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Geese fillets flavor stability and quality characteristics at different stages of *sous-vide* cooking*

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The scope of the research was analysis of geese fillets at low-temperature heat treatment including three temperatures (60°C; 70°C; 80°C) and two cooking moments (6h, 24h) in terms of the profile of volatile compounds depending on the degree of protein denaturation. Lipid oxidation, L * a * b * color, shear force, cooking yield and pH were also analyzed. The analysis of the obtained results allowed to determine the characteristic temperature parameters, which can improve a physicochemical processes. It was noticed that, while the cooking yield, L*, a* and shear force decreased with the prolonged cooking time and increased temperature, the b* and TBARS showed increased values. Furthermore, longer cooking times caused a greater amount of volatile compounds presence and the 2-3-dimethylpyrazine was indicated as a marker of baked flavor of *sous-vide* treated geese fillets.

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Goose meat has a high nutritional value and is a good source of protein. It is less caloric than red meat, and has a characteristic flavor, because of the traditional method of fattening birds on oat grain, so the goose meat ics characterized by the fat with a higher content of valuable polyunsaturated fatty acid (PUFA) [Horbańczuk *et al.* 1998, Haraf, 2014, Oz and Celik 2015, Orkusz 2018, Pogorzelska-Nowicka *et al.* 2018, Uhlířová *et al*. 2018, Yang *et al*. 2018]. Heat treatment of meat including goose meat modifies its eating quality including texture, flavor and color [Aaslyng *et al*. 2003, Dominguez-Hernandez *et al*. 2018]. One of the heat treatment methods is *sous-vide* based on immersing a vacuum packed food in a water bath under controlled time and temperature conditions [Ayub and Ahmad 2019, Ismail *et al.* 2019, Schellekens 1996]. This low temperature cooking technique has been noticed in research for ensuring control of the product quality and repeatability [Macharáčková *et al*. 2021, Baldwin 2012]. Aroma is an important component of the overall acceptance of meat. In low-temperatures flavor and tenderness are improved [Aguilera 2018]. It also has been proved that the *sous-vide* technique preserved the volatiles and avoided an accumulation of off-flavours [Rinaldi *et al*. 2013]. The application of the sous-vide prevents the loss of volatile compounds and nutrients sensitive to high temperature. It offers better sensory characteristics and enhances the meat flavor [Christensen *et al*. 2012, Mortensen *et al.* 2012]. Previous studies have indicated also that sous vide cooking improves meat tenderness [Botinestean *et al*. 2016, Naqvi *et al.* 2021]. Meat parameters are affected by both the processing time and temperature. Understanding the effect of temperature on food properties significantly helps to adapt the processing conditions of food raw materials and improve the quality of the final products. Low-temperature heat treatment using vacuum minimises product waste and quality reduction, as well as influence on the cooking yield. Vacuum conditions prevent the development of aerobic microorganisms that are responsible for the spoilage of food products. It also ensures the nutritional value of the product by higher retention rates of vitamins and minerals compared to traditional cooking techniques [Rinaldi *et al.* 2013, Bernat 2021, Kathuria *et al.* 2021].

Previous studies have indicated also that *sous vide* cooking results in a uniform and consistent meat texture and improves tenderness [Botinestean *et al*. 2016, Del Pulgar *et al.* 2012]. A continuing objective of the meat industry is to find improvements in processing that ensure and enhance these desirable sensory attributes, while still yielding a product that is safe to consume [Barbosa-Cánovas *et al.* 2015]

Therefore, the aim of the research was to was analysis of geese fillets at low-temperature heat treatment including three temperatures (60, 70 and 80°C) and two cooking moments (6 and 24 h) in terms of the profile of volatile compounds depending on the degree of protein denaturation. This would allow to indicate recommendations regarding the application of appropriate parameters of low-temperature heat treatment (*sous-vide*) for fillets of oat geese during refrigerated storage.

Material and methods

Experimental design

Geese fillets for analysis were obtained from oat geese acquired from a commercial plant (ZD DROP SA, Ostrzeszów, Poland). The welfare of the geese was as specified by universally accepted standards for geese in Poland [Puchajda-Skowrońska 2012]. Animals were fed with a complete concentrated diets in accordance with the requirements of the Poultry Feeding Standards [Smulikowska 2018]. 54 males were selected at random from 180 birds. The animals were slaughtered in a commercial slaughterhouse according to standard procedure. The left fillets were taken for further processing. The carcasses were transported to the laboratory an in ice boxes, under chilled conditions (4°C±1°C).

The geese fillets were divided randomly into six groups. The groups were divided by different combinations of temperatures (60, 70 and 80°C) and times (6 and 24 h). Samples were weighed, color parameters and pH analyses were noted. Than the samples were placed in plastic bags (polyethylene/polypropylene) and vacuum packed (vac. 98%) and placed in circulator *sous-vide* equipment at 60, 70 and 80°C for 6 and 24 h for each temperature (60°C/6h, 60°C/24h, 70°C/6h, 70°C/24h, 80°C/6h and 80°C/24h, respectively). Samples were stored in vacuum bags and in refrigerated storage at 4±1°C and volatile compounds profile, color, lipids oxidation, shear force, DSC measurement were analyzed on the first day (D0), third day (D3) and ninth day (D9) of storage. A total of 162 samples were examined (6 treatments for each replicate x 3 storage period x 9 samples of each treatment group).

Physicochemical analysis

pH, cooking yield, instrumental color and texture analysis was carried out to find out the optimum *sous-vide* cooking parameters. pH − analysis of pH of raw geese fillets and after cooking process was conducted with an application of a potentiometric method and using a hand-held pH meter (Model 205, Testo AG, Lenzkirch, Germany). The pH meter was calibrated by two buffers (pH = 4.01, pH = 7.00). 3 replicates (9 samples of each treatment group). Cooking yield − before analysis on each treatment day the geese fillets were removed from a vacuum bags and wiped using kimwipes in order to dispose liquid from the meat surface. The % value of cooking yields was analysed by a weight differences of sample before and after *sous-vide* treatment. 3 replicates (9 samples of each treatment group). Measurement of color − the color measurement on the surface and on the cross-section of goose fillet was analyzed in the CIE L*a*b* system. The analysis was performed using a Minolta chromameter (CR-400, Konica Minolta Inc., Tokyo, Japan). The chromameter was calibrated using a white standard calibration plate (L* = 98.45, a* = -0.10, b* = -0.13). The measuring head with a D65 illuminant and a standard 2^{o} observer and diameter of 8 mm was used. The measurements were performed in 3 replicates (9 samples of each treatment group). Texture analysis − instrumental measurement of Warner-Bratzler shear force

(WBSF) was performed with a universal testing machine (Instron, 5965 model, MA, USA) equipped with a Warner-Bratzler add-on device with a Warner-Bratzler shear attachment consisting of a V-notch blade according to [Wyrwisz *et al*. 2016]. To perform the WBSF measurement, geese fillets after *sous-vide* treatment were cooled and stored overnight at 4±1°C. Shear force (N) (maximum force of the shear) was calculated. Cores of 1.27 cm in diameter and 2.5±0.2 cm in length were obtained, which were in parallel to the muscle fiber orientation. A 500 N load cell was used, and the crosshead speed was set at 200 mm min-1. The measurements were performed in 3 replicates (9 samples of each treatment group).

Lipid oxidation − Thiobarbituric acid reactive substances (TBARS)

The secondary lipid oxidation of the goose meat was analyzed [Robles-Martinez *et al.* 1982] with modifications [Brodowska *et al*. 2016]. 2.5 g of ground meat was homogenized with 25 ml of trichloroacetic acid solution and 1.25 ml of antioxidant (0.5% PG and ethylenediaminetetraacetic acid in ethyl alcohol/water 1:1) for 30 s at 1200 rpm (WT 500 homogenizer, Wiggenhauser, Germany). After centrifugation for 10 min at 8000 rpm (centrifuge MPW-251, MPW Med. Instruments, Warsaw, Poland), 5 ml of 2-thiobarbituric acid (0.02 mM/l) was added to 5ml of supernatant. Then, samples were heated in a water bath (90°C) for 40 min. Samples were cooled and the absorbance was measured at 532 nm, against a blank, using a UV-VIS spectrophotometer Tecan Spark™ 10M spectrophotometer (Männedorf, Switzerland). A calibration curve was evaluated with 1.1.3.3-tetramethoxypropane. The results were expressed as mg of MDA/kg of fat. The measurements were performed in 3 replicates (9 samples of each treatment group).

Differential scanning calorimetry (DSC) measurement

Thermal denaturation temperatures of goose muscle proteins were measured using differential scanning calorimetry DSC 1 from Mettler Toledo (Schwerzenbach, Switzerland) in an argon atmosphere (100 cm^3/min). The instrument was calibrated with pure indium and zinc. The samples (10.0±0.1 mg) were placed into standard 40 µl aluminum pan (ME-51119870) closed with lids (ME-51119871) by Mettler Toledo Crucible Sealing Press. DSC scans were recorded from 35 to 100°C at a rate of 10°C/min. The thermograms were analysed in STARe Software where: start (T_{on}), maximum (T_{max}), end (T_{end}) temperatures and areas under the peaks (ΔH) were determined. The DSC measurements were performed in 3 replicates (9 samples of each treatment group).

Analysis of volatile compounds profile

Volatile compounds from the goose abdominal fat was obtained using the Heracles II an electronic nose (Alpha M.O.S., Toulouse, France). The method was earlier presented in the different works. The electronic nose is based on ultra-fast gas chromatography with headspace. The equipment consists of a detector system

with two metal columns of different polarities (nonpolar MXT-5 and slightly polar MXT1701, diameter = 180 μm, length = 10 m) and also two flame ionisation detectors (FID). The Kovats indexes were determined based on an alkanes standards (n-butane to n-hexadecane) (Restek) measured under the same conditions as the samples. Volatile compound identification was conducted using the AroChemBase (Alpha MOS Co., Toulouse, France) which contains 44 000 compounds and also includes a base of sensory descriptors for each single compound. 2 g of fat was placed in 20-mL headspace vials and capped with a teflon-faced silicon rubber cap. Then vials with the analysed samples were incubated at 55°C for 900 s under agitation speed (8.33 Hz). Carrying gas (hydrogen) was circulated at a constant flowrate (1 ml min^{-1}). The injector temperature was 200°C, injected volume was 2500 μL and injection speed 125 $mL \cdot s^{-1}$. The analytes were collected in the trap at 15°C and then divided and simultaneously transferred into the two columns. A carrying gas was applied at a constant pressure of 80 kPa. The split flowrate was 10 mL min-^{1} at the column heads. The temperature programme in the oven was set as: 60°C for 2 s; 3°C·s-1 ramp to 270°C and kept for 20 s, and FID1/FID2 at 280°C. Wojtasik-Kalinowska *et al*. [2017]. The procedure of PCA was used for data processing with application the Alpha Soft (v.8.0) software. Five repetitions of the samples were performed on 1st, 3rd and 9th day of refrigerated storage.

Statistical analysis

A total of 162 samples were examined (6 treatments for each replicate x 3 storage period x 9 samples of each treatment group). A random block design was used to analyze the goose meat quality, considering a mixed linear model with treatment (60°C/6h, 60°C/24h, 70°C/6h, 70°C/24h, 80°C/6h, 80°C/24h,) and storage period (1, 3, 9 days) as fixed effects. The results were analyzed statistically using one-way (cooking yield, pH) and two-way (color, texture, TBARS) ANOVA (the Statistica 13.1, StatSoft Inc., Tulsa, USA). The differences between the groups were tested according to the Tukey's multiple-range test and performed at the significant level of $p < 0.05$. All results were presented as mean values with a standard error (SE). The profile of flavor data were presented as *Principal Component Analysis* (PCA) using AlphaSoft Version 8.0 program.

Results and discussion

Physicochemical analysis

The results of cooking yield and physicochemical analysis carried out on the *sous-vide* cooked geese fillets at various temperature and time combinations are presented in the Table 1 and Table 2. Longer time of *sous-vide* cooking caused a reduction in the cooking yield from 81.39 to 72.12 at 60°C, 63.14 to 58.87 at 70°C and 57.49 to 54.28 at 80°C. There was no statistically significant difference between cooking yield for 70°C/24h and 80°C/6h samples ($p>0.05$).

No differences between pH of the samples for different cooking combinations were observed. The exception was statistically significant difference between 60°C/6h and 60°C/24h (5.88, 5.73, respectively).

Meat color is an important visual indicator of its quality. The changes in color of goose fillets can result from the protein denaturation, Maillard reaction and also by the formation of different color compounds [Del Pulgar *et al.* 2012, Oz and Seyyar 2016]. Instrumental parameters of color such as lightness (L*), redness (a*) and yellowness (b*) were presented in Table 2 . In the study, samples cooked at 60°C characterized a lighter color in all analyzed days (p<0.05) compared to the samples cooked at 70 and 80°C. Similar observations were also stated by Ismail *et al*. [2019], Roldan *et al.* [2013] and Sánchez *et al*. [2012] who found *sous-vide* samples cooked at 60°C was brighter compared *sous-vide* cooked at 80°C for beef, lamb and pork, respectively. On D0 lighter goose meat was obtained at 60°C/6h (57.35), whereas darker color was obtained at 70°C (42.05). The L* parameter in the case of all analyzed samples exhibited significant variation (except 60°C/24h and 70°C/6h) where L* value was statistically lower within the refrigerated storage. Cooking process at 60°/24h and 70°/6h led to a reduction of the red color during the storage. In the case of the other samples time of storage had no significant effect on a* parameter during the storage. The a* values were in a declining trend (from 15.19 to 7.40 on D0), which was in correspondence with the results obtained by Bıyıklı *et al.* [2020] and Rinaldi *et al. [*2013]. Redness parameters decrease with increasing temperature while yellowness parameters increased which is in accordance with the results obtained by Dominguez-Hermandes *et al.* [2018]. No changes of b* parameter during the storage time were observed in the case of 60°/6h and 70°/24h. In the case of the other temperatures x times a significant increase (p<0.05) was observed. As it was demonstrated in Table 4 L* parameter was affected by both treatment groups (p<0.001) and day of storage (p<0.001). a* and b*

Table 1. Effect of temperature and time of sous-vide cooking on geese fillets cooking yield and pH on the first day (D0) of refrigerated storage

Item		60°C/6h	60°C/24h	70°C/6h	70°C/24h	80°C/6h	80°C/24h	*p*-value
D0	yield (%)	81.39^{e}±1.53	72.12^{d}±1.00	63.14^{c}±1.10	58.87^{b}±0.50	57.49^{ab}±0.33	54.28^{a}±0.27	***
D0	pH	5.88^{b}±0.03	5.73^{a}±0.02	5.77^{ab}±0.01	5.84^{ab}±0.03	5.78^{ab}±0.06	5.76^{ab}±0.02	**

[abc]Means in rows bearing different letters show a significant effect of storage time. **p<0.01; ***p<0.001.
Data are expressed as mean ±SE (n = 27).
6h/60°C – sample after 6 h heat treatment in 60°C; 24h/60°C – sample after 24 h heat treatment in 60°C; 6h/70°C – sample after 6 h heat treatment in 70°C; 24h/70°C – sample after 24 h heat treatment in 70°C; 6h/80°C – sample after 6 h heat treatment in 80°C; 24h/80°C – sample after 24 h heat treatment in 80°C.

Table 2. Effect of temperature and time of *sous-vide* cooking on geese fillets color parameters, hardness, during refrigerated storage

Item		60°C/6h	60°C/24h	70°C/6h	70°C/24h	80°C/6h	80°C/24h
D0		$57.35^{dB}\pm0.49$	$53.98^{cA}\pm0.62$	$48.22^{bA}\pm0.50$	$42.05^{aA}\pm0.45$	$46.73^{bA}\pm0.63$	$49.24^{bA}\pm0.62$
D6	L*	$54.12^{dA}\pm0.68$	$52.76^{dA}\pm0.63$	$46.76^{bcA}\pm0.48$	$41.69^{aA}\pm0.37$	$44.26^{abA}\pm0.42$	$48.45^{cA}\pm0.66$
D9		$54.95^{dA}\pm0.46$	$51.97^{aA}\pm0.50$	$49.35^{cA}\pm0.52$	$45.10^{aB}\pm0.46$	$46.61^{abA}\pm0.57$	$47.72^{bcA}\pm0.28$
D0		$15.19^{dA}\pm0.41$	$7.40^{aA}\pm0.58$	$11.66^{cA}\pm0.33$	$8.61^{abA}\pm0.28$	$12.42^{cA}\pm0.36$	$9.29^{bA}\pm0.26$
D6	A*	$14.79^{dA}\pm0.37$	$9.11^{abB}\pm0.24$	$12.49^{cAB}\pm0.19$	$8.06^{aA}\pm0.23$	$12.21^{cA}\pm0.26$	$10.19^{bA}\pm0.23$
D9		$12.51^{dA}\pm0.38$	$9.39^{aB}\pm0.26$	$13.82^{dB}\pm0.23$	$9.18^{abA}\pm0.36$	$12.14^{cA}\pm0.27$	$10.03^{bA}\pm0.20$
D0		$10.55^{aA}\pm0.33$	$12.55^{bA}\pm0.30$	$13.73^{cdA}\pm0.19$	$12.65^{bcA}\pm0.19$	$13.26^{bcB}\pm0.23$	$14.46^{dB}\pm0.29$
D6	B*	$10.11^{aA}\pm0.30$	$14.06^{cB}\pm0.28$	$13.71^{cA}\pm0.19$	$13.21^{cA}\pm0.30$	$12.00^{bA}\pm0.12$	$14.22^{cB}\pm0.23$
D9		$13.27^{aA}\pm0.40$	$13.41^{bB}\pm0.15$	$15.34^{cB}\pm0.18$	$13.29^{bA}\pm0.21$	$12.80^{abAB}\pm0.19$	$12.85^{aA}\pm0.18$
D0	shear force (N)	$18.91^{bA}\pm0.49$	$13.70^{aA}\pm0.47$	$17.99^{bA}\pm0.44$	$18.33^{bAB}\pm0.40$	$21.03^{bA}\pm0.62$	$18.72^{bB}\pm0.56$
D6		$23.06^{cB}\pm1.0$	$16.11^{aA}\pm0.39$	$18.90^{abA}\pm0.52$	$20.23^{bcB}\pm0.57$	$23.23^{cA}\pm0.60$	$18.75^{abB}\pm0.76$
D9		$24.51^{cB}\pm0.89$	$13.75^{aA}\pm0.30$	$20.29^{bA}\pm0.71$	$16.69^{aA}\pm0.63$	$23.05^{bcA}\pm1.09$	$14.35^{aA}\pm0.50$

^{abc}Means in row bearing different letters show a significant effect of storage time.
^{ABC}Means in column bearing different letters show a significant effect of storage time.
Data are expressed as mean ±SE (n = 27).
6h/60°C – sample after 6 h heat treatment in 60°C; 24h/60°C – sample after 24 h heat treatment in 60°C; 6h/70°C – sample after 6 h heat treatment in 70°C; 24h/70°C – sample after 24 h heat treatment in 70°C; 6h/80°C – sample after 6 h heat treatment in 80°C, 24h/80°C – sample after 24 h heat treatment in 80°C.

parameters were affected by treatment groups ($p<0.001$) but not affected by day of storage.

Meat texture is an important aspect of eating quality. Critical for meat texture is temperature of cooking process, therefore the temperature parameters higher than the collagen shrinkage temperature did not decrease the tenderness, while the higher temperature caused the less tender tissues due to collagen coagulation [Ayub and Ahmad 2019, Laakkonen Wellington and Sherbon 1970]. *Sous-vide* cooking solubilizes connective tissues causing the meat to be tender with shear force reduction [Rinaldi *et al*. 2014]. Palka [2003], on the other hand, reported that meat cooked at 80°C characterized higher value of shear force compared to meat cooked at 60°C. In our study on D0 no changes in shear force was observed, except 60°C/24h where statistically the lowest value ($p<0.05$) was observed (13.70). On D6 different tendency was observed, statistically the lowest values of shear force were noted for 60°C/24h, 70°C/24h and 80°C/24h. On D9 the hardest sample was at 60°C/6h.

Lipid oxidation

Table 3 indicates the results of lipid oxidation in geese fillets obtained by a combination of time and temperature using *sous-vide* cooking technique. TBARS on D0 60**°C** and 70°C groups in both temperatures displayed the highest oxidation stability, as demonstrated by the low MDA content (approx. 0.15-0.17 MDA/kg of meat). The use of a higher temperature (80°C) during the cooking process contributed to a statistically significant **(***p*<0.05) increase in fat oxidation in the geese fillets for 80**°C**/6h and 80°C/ 24°C, 0.20 and 0.21 MDA/kg of meat, respectively.

Table 3. Effect of temperature and time of *sous-vide* cooking on geese fillets lipid oxidation – substances reactive with thiobarbituric acid (TBARS) during refrigerated storage

Item		60°C/6h	60°C/24h	70°C/6h	70°C/24h	80°C/6h	80°C/24h
D0		0.15^{aA}±0.00	0.17^{aAB}±0.00	0.15^{aA}±0.00	0.15^{aA}±0.00	0.20^{bA}±0.00	0.21^{bA}±0.00
D6	TBARS	0.13^{aA}±0.00	0.16^{abA}±0.00	0.16^{abA}±0.00	0.17^{bcA}±0.01	0.22^{cAB}±0.01	0.19^{cA}±0.01
D9		0.15^{aA}±0.01	0.19^{bB}±0.00	0.16^{aA}±0.01	0.28^{dB}±0.01	0.25^{bcB}±0.01	0.28^{dB}±0.01

^{abc}Means in row bearing different letters show a significant effect of storage time.
^{ABC}Means in column bearing different letters show a significant effect of storage time.
Data are expressed as mean ±SE (n = 27).
6h/60°C – sample after 6 h heat treatment in 60°C; 24h/60°C – sample after 24 h heat treatment in 60°C; 6h/70°C – sample after 6 h heat treatment in 70°C; 24h/70°C – sample after 24 h heat treatment in 70°C; 6h/80°C – sample after 6 h heat treatment in 80°C, 24h/80°C – sample after 24 h heat treatment in 80°C.

The highest level of lipid oxidation was found in the case of 70°C/24 and 80°/24h groups on D9 day of refrigerated storage (0.28 MDA/kg). Different researchers obtained values of TBARS for *sous-vide* cooked patties from 0.33 to 0.59 mg MDA/kg meat [Ortuño *et al.* 2021]. The MDA concentration increased during *sous-vide* cooking at different temperatures what was consistent with results obtained also by Roldán *et al*. [2014]. The rate of the lipid oxidative process in meat during cooking depends upon the temperature of thermal processing [Shahidi *et al.* 1987] and therefore, it might be expected that higher cooking temperatures and times would lead to higher TBARS value.

As it was noted by Georgantelis *et al.* [2007] a rancid flavor is detected in animal products with TBARS values higher than 1 mg MDA/kg. In the analyzed period of refrigerated storage without oxygen access, all TBARS values were below this value.

MDA is very prone to react with other compounds located in meat that contain proteins, phospholipids, DNA or amino acids [Ventanas *et al.* 2007]. This fact caused a decrease in the amount of MDA and other reactive lipid carbonyls available to react with TBA and consequently a decrease in the TBARS values. It would be then reasonable to assume that at higher temperatures, MDA would further react at a higher rate with other compounds, explaining the decrease from 6 to 12 h or 24 h of cooking time at 70°C and especially at 80°C. Other authors received the opposite situation to that obtained in our research [Roldan *et al.* 2008] and they observed a positive effect

Table 4. Test probabilities for selected physical, chemical parameters of geese fillets depot fat, depending on temperature and time of *sous-vide* cooking – multiaspect variance analysis including interactions

Item	Group (G)	Day of storage (D)	Interaction G x D
TBARS	***	***	***
L*	***	**	***
a*	***	NS	***
b*	***	NS	
Shear force (N)	***	***	

*p<0.05; ** p<0.01; *** p<0.001; NS – not significant.

of temperature on a faster decrease in MDA and increase in compounds from the reaction of MDA. The degree of lipid oxidation increased with storage time in the case of 70°C/ 24h, 80°C/6h and 80°C/ 24h. samples. In the case of the rest of samples the storage time was not significant. As it was demonstrated in Table 4 TBARS were affected by both treatment group (p<0.001) and day of storage (p<0.001).

Differential scanning calorimetry (DSC) measurement

Differential scanning calorimetry was utilized to investigate thermal denaturation temperatures of goose fillet proteins. In the Figure 1 the DSC thermogram of raw goose fillet and samples after heat treatment are presented. The plot of the control shows 3 peaks and indicates the denaturation of 3 muscle proteins as thermal events. The first thermal pick occurs over a range from 50 to 59°C, the second from 59 to 72°C, and the third from 72 to 83°C. The first thermal event corresponds to denaturation of myosin. It is similar to thermal denaturation temperature ranges for chicken and turkey muscle [Agafonkina *et al.* 2019]. On the other hand, a lower myosin denaturation temperatures were recorded in fish meat, e.g. tuna [Bell *et al.* 2001]. The onset temperature (50°C) presents the initiation of myosin denaturation. The peak reaches the apex at 56°C (T_{max}). This is the temperature at which half of the protein (myosin) is denatured. The second thermal event corresponds to collagen and sarcoplasmic proteins (T_{max} at 63°C) - Rochdi *et al.* [2000]. The third DSC peak corresponds to actin (T_{max} at 80°C). Thermal analysis of goose muscle proteins showed that the thermal denaturation temperatures of actin are very similar to other species such as beef and pork. Other poultry species such as turkeys and chickens also had a similar actin denaturation temperature [Agafonkina *et al*. 2019, Purslow *et al.* 2016]. Changes caused by low-temperature *sous-vide* heating can be observed in all treatment

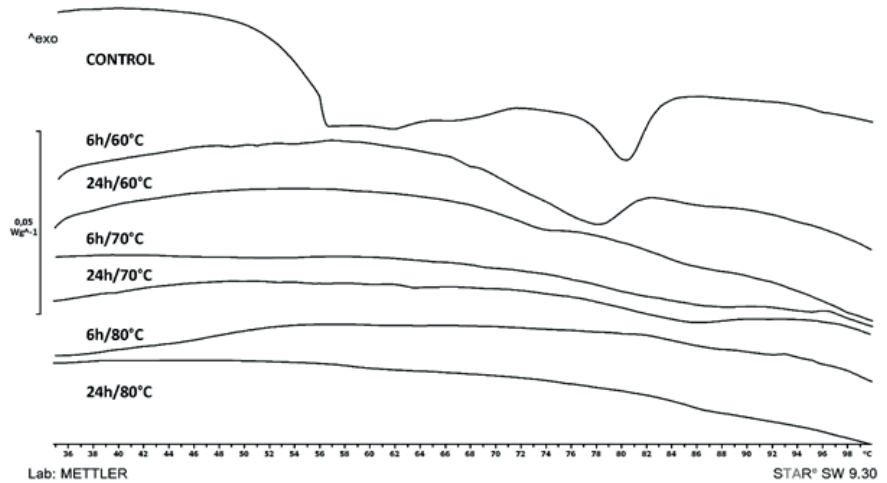

Fig. 1. The DSC thermogram of raw geese fillet and samples after heat treatment.

samples (Tab. 5). Myosin, collagen, and sarcoplasmic proteins were denatured in the samples 6h/60°C, 24h/60°C, 6h/70°C, 24h/70°C, 6h/80°C and 24h/80°C. Statistically significant changes were found for the actin denaturation temperature. Sous-vide heat treatment caused a statistically significant increase in initiation temperature (T_{on}), peak peak (T_{max}) and end of reaction (T_{end}) for samples 24h/60°C, 6h/70°C and 24h/70°C ($p<0.05$). A significant decrease of T_{on}, T_{max} and T_{end} as observed only in sample 6h/60°C. In samples 6h/80°C and 24h/80°C actin was completely denatured and no DSC peaks were detected. Extending the time and increasing the temperature of the thermal treatment resulted in a decrease in the enthalpy (ΔH) of the actin denaturation process ($p<0.05$). Similar results of the experiment were obtained by Llave *et al*. [2018] who investigated the effect of low-temperature *sous-vide* cooking on the degree of denaturation of tuna proteins [Llave *et al*. 2018] long time.

Table 5. The DSC results for protein denaturation

Protein	Sample	T_{on} (°C)	T_{max} (°C)	T_{end} (°C)	ΔH (J/g)
Myosin	control	50.66±0.01	56.65±0.01	59.12±0.01	0.61±0.01
	60°C/6h	ND	ND	ND	ND
	60°C/24h	ND	ND	ND	ND
	70°C/6h	ND	ND	ND	ND
	70°C/24h	ND	ND	ND	ND
	80°C/6h	ND	ND	ND	ND
	80°C/24h	ND	ND	ND	ND
Collagen and sarcoplasmic proteins	control	59.12±0.01	63.03±0.01	67.58±0.01	0.03±0.01
	60°C/6h	ND	ND	ND	ND
	60°C/24h	ND	ND	ND	ND
	70°C/6h	ND	ND	ND	ND
	70°C/24h	ND	ND	ND	ND
	80°C/6h	ND	ND	ND	ND
	80°C/24h	ND	ND	ND	ND
Actin	control	67.58^{B}±0.01	80.46^{B}±0.01	83.02^{B}±0.01	0.29^{E}±0.01
	60°C/6h	66.11^{A}±0.01	72.25^{A}±0.01	74.10^{A}±0.01	0.14^{D}±0.01
	60°C/24h	77.32^{C}±0.01	83.97^{C}±0.01	89.07^{C}±0.01	0.09^{C}±0.01
	70°C/6h	77.73^{C}±0.01	83.43^{C}±0.01	89.18^{C}±0.01	0.04^{B}±0.01
	70°C/24h	77.58^{D}±0.01	86.68^{D}±0.01	89.39^{D}±0.01	0.02^{A}±0.01
	80°C/6h	ND	ND	ND	ND
	80°C/24h	ND	ND	ND	ND

^{ABCDE}Mean values with different letters showing significant effect of the treatment group.
T_{on} – start temperature (°C); T_{max} – maximum temperature (°C); T_{end} – end temperature (°C); ΔH – area under the peaks (J/g); ND – not detected.
Treatment: control – control sample; 6h/60°C – sample after 6 h heat treatment in 60°C; 24h/60°C – sample after 24 h heat treatment in 60°C; 6h/70°C – sample after 6 h heat treatment in 70°C; 24h/70°C – sample after 24 h heat treatment in 70°C; 6h/80°C – sample after 6 h heat treatment in 80°C; 24h/80°C – sample after 24 h heat treatment in 80°C.

Volatile compounds visualization

Figure 2 presents the classification of scent profiles in relation to their experimental group a) all analyzed days, D0 (Fig. 3), D3 (Fig. 4) and D9 (Fig. 5) of refrigerated storage. Samples are represented in two-dimensional plane with reference to selected

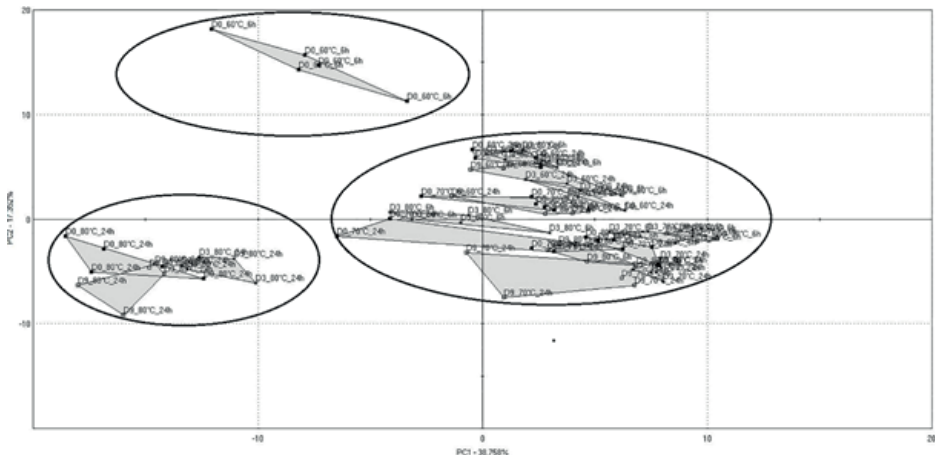

Fig. 2. Principal component analysis (PCA) for geese fillets depending on the effect of time and temperature of *sous-vide* cooking on D0, D3 and D9 of the refrigerated storage.

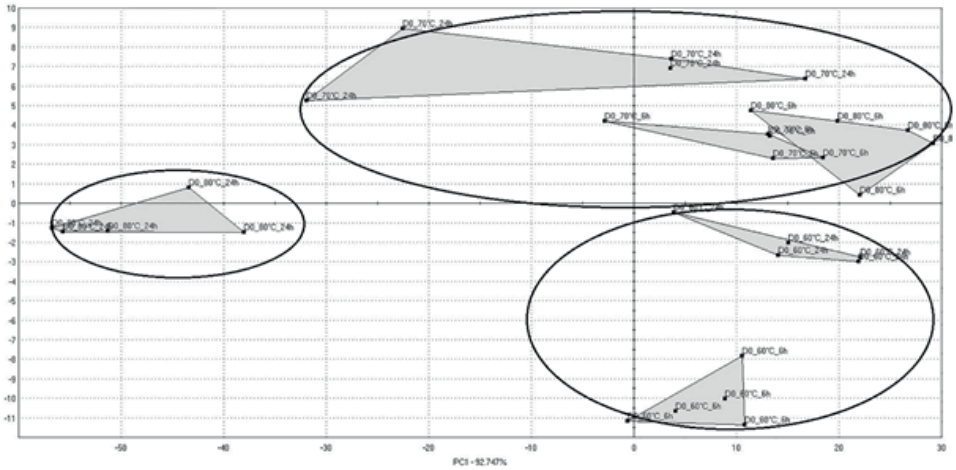

Fig. 3. Principal component analysis (PCA) for geese fillets depending on the effect of time and temperature of *sous-vide* cooking on D0 of the refrigerated storage.

components: principal component 1 and principal component 2. On the graph a) values of 38.75% data variance was explained by the vertical axis and 17.35% intercepted by the horizontal axis explained the differences among samples along the axis. The formation of three sets was observed and analyzed groups appeared on separate parts of the score plot. In the case of D0 60°C/6h group, the flavor changed compared to the other groups. Also the highest applied temperature (80°C) and the highest applied time (24h) caused separation of all analyzed days so it can be concluded that the flavor is stable and does not change during the storage.

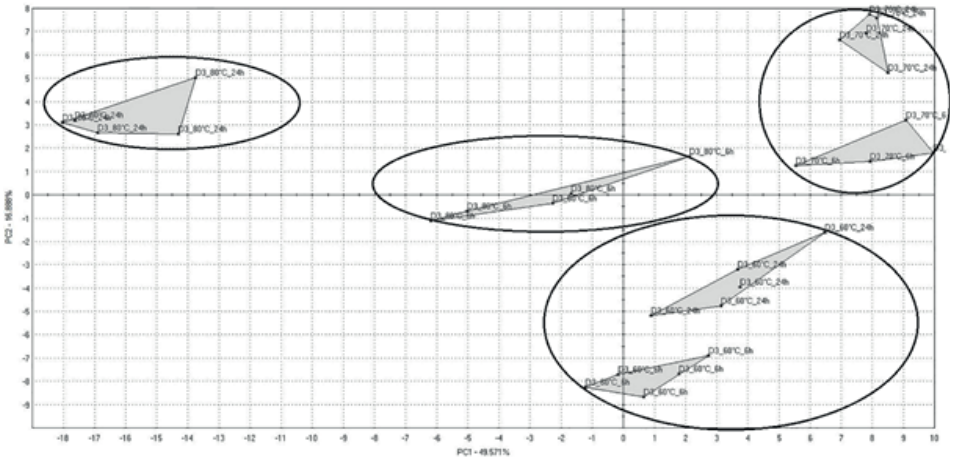

Fig. 4. Principal component analysis (PCA) for geese fillets depending on the effect of time and temperature of *sous-vide* cooking on D3 of the refrigerated storage.

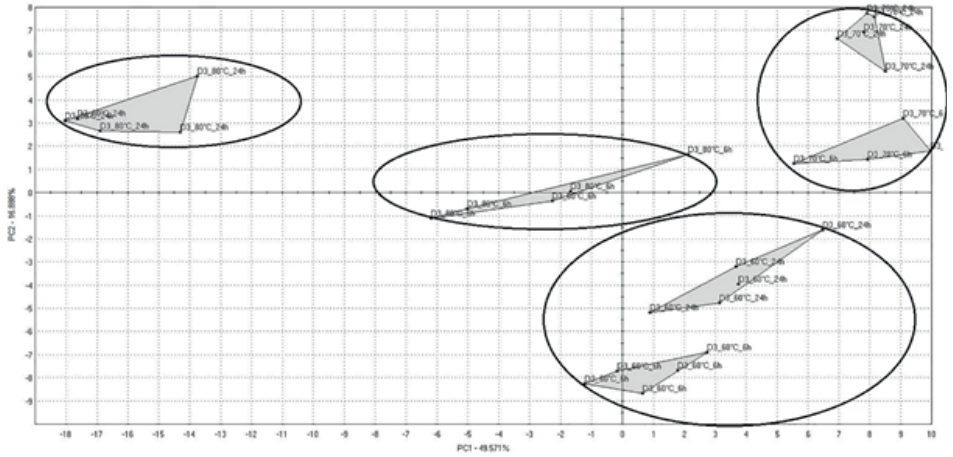

Fig. 5. Principal component analysis (PCA) for geese fillets depending on the effect of time and temperature of *sous-vide* cooking on D9 of the refrigerated storage.

Considering each day separately it can be concluded that on D0 and D9 (Fig. 3 and Fig. 5, respectively) three separate groups were formed. The first one 60°C/6h and 60°C/24h, second group 70°C/6h, 70°C/24h and 80°C/6h and the third group 80°C/24h. On D3 in addition group 80°C/24 was separated. The highest differences between analyzed groups were observed on D0 (92.7%). In the next days this value has decreased to 49.5 and 49.7% on D3 and D9, respectively.

Based on the conducted analysis 18 (60°/6h) to 23 volatile compound in both 70°/6h and 70°/24h (Tab. 6) were observed. According to AroCHemBase 13 volatile

Table 6. Effect of temperature and time of *sous-vide* cooking on volatile compounds in geese fillets

Compound	DB 5	DB 1701	Sensory descriptor	60°C/ 6h[a]	60°C/ 24h[a]	70°C/ 6h[a]	70°C/ 24h[a]	80°C/ 6h[a]	80°C/ 24h[a]
Ethanol	444	554	alcoholic	+	+	+	+	+	+
Propanal	504	607	acetaldehyde	+	+	+	+	+	+
2-Propanol	509	612	alcoholic	+	+	+	+	+	+
2-methylpropanal	515	617	aldehydic	+	+	+	+	+	+
Butane-2,3-dione	589	690	butter	+	+	+	+	+	+
Methyl propanoate	600	755	apple		+	+	+	+	+
1-Propanol, 2-methyl-	626	738	alcoholic	+	+	+			
1-Butanamine	643	702	ammpniacal		+	+	+	+	
Trichloroethane	645	691	etheral		+				
Isopropyl acetate	650	718	banana	+	+	+	+	+	+
3-Pentanone	694	769	acetone	+	+	+	+	+	+
Propyl acetate	717	804	carmelized	+	+	+	+	+	+
Cyclopentanone	794	917	peppermint				+	+	+
2,3-Butanediol	788	989	creamy	+	+	+			
Methyl pentanoate	823	893	apple	+	+	+	+	+	+
Furfural	836	978	almond		+	+	+	+	+
Ethyl 2-methylbutyrate	849	907	apple				+	+	+
Dimethyl sulfoxide	839	1062	allieceous	+	+	+			
Methional	907	1040	baked potato	+	+	+	+	+	+
2,3-dimethylpyrazine	925	1005	baked			+	+	+	+
4-Hydroxy-5-methyl-3(2H)-furanone	1049	1263	balsamic	+	+	+	+	+	+
m-cresol	1081	1310	animal				+		+
Guaiacol	1103	1244	aromatic	+	+	+		+	
1-Octanethiol	1122	1190	sulfurous	+	+	+	+	+	+
2,3-Diethyl-5-methylpyrazine	1158	1219	meaty				+		
Pentyl pentanoate	1172	1257	fruity	+	+	+	+	+	+
2-Isobutyl-3-methoxypyrazine	1183	1228	dry				+	+	+
Propyl heptanoate	1199	1262	apple			+			
2,6-dimethoxy-phenol	1379	1320	balsamic	+	+	+	+	+	+

*MXT-5 – non polar column; **MXT-1701 – slighty polar column.
6h/60°C – sample after 6 h heat treatment in 60°C; 24h/60°C – sample after 24 h heat treatment in 60°C; 6h/70°C – sample after 6 h heat treatment in 70°C; 24h/70°C – sample after 24 h heat treatment in 70°C; 6h/80°C – sample after 6h heat treatment in 80°C; 24h/80°C – sample after 24h heat treatment in 80°C.
[a]The presence of volatile compounds in a given group (+).

compounds and their sensory descriptors were detected in all samples: ethanol, propanal, 2-Propanol, 2-methylpropanal, butane-2,3-dione, isopropyl acetate, 3-pentanone, methyl petanoate, methional, 4-hydroxy-5-methyl-3(2H)-furanone, 1-octanethiol, pentyl pentanoate, 2,6-dimethoxy-phenol. The increase in the heat treatment temperature resulted in the presence such compounds as 2,3-dimethylpyrazine, 2,3-dimethyl-5-methylpyrazine, 2-isobutyl-3-methoxypyrazine which are products of Maillard reactions. As it was demonstrated on Figure 6, 2,3-dimethylpyrazine was detected at 70°/*6h*, 70°/24h, 80°/6h, 80°/24h samples and characterized baked sensory descriptor so it means that it can be an indicator of flavor intensity and stability of *sous-vide* heat treatment. The relative peak areas of 2,3-dimethylpyrazine increased statistically significant with increasing the time and the temperature ($p<0.05$) of *sous-vide* cooking on all days of storage. 2,3-dimethylpyrazine belongs to alkylpyrazines compounds. Alkylpyrazines are naturally occurring highly aromatic substances which often characterized a very low odor threshold [Fors and Olofsson 1985] and are responsible for the taste and aroma of food [Chao *et al.* 2020, Satoru and Hideki 1988]. Simultaneously, these volatile compounds are also formed during the cooking

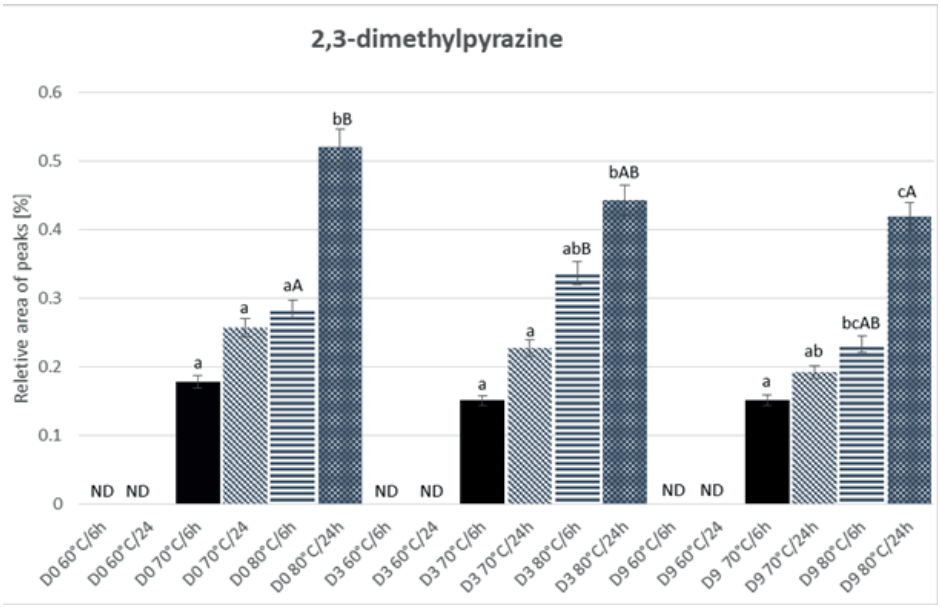

Fig. 6. Monitoring of relative surface areas of peaks changes of 2,3-dimethylpyrazine in goose fillets after *sous-vide* cooking during refrigerated storage.

of food via Maillard reactions The Maillard reaction can occur over a wide range of temperatures, but the lower limit is not well defined [Fors and Olofsson 1985].

No statistically significant differences (p>0.05) were found during storage in samples 70°/6h and 70°/24h, therefore it can be concluded that the identified baked flavor is stable.

A decrease in the value of the relative surface areas of peaks during the storage was found in the samples 80°**C**/24h what resulted in flavor instability.

Conclusions

It can be concluded that *sous-vide* cooking of goose fillets has a great potential to limit the quality losses and cooking yields depend on time and temperature parameters. The highest oxidation stability was noted at temperatures of 60 and 70°C. It can be stated that the hardness of the samples increased with the increase of actin. The *sous-vide* cooking temperature of 80°C/24 changed the aroma profile of the goose fillets on the analyzed days of refrigerated storage. In addition, longer cooking times caused a greater amount of volatile compounds presence and the 2,3-dimethylpyrazine can be recommended as a marker of baked flavor of *sous-vide* treated geese fillets. However, the effects of *sous-vide* on the specific changes of geese flavor need to be further investigated.

Conflict of interest

The authors declare no conflict of interest.

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