. Proximate Composition and Fatty Acid Profile

The determination of proximate composition was conducted in triplicate at an accredited laboratory of the Analytic Centre of Warsaw University of Life Sciences. Water content was measured by drying the samples in an oven at 105 °C to a constant weight and calculating in accordance with PN-ISO 1442:2000 [35]. The total protein content (expressed as the content of nitrogen) was measured by the Kjeldahl method. The fat content was evaluated by the Soxhlet method in agreement with PN-ISO 1444:2000 [36], using ether extraction.

The fatty acid profile was determined by gas chromatography (GC). Methyl esters of FAs (FAMEs—Fatty Acid Methyl Esters) were prepared by transmethylation of the fat samples using 5 M KOH and methanol as a catalyst. The fatty acid composition as FAME was analyzed using an Agilent 7890A (USA) gas chromatograph equipped with a flame ionization detector (GC-FID), a split/splitless injector and a capillary column Restek-2330 (105 m × 0.25 mm I.D. 0.2 µm df; Restek Corp., USA). Helium was the carrier gas at a flow rate of 0.9 mL/min. Parameters of GC analysis: injection of 1 µL, a split ratio of 1:50, FID temperature was set to 250 °C. The oven temperature program was set to 100 °C, at a rate of 3 °C/min up to 210 °C. Peaks were identified by comparison with Supelco 37 No.47885-U and PUFA-3 standards No.47085 (Sigma-Aldrich, Germany). The FAs in g/100 g total lipids were quantified in relation to the internal standard (C23:0) which was added before transesterification to lipid samples [37].

2.4. Microbiological Analyses

The microbiological quality assessment was carried out in a raw chicken breast (before storage and cooking), after thermal heating (after cooking) and after storage of the cooked chicken under controlled conditions (2 °C) for 5 and 10 days. The following microbiological assays were performed in triplicates:

- –Total viable aerobic count (TVC) [38],
- –Yeast and mold count [39],
- –Coagulase-positive Staphylococci counts [40],
- –Beta-glucuronidase-positive *E. coli* count [41],
- –Enterobacteriaceae count [42],
- –*Listeria monocytogenes* count [43],
- –Detection of *Salmonella* spp. [44].

2.5. Statistical Analysis

An analysis of variance (ANOVA) with Fisher's Least Significant Difference (LSD) post hoc test was performed to examine the significance of differences between yield, pH proximate composition, FA content, TVC. A coefficient of correlation according to Pearson calculation was also computed. A significance level of $p \leq 0.05$ was used (STATISTICA software version 13.1 PL, StatSoft, Kraków, Poland).

3. Results

3.1. Energy Consumption

The total energy consumption (EC) of the heat-treatment (with preheat) using the sous-vide method was approximately 5–10 times higher than the traditional methods (SP_{100}, BP_{100}), Table 1. Most of the costs were related to preheating the water bath (10 L). The EC of boiling a portion of chicken breast was 0,057 kWh, and in the case of steaming—0.116 kWh. The total energy consumption of the sous-vide method increased with an increase of the applied temperature from 64 to 75 °C (0.548–0.743 kWh). The energy consumption for chicken cooking was 0.017–0.025 kWh (without taking into consideration the preheating of water bath).

Table 1. Technological quality parameters of chicken breast processed with heat treatment methods.

Parameter	Raw	Heat Treatment Method $\bar{x} \pm SE$					*SEM*
		Sous-Vide Method			Steaming (SP_{100})	Boiling (BP_{100})	
		64°C × 60 min (SV_{64})	66°C × 80 min (SV_{66})	75°C × 35 min (SV_{75})			
Total process duration (min)	-	126	149	117	55	42	0.31
Energy consumption (kWh)* *(only for cooking process)*	-	0.548 (0.023)	0.585 (0.025)	0.743 (0.017)	0.116 (0.058)	0.057 (0.025)	0.02
Yield (%)	-	89.40 ^{e}	82.40 ^{d}	83.10 ^{c}	72.44 ^{b}	69.49 ^{a}	0.71
pH	6.14 ^{a}	6.16 ^{a}	6.30 ^{b}	6.32 ^{b}	6.33 ^{b,c}	6.40 ^{c}	0.04

* Energy consumption taking consideration preheating the water bath and cooking chicken samples.Values in brackets mean average energy consumption of the heat treatment process only. In the case of sous-vide, the vacuum packaging is included as well; SEM—standard error of measurement; $^{a, b, c}$—mean values marked by different letters in rows, differ significantly at $p \leq 0.05$.

Remarkably, conventional boiling (~20 min) was more energy-consuming than vacuum packing and heating for an hour at 64 °C in the sous-vide method. Further estimation (data not shown) revealed that to equalize the energy consumption of the sous-vide method with traditional boiling and steaming, 16–19 portions of sous-vide breasts in relation to 6–8 portions of conventionally heat-treated fillets should be made.

3.2. The Yield of the Various Heat Treatment Methods of the Chicken Breast

The yield of chicken breasts processed with the sous-vide method at different temperatures (64, 66, 75 °C) was significantly higher (82.4–89.4%; $p \leq 0.05$) than after heat treatment with traditional methods (69.5-72.4%), where the process temperature was the highest (Table 1). Among the tested sous-vide parameters, the highest yield was obtained at 64 °C—SV_{64} (89.4%). The yields of SV_{66} (66 °C, 80 min) and SV_{75} (75 °C, 35 min) samples were at a similar level (82.4–83.1%), as the Baldwin [30] calculation used in this study refers to the same time-temperature combination (70 °C, 2 min). Moreover, the yield of steaming SP_{100} (72.4%) was higher ($p \leq 0.05$) than boiling (69.5%).

3.3. Changes in the pH Value of the Chicken Breast Processed with Various Heat Treatment Methods

Chicken breasts prepared using the sous-vide method at a temperature of 64 °C (SV_{64}) had the least change in pH in relation to the raw material ($p > 0.05$) (Table 1). The pH of other samples differed significantly from raw samples. The pH value of the steamed samples (SP_{100}) and processed with the sous-vide method at 66 and 75 °C (SV_{66}, SV_{75}) did not differ significantly. The pH value of boiled chicken did not differ significantly from steamed chicken, but it was higher than samples made using sous-vide, as both were cooked until the same temperature in the core was reached.

3.4. The Proximate Composition of the Chicken Breast after Heat Treatment

A raw chicken breast (100g) contained 23.4 g of dry matter; 22.6 g of protein and 0.50 g of fat (Table 2).

Table 2. Proximate composition in raw and cooked chicken breasts

Parameter	Raw	Heat Treatment Method % [($\bar{x}$ ± SE]					SEM
		Sous-Vide Method			Steaming (SP_{100})	Boiling (BP_{100})	
		64°C × 60 min (SV_{64})	66°C × 80 min (SV_{66})	75°C × 35 min (SV_{75})			
Water content	76.90 ^{c}	74.50 ^{c}	71.30 ^{b}	70.50 ^{a,b}	71.20 ^{b}	68.50 ^{a}	0.81
Protein content	22.60 ^{a}	22.90 ^{a}	27.40 ^{b}	24.50 ^{a}	27.40 ^{b}	29.20 ^{b}	0.89
Fat content	0.49 ^{a}	1.94 ^{c}	1.23 ^{b}	1.94 ^{c}	1.48 ^{b}	1.42 ^{b}	0.09

$^{a, b, c}$—mean values marked by different letters in rows, differ significantly at $p \leq 0.05$; SEM—standard error of measurement.

Samples boiled in a pot (BP_{100}) and steamed (SP_{100}), as well as subjected to higher parameters of the sous-vide process (SV_{66}, SV_{75}), had a lower water content than samples with the lowest temperature among the ones evaluated (SV_{64}). The (SV_{64}) sample did not differ in the water content from the raw material ($p \leq 0.05$). It was observed that the applied methods of heat treatment reduced the water content and increased the protein and fat content. The yield of the process was correlated with the water content ($r = 0.70$, $p \leq 0.05$). The protein content decreased with increasing water content ($r = -0.88$, $p \leq 0.05$). A similar trend was found for fat content ($r = 0.55$, $p \leq 0.05$).

3.5. Profile of Fatty Acid Content in the Chicken Breast After the Heat Treatment Method

Twenty-two fat acids were identified in fat extracted from both raw and cooked breasts. The fatty acid profile of the raw chicken breast was characterized by the highest share of MUFA (39.8%) and a slightly lower share of SFA (33.5%) (Table 3).

Table 3. Fatty acid content of fat extracted from raw and cooked chicken breast.

Parameter	Raw	Heat Treatment Method [$\bar{x}$ (g·100 g^{-1} KT) ±*SE*]				
		Sous-Vide Method			Steaming (SP_{100})	Boiling (BP_{100})
		64°C × 60 min (SV_{64})	66°C × 80 min (SV_{66})	75°C × 35 min (SV_{75})		
SFA	33.50 ^{a} ± 0.10	33.09 ^{a} ± 0.01	34.02 ^{a} ± 0.12	34.24 ^{a} ± 0.03	37.08 ^{b} ± 0.01	35.67 ^{b} ± 0.10
C12:0	3.72 ^{a} ± 0.12	3.41 ^{a} ± 0.03	3.79 ^{a} ± 0.09	3.74 ^{a} ± 0.05	3.65 ^{a} ± 0.01	4.04 ^{b} ± 0.04
C14:0	3.06 ^{b} ± 0.03	2.86 ^{a} ± 0.01	3.14 ^{b} ± 0.00	3.09 ^{b} ± 0.00	3.28 ^{c} ± 0.00	3.18 ^{c} ± 0.00
C16:0	20.30 ^{a} ± 0.06	20.20 ^{a} ± 0.03	20.90 ^{a,b} ± 0.01	21.00 ^{b} ± 0.02	22.50 ^{b} ± 0.03	21.60 ^{b} ± 0.04
C17:0	0.13 ^{a} ± 0.01	0.13 ^{a} ± 0.00	0.16 ^{a} ± 0.00	0.14 ^{a} ± 0.00	0.14 ^{a} ± 0.00	0.12 ^{a} ± 0.00
C18:0	6.08 ^{a} ± 0.02	6.26 ^{a,b} ± 0.01	5.82 ^{a} ± 0.02	6.04 ^{a} ± 0.00	7.30 ^{c} ± 0.01	6.57 ^{b,c} ± 0.01
C20:0	0.10 ^{a} ± 0.01	0.08 ^{a} ± 0.01	0.08 ^{a} ± 0.01	0.07 ^{a} ± 0.01	0.09 ^{a} ± 0.00	0.08 ^{a} ± 0.00
C22:0	0.03 ^{a} ± 0.03	0.07 ^{a} ± 0.01	0.00 ^{a} ± 0.00	0.00 ^{a} ± 0.00	0.05 ^{a} ± 0.00	0.05 ^{a} ± 0.01
C23:0	0.16 ^{a} ± 0.01	0.08 ^{a} ± 0.01	0.11 ^{a} ± 0.01	0.10 ^{a} ± 0.02	0.08 ^{a} ± 0.02	0.07 ^{a} ± 0.00
MUFA	39.84 ^{a} ± 0.08	38.81 ^{a} ± 0.18	43.91 ^{b} ± 0.07	40.85 ^{a} ± 0.02	39.66 ^{a} ± 0.01	40.00 ^{a} ± 0.09
C14:1 (cis-9)	0.29 ^{a} ± 0.04	0.37 ^{b} ± 0.01	0.34 ^{b} ± 0.01	0.38 ^{b} ± 0.01	0.35 ^{b} ± 0.00	0.35 ^{b} ± 0.00
C16:1 (cis-9) n-7	3.49 ^{a} ± 0.00	3.97 ^{b} ± 0.13	3.88 ^{b} ± 0.00	3.97 ^{b} ± 0.00	3.54 ^{a} ± 0.00	3.85 ^{b} ± 0.12
C17:1 (cis-10)	0.11 ^{a} ± 0.00	0.11 ^{a} ± 0.00	0.07 ^{a} ± 0.00	0.10 ^{a} ± 0.00	0.09 ^{a} ± 0.00	0.09 ^{a} ± 0.00
C18:1 n-9 (OA)	33.10 ^{a} ± 0.10	31.60 ^{b} ± 0.05	36.40 ^{c} ± 0.05	33.50 ^{a} ± 0.01	32.90 ^{a} ± 0.00	32.90 ^{a} ± 0.05
C18:1 n-3 (cis 11)	2.24 ^{a} ± 0.02	2.24 ^{a} ± 0.00	2.63 ^{a} ± 0.00	2.40 ^{a} ± 0.00	2.27 ^{a} ± 0.01	2.32 ^{a} ± 0.00
C20:1 n-9	0.56 ^{c} ± 0.01	0.49 ^{a,b} ± 0.01	0.57 ^{c} ± 0.01	0.46 ^{a} ± 0.02	0.47 ^{a} ± 0.00	0.50 ^{b} ± 0.02
PUFA	24.774 ^{b} ± 0.10	26.00 ^{b} ± 0.15	19.07 ^{a} ± 0.01	21.63 ^{a} ± 0.02	20.86 ^{a} ± 0.04	21.51 ^{a} ± 0.04
C18:2 n-6 (LA)	21.00 ^{e} ± 0.11	21.40 ^{e} ± 0.04	16.10 ^{a} ± 0.02	18.70 ^{d} ± 0.05	17.60 ^{b} ± 0.01	18.20 ^{c} ± 0.04
C18:3 n-6 (GLA)	0.19 ^{b} ± 0.04	0.22 ^{b} ± 0.00	0.10 ^{a} ± 0.01	0.12 ^{a} ± 0.03	0.16 ^{b} ± 0.01	0.11 ^{a} ± 0.02
C18:3 n-3 (ALA)	2.11 ^{e} ± 0.01	2.19 ^{e} ± 0.00	1.42 ^{a} ± 0.01	1.61 ^{c} ± 0.02	1.55 ^{b} ± 0.01	1.70 ^{d} ± 0.01
C20:2 n-6	0.25 ^{d} ± 0.00	0.29 ^{e} ± 0.00	0.22 ^{b} ± 0.00	0.21 ^{a} ± 0.00	0.25 ^{d} ± 0.00	0.24 ^{c} ± 0.00
C20:3 n-6	0.27 ^{b} ± 0.01	0.37 ^{d} ± 0.00	0.23 ^{a} ± 0.00	0.20 ^{a} ± 0.00	0.30 ^{c} ± 0.00	0.31 ^{c} ± 0.01
C20:4 n-6 (AA)	0.84 ^{c} ± 0.02	1.30 ^{e} ± 0.01	0.74 ^{a} ± 0.02	0.81 ^{b} ± 0.01	0.89 ^{d} ± 0.02	0.88 ^{d} ± 0.00
C20:5 n-3 (EPA)	0.00 ^{a} ± 0.00	0.08 ^{d} ± 0.00	0.10 ^{e} ± 0.00	0.00 ^{a} ± 0.00	0.06 ^{b} ± 0.00	0.07 ^{c} ± 0.00
C22:6 n-3 (DHA)	0.06 ^{a} ± 0.00	0.12 ^{c} ± 0.01	0.15 ^{c} ± 0.00	0.06 ^{a} ± 0.00	0.08 ^{b} ± 0.00	0.08 ^{b} ± 0.00
Non identified FAs	1.97 ^{a} ± 0.08	2.10 ^{b} ± 0.24	2.99 ^{d} ± 0.04	3.25 ^{e} ± 0.06	2.40 ^{b} ± 0.02	2.79 ^{c} ± 0.05
n-3 g/100g	2.17 ^{b} ± 0.01	2.39 ^{b} ± 0.01	1.67 ^{a} ± 0.02	1.67 ^{a} ± 0.02	1.69 ^{a} ± 0.01	1.84 ^{a} ± 0.01
n-6 g/100g	22.57 ^{c} ± 0.16	23.61 ^{d} ± 0.04	17.40 ^{a} ± 0.01	19.96 ^{b} ± 0.06	19.18 ^{b} ± 0.04	19.67 ^{b} ± 0.05
n-6: n-3	9.42	9.83	10.24	11.76	11.29	10.94

Data expressed as a g FA/100 g fat; SFA: Saturated Fatty Acids; MUFA: Monounsaturated Fatty Acids; PUFA: Polyunsaturated Fatty Acids; $^{a, b, c, d}$—mean values marked by different letters in rows, differ significantly at $p \leq 0.05$; *SE*—standard error.

The smallest group of fatty acids were polyunsaturated fatty acids PUFA (24.7%). In the MUFA group, the main fatty acid in the fat extracted from the chicken breast was oleic acid (C18: 1, n-9), whose share in the fatty acid profile was statistically significantly highest in the SV_{66} samples (36.4 g/100 g FAs). The proportion of these acids increased after heat treatment. The group of saturated FAs was dominated by palmitic acid (C16: 0), whose share in the acid profile depended on the method of heat treatment and was in the range of 20.2–22.5 g × 100 g^{-1} FAs. Among polyunsaturated fatty acids, the highest identified was linoleic acid (C18: 2), which, depending on the sample, ranged from 16.1 to 21.45 g × 100 g^{-1} FAs. The fatty acid profile of chicken after cooking in water (BP_{100}) and steaming (SP_{100}) was characterized by a higher proportion of saturated acids than in the case of raw material and sous-vide samples. It resulted mainly from a statistically significant ($p \leq 0.05$) higher proportion of palmitic acid (C16: 0), myristic acid (C14: 0), and stearic acid (C18: 0). It was found that the share of SFA in the fatty acid profile increased with the intensity of heat treatment.

A chicken breast prepared at a moderately high-temperature SV_{66} (66 °C, 80 min) was characterized by a higher MUFA share due to a statistically significantly ($p \leq 0.05$) higher content of oleic acid (C18: 1 n-9), octadecenoic acid (C18: 1 n-3), and eicosenoic acid (C20: 1 n-9).

This was reflected in the lowest proportion of polyunsaturated FAs, which did not differ a statistically significant ($p > 0.05$) way from traditional methods and the SV_{75} samples. The long treatment time affected the oxidation of linoleic acid (C18: 2, n-6). The sous-vide chicken breast using the lowest SV_{64} temperature (64 °C, 60 min) had the most similar fatty acid profile to the raw material, confirming the lack of a statistically significant difference between them ($p > 0.05$) in the share of the three main FAs groups (SFA, MUFA, PUFA).

This sample particularly was characterized by a higher content ($p \leq 0.05$) of linoleic acid (C18: 2, n-6) and arachidonic acid (C20: 4, n-6), as well as a slightly higher content of DGLA (C20: 3, n- 6) and α-linolenic acid (C18: 3, n-3). This resulted in a higher content of n-6 and n-3 PUFAs and the ratio of these acids was closest to the raw material. The SV_{75} sample, cooked for 35 min at 75 °C, had an FAs profile between the traditional methods and the sous-vide method with low process parameters.

3.6. Effect of Heat Treatment on the Microbiological Quality of the Chicken Breast

The raw chicken breast was characterized by satisfactory microbiological quality (Figure 1). The initial (0 days) TVC load of a raw chicken breast was 3.9 $\log_{10}$ CFU/g, while yeast and mold counts were—3.5 $\log_{10}$ CFU/g (not presented in Figure 1). Pathogens: coagulase-positive *Staphylococcus*, *E. coli*, *Listeria monocytogenes*, Enterobacteriaceae, and *Salmonella* spp. were not detected in any raw or cooked samples on the day of preparation as well as on days 5 and 10 of storage.

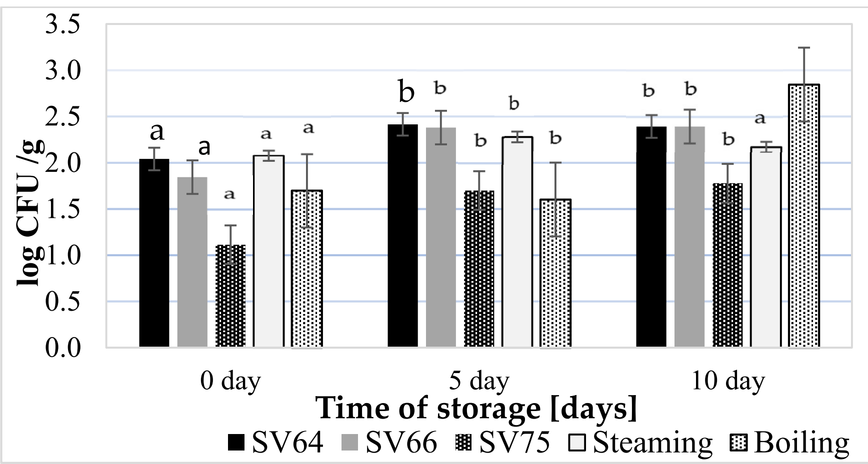

Figure 1. Total viable aerobic count in chicken breast after processed by various heat treatment methods. a, b, c—mean values, marked by different letters between time of storage, differ significantly at $p \leq 0.05$ CFU/g—colony-forming units/g

The applied parameters of the sous-vide heat treatment, as well as the temperature of 75 °C achieved inside the boiled or steamed chicken, resulted in a significant reduction of the microbial count. The number of aerobic colony-forming bacteria according to the guidelines of the Expert Panel on Food Microbiological Safety [45] for portioned chicken can be considered satisfactory for all samples (<10^4). Microbiological limits for ready-to-eat foods should be as follows: Total aerobic bacteria count: <10^5 CFU/g; *E. coli*: < 10; *Salmonella* spp.: not detected in 25 g; *L. monocytogenes*: not detected in 25 g [46,47]. The highest microbiological quality of chicken samples prepared by the sous-vide method were those prepared at the temperature of 75 °C. The highest microbiological quality was found in poultry boiled in a pot. The microbiological quality of the steamed samples was comparable to the samples cooked using the sous-vide method. The small variation in microbiological quality between the samples is due to the high quality of the raw material.

4. Discussion

4.1. Technological Quality of the Chicken Breast Cooking

As various temperature regimes (no linear time and temperature combinations) were used in the sous-vide method, it was not possible to demonstrate a linear relationship in the yield between the samples. However, there is a noticeable tendency, indicating that a lower process temperature is associated with a higher yield and is correlated with the water content in the product. Our findings appear to be supported by the results of other authors [48,49]. It shows the effect of increasing the internal temperature of chicken breast on greater thermal leakage. Similar conclusions were reached in studies on ostrich [50] and turkey [51] meat.

In the model studies of Zhang and Wang [52], vacuum-packed samples were subjected to a 30-min heat treatment at various temperatures. It was found that the thermal-induced losses increased with increasing temperature. Myofibrillar proteins hold most of the water retained within the muscle. At higher temperatures (40–90 °C), the denaturation of myofibrillar proteins starts, then leads to shrinkage and losing water from the matrix [21]. The highest cooking loss occurred at a temperature of 75–85 °C [52], while in other studies [48,49] at the temperature of 80–100 °C. Similar observations were made in the study on duck meat [53].

Few researchers [51,54,55] have evaluated the effect of the process parameters (time and temperature) on the yield or water content in the chicken or turkey breast after sous-vide treatment, but have indicated its significant effect. Only two papers compare the yield of sous-vide to other heat treatment methods. A higher yield of the sous-vide method than boiling was observed by Soletska and Krasota [23], while a higher water content in the sous-vide breast than that of fried, grilled, and roasted ones was found by Silva et al. [56]. A slightly higher yield of the chicken breast by boiling than in our study was reported by Ormian et al. [57] and Sałek et al. [7], 71.7% and 71.0% respectively. The yield of the steaming process depends on relative humidity; it was higher and ranged from 77.2–84.1% [58]. This is confirmed by the results of Zhuang and Savage [59], in which the yield of chicken breast boiling (79.5%) was higher ($p \leq 0.05$) than in steaming (81.1%).

The past decade has seen a renewed importance of studies on the energy requirement of various cooking methods in the context of reducing the carbon footprint of food processing [30,31,60]. However, there remains a gap in the knowledge on the energy requirements of various cooking methods, and not many recent papers [61] were found on this topic. Warthesen et al. [62] found that steaming was more energy consuming than boiling when processing vegetables. Many novel cooking appliances allowed for saving energy. Heat treatment of beef patties in a microwave oven consumed less energy than boiling and baking [63]. Cooking in pasta cookers saved energy by up to 60% [60], while rice in a rice cooker saved up to 23–57% [64] in relation to conventional methods.

In this study, the total energy consumption of the sous-vide method was approximately 5–10 times higher than traditional methods, and most of the costs were related to preheating the water bath. The energy consumption of only a cooking process in sous-vide was lower than during steaming and boiling, even if cooking times were 1.5–4 times longer. The results of Baker et al. [65] indicated that the energy used in cooking chicken might best be saved by using the smallest size appliance and minimizing moisture loss by covering the product and/or shortening cooking time. A commercially available water bath for sous-vide requires a high volume of fluid to be preheated; therefore, sous-vide is remunerative when many batches are prepared. In terms of energy-savings, then sous-vide should be used primarily in foodservice, rarely in domestic conditions. The level of yield deviation in the sous-vide heat treatment was lower than that observed in boiling and steaming. These observations confirm the greater repeatability of the sous-vide process and the possibility of its control [32]. An increase in the pH value along with an increase in the intensity of cooking parameters in our research is confirmed in the literature [50,66].

4.2. Nutritional Value and Fatty Acid Profile of the Chicken Breast

Our research determined that as the intensity of the thermal treatment parameters increases, water content decreases and the protein and fat content increases. This aligns with research carried out on fish [67–69].

The protein content in beef and poultry processed with the sous-vide method was significantly higher than in raw flesh [11,14,17,18,20,55,57,70,71]. Similar results were found while examining the fat content of sous-vide beef, poultry, and rabbit [15], as well as after other heat treatment methods [57]. Increased protein and fat concentration after heat treatment was explained by water loss.

Contrary to our results, previous research indicated that chicken breast processed in low parameters of sous-vide had similar fat content to raw samples [55], or that there were minor changes [11].

Additionally, in the studies of Silva et al. [56], it was found that the protein content in the chicken after sous-vide treatment did not differ significantly from that in grilled and roasted chicken, while it was higher in pan-fried chicken. A similar relationship was found in the fat content, but was higher in fried chicken. Other trends are indicated by Nithyalakshmi and Preetha [50], who found that an increase in temperature in the range of 40 °C led to an increase in dry matter and protein loss in ostrich meat.

Comparing the sous-vide meat preparation with grilled and roasted products, differences are less clear. Frying increases the fat content of beef and poultry. In turn, roasting and grilling processes result in a lower increase in the protein and fat content in relation to raw meat. The oil-frying process seems to increase the fat content of beef and poultry whereas roasting and grilling processes may result in a lower increase in the protein and fat content in relation to raw meat [18]. It is difficult to synthesize authoritative conclusions due to the limited data from studies carried out under various process conditions. Hence, there is still a need for further research, especially on popular types of meats.

The analysis of the fatty acid profile in the present study shows that our parameters increased the content of SFA, which was a statistically significant result in boiled and steamed chicken breasts. The MUFA group's share had a statistically significantly result higher in the sous-vide samples for the longest cooked (SV_{66}). The proportion of PUFA was lower after the thermal treatment, although their level did not differ significantly from the raw material in the sous-vide method, where the mildest parameters of the SV_{64} process were used.

Other observations were made by Falowo et al. [16]. In studies on beef fat, they found that the total fatty acid content did not differ significantly depending on the parameters used (120 min at 65 °C/60 min at 85 °C) in the sous-vide method. However, beef after sous-vide treatment at 85 °C had a higher increase in PUFA, n-6, a higher PUFA/SFA ratio, and PUFA/MUFA content than after treatment at 65 °C. In studies by Silva et al. [56], the share of SFA, MUFA, and PUFA in the fatty acid profile of poultry meat (grilled, baked, fried and sous-vide) was not differentiated, except in the fried sample, which had a higher share of acids from the MUFA family, but a smaller share of PUFA and SFA.

4.3. Microbiological Quality of Chicken Breasts

In our study, the microbiological quality of the sous-vide processed, boiled, and steamed chicken breasts were good both on the day of preparation and after storage in refrigerated conditions for 5 and 10 days. None of the coagulase-positive *Staphylococcus*, *E. coli*, *Listeria monocytogenes* and *Salmonella* spp. were detected in any raw or cooked samples, and the counts of total mesophilic aerobic bacteria were satisfactory <10^4 CFU/g. The highest microbiological quality of sous-vide chicken was obtained in the sample processed at a temperature of 75 °C, which was very similar to the temperature reached inside the boiled and steamed samples.

Soletska and Krasota [23] identified a higher TVC in the boiled breasts (2.8 log CFU/g) than in the sous-vide treated samples (63–65 °C, 60 min—2.5 log CFU/g). After 6-days of refrigerated storage, they noted a slight increase in the TVC of the sous-vide samples (2.6 log CFU/g) and a slightly higher one in the conventionally cooked samples (3.1 log CFU/g). The use of a lower sous-vide processing temperature (62 °C, 35 min) in the study of Hong et al. [22] resulted in higher TVC of 4.4 log (CFU/g) on the day of preparation, while after 7 days of storage, the count decreased (3.5 log CFU/g). In a recent study by Bıyıklı et al. [51], cooking a turkey cutlet in various temperature-time combinations induced 2 log CFU/g reduction of TVC, similar as in our study. Based on the analysis of previous works, the sous-vide method seems to improve the microbiological quality of the chicken breast compared to the raw one. The results of Wang et al. [72] indicate a higher microbiological quality of vacuum-packed sous-vide samples compared to those cooked traditionally, wherein the increased temperature of sous-vide treatment, similar to our research, reduced the number of microbes. In our study, the initial microbial load of flesh was high. However, commercially available breasts, which are stored at a retail chain for a couple of days and are usually transported by consumers without cold chain should be subjected to more intensive heat treatment. Parameters that are too low are typically not sufficient to inactivate harmful pathogens, as shown in the research of Bıyıklı et al. [51], in which a *Listeria spp.* in turkey meat cooked at 65 °C for 20 min was detected.

The authors [73] analyzed the microbiological status of ready-to-eat foods, and the highest percentage of unsatisfactory samples was found in the sous-vide food group. The presence of *Salmonella* spp. was detected in five samples of sous-vide duck breast (54 °C, 80 min) and *L. monocytogenes* in foie gras confit ballotin (82.5 °C, 12 h). In a study by McIntyre et al. [74], a case of Salmonellosis caused by consumption of a sous-vide duck cooked for 25 min at 62.5 °C was analyzed. Recently, the consumption of sous-vide food prepared at a low temperature (60–70 °C) has been observed [75]. In a report made by the Institute of Food Research [76], the adequacy of nearly 1000 different heat treatment parameters from various sources was assessed. The examined temperature range for the sous-vide cooking of chicken breast oscillated between 57.5–66 °C, and ten recipes for sous-vide poultry preparation did not reach the commonly recommended 70 °C/2 min pasteurization parameters.

5. Conclusions

The present preliminary study suggests potential application of sous-vide in the reduction of food waste at home and in catering establishments. This method is in line with both zero waste and healthy eating trends. It causes lower cooking losses and extend the shelf-life of the product while eliminating overproduction, resulting in reduced food waste.

Chicken breasts processed with the sous-vide method were characterized by a significantly higher yield ($p \leq 0.05$) and water content than those processed by boiling and steaming in a pot, as well as good stability of microbiological quality for up to 10 days of storage. The nutritional value (protein and fat content, fatty acids profile) of sous-vide products depended on the process parameters.

The low parameters sous-vide method resulted in the least change of protein content and fatty acid profile after processing, while higher temperature led to a profile similar to that of conventionally cooked samples. The use of the sous-vide method allows for the extension of the shelf life of meat and a better nutritional value.

Although the energy and time consumption of sous-vide was on average 5–10 times higher than traditional methods (boiling and steaming), that increase can be attributed primarily to preheating the water bath for cooking. The consumption of energy during preheating may be justified only when many batches are prepared, and therefore is more suitable for foodservice than use in homes, despite the protection of nutritional value.

Further studies should focus on estimating the real energy consumption of many batches measured in a restaurant as well as the carbon footprint and life cycle assessments of sous-vide food.

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