

Oxidative stability of chicken meat at different oxygen concentrations in the packaging unit

Tomaž Polak¹, Mateja Lušnic Polak¹, Iva Zahija¹, Katja Japelj¹, Mojca Kuhar¹,
Eva Golob¹, Lea Demšar^{1*}

Abstract

The aim of this study was to preserve the quality and prevent the colour, lipid and protein oxidation in chicken breast fillet (pectoralis major muscle) during storage. For this purpose, modified atmospheres (MA) with four different gas mixtures (vol. %) of oxygen (O₂), carbon dioxide (CO₂) and nitrogen (N₂) were used: oxygen free (0: 20: 80), low (20: 20: 60), medium (40: 20: 40), and high oxygen MA (70: 20: 10). After 9 days of storage in a refrigerator at 2 ± 1 °C, pH was measured, colour was evaluated instrumentally and sensorially, the basic chemical composition, thiobarbituric acid reactive substances (TBARs), and protein carbonyl content of raw chicken breast were determined. After thermal treatment (82 °C, 1 hour, sous-vide) of the breast fillet, the sensory characteristics of odour and aroma were evaluated, and the texture (Warner-Bratzler shear force) was measured instrumentally. The composition of the gas mixture affected all oxidation dependent parameters: (i) colour: *L** and *b** values were the highest under all MA with oxygen, and the *a** value under MA without, medium and high-oxygen, (ii) lipids: the TBARs increased significantly under high oxygen MA after 7 days of storage (below the sensory thresholds value for rancidity), (iii) proteins: protein carbonyl content was the highest under medium and high oxygen MA, and (iv) sensory properties: colour oxidation and intensity of odd aromas under all MA with oxygen, as well as odour and aroma of stale in oxygen-free MA were increased. For chicken breast the most suitable is packaging under modified atmosphere without O₂, because the oxidation rate of colour, lipids and proteins during storage was the lowest.

Keywords: chicken meat, storing, gas composition, lipids oxidation products, protein carbonyls

Introduction

Chicken meat is one of the most popular meats due to its low price and favourable nutrient composition (Patsias et al., 2006). The consumption of chicken meat is increasing compared to beef and pork mainly because of its low price, easy and quick preparation, and desirable nutritional value, as it

contains many highly usable proteins, low fat, and many polyunsaturated fatty acids (Brenes and Roura, 2010). Despite the above advantages, chicken meat has a relatively short shelf life, even when stored in a cold environment. Therefore, scientists and the meat industry are looking for new ways to

¹ prof. dr. sc. Tomaž Polak, associate professor, doc. dr. sc. Mateja Lušnic Polak, assistant, Iva Zahija, mag. ing. techn. aliment., Katja Japelj, univ. dipl. inž. živ. tehnol., Mojca Kuhar, mag. inž. živ., Eva Golob, dipl. inž. živ. in preh., prof. dr. sc. Lea Demšar, full professor; University of Ljubljana, Biotechnical Faculty, Jamnikarjeva 101, 1000 Ljubljana

*Corresponding author: lea.demsar@bf.uni-lj.si

extend the shelf life of chicken meat (Patsias et al., 2008). Due to the increasing demand for chicken meat, it is crucial to choose the optimal packaging method to ensure adequate safety and quality of the meat during storage and transportation to the final consumer (Zhang et al., 2015).

Although the packaging requirements for fresh chicken meat are similar to those for red meat, their packaging is particularly challenging due to physiological and biological factors. Raw poultry meat is perishable due to its relatively high pH (5.7-6.7), which allows rapid growth of microorganisms both at room temperature and during refrigeration. In addition, poultry meat is rich in protein and fat with a high content of unsaturated fatty acids and is therefore susceptible to oxidative reactions.

The high content of polyunsaturated fatty acids is the main reason why chicken meat is more susceptible to oxidation, which in turn influences the shorter shelf life due to the deterioration of sensory quality (Cortinas et al., 2004; Xiao et al., 2011). Oxidation of meat leads to negative changes in colour, odour, aroma, and texture, as well as the appearance of potentially toxic substances, so oxidative spoilage must be stopped or prevented. One of the most successful methods to prevent the oxidation of colour, lipids and proteins and the deterioration of sensory quality of meat is proper packaging.

Modified atmosphere (MA) packaging (MAP) is a packaging method that is increasingly used today for packaging a variety of foods, especially raw meat and meat products. The air atmosphere is replaced by a mixture of gases, usually consisting of oxygen, carbon dioxide and nitrogen. The concentration of each gas in the gas mixture depends on the food to be packaged and the desired effect. It is important to choose the right atmosphere for each food to extend the shelf life while maintaining safety and sensory quality. Raw meat is usually packaged in a very low-oxygen (possibly with additional oxygen scavengers) or very high-oxygen atmosphere.

The aim of our study was to maintain quality during 9 days of storage and to prevent the oxidation of colour, lipids and proteins in chicken breast fillets by packing them in a modified atmosphere. For this purpose, different gas mixtures, nitrogen, carbon dioxide and different concentrations of oxygen were tested.

Material and methods

Material and experiment design

Chicken breast muscles (musculus pectoralis major) were packaged in four different atmospheres at a local meat processing plant. The approximate ratio of gases (vol. %, oxygen (O₂): carbon dioxide (CO₂): nitrogen (N₂)) during packaging was as follows: modified atmosphere (MA) without oxygen (0: 20: 80), with low oxygen MA (20: 20: 60), with medium oxygen MA (40: 20: 40), and with high oxygen MA (70: 20: 10). For each atmosphere, 9 packaging units (each unit consisted of two breasts) were prepared, as the analyses were repeated on the 2nd, 7th and 9th day after slaughter, taking three units each time (4 atmospheres × 9 packaging units = 36 samples).

On the 2nd day after slaughter, the meat samples were delivered to the Biotechnical Faculty, where they were stored in a refrigerator at 2 ± 1 °C. First, the composition of the gas mixture in the atmosphere of the packaging units was measured (3 units from each atmosphere). One chicken breast from each of the twelve packaging units was used for the analysis of physicochemical parameters. The pH and instrumental colour values were then measured. Breast fillets were homogenised and used for immediate determination of nutrient composition (water, protein and fat content). Further chemical analyses (thiobarbituric acid reactive substances (TBARs) and protein carbonyl content) were performed after one week of storage of the frozen homogenised samples at 18 ± 1 °C. Chemical analyses were performed in parallel, measuring nutrient composition in one parallel and colour and texture in four parallels. The colour of the second chicken breast from each of the twelve packaging units was sensory evaluated, and each piece was vacuum-packed in a high-barrier sealable lidding film for food trays made of polypropylene and polyethylene (PP/PE) (thickness 50 µm) (Lin Top PP HB A 50; Linpac Plastic Pointivy, France): O₂ transmission, < 5 × 10⁻⁶ m³ (m³ × 24 h × bar)⁻¹; carbon dioxide transmission, < 25 × 10⁻⁶ m³ (m³ × 24 h × bar)⁻¹; water vapour transmission, < 0.003 kg (m² × 24 h × bar)⁻¹. This was followed by a one-hour heat treatment in a combi oven (Rational FRIMA (SCC61)) at a moist heat of 82 °C. The technique used is referred to as sous vide cooking or vacuum cooking. The heat-treated samples were subjected

to sensory analysis focusing on texture, odour and aroma attributes, and texture (shear force) was measured instrumentally after cooling to room temperature (20 ± 1 °C).

The whole procedure was repeated on the 7th and 9th day after slaughter.

Methods

Instrumental methods: A mobile gas analyser for the testing of modified atmospheres in food packaging, calibrated OXYBABY® V instrument (WITT Gasetechnik GmbH & Co. KG, Austria), was used to determine the gas compositions in the packages under each of the packaging atmosphere conditions as % O₂ and % CO₂. An absolute accuracy of 0.1 % was achieved at O₂ concentrations < 10 vol. %, with < 1 % relative accuracy at O₂ concentrations of 10-100 vol. %, at 20 °C (Penko et al., 2015). Water, protein and fat content in the samples were determined using the Food Scan™ Analyser with self-calibration (FOSS, Denmark), pH values were measured directly using a combined glass-gel spear electrode (Type 03, Testo Pty Ltd, Australia), colour *L** (lightness), *a** (±, red to green) and *b** (±, yellow to blue) values on the surface of a 2.54 cm raw slice were measured by CR-400 colorimeter (Konica Minolta Optics, Inc., Osaka, Japan), and instrumental analysis of texture was performed using the TA-XT Plus texture analyser (Stable Micro Systems Ltd., Godalming, Surrey, UK) as described in Zahija et al. (2020).

Chemical analyses: Approximately 100 g of a representative sample was homogenised for 20 s with a Grindomix homogeniser (GM 200; Retch, Germany) at 5000-6000 rpm (ISO 3100-1, 1991). The extent of lipid oxidation of the chicken samples was monitored by measuring the thiobarbituric acid reactive substances (TBARS) as described by Penko et al. (2015). A slightly modified (Rotar, 2019) spectrophotometric method by Soglia et al. (2016) was used to determine the protein carbonyl content. The absorbance was measured with a spectrophotometer (Agilent Technologies, Cary 8454 UV-Vis) at two wavelengths, 280 nm and 370 nm. The content of protein carbonyls was expressed in nmol/mg protein.

Sensory evaluation: A panel of five qualified and experienced panellists in the field of meat products was used to assess the sensory qualities. The sensory evaluation of chicken breast samples

was performed according to international standards (ISO 8589:2007, ISO 8586:2012). The panel evaluated the samples separately in three session (days) consisting of 12 samples. The analytical-descriptive test (Golob et al., 2005) was performed by scoring the sensory attributes on a structured scale from 0 to 4 points, where 0 means that the attribute is not expressed, 1 defines a slightly expressed attribute, 2 medium (strongly) expressed, 3 strongly expressed and 4 very strongly expressed attribute of the sample. The panel could also use half values (i.e., 0.5, 1.5, 2.5, and 3.5). The sensory profile of the chicken breast samples was evaluated using 7 descriptors, which were divided into three blocks. The first block related to the visual attribute on the surface of a raw breast fillets as oxidation rate of colour; at higher values, the grey-brown oxidised colour appeared. The second block related to the olfactory attributes, such as rancid odour, stale odour (appearance of stale components, cardboard odour, wet dog hair odour, etc.) and odd odours (presence of foreign, undesirable components). The third block was related to the aroma attributes, such as the aroma of rancid and stale/old (warm over flavour) as well as odd aromas (appearance of undefined acidic, bitter perception).

Data analysis: The data were analysed for normal distributions using the UNIVARIATE procedure (SAS/STAT). The differences according to the atmospheric composition (oxygen MA: without, low, medium and high), time of storage (on day 2, 7 and 9 (d)), as well as to their interaction (without_2 d, low_2 d, medium_2 d, high_2 d, without_7 d, low_7 d, medium_7 d, high_7 d, without_9 d, low_9 d, medium_9 d, high_9 d) were analysed through a general linear model procedure and least squares mean test (SAS/STAT), with a 0.05 level of significance. The effect of production repetition (1-3) was not significant and was excluded from the model.

Results and discussion

Basic chemical composition

On average, 100 g wet weight of chicken breast contained 24.28 ± 0.59 g protein, 76.94 ± 0.45 g moisture and 1.73 ± 0.36 g fat (not shown in tables). The data agree well with the reference values from the Slovenian nutritional tables (Golob et al., 2006) for 100 g of boneless and skinless chicken breast: 22.8 g of protein, 74.8 g of moisture and

1.5 g of fat. Chmiel et al. (2019) confirmed that the duration and conditions of storage, as well as the type of packaging, did not affect the basic chemical composition of chicken breast.

Gas composition in the packages

After 9 days of storage, the concentrations of O₂, CO₂, and N₂ in the packaging units changed significantly (P ≤ 0.001) in all experimental groups, depending on the composition of the gases at filling (Table 1). Changes in the composition of the atmosphere during storage may be due to the absorption of gases into the tissues (meat), the production of gases during muscle respiration, and some gases could also be produced during bacterial growth in the meat (Keokamnerd et al., 2008; Penko, 2015). In MA without oxygen, CO₂ content decreased and N₂ content increased significantly after the 9-day storage period, while O₂ content remained unchanged. In low oxygen MA, O₂ content decreased by more than half and N₂ content increased by more

than 20 %, while CO₂ content remained unchanged during storage. In MA with medium oxygen content, a decrease in O₂ content (about 9 %) and an increase in N₂ concentration (about 10 %) were also observed. In high oxygen MA the gas ratios did not change significantly during the storage period.

Gill (1988) noted that CO₂ is highly soluble in water and oils, so it is easily absorbed into muscle and fat during storage (Penko, 2015). However, Demirhan and Candoğan (2017) found that CO₂ concentration also decreases during storage due to the transfer of CO₂ from inside the packaging unit to the external environment and vice versa (Tománková et al., 2012; Rossaint et al., 2014; 2015). Even more, Chmiel et al. (2019) concluded that O₂ content in packaging units under high oxygen MA (75 % O₂, 25 % CO₂) decreased and CO₂ content increased, which was due to the fact that microorganisms present on chicken breast consumed O₂ and produced CO₂.

Table 1 Composition of gas mixture in packaging units during 9-day storage period at 2 ± 1 °C of raw chicken breast muscle (n = 36)

Composition (vol. %; LSM ± SD) of gas mixture in the modified atmosphere:						
Parameter (%)	Storage (day)	Without O ₂	Low O ₂	Medium O ₂	High O ₂	Significance
O ₂	2	0.95 ± 0.19 ⁱ	20.61 ± 0.22 ^f	39.60 ± 0.06 ^c	69.78 ± 0.04 ^b	P _A ≤ 0.001
	7	0.07 ± 0.10 ⁱ	14.11 ± 0.98 ^g	33.97 ± 1.13 ^d	72.61 ± 0.86 ^a	P _S ≤ 0.001
	9	0.06 ± 0.07 ⁱ	8.66 ± 2.00 ^h	30.33 ± 2.28 ^e	70.09 ± 0.16 ^b	P _{AxS} ≤ 0.001
CO ₂	2	20.00 ± 0.36 ^{ba}	20.27 ± 0.57 ^a	19.53 ± 0.32 ^{ba}	18.60 ± 0.30 ^{dc}	P _A ≤ 0.001
	7	14.43 ± 0.64 ^g	17.83 ± 0.25 ^{de}	17.20 ± 0.26 ^e	16.20 ± 0.62 ^f	P _S ≤ 0.001
	9	13.37 ± 0.42 ^h	19.77 ± 0.59 ^{ba}	19.27 ± 0.90 ^{bc}	18.03 ± 0.06 ^{de}	P _{AxS} ≤ 0.001
N ₂	2	79.07 ± 0.49 ^b	59.17 ± 0.40 ^e	40.87 ± 0.23 ^h	11.73 ± 0.15 ⁱ	P _A ≤ 0.001
	7	85.50 ± 0.52 ^a	68.07 ± 0.80 ^d	48.80 ± 1.05 ^g	11.20 ± 0.30 ^j	P _S ≤ 0.001
	9	86.60 ± 0.46 ^a	71.57 ± 1.63 ^c	50.40 ± 1.77 ^f	11.90 ± 0.20 ^j	P _{AxS} ≤ 0.001

Without O₂ – 0 % O₂, 20 % CO₂, 80 % N₂; Low O₂ – 20 % O₂, 20 % CO₂, 60 % N₂; Medium O₂ – 40 % O₂, 20 % CO₂, 40 % N₂; High O₂ – 70 % O₂, 20 % CO₂, 10 % N₂; n, number of observations; LSM, least square means; SD, standard deviation; P_A, statistical probability of the gas mixture composition effect; P_S, statistical probability of storage effect; P_{AxS}, statistical probability of interaction of the gas mixture composition and storage; data with different superscript letters within parameter (a-i) differ significantly (P ≤ 0.05).

Table 2 Effect of the atmosphere composition in the packaging unit during 9-day storage period at a temperature of 2 ± 1 °C on the pH of raw chicken breast muscle

Value of parameter (LSM ± SD) according the atmosphere:						
Parameter (%)	Storage (day)	Without O ₂	Low O ₂	Medium O ₂	High O ₂	Significance
pH value (n = 72)	2	6.11 ± 0.21 ^{bac}	6.06 ± 0.45 ^{bac}	6.12 ± 0.14 ^{ba}	5.95 ± 0.19 ^{bac}	P _A = 0.799
	7	5.87 ± 0.10 ^{bac}	6.02 ± 0.12 ^{bac}	6.14 ± 0.18 ^a	6.12 ± 0.19 ^{ba}	P _S = 0.159
	9	6.11 ± 0.15 ^{bac}	6.01 ± 0.17 ^{bac}	5.85 ± 0.09 ^c	5.86 ± 0.08 ^{bc}	P _{AxS} = 0.024

Without O₂ – 0 % O₂, 20 % CO₂, 80 % N₂; Low O₂ – 20 % O₂, 20 % CO₂, 60 % N₂; Medium O₂ – 40 % O₂, 20 % CO₂, 40 % N₂; High O₂ – 70 % O₂, 20 % CO₂, 10 % N₂; n, number of observations; LSM, least square means; SD, standard deviation; P_A, statistical probability of the gas mixture composition effect; P_S, statistical probability of storage effect; P_{AxS}, statistical probability of interaction of the gas mixture composition and storage; data with different superscript letters within parameter (a-c) differ significantly (P ≤ 0.05).

Instrumentally measured texture

The composition of the gas mixture in the packaging unit had no significant effect ($P = 0.397$) on the Warner-Bratzler shear force (Table 3). However, shear force significantly decreased ($P \leq 0.05$) during 9 days of storage under three of the four MA: without, low and high oxygen MA (27 %, 40 %, and 40 %, respectively). Jongberg et al. (2013) found, based on sensory evaluation of texture, that breast stored for 9 days under high oxygen MA (80 % O_2 and 20 % CO_2) was significantly less tender than breast stored without oxygen. The author's results did not agree with our results at MA of 70 % O_2 .

Instrumentally measured colour

The effects of 9-day storage period in four different atmospheres on the instrumentally measured surface colour of raw chicken breast were

observed (Table 3). The interaction of storage time and gas mixture composition had a significant effect on all measured colour values. For samples packed under MA without oxygen, after 9 days of storage, the b^* value decreased and the a^* value increased, the samples were less yellow and redder, while the L^* value did not change significantly. Under low oxygen MA, chicken breast L^* value increased and b^* value decreased during storage, samples became brighter and less yellow. The colour of the samples under medium and high oxygen MA did not change significantly after storage.

Jongberg et al. (2013) found that breast meat stored under high oxygen MA (80 % O_2 , 20 % CO_2) showed yellow discolouration, whereas this was not the case for thigh and breast meat under MA without oxygen (80 % N_2 , 20 % CO_2) and for vacuum packed samples. Penko et al. (2015) found that chicken burg-

Table 3. Effect of the atmosphere composition in the packaging unit during 9-day storage period at a temperature of 2 ± 1 °C on instrumentally measured texture and colour, as well as oxidation parameters of chicken breast muscle

Parameter (%)	Storage (day)	Value of parameter (LSM \pm SD) according the atmosphere:				Significance
		Without O_2	Low O_2	Medium O_2	High O_2	
Texture parameter (N) (n = 144)						
WBSF ^s	2	40.35 \pm 13.51 ^{ba}	38.55 \pm 14.63 ^{ba}	29.58 \pm 7.31 ^{bdc}	43.52 \pm 12.56 ^a	$P_A = 0.397$
	7	34.55 \pm 17.83 ^{bac}	38.05 \pm 15.17 ^{ba}	38.95 \pm 18.45 ^{ba}	35.93 \pm 13.05 ^{ba}	$P_S \leq 0.001$
	9	24.52 \pm 7.43 ^{dc}	23.24 \pm 7.86 ^d	31.38 \pm 10.33 ^{bdc}	31.87 \pm 7.84 ^{bdc}	$P_{A \times S} = 0.061$
Colour values (n = 144)						
L^*	2	54.33 \pm 2.82 ^{dc}	54.34 \pm 3.68 ^{dc}	55.63 \pm 3.34 ^{bc}	56.62 \pm 1.94 ^{bac}	$P_A = 0.018$
	7	56.35 \pm 3.03 ^{bac}	54.29 \pm 2.47 ^{dc}	54.78 \pm 4.21 ^{dc}	54.41 \pm 2.66 ^{dc}	$P_S = 0.171$
	9	51.98 \pm 2.29 ^d	57.62 \pm 3.35 ^{ba}	56.15 \pm 2.34 ^{bac}	58.63 \pm 5.23 ^a	$P_{A \times S} \leq 0.001$
a^*	2	1.51 \pm 1.24 ^{bc}	0.98 \pm 0.77 ^{dc}	0.92 \pm 1.32 ^{dc}	1.21 \pm 1.08 ^{bdc}	$P_A \leq 0.001$
	7	1.58 \pm 1.12 ^{bac}	0.37 \pm 0.89 ^{ed}	1.99 \pm 1.49 ^{ba}	1.90 \pm 0.98 ^{ba}	$P_S = 0.001$
	9	2.44 \pm 0.65 ^a	-0.29 \pm 0.84 ^e	0.32 \pm 0.77 ^{ed}	0.46 \pm 0.88 ^{ed}	$P_{A \times S} \leq 0.001$
b^*	2	6.52 \pm 1.68 ^c	7.29 \pm 1.15 ^{bc}	7.80 \pm 2.27 ^{bc}	8.84 \pm 1.50 ^{ba}	$P_A \leq 0.001$
	7	6.88 \pm 2.16 ^c	7.96 \pm 1.63 ^{bc}	8.03 \pm 2.64 ^{bc}	7.26 \pm 1.67 ^{bc}	$P_S = 0.383$
	9	4.43 \pm 0.88 ^d	8.72 \pm 1.72 ^{ba}	8.85 \pm 3.07 ^{ba}	10.15 \pm 1.96 ^a	$P_{A \times S} = 0.001$
Lipid oxidation parameter (mg malondialdehyde/kg) (n = 72)						
TBARs	2	0.23 \pm 0.07 ^{bcd}	0.21 \pm 0.03 ^{cd}	0.19 \pm 0.04 ^d	0.20 \pm 0.03 ^d	$P_A = 0.001$
	7	0.27 \pm 0.03 ^{bc}	0.26 \pm 0.05 ^{bc}	0.24 \pm 0.03 ^{bcd}	0.32 \pm 0.02 ^a	$P_S \leq 0.001$
	9	0.28 \pm 0.04 ^{ba}	0.22 \pm 0.05 ^{cd}	0.21 \pm 0.03 ^{cd}	0.28 \pm 0.05 ^{ba}	$P_{A \times S} = 0.109$
Protein oxidation parameter (nmol/mg protein) (n = 72)						
Protein carbonyls	2	1.99 \pm 0.17 ^{ed}	1.75 \pm 0.15 ^e	2.31 \pm 0.49 ^{ed}	3.56 \pm 0.86 ^{bc}	$P_A \leq 0.001$
	7	2.94 \pm 1.04 ^{dc}	2.55 \pm 0.89 ^{ed}	3.99 \pm 0.58 ^{ba}	2.88 \pm 1.04 ^{dc}	$P_S \leq 0.001$
	9	2.06 \pm 0.56 ^{ed}	2.88 \pm 0.85 ^{dc}	3.77 \pm 1.24 ^{bac}	4.58 \pm 1.01 ^a	$P_{A \times S} = 0.011$

Without O_2 – 0 % O_2 , 20 % CO_2 , 80 % N_2 ; Low O_2 – 20 % O_2 , 20 % CO_2 , 60 % N_2 ; Medium O_2 – 40 % O_2 , 20 % CO_2 , 40 % N_2 ; High O_2 – 70 % O_2 , 20 % CO_2 , 10 % N_2 ; n, number of observations; LSM, least square means; SD, standard deviation; P_A , statistical probability of the gas mixture composition effect; P_S , statistical probability of storage effect; $P_{A \times S}$, statistical probability of interaction of the gas mixture composition and storage; data with different superscript letters within parameter (a-d) differ significantly ($P \leq 0.05$);^s, determined after thermal treatment.

ers under air atmosphere and high-oxygen MAP (80 % O₂, 20 % CO₂) stored in the refrigerator for 11 days developed a more expressed and brighter colour, which is partially consistent with our results in terms of increasing L^* value. At low oxygen MA (< 1 % O₂) with added oxygen scavenger, the colour of burgers was pale, greyish, and less expressed (Penko et al., 2015). These results are supported by previous findings that high oxygen concentrations are required for a distinct red colour of meat because myoglobin is then in an oxygenated state (Luño et al., 1998; Belcher, 2006).

Thomas et al. (2020) found that chicken meat samples stored under 100 % N₂ MA became darker and redder after 7 days due to a decrease in L^* and an increase in a^* values, which is partially (a^* value) consistent with results for samples under MA without oxygen. Meat samples under MA (75 % O₂ and 25 % CO₂) became yellower (increase in b^* value) after 7 days of storage (Thomas et al., 2020), which is not consistent with the results of this experiment. Orkusz et al. (2017) found similar for goose meat stored 11 days under MA (80 % O₂, 20 % CO₂), where an increase in L^* and b^* and a decrease in a^* value were observed, while colour values did not change for meat stored under vacuum. Goose meat stored under vacuum was darker than meat stored under MA conditions, because the O₂ concentration was higher, so more O₂ was available for myoglobin to oxygenate and therefore the meat had brighter colour (Orkusz et al., 2017).

However, Chouliara et al. (2007), Patsias et al. (2008), and Latou et al. (2014) found that storage of chicken meat under the conditions of MA had no statistical effect on all colour values. Changes in a^* values are generally more characteristic of red meat than white meat, which includes chicken meat (Latou et al., 2014). In their study of beef steaks, Zakrys et al. (2008) found that a^* values decreased during storage of steaks in the light, meaning that the red colour was less intense over time, and on the other hand, the brightness (L^* value) increased.

Thiobarbituric acid reactive substances

The effects of the atmosphere composition in the packaging unit and 9-day storage period on thiobarbituric acid reactive substances (TBARs) of raw chicken breast muscle were significant (Table 3). The highest TBARs were determined for breast samples stored under high and without oxygen MA after 7 and 9 days of storage, respectively, the lowest

for breast samples from all modified atmosphere groups after 2 days post mortem, and for samples stored under medium and low oxygen MA after 9 days of storage. Significant increase in TBARs can be observed only under high oxygen MA after 7 days of storage. Significantly less (21 %) secondary products of lipid oxidation (0.22-0.21 mg malondialdehyde (MDA)/kg) were formed in the samples under low and medium MA after 9 days of storage than under without and high-oxygen MA (0.28 mg MDA/kg). An increase in TBARs means a higher degree of oxidation, but not always noticeable changes in sensory properties. An appropriate TBARs value is up to 0.70 mg MDA/kg, and a TBARs value above 1 mg MDA/kg predicts sensory perceived rancidity (Nam in Ahn, 2003; Penko et al., 2015). In this experiment, TBARs values did not exceed 0.70 mg MDA/kg.

Demirhan and Candoğan (2017) found that TBARs values of chicken thighs increased during storage under the following atmospheres: air > MA 70 % CO₂ and 30 % N₂ > MA 70 % CO₂ and 30 % N₂ + oxygen scavenger, but did not exceed the threshold value for rancidity. Oxidation of thigh meat lipids occurred to a lesser extent, probably due to the low oxygen concentration in the packaging units (Jeun-Horng et al., 2002) and storage of the samples in the dark. In a study by Chmiel et al. (2019), TBARs values for breast meat were highest under high oxygen MA (75 % O₂, 25 % CO₂) and lowest under vacuum because high oxygen concentrations in MA, light exposure and light-induced larger temperature fluctuations accelerated oxidation processes (Rogers et al., 2014; Penko et al., 2015). Orkusz et al. (2017) found higher TBARs values in goose meat samples stored under high oxygen MA (80 % O₂ and 20 % CO₂) than when stored under vacuum.

Protein carbonyls

The effects of the atmosphere composition in the packaging unit, 9 days of storage and their interaction on the protein carbonyl content in raw chicken breast were significant (Table 3). On the day 2 after slaughter, significantly higher protein carbonyl content was determined in the samples stored under highest oxygen MA than in the samples stored under medium, low or without oxygen. Carbonyl content in chicken breast under modified atmosphere increased with increasing storage time, except for MA without oxygen, where it remained unchanged for 9 days. Breast meat stored under medium oxygen MA for 7 days and under low and high oxygen MA

for 9 days showed a significant increase (72 %, 65, and 27 %, respectively) in protein carbonyl content. Therefore, the highest protein carbonyl content was observed in breast samples under high oxygen MA after 9 days of storage and under medium oxygen MA after 7 and 9 days of storage, respectively.

Protein and lipid oxidation increased after 9 days of storage for both breast and thigh meat packed under high oxygen MA (80 % O₂, 20 % CO₂), but this increase was greater in thigh than in breast meat, indicating lower oxidative stability of chicken thighs. Breast and thigh meat packed under MA without oxygen or vacuum were almost completely protected from oxidation during 9 days of storage (Jongberg et al., 2013). Higher concentrations of O₂ in the packaging atmosphere also resulted in greater oxidation of proteins during storage of beef steaks (Zakrys et al., 2008). This is consistent with the results of this study, as maximum protein carbonyl levels were determined under medium and high oxygen MA. Increased protein carbonyl levels in air-packed chicken thighs, under high oxygen MA (70 % CO₂ and 30 % N₂) and under MA with oxygen scavengers were also found by Demirhan and Candoğan (2017). It is obvious that MAP and the application of oxygen scavenger could successfully delay oxidation of chicken thigh meat proteins considering the low carbonyl content of the samples during storage (less than 2 nmol/mg protein).

Sensory properties

Table 4 shows the professional panel data for sensory analysis of the thermally treated chicken breast samples with respect to the composition of the atmosphere in the packaging unit after storage at a temperature of 2 ± 1 °C. The data show that the composition of the gas mixture affected the sensory properties: oxidation of colour and odd aromas were most expressed in meat stored under oxygen MA (low, medium, and high), stale odours and aromas were most expressed at MA without oxygen. However, during the 9-day storage period, some sensory properties of the meat changed. Rate of colour oxidation increased (most noticeable under low and medium oxygen MA, least noticeable under without oxygen MA), odour and aroma of stale became more expressed under without oxygen and under high oxygen MA.

Before storage, the odd odours on the breast meat were more expressed under an oxygen-free than under an oxygen-containing MA, but by the

9 day of storage they had decreased significantly. Rancidity during the 9-day storage period was not noted by the testers in any of the samples. More than rancidity and stale aroma, the testers noticed distinct odd aromas, after 7 days of storage under low and high oxygen MA. After the 9 day of storage, odd aromas were similar in all atmospheres (the differences are not significant). The testers associated odd odours and odd aromas detected after 7 days of storage under low oxygen MA with the descriptor of the odour and aroma of the soup.

Based on sensory evaluation, oxygen was found to have no positive effect on the colour of poultry meat (Rossaint et al., 2015). This is likely due to the fact that poultry meat has a lower myoglobin content, and thus the ability to form oxymyoglobin than beef or pork (Millar et al., 1994). In addition to packaging conditions, the colour of poultry meat is influenced by several factors such as sex, age, water content, pre-slaughter conditions, and processing (Faustman and Cassens, 1990).

In their study, Penko et al. (2015) compared the instrumentally measured colour of raw chicken patties with a sensory evaluation of colour oxidation. It was confirmed that the patties packed under high oxygen MA were brighter and more expressed in colour, while patties packed under low oxygen MA were described as greyish. The rancid odour and aroma were also more expressed in the patties packaged under high oxygen MA, which was to be expected since the highest TBARs levels were also detected in these patties. In contrast, Jongberg et al. (2013) could not confirm any correlation between TBARs and sensory analysis of rancid odour. Higher TBARs values were found for thighs packed under high oxygen MA (80 % O₂, 20 % CO₂), while a higher expression of rancid odour was found for packed breast. The breasts have a less expressed natural odour than the thighs, so the rancid odour was more expressed in the breast, while the rancid odour remained masked in the thighs (Jongberg et al., 2013).

Conclusion

Producers of meat and meat preparations are often faced with a task that seems simple at first glance, but often turns out to be not so simple. Poultry can become discoloured under a low oxygen modified atmosphere, and under a high oxygen modified atmosphere it becomes odour-tainted, rancid, or stale

Table 4. Sensory attributes of thermally treated chicken breast samples regarding the composition of the atmosphere in the packaging unit during 9 days storage period at a temperature of 2 ± 1 °C evaluated by descriptive analysis with professional panel.

Sensory attribute (0-4) (n = 180)	Storage (day)	Value of parameter (LSM \pm SD) according the atmosphere:				Significance
		Without O ₂	Low O ₂	Medium O ₂	High O ₂	
Rate of colour oxidation [§]	2	0.0 \pm 0.0 ^d	0.0 \pm 0.0 ^d	0.0 \pm 0.0 ^d	0.0 \pm 0.0 ^d	P _A = 0.003
	7	0.0 \pm 0.0 ^d	0.0 \pm 0.0 ^d	0.0 \pm 0.0 ^d	0.0 \pm 0.0 ^d	P _S \leq 0.001
	9	0.8 \pm 0.4 ^c	1.6 \pm 0.6 ^a	1.4 \pm 0.6 ^{ba}	1.3 \pm 0.7 ^b	P _{AxS} \leq 0.001
Odour of stale	2	0.1 \pm 0.3 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	P _A = 0.002
	7	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	P _S \leq 0.001
	9	0.8 \pm 0.9 ^a	0.3 \pm 0.6 ^b	0.1 \pm 0.3 ^b	0.1 \pm 0.4 ^b	P _{AxS} = 0.001
Odd odours	2	2.8 \pm 0.6 ^a	1.2 \pm 0.8 ^c	1.0 \pm 0.8 ^{dce}	0.1 \pm 0.3 ^b	P _A \leq 0.001
	7	0.7 \pm 1.1 ^{dfce}	1.9 \pm 0.6 ^b	1.1 \pm 0.5 ^{dce}	1.1 \pm 0.6 ^{dc}	P _S \leq 0.001
	9	0.5 \pm 0.5 ^{fge}	0.8 \pm 0.7 ^{dfce}	0.6 \pm 0.6 ^{dfge}	0.4 \pm 0.5 ^{fg}	P _{AxS} \leq 0.001
Aroma of stale	2	0.0 \pm 0.0 ^c	0.1 \pm 0.3 ^c	0.1 \pm 0.4 ^c	0.0 \pm 0.0 ^c	P _A = 0.081
	7	0.1 \pm 0.3 ^c	0.0 \pm 0.0 ^c	0.0 \pm 0.0 ^c	0.0 \pm 0.0 ^c	P _S \leq 0.001
	9	0.6 \pm 0.6 ^a	0.2 \pm 0.4 ^{bc}	0.1 \pm 0.3 ^c	0.4 \pm 0.5 ^{ba}	P _{AxS} = 0.002
Rancidity	2	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	P _A = 0.562
	7	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	0.0 \pm 0.0 ^b	P _S = 0.018
	9	0.1 \pm 0.4 ^a	0.1 \pm 0.3 ^{ba}	0.0 \pm 0.0 ^b	0.1 \pm 0.3 ^{ba}	P _{AxS} = 0.662
Odd aroma	2	0.0 \pm 0.0 ^d	0.7 \pm 0.8 ^b	0.6 \pm 0.8 ^{cb}	0.1 \pm 0.5 ^{cd}	P _A \leq 0.001
	7	0.6 \pm 0.9 ^{cb}	1.5 \pm 0.6 ^a	0.9 \pm 0.6 ^b	1.4 \pm 0.7 ^a	P _S \leq 0.001
	9	0.6 \pm 0.5 ^{cb}	1.0 \pm 0.6 ^b	0.5 \pm 0.5 ^{cbd}	0.5 \pm 0.5 ^{cbd}	P _{AxS} = 0.01

Without O₂ – 0 % O₂, 20 % CO₂, 80 % N₂; Low O₂ – 20 % O₂, 20 % CO₂, 60 % N₂; Medium O₂ – 40 % O₂, 20 % CO₂, 40 % N₂; High O₂ – 70 % O₂, 20 % CO₂, 10 % N₂; n, number of observations; LSM, least square means; SD, standard deviation; P_A, statistical probability of the gas mixture composition effect; P_S, statistical probability of storage effect; P_{AxS}, statistical probability of interaction of the gas mixture composition and storage; data with different superscript letters within parameter (a-i) differ significantly (P \leq 0.05);[§], evaluated on raw samples.

and rancid in aroma after a period of storage under refrigerated conditions. Therefore, producers must find a compromising atmosphere composition in the packaging unit that maintains the acceptable colour of the meat while minimising the extent of oxidation processes.

Based on the results of our experiment, we can say that a modified atmosphere with high oxygen content (70 % O₂, 20 % CO₂, 10 % N₂) is the least suitable for packaging chicken breast, because due to the high oxygen concentration, the oxidation of lipids and proteins was the greatest. As for colour acceptance, chicken breast contains very little myoglobin, so the bright red or pink colour produced by myoglobin at high oxygen concentrations is not such an important parameter that would significantly influence consumer purchase. For these reasons, it is better to use a modified atmosphere with low or without oxygen to pack chicken, especially breast. In addition, it was found that storing chicken meat under low-oxygen modified atmosphere (20 % O₂, 20 % CO₂, 60 % N₂),

which is the first choice in the meat industry, is not suitable because the rate of colour oxidation is the highest. A modified atmosphere without oxygen would probably be the best choice, since protein and colour oxidation were minimal in the breast stored in this way. Although the determined TBARs values after 9 days of storage under modified atmosphere without oxygen were as high as under high oxygen MA (0.28 mg MDA/kg) and still below the sensory threshold for rancidity (1 mg MDA/kg), so lipid oxidation would be minimised and sensory properties would not be affected.

Acknowledgements: The authors gratefully acknowledge the company Pivka Perutninarstvo, d. d. and the Slovenian Research Agency (P4-0234, Integrated food technology and nutrition) for the financial support.

*This article is part of a MSc. thesis named Oxidative stability of chicken meat at different oxygen concentrations in the packaging unit, issued by Eva Golob.

References

- [1] Al-Nehlawi, A., J. Saldo, L.F. Vega, S. Guri (2013): Effect of high carbon dioxide atmosphere packaging and soluble gas stabilization pre-treatment on the shelf-life and quality of chicken drumsticks. *Meat Science* 94, 1-8. doi: 10.1016/j.meatsci.2012.12.008
- [2] Belcher, J.N. (2006): Industrial packaging developments for the global meat market. *Meat Science* 74, 143-148. doi: 10.1016/j.meatsci.2006.04.031
- [3] Brenes, A., E. Roura (2010): Essential oils in poultry nutrition: Main effects and modes of action. *Animal Feed Science and Technology* 158, 1-14. doi: 10.1016/j.anifeeds.2010.03.007
- [4] Chmiel, M., M. Roszko, L. Adamczak, T. Florowski, D. Pietrzak (2019): Influence of storage and packaging method on chicken breast meat chemical composition and fat oxidation. *Poultry Science* 98, 2679-2690. doi: 10.3382/ps/pez029
- [5] Chouliara, E., A. Karatapanis, I.N. Savvaidis, M.G. Kontominas (2007): Combined effect of oregano essential oil and modified atmosphere packaging on shelf-life extension of fresh chicken breast meat, stored at 4 °C. *Food Microbiology* 24, 607-617. doi: 10.1016/j.fm.2006.12.005
- [6] Cortinas, L., C. Villaverde, J. Galobart, M.D. Baucells, R. Codoni, A.C. Barroeta (2004): Fatty acid content in chicken thigh and breast as affected by dietary polyunsaturation level. *Poultry Science*, 83: 1155-1164. doi: 10.1093/ps/83.7.1155
- [7] Demirhan, B., K. Candoğan (2017): Active packaging of chicken meats with modified atmosphere including oxygen scavengers. *Poultry Science* 96, 1394-1401. doi: 10.3382/ps/pew373
- [8] Faustman, C., R.G. Cassens (1990): The biochemical basis for discoloration in fresh meat: a review. *Journal of Muscle Foods* 1, 217-243. doi: 10.1111/j.1745-4573.1990.tb00366.x
- [9] Gill, C.O., N. Penney (1988): The effect of the initial gas volume to meat weight ratio on the storage shelf life of chilled beef packaged under carbon-dioxide. *Meat Science* 22, 53-63. doi: 10.1016/0309-1740(88)90026-5
- [10] Golob, T., M. Jamnik, J. Bertonec, U. Doberšek (2005): Sensory analysis: methods and assessors. *Acta Agriculturae Slovenica* 85, 55-66. <http://aas.bf.uni-lj.si/index-en.htm>. ISSN: 1581-9175
- [11] Golob, T., V. Stibilj, B. Žlender, U. Doberšek, M. Jamnik, T. Polak, J. Salobir, M. Čandek-Potokar (2006): Slovenian nutrition tables. Meat and meat products. Ljubljana: Biotechnical Faculty, Department of Food Science: 84-85 p.
- [12] ISO 3100-1 (1991): Meat and meat products – Sampling and preparation of test samples – Part 1: Sampling.
- [13] ISO 8589 (2007): Sensory analysis - General guidance for the design of test rooms: International Organization for Standardization: 16 pp.
- [14] ISO 8586 (2012): Specifies criteria for the selection and procedures for the training and monitoring of selected assessors and expert sensory assessors: International Organization for Standardization: 28 pp.
- [15] Jeun-Horng, L., L. Yaun-Hui, K. Chun-Chin (2002): Effect of dietary fish oil on fatty acid composition, lipid oxidation and sensory property of chicken frankfurters during storage. *Meat Science* 60, 161-167. doi: 10.1016/S0309-1740(01)00118-8
- [16] Jongberg, S., J. Wen, M.A. Tørngren, M.N. Lund (2013): Effect of high-oxygen atmosphere packaging on oxidative stability and sensory quality of two chicken muscles during chill storage. *Food Packaging and Shelf Life* 1, 38-48. doi: 10.1016/j.fpsl.2013.10.004
- [17] Latou, E., S.F. Mexis, A.V. Badeka, S. Kontakos, M.G. Kontominas (2014): Combined effect of chitosan and modified atmosphere packaging for shelf-life extension of chicken breast fillets. *Journal of Food Science and Technology* 55, 263-268. doi: 10.1016/j.lwt.2013.09.010
- [18] Luño, M., J.A. Bletrán, P. Roncalés (1998): Shelf-life extension and colour stabilization of beef packaged in a low O₂ atmosphere containing CO. *Meat Science* 48, 75-84. doi: 10.1016/S0309-1740(97)00078-8
- [19] Millar, S., R. Wilson, B.W. Moss, D.A. Ledward (1994): Oxymyoglobin formation in meat and poultry. *Meat Science* 36, 397-406. doi: 10.1016/0309-1740(94)90135-X
- [20] Nam, K.C., D.U. Ahn (2003): Double-packaging is effective in reducing lipid oxidation and off-odor volatiles of irradiated raw turkey meat. *Poultry Science* 82, 1468-1474. doi: 10.1093/ps/82.9.1468
- [21] Orkusz, A., G. Haraf, A. Okruszek, M. Wereska-Sudnik (2017): Lipid oxidation and colour changes of goose meat stored under vacuum and modified atmosphere conditions. *Poultry Science* 96, 731-737. doi: 10.3382/ps/pew325
- [22] Patsias, A., A.V. Badeka, I.N. Savvaidis, M.G. Kontominas (2008): Combined effect of freeze chilling and MAP on quality parameters of raw chicken fillets. *Food Microbiology* 25, 575-581. doi: 10.1016/j.fm.2008.02.008
- [23] Patsias, A., I. Chouliara, A. Badeka, I.N. Savvaidis, M.G. Kontominas (2006): Shelf-life of a chilled precooked chicken product stored in air and under modified atmospheres: microbiological, chemical, sensory attributes. *Food Microbiology* 23, 423-429. doi: 10.1016/j.fm.2005.08.004
- [24] Penko, A. (2015): The effect of plant extracts on heterocyclic aromatic amines and cholesterol oxides reduction in thermally treated chicken meat. Doctoral dissertation, Ljubljana, Biotechnical Faculty, Department of Food Technology: 135 p.
- [25] Penko, A., T. Polak, M. Lušnic Polak, T. Požrl, D. Kakovič, B. Žlender, L. Demšar (2015): Oxidative stability of n-3-enriched chicken patties under different package-atmosphere conditions. *Food Chemistry* 168, 372-382. doi: 10.1016/j.foodchem.2014.07.075
- [26] Rogers, H.B., C.J. Brooks, J.N. Martin, A. Tittor, M.F. Miller, M.M. Brashears (2014): The impact of packaging system and temperature abuse on the shelf life characteristics of ground beef. *Meat Science* 97, 1-10. doi: 10.1016/j.meatsci.2013.11.020
- [27] Rossaint, S., S. Klausmann, U. Herbert, J. Kreyenschmidt (2014): Effect of package perforation on the spoilage process of poultry stored under different modified atmospheres. *Food Packaging and Shelf Life* 1, 68-76. doi: 10.1016/j.fpsl.2014.01.002
- [28] Rossaint, S., S. Klausmann, J. Kreyenschmidt (2015): Effect of high-oxygen and oxygen-free modified atmosphere packaging on the spoilage process of poultry breast fillets. *Poultry Science* 94, 93-103. doi: 10.3382/ps/peu001
- [29] Rotar, A. (2019): Development and application of an analytical method for determining the content of protein carbonyls in chicken meat. M. Sc. Thesis, Ljubljana, Biotechnical Faculty, Department of Food Technology: 20-23 p.
- [30] Soglia, F., M. Petracci, P. Ertbjerg (2016): Novel DNPH-based method for determination of protein carbonylation in muscle and meat. *Food Chemistry* 197, 670-675. doi: 10.1016/j.foodchem.2015.11.038
- [31] Thomas, C., A. Martin, J. Sachsenröder, N. Bandick (2020): Effects of modified atmosphere packaging on an extended-spectrum beta-lactamase-producing *Escherichia coli*, the microflora, and shelf life of chicken meat. *Poultry Science* 99, 7004-7014. doi: 10.1016/j.psj.2020.09.021
- [32] Tománková, J., G. Bořilová, I. Steinhäuserová, L. Gallas (2012): Volatile organic compounds as biomarkers of the freshness of poultry meat packaged in modified atmosphere. *Czech Journal of Food Science* 5, 395-403. doi: 10.17221/408/2011-CJFS

- [33] Xiao, S., W.G. Zhang, E.J. Lee, C.W. Ma, D.U. Ahn (2011): Effects of diet, packaging, and irradiation on protein oxidation, lipid oxidation, and color of raw broiler thigh meat during refrigerated storage. *Poultry Science* 90, 1348-1357. Quality parameters and oxidative stability doi: 10.3382/ps.2010-01244
- [34] Zahija I., T. Polak, M. Lušnic Polak, M., L. Demšar (2020): Quality parameters and oxidative stability of lamb during ageing. *Meso* 22, 357-365. dpo: 10.31727/m
- [35] Zakrys, P.I., S.A. Hogan, M.G. O` Sullivan, P. Allen, J.P. Kerry (2008): Effects of oxygen concentration on the sensory evaluation and quality indicators of beef muscle packed under modified atmosphere. *Meat Science* 79: 648-655. doi: 10.1016/j.meatsci.2007.10.030
- [36] Zhang, X., H. Wang, N. Li, M. Li, X. Xu (2015): High CO₂-modified atmosphere packaging for extension of shelf-life of chilled yellow-feather broiler meat: A special breed in Asia. *LWT - Food Science and Technology* 64, 1123-1129. doi: 10.1016/j.lwt.2015.07.039

Delivered: 21.04.2022.

Accepted: 15.05.2022.

Oksidativna stabilnost pilećeg mesa pri različitim koncentracijama kisika u jedinici pakiranja

Sažetak

Cilj ovog istraživanja bio je sačuvati kvalitetu i spriječiti oksidaciju boje, lipida i proteina u filetima pilećih prsa (mišić pectoralis major) tijekom skladištenja. U tu svrhu korištene su modificirane atmosfere (MA) s četiri različite mješavine plinova (vol. %) i to kisika (O₂), ugljikovog dioksida (CO₂) i dušika (N₂). MA su bile: bez kisika (0: 20: 80), s niskim sadržajem kisika (20: 20: 60), sa srednjim sadržajem kisika (40: 20: 40) i atmosfera s visokim sadržajem kisika (70: 20: 10). Nakon 9 dana skladištenja u hladnjači pri 2 ± 1 °C izmjeren je pH, boja je ocijenjena instrumentalno i senzorski te su utvrđeni osnovni kemijski sastav, reaktivne tvari tiobarbiturne kiseline (TBAR) i proteinsko-karbonilni sadržaj sirovih pilećih prsa. Nakon termičkog tretmana (82 °C, 1 sat, sous-vide) pilećeg fileta ocijenjene su senzorne karakteristike mirisa i arome, a tekstura je izmjerena instrumentalno (Warner-Bratzler rezivim sječivom). Sastav smjese plinova utjecao je na sve parametre zavisne o oksidaciji: (i) boja: L* and b* vrijednosti bile su najviše pod svim MA s kisikom, s a* vrijednost pod MA bez kisika, sa srednjim i visokim sadržajem kisika, (ii) lipidi: TBAR su se znatno povećale pod MA s visokim sadržajem kisika nakon 7 dana skladištenja (ispod senzornih graničnih vrijednosti užeglosti), (iii) proteini: proteinsko-karbonilni sadržaj bio je najviši pod MA sa srednjim i visokim sadržajem kisika, i (iv) senzorne karakteristike: povećana je oksidacija boje i intenzitet neobičnih aroma pod svima MA s kisikom, kao i miris i aroma ustajalog pod MA bez kisika. Za pileća prsa najprikladnije je pakiranje s modificiranom atmosferom bez kisika jer je brzina oksidacije boje, lipida i proteina tijekom skladištenja bila najniža.

Ključne riječi: pileće meso, skladištenje, sastav plina, produkti oksidacije lipida, proteinski karbonili

Oxidationsstabilität Hühnerfleisch bei Unterschiedlichen Sauerstoffkonzentrationen in der Verpackungseinheit

Zusammenfassung

Ziel dieser Studie war es, die Qualität zu erhalten und die Oxidation von Farbe, Lipiden und Proteinen in Hähnchenbrustfilet (Musculus pectoralis major) während der Lagerung zu verhindern. Zu diesem Zweck wurden modifizierte Atmosphären (MA) mit vier verschiedenen Gasmischungen (Vol.-%)

aus Sauerstoff (O₂), Kohlendioxid (CO₂) und Stickstoff (N₂) verwendet: sauerstofffrei (0: 20: 80), niedrig (20: 20: 60), mittel (40: 20: 40) und hoch sauerstoffhaltig (70: 20: 10). Nach einer 9-tägigen Lagerung im Kühlschrank bei 2 ± 1 °C wurden der pH-Wert gemessen, die Farbe instrumentell und sensorisch bewertet sowie die chemische Grundzusammensetzung, die reaktiven Substanzen der Thiobarbitursäure (TBAR) und der Proteincarbonylgehalt der rohen Hühnerbrust bestimmt. Nach der thermischen Behandlung (82 °C, 1 Stunde, sous-vide) des Brustfilets wurden die sensorischen Merkmale Geruch und Aroma bewertet und die Textur (Warner-Bratzler-Scherklinge) instrumentell gemessen. Die Zusammensetzung des Gasgemisches beeinflusste alle oxidationsabhängigen Parameter: (i) Farbe: L* und b*-Werte waren bei allen MA mit Sauerstoff am höchsten und der a*-Wert bei MA ohne Sauerstoffgehalt, bei mittlerem und hohem Sauerstoffgehalt, (ii) Lipide: die TBARs stiegen bei MA mit hohem Sauerstoffgehalt nach 7 Tagen Lagerung signifikant an (unterhalb des sensorischen Schwellenwerts für Ranzigkeit), (iii) Proteine: der Proteincarbonylgehalt war bei MA mit mittlerem und hohem Sauerstoffgehalt am höchsten und (iv) sensorische Eigenschaften: die Oxidation der Farbe und die Intensität der ungeraden Aromen bei allen MA mit Sauerstoff sowie der Geruch und das Aroma von abgestandenem Fleisch bei sauerstofffreier MA waren erhöht. Für Hähnchenbrust ist die Verpackung unter modifizierter Atmosphäre ohne O₂ am besten geeignet, da die Oxidationsrate von Farbe, Lipiden und Proteinen während der Lagerung am geringsten war.

Schlüsselwörter: Hähnchenfleisch, Lagerung, Gaszusammensetzung, Lipid-Oxidationsprodukte, Protein-Carbonyls

Estabilidad oxidativa de la carne de pollo a diferentes concentraciones de oxígeno en la unidad de envase

Resumen

El fin de este estudio fue preservar la calidad y prevenir la oxidación del color, de los lípidos y proteínas en los filetes de la pechuga de pollo (el músculo pectoralis mayor) durante el almacenamiento. Para ello fueron utilizadas las atmósferas modificadas (AM) con cuatro mezclas diferentes de gases (vol %), a saber, el oxígeno (O₂), el dióxido de carbono (CO₂) y el nitrógeno (N₂). Las AM fueron: la atmósfera libre de oxígeno (0: 20: 80), la AM baja en oxígeno (20: 20: 60), la AM media en oxígeno (40: 20: 40) y la AM alta en oxígeno (70: 20: 10). Después de 9 días de almacenamiento en frío a 2 ± 1 °C, fue medido el pH, evaluado el color de forma instrumental y sensorial y fueron determinados la composición química básica, las sustancias reactivas al ácido tiobarbitúrico (TBAR) y el contenido de proteína-carbonilo de la pechuga de pollo cruda. Luego del tratamiento térmico (82 °C, 1 hora, sous-vide) del filete de pollo, fueron evaluadas las características sensoriales de olor y aroma, y fue medida la textura de manera instrumental (corte tipo Warner-Bratzler). La composición de la mezcla de gases afectó todos los parámetros dependientes de la oxidación: (i) color: los valores L* y b* fueron los más altos en todos los AM con oxígeno, con un valor a* en AM sin oxígeno, con contenido de oxígeno medio y alto, (ii) lípidos: los TBAR aumentaron significativamente bajo MA con alto contenido de oxígeno después de 7 días de almacenamiento (por debajo de los valores límite sensoriales), (iii) proteínas: el contenido de proteína-carbonilo fue más alto bajo AM con contenido de oxígeno medio y alto, y (iv) características sensoriales: mayor oxidación del color e intensidad de aromas inusuales bajo todos los AM con oxígeno, así como el olor y el aroma rancio bajo AM sin oxígeno. Para las pechugas de pollo, el envasado con una atmósfera libre de oxígeno modificado es más apropiado porque la tasa de oxidación del color, los lípidos y las proteínas durante el almacenamiento fue la más baja.

Palabras claves: carne de pollo, almacenamiento, composición de gases, productos de oxidación de lípidos, carbonilos de proteínas

Stabilità ossidativa della carne di pollo a diverse concentrazioni di ossigeno nell'unità di confezionamento

Riassunto

Lo scopo di questo studio consisteva nel preservare la qualità e prevenire l'ossidazione del colore, dei lipidi e delle proteine nei filetti di petto di pollo (muscolo grande pettorale) durante la conservazione. A tale scopo sono state utilizzate atmosfere modificate (MA) con quattro diverse miscele di gas (vol. %) a base di ossigeno (O_2), anidride carbonica (CO_2) e azoto (N_2). Sono state utilizzate le seguenti MA: senza ossigeno (0: 20: 80), a bassa (20: 20: 60), media (40: 20: 40) e alta concentrazione di ossigeno (70: 20: 10). Dopo 9 giorni di conservazione in frigorifero a 2 ± 1 °C, è stato misurato il pH, il colore è stato valutato strumentalmente e sensorialmente, sono state determinate la composizione chimica di base, le sostanze reattive all'acido tiobarbiturico (TBAR) e il contenuto di carbonile proteico del petto di pollo crudo. Dopo il trattamento termico (82 °C, 1 ora, sottovuoto) dei filetti di petto di pollo, sono state valutate le caratteristiche sensoriali di odore e aroma, mentre la consistenza è stata misurata strumentalmente (con dispositivo Warner-Bratzler). La composizione della miscela di gas ha influenzato tutti i parametri dipendenti dall'ossidazione: (i) colore: i valori L^* e b^* erano i più alti in tutti gli MA con ossigeno e il valore a^* in MA senza O_2 e con ossigeno medio e alto, (ii) lipidi: i TBAR sono aumentati significativamente con MA ad alto contenuto di ossigeno dopo 7 giorni di conservazione (al di sotto del valore delle soglie sensoriali per l'irrancidimento), (iii) proteine: il contenuto di carbonile proteico è risultato il più alto con MA con ossigeno medio e alto e (iv) le proprietà sensoriali: l'ossidazione del colore e l'intensità degli aromi insoliti sono aumentate in tutte le MA con ossigeno, così come l'odore e l'aroma di stantio nelle MA senza ossigeno. Per il petto di pollo, il confezionamento più indicato sembra essere quello in atmosfera modificata senza ossigeno, perché il tasso di ossidazione del colore, dei lipidi e delle proteine durante la conservazione è risultato il più basso.

Parole chiave: carne di pollo, stoccaggio, composizione del gas, prodotti di ossidazione dei lipidi, carbonili proteici