Time evolution of microbiological quality and content of volatile compounds in chicken fillets packed using various techniques and stored under different conditions

M. Chmiel,[*,1] M. Roszko,[†] E. Hać-Szymańczuk,[‡] L. Adamczak,[*] T. Florowski,[*] D. Pietrzak,[*] A. Cegiełka,[*] and M. Bryła[†]

*Division of Meat Technology, Department of Food Technology and Food Evaluation, Warsaw University of Life Sciences - SGGW, Warsaw, Poland; [†]Department of Food Analysis, Institute of Agricultural and Food Biotechnology, Warsaw, Poland; and [‡]Department of Food Biotechnology and Food Microbiology, Warsaw University of Life Sciences - SGGW, Poland

ABSTRACT The aim of this study was to evaluate dependence of microbiological quality of chicken fillets and profile of volatile compounds in their packages on the applied packaging technique and storage conditions. Samples packaged in either normal atmosphere (AP, air packaging, PVC overwrap), in modified atmosphere with high oxygen content (**Hi-O_2-MAP**), or in vacuum (**VP**) were stored in a cold room or exposed in a display case for 8 days. Quality of the meat was determined on day 1, 3, 6, 7, and 8 of the storage or exposition time. The microbiological quality of chicken fillets was assessed by determining the number of mesophilic aerobic bacteria, lactic acid bacteria, *Pseudomonas* spp. bacteria, and *Enterobacteriaceae* family bacteria. The profile of volatile compounds in the packaging of chicken fillets was also determined. At the beginning of the storage, bacteria of all major groups were growing at similar rates regardless of the used packaging technique. However, at the end of the period, the growth dynamic was diversified. The profile of the volatile compounds did not depend on the storage or exposition time regardless of the storage conditions and/or the packaging technique. The results of this study indicate that there is a potential to gain understanding of spoilage of packed chicken meat through the analysis of volatile compounds in association with microbiological analysis. However, future research should be based on standardized material with similar bacterial load.

Key words: chicken breast fillets, microbiological quality, packaging techniques, volatile compounds

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INTRODUCTION

Major challenges currently faced by the meat industry include to ensure food safety, to keep up with ever-growing requirements concerning food quality, and to extend food product shelf-life (Tománková et al., 2012). Fresh poultry meat (including chicken breasts) is a highly perishable product. Its storage time is short because meat quality quickly deteriorates mainly because of bacterial growth, activity of tissue as well as exogenous enzymes, and oxidation of lipids and heme pigments (Balamatsia et al., 2007; Mantilla et al., 2012; Wang et al., 2017). Therefore, an appropriate choice of meat packaging technique plays a crucial role in extension of meat shelf-life (Byrd et al., 2011; Cortez-Vega et al., 2012). Styrofoam trays wrapped in stretch films (air packaging, **AP/PVC** overwrap), modified atmosphere with high oxygen content (**Hi-O_2-MAP**) as individual/unit packages or masterpacks, and vacuum (**VP**) are most commonly used packaging techniques in meat industry (Latou et al., 2014; McMillin, 2017). The packaging technique determines such qualities of a culinary meat as its color, tenderness, microbiological quality, and sensory characteristics (Droval et al., 2012). Meat product shelf-life is determined by several factors including initial meat quality and microbiological contamination, packaging type, composition of gas mixture under which the meat was MAP-packed, and cold supply chain assurance (Fraqueza et al., 2008; Säde et al., 2013; Latou et al., 2014). Chicken meat quality deterioration rate may also depend on conditions in which it is stored, in cold rooms in meat plants and/or exposed in display

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[1]Corresponding author: marta_chmiel@sggw.pl

cases in supermarkets, especially at fluctuations of direct/artificial light and temperature (Arvanitoyannis and Stratakos, 2012; Rogers et al., 2014). Chemical changes and growth of specific groups of microorganisms in meat can be controlled to various extent by the selected packaging type. According to Jääskeläinen et al. (2016), temperature and packaging atmosphere are the most important extrinsic factors determining growth of microorganisms. Combination of refrigeration with the MAP or VP packaging technique favors growth of *Pseudomonas* spp., *Enterobacteriaceae*, *Brochothrix thermosphacta*, and/or lactic acid bacteria (**LAB**).

Practically meat freshness is determined on the basis of its sensory parameters, for example, off-odors and discoloration (Nychas et al., 2008). Changes in aroma profile usually occur before changes in product's appearance, that is, discoloration and/or sliminess (Ayseli et al., 2014; Wojnowski et al., 2017). However, neither clear early signs of meat spoilage have been generally agreed for, nor the sensorial meat evaluation method is an objective one. Therefore, other methods capable to determine meat spoilage more objectively would be useful. Chemical reactions running in meat and growing microflora are producing a number of volatile compounds (Balamatsia et al., 2007; Tománková et al., 2012). Some of them are formed through lipid and protein oxidation (Lovestead and Bruno, 2010). Analysis of such volatile compounds may provide important information not only on sensory but also on hygienic quality of the packed meat. Also, Tait et al. (2014) and Jääskeläinen et al. (2016) pointed out that qualitative assessment of volatile compounds produced during storage of MAP-packed meat might be used to analyze meat microbiome. Literature data on volatiles formed in chicken breasts packaged using various techniques and stored under different conditions are limited.

The aims of this study included: 1) to determine microflora growing for 8 days in differently packaged chicken fillets stored in a cold room or exposed in a display case; 2) to determine profile of volatile compounds produced in the fillets during the storage/exposition; 3) to compile the results to assess time evolution of the fillet quality during the storage/exposition period.

MATERIALS AND METHODS

Research Material and Sampling Procedure

Skinless, boneless fillets (*Pectoralis major* muscles) from intensively-bred chickens were studied. Three meat batches for 3 replications of the experiment were obtained on different slaughter days. The fillets were packaged under regular industrial conditions using 3 different packaging techniques: air packaging (**AP**) also known as PVC overwrap, high-oxygen modified atmosphere packaging (**Hi-O_2-MAP**), and vacuum packaging (**VP**). Samples were packaged as presented by Chmiel et al. (2019). Each package contained 2 fillets of a total weight of about 500 g. In total, 54 meat packages were prepared: 18 AP-packed ones, 18 Hi-O_2-MAP−packed ones, and 18 VP-packed ones. Industrial practice requires to deliver packaged meat to retailers not earlier than 24 h after packaging. Therefore, raw material in this study was stored for that time in a cold room (at 2.2°C ± 0.3°C) without light access. After that, 2 packages of each of the three used packaging techniques were allocated to determine initial meat quality (on day 1 of the storage). Then, rest of the samples were divided into 2 equal groups and stored under various conditions (cold room or display case) as described in detail by Chmiel et al. (2019). Hereafter, meat stored in the cold room (at 2.2°C ± 0.3°C) will be referred to as the "cold-stored meat" and meat exposed to the light in the display case (at average temperature 3.5°C) will be referred to as the "exposed meat". The cold-stored and exposed meat were tested repeatedly on day 3, 6, 7, and 8. Each time, 2 AP/Hi-O_2-MAP/VP-packed packages randomly selected from the cold room and 2 packages randomly selected from the display case were tested. Scope of the tests was identical as scope of the initial tests done on day 1: the left fillet from each package was subjected to microbiological analysis and the right one to analysis of volatile compounds.

Methods

Microbiological Analysis Samples for microbiological analyses were acquired using a sterile scalpel (PCS, 2017), both from fillet surface deep layers and from fillet deep layers. Pieces were cut from the exposed fillet area, about 2 cm × 2 cm and 1 cm deep into the fillet. The material was collected from 3 places in each fillet. Then, 20 g of the collected sample together with 180 cm^3 of buffered peptone water (bioMérieux, Marcy-l'Étoile, France) was homogenized in a Stomacher laboratory blender (Lab Blender 400 Circulator, Seward Laboratory, London, UK) for 2 min at room temperature (18°C). Subsequent decimal dilutions were made by transferring 1 cm^3 of the resulting suspension to consecutive tubes with 9 cm^3 of buffered peptone water (bioMérieux, Marcy-l'Étoile, France) until dilutions appropriate for culturing and determination of individual groups of microorganisms were obtained. The analyses were carried out in duplicate.

Microbiological analyses included determination of 1) total plate count (**TPC**) of mesophilic aerobic bacteria (30°C for 48 h; PCS, 2013) on Plate Count Agar medium (BTL, Łódź, Poland); 2) LAB (30°C for 72 h; PCS, 2002) on MRS medium (de Man, Rogosa and Sharpe Agar; Bio-Rad Laboratories, Inc., Hercules, CA); 3) *Pseudomonas* spp. bacteria (28°C for 48 h; PCS, 2010) on KING B Agar medium with an addition of 5 cm^3 CFC (selective, lyophilized supplement containing cetrimide and antibiotics: fucidine and cephalosporin) for every 500 cm^3 of sterile medium (bioMérieux, Marcy-l'Étoile, France); and 4) *Enterobacteriaceae* family bacteria (37°C for 24 h; PCS, 2005) on Violet Red Bile Glucose Agar medium (BTL, Łódź, Poland). The bacteria count

was expressed as $\log_{10}$ of the number of colony-forming units per gram of meat (log cfu/g).

Analyses of Volatile Compounds CombiPal autosampler (CTC Analytics AG, Zwingen, Switzerland) was used to condition/extract samples and to introduce them into a GC instrument. Five grams of ground meat were placed in 20-ml glass auto sampler vial closed with screw caps sealed with Teflon and conditioned for 10 min at 50°C. Headspace was extracted for 180 min using SPME fibers coated with 50-/30-µm-thick Divinylbenzene/Carboxen/Polydimethylsiloxane (**DVB/CAR/PDMS**) films. Before use, the fibers were conditioned for 60 min at 270°C in the GC injector port. The fibers were desorbed for 10 minutes at the injector port operated at 260°C in the split-less mode. Agilent 5975 C/6890 GC/MS instrument was used for analysis. Chromatographic separation was performed on ZB-WAX fused-silica capillary column 30 m × 0.25 mm id × 0.5 µm film thickness. Helium flowing at 1.2 ml min^{-1} constant rate was used as the carrier gas. The oven was programmed from 6 min hold at 40°C, ramped at 4°C/min to 150°C, ramped at 20°C/min to 250°C, held for 5 min. Samples were analyzed in triplicates. Trimethylpyridine was used as internal standard. The results were expressed as relative peak area of individual quantified peaks.

Statistical Analysis The experimentally obtained data were analyzed using the STATISTICA software package version 10 PL (StatSoft Inc., Tulsa, OK). The one-way ANOVA variance analysis method was applied to determine the influence of time, conditions of storage, and packaging technique on quality of the tested chicken breasts (volatile compounds and microbiological quality). In particular, the Tukey's HSD test at significance level $\alpha = 0.05$ was used.

RESULTS AND DISCUSSION

Microbiological Quality

Numerous volatile compounds produced during poultry meat storage by spoilage-causing microbiota result in slime and off-odor, with decreasing consumer interest as a direct consequence. Various alcohols, aldehydes, and ketones produced by microorganisms such as *Pseudomonas* spp., *Shewanella* spp., *Enterobacteriaceae*, *B. thermosphacta*, and LAB have been reported in the literature (Nychas et al., 2008; Casaburi et al., 2014, 2015; Parlapani et al., 2014).

Evolution of TPCs and counts of individual major bacterial groups in chicken breasts AP/Hi-O_2-MAP/VP-packed during 8-day-long cold room storage/display case exposure period are shown in Table 1. Initial (i.e., measured on day 1) TPCs were below 3 log cfu/g, which indicates good microbiological quality of the raw material (Latou et al., 2014). Increase ($P \leq 0.05$) of TPCs with storage time was found in both the cold-stored and the exposed meat. Regardless of the packaging technique, TCPs in the cold-stored meat did not reach the maximum limit for fresh meat during 8 D of the experiment, that is, 7 − 8 log cfu/g (ICMSF 1986, Balamatsia et al., 2007, Latou et al., 2014). However, the 7 log cfu/g level was exceeded on day 8 in AP- and VP-packed exposed meat. Rossaint et al. (2015) reported that the 7 log cfu/g level was exceeded after 10 D of cold room storage of chicken breasts packaged in a modified atmosphere (high oxygen content). Clearly different TPC levels were observed between meat packaged with different packaging techniques beginning from day 6 or 7 for the cold-stored meat, but in some cases, it began already from day 3 for the exposed meat. Significantly lower (including the lowest) TPCs were noted in Hi-O_2-MAP-packed meat than in AP- and VP-packed one. The Hi-O_2-MAP packaging technique delayed growth of microflora in the exposed meat above 7 log cfu/g by at least 1 D compared with AP- and VP-packed meat, most probably due to CO_2 content. Lower TPCs in Hi-O_2-MAP–packed meat than in AP-packed one were also reported by Latou et al. (2014). Starting from day 6, TPCs in the exposed meat were higher than those in the cold-stored meat, regardless of the used packaging technique (Table 1).

LAB, which are facultative anaerobic bacteria species, are important competitors for other microorganism growing in fresh chicken meat. Their ability to spoil meat through tissue discoloration or production of off-odor vary (Casaburi et al., 2015; Jääskeläinen et al., 2016). In our studies, LAB exceeded the 7 log cfu/g level (limit for fresh meat according to Nychas et al., 2008) on day 8 in Hi-O_2-MAP–packed cold-stored meat, on day 6 and 8 in AP-packed exposed meat, and on day 8 in VP-packed exposed meat. Significantly more LAB were detected in the exposed meat than in the cold-stored meat, regardless of the packaging technique (Table 1).

Pseudomonas spp. are responsible for off-odor and off-flavor growing in stored poultry meat. According to Schöller et al. (1997), volatile metabolites with an unpleasant odor produced by bacteria of the genus *Pseudomonas* grown in model media are, among others, dimethyl disulphide as well as isoprene and 1-undecene. According to Franke et al. (2017), *Pseudomonas* spp. are a typical cause of spoilage of chicken meat stored under aerobic packaging conditions. Growth of these bacteria is strongly inhibited by high CO_2 concentration. In this study, the effect ($P \leq 0.05$) of the cold-storage and exposure time in a display case on *Pseudomonas* spp. count was found regardless of the meat packaging technique. Let us recall that according to Nychas et al., 2008, 7 − 8 log cfu/g for *Pseudomonas* spp. is the determinant of the fresh meat spoilage. This level for *Pseudomonas* spp. was reached on day 8 in Hi-O_2-MAP–packed and VP-packed in both cold-stored and/or exposed meat but 1 D earlier in AP-packed exposed meat (Table 1). This level of *Pseudomonas* spp. indicates spoilage of meat.

Enterobacteriaceae count in chicken fillets remained below 3.5 log cfu/g during the entire storage time, irrespective of the storage conditions and the packaging technique (Table 1).

Table 1. Evolution of bacterial count in differently packaged chicken breasts stored for 8 D.

Bacterial counts (log cfu/g)	Packaging technique	Cold room, day					Display case, day				
		1 (initial)[1]	3	6	7	8	1 (initial)[1]	3	6	7	8
Total plate count	AP	2.81a ± 0.55	4.11b ± 0.94	6.23cB* ± 0.09	6.60dB ± 0.05	6.68d* ± 0.15	2.81a ± 0.55	5.29aB ± 0.27	6.87aB* ± 0.05	6.72RaB ± 0.07	7.43bB* ± 0.11
	Hi-O_2-MAP	2.63a ± 0.19	3.50a ± 1.40	5.00aA* ± 0.13	6.17bA ± 0.24	6.51c ± 0.08	2.63a ± 0.19	3.41aA ± 0.36	6.16bA* ± 0.08	6.32bA ± 0.09	6.63cA ± 0.06
	VP	2.40a ± 0.32	3.64a ± 1.47	6.38bB ± 0.14	6.19bA* ± 0.04	6.37b* ± 0.03	2.40a ± 0.32	4.04aA ± 0.47	6.42bA ± 0.07	6.44bA* ± 0.02	7.22cB* ± 0.09
Lactic acid bacteria	AP	2.77a ± 0.42	3.81a ± 0.79	5.37aA* ± 0.08	6.45bB ± 0.05	6.63bA* ± 0.15	2.77a ± 0.42	4.22a ± 0.15	7.32cB* ± 0.06	6.68bB ± 0.13	7.51cC* ± 0.06
	Hi-O_2-MAP	2.40a ± 0.06	3.15a ± 1.91	5.20aA ± 0.17	6.48aB ± 0.09	7.45bB* ± 0.08	2.40a ± 0.06	2.94a ± 0.82	4.87aA ± 0.31	6.35bA ± 0.03	6.78cA* ± 0.04
	VP	2.24a ± 0.40	3.98a ± 0.54	6.00aB ± 0.03	6.03aA* ± 0.02	6.66bA* ± 0.05	2.24a ± 0.40	4.55a ± 0.65	6.18aB ± 0.03	6.36aA* ± 0.06	7.21bB* ± 0.08
Pseudomonas spp.	AP	3.48a ± 0.67	5.07aB ± 0.19	6.70bC ± 0.18	6.86bB* ± 0.04	6.49bA* ± 0.04	3.48a ± 0.67	5.00a ± 0.38	6.68bB ± 0.18	7.14bB* ± 0.13	8.33cB* ± 0.06
	Hi-O_2-MAP	2.62a ± 0.06	4.12aA ± 0.73	5.30aA ± 0.10	6.29aA ± 0.29	7.63bC* ± 0.04	2.62a ± 0.06	3.77a ± 0.81	5.20aA ± 0.12	6.67bA ± 0.17	7.15cA* ± 0.07
	VP	2.88a ± 0.42	3.78aA ± 0.74	6.49bB ± 0.05	6.60bA ± 0.02	7.25cB* ± 0.05	2.88a ± 0.42	4.70a ± 0.51	6.50aB ± 0.11	6.60aA ± 0.22	8.26bB* ± 0.04
Enterobacteriaceae	AP	0.42a ± 0.72	0.33a ± 0.58	2.81bB ± 0.08	2.72b* ± 0.04	1.97a ± 0.08	0.42a ± 0.72	1.06a ± 1.09	2.82bB ± 0.16	3.25c* ± 0.02	1.85a ± 0.14
	Hi-O_2-MAP	Nd	0.33a ± 0.58	2.52aA* ± 0.20	2.55a ± 0.52	1.98a ± 0.09	nd	0.63a ± 1.10	1.33aA* ± 1.15	2.99c ± 0.05	2.65b ± 0.23
	VP	0.49a ± 0.84	0.91a ± 0.80	2.48bA* ± 0.07	2.91c ± 0.06	1.99a ± 0.09	0.49a ± 0.84	0.93a ± 0.58	2.99aB* ± 0.12	3.43b ± 0.20	2.51a ± 0.35

Notes: Lowercase letters (a–c) indicate that average values in rows with different letters are significantly different at $P \leq 0.05$. The letters refer to the differences between particular days of storage separately for cold room and display case. Uppercase letters (A-C) indicate that average values in the columns, for particular characteristic, marked with different letters are significantly different at $P \leq 0.05$. The letters refer to the differences between packaging techniques in particular day of storage. Symbol (*) indicate that average values in rows, for particular days of storage, marked with * are significantly different at $P \leq 0.05$. The letters refer to the differences between storage conditions (cold room and display case). Nd-below detection limit. Left: the cold-stored meat. Right: meat exposed in a display case (mean ± standard deviation).

[1]The results for the initial day 1 were included in both analyses for cold-stored and exposed meat.

Results of the microbiological tests showed that bacteria of all major groups were growing at similar rates at the beginning of the storage period regardless of the used packaging technique. However, at the end of the storage, the growth dynamic was different for different packaging techniques.

Volatile Compounds

Volatile compounds most commonly detected in MAP-packed meat include 1-octen-3-ol, 3-methyl-1-butanol, acetoin, 1-hexanal, butanoic acid, hexanoic acid, ethyloctanoate, and dimethylsulfide (Ercolini et al., 2011, Casaburi et al., 2015). These compounds usually accompany growth of bacteria including LAB and *Enterobacteriaceae*. Some of the compounds were detected also in our study. Mainly aldehydes, alcohols, and organic acids were isolated from the meat package headspace using the applied method of analysis. Breakdowns of the identified volatile compounds by the packaging technique (AP/Hi-O_2-MAP/VP) and the storage conditions (cold room/display case) are given in Table 2 (aldehydes), Table 3 (alcohols), and Table 4 (acids and other compounds).

N-hexanal and n-nonanal were the dominant aldehydes identified in the headspace profile of tested meat aroma. An effect ($P \leq 0.05$) of storage time on their content was found in the tested Hi-O_2-MAP–packed and AP-packed cold-stored meat. The highest content of n-hexanal was found in Hi-O_2-MAP-packed meat on day 6 of cold-storage. The highest content of n-nonanal was found in AP-packed meat on day 3 of exposition in the display case. Significant changes during cold storage of AP-packed meat were also observed for n-pentanal; its content reached maximum on day 3 of the storage. However, we did not find any simple relation between aldehydes concentration and meat storage time because of a high variability of the results (Table 2).

Presence of aldehydes in the headspace profile of meat aroma can be explained by lipid oxidation processes and/or chemical processes catalyzed by the growing bacteria. The highest number of aldehydes is produced by *Pseudomonas* spp. and *Enterobacteriaceae*. Casaburi et al. (2015) pointed out that concentration of some aldehydes commonly found in spoiled meat could not be easily linked with bacteria growth because of low absolute concentration of the aldehydes and their fast oxidation to acids at an early phase of the storage. Hexanal, nonanal, and heptanal are the most commonly reported aldehydes found in naturally spoiled meat. They are important contributors to meat flavor profiles because they have low odor thresholds (Muriel et al., 2004). They were also found in the samples tested in this study. Wang et al. (2017) identified hexanal as the dominant aldehyde in chicken meat stored for 7 D at 8°C. Jääskeläinen et al. (2016) found a systematic increase in the content of hexanal and nonanal in MAP- and VP-packed beef meat during 14 and 26 D of storage, respectively. Octanal and nonanal (among other volatiles) have been proposed as indicators of raw beef

Table 2. Evolution of aldehydes in differently packaged chicken breasts stored for 8 D.

Aldehydes	Packaging technique	Cold room, day					Display case, day				
		1 (initial)[1]	3	6	7	8	1 (initial)[1]	3	6	7	8
Hept-2-enal	AP	0.12 ± 0.01	0.30 ± 0.26	0.13 ± 0.05	0.10AB ± 0.08	0.13* ± 0.09	0.12 ± 0.01	0.12 ± 0.06	0.11 ± 0.06	0.39 ± 0.27	0.31* ± 0.03
	Hi-O_2-MAP	0.30 ± 0.39	0.22 ± 0.17	0.49* ± 0.05	0.04A ± 0.05	0.20 ± 0.20	0.30 ± 0.39	0.18 ± 0.25	0.18* ± 0.16	0.06 ± 0.05	0.74 ± 0.79
	VP	0.63 ± 0.47	0.32* ± 0.09	0.43 ± 0.27	0.33B ± 0.15	0.33 ± 0.23	0.63 ± 0.47	0.13* ± 0.01	0.30 ± 0.04	0.43 ± 0.36	0.74 ± 0.99
n-Octanal	AP	0.12 ± 0.02	0.27 ± 0.21	0.23 ± 0.22	0.10 ± 0.09	0.24 ± 0.12	0.12 ± 0.02	0.37 ± 0.03	0.37 ± 0.26	0.07 ± 0.03	0.38 ± 0.27
	Hi-O_2-MAP	0.17 ± 0.22	0.17 ± 0.01	0.03 ± 0.0	0.25 ± 0.33	0.16 ± 0.08	0.17 ± 0.22	0.12 ± 0.05	0.25 ± 0.20	0.18 ± 0.07	0.25 ± 0.20
	VP	0.18 ± 0.19	0.46 ± 0.17	0.29 ± 0.08	0.16 ± 0.13	0.16 ± 0.17	0.18 ± 0.19	0.28 ± 0.17	0.49 ± 0.41	0.12 ± 0.11	0.55 ± 0.48
2-Hexen-1-al	AP	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.04 ± 0.06	0.05 ± 0.04	0.01 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.02	0.02 ± 0.02
	Hi-O_2-MAP	0.01 ± 0.02	0.01 ± 0.01	0.02 ± 0.0	0.01 ± 0.02	0.01 ± 0.01	0.01 ± 0.02	nd	0.02 ± 0.01	0.02 ± 0.01	0.05 ± 0.07
	VP	0.08 ± 0.11	0.12 ± 0.15	0.06 ± 0.09	0.01 ± 0.01	0.01 ± 0.01	0.08 ± 0.11	0.02 ± 0.02	0.03 ± 0.01	0.03 ± 0.05	0.01 ± 0.01
n-Heptanal	AP	0.21 ± 0.08	0.42AB ± 0.13	0.55 ± 0.53	0.18 ± 0.11	0.33 ± 0.20	0.21 ± 0.08	0.33 ± 0.26	0.30 ± 0.14	1.18 ± 0.90	0.41 ± 0.30
	Hi-O_2-MAP	0.57 ± 0.59	0.21A ± 0.03	0.42* ± 0.05	0.40 ± 0.56	0.32 ± 0.24	0.57 ± 0.59	0.20 ± 0.08	0.25* ± 0.08	0.48 ± 0.09	0.42 ± 0.20
	VP	0.45 ± 0.28	0.54B ± 0.16	0.43 ± 0.06	0.26 ± 0.11	0.49 ± 0.19	0.45 ± 0.28	0.38 ± 0.02	0.57 ± 0.27	0.36 ± 0.18	0.69 ± 0.29
n-Hexanal	AP	7.12 ± 5.23	11.27 ± 1.23	9.12 ± 3.69	2.98A ± 0.88	2.76A ± 1.55	7.12 ± 5.23	8.03 ± 4.03	9.13AB ± 3.42	4.33 ± 1.68	13.10 ± 9.14
	Hi-O_2-MAP	7.69ab ± 5.59	4.51a ± 1.47	14.33b* ± 2.01	2.63aA ± 3.72	3.51aA ± 2.70	7.69 ± 5.59	2.93 ± 1.80	6.27A* ± 2.60	6.45 ± 4.21	12.71 ± 9.29
	VP	10.27 ± 3.23	12.34 ± 8.52	10.60 ± 5.10	8.87B ± 1.69	8.42B ± 1.26	10.27 ± 3.23	7.48 ± 3.53	16.89B ± 5.41	11.39 ± 5.71	24.8 ± 23.88
n-Pentanal	AP	0.34ab ± 0.14	0.53b ± 0.11	0.39ab ± 0.19	0.14aA ± 0.04	0.14aA ± 0.03	0.34 ± 0.14	0.31 ± 0.11	0.46AB ± 0.20	0.12 ± 0.02	0.56 ± 0.40
	Hi-O_2-MAP	0.47 ± 0.35	0.24 ± 0.06	0.57* ± 0.09	0.15A ± 0.09	0.28AB ± 0.18	0.47 ± 0.35	0.15 ± 0.09	0.26A* ± 0.12	0.29 ± 0.22	0.53 ± 0.50
	VP	0.52 ± 0.32	0.50 ± 0.24	0.62 ± 0.29	0.48B ± 0.13	0.51B ± 0.04	0.52 ± 0.32	0.37 ± 0.09	0.80B ± 0.25	0.55 ± 0.26	1.12 ± 1.14
2-Undecanal	AP	0.02 ± 0.01	0.05 ± 0.02	0.03 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.02 ± 0.01	0.03 ± 0.02	0.03 ± 0.02	0.02 ± 0.01	0.04 ± 0.02
	Hi-O_2-MAP	0.03 ± 0.03	0.02 ± 0.01	0.05 ± 0.0	0.01 ± 0.01	0.02 ± 0.01	0.03 ± 0.03	0.02 ± 0.0	0.03 ± 0.01	0.02 ± 0.01	0.08 ± 0.09
	VP	0.04 ± 0.01	0.08 ± 0.05	0.04 ± 0.03	0.04 ± 0.02	0.05 ± 0.02	0.04 ± 0.01	0.04 ± 0.02	0.07 ± 0.04	0.06 ± 0.04	0.10 ± 0.12
2-Nonenal	AP	0.01 ± 0.01	0.04 ± 0.02	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.02	0.03 ± 0.01	0.02 ± 0.01	0.04 ± 0.03
	Hi-O_2-MAP	0.03 ± 0.02	0.07 ± 0.05	0.04 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.03 ± 0.02	0.01 ± 0.01	0.04 ± 0.03	0.11 ± 0.17	0.04 ± 0.04
	VP	0.14 ± 0.2	0.04 ± 0.03	0.03 ± 0.02	0.02 ± 0.01	0.06 ± 0.04	0.14 ± 0.2	0.03 ± 0.02	0.03 ± 0.02	0.05 ± 0.03	0.05 ± 0.06
Decanal	AP	0.06 ± 0.03	0.19B ± 0.03	2.22 ± 2.02	0.09 ± 0.03	0.13 ± 0.09	0.06 ± 0.03	0.12 ± 0.07	0.07 ± 0.05	0.07 ± 0.01	0.13 ± 0.04
	Hi-O_2-MAP	0.24 ± 0.14	0.11A ± 0.03	0.05 ± 0.01	0.18 ± 0.19	0.07 ± 0.04	0.24 ± 0.14	0.05 ± 0.03	0.35 ± 0.22	0.07 ± 0.05	0.14 ± 0.08
	VP	0.10 ± 0.04	0.16AB ± 0.03	0.11 ± 0.06	0.09 ± 0.02	0.16 ± 0.08	0.10 ± 0.04	0.13 ± 0.03	0.16 ± 0.05	0.11 ± 0.03	0.18 ± 0.03
2-Octen-1-al	AP	0.06 ± 0.06	0.13 ± 0.07	0.10 ± 0.03	0.15 ± 0.20	0.11 ± 0.07	0.06 ± 0.06	0.10B ± 0.01	0.13AB ± 0.04	0.26 ± 0.18	0.21 ± 0.03
	Hi-O_2-MAP	0.29 ± 0.18	0.13 ± 0.07	0.14 ± 0.01	0.04 ± 0.06	0.08 ± 0.08	0.29 ± 0.18	0.02A ± 0.02	0.09A ± 0.03	0.09 ± 0.01	0.28 ± 0.33
	VP	0.12 ± 0.05	0.22 ± 0.19	0.14 ± 0.11	0.05 ± 0.05	0.13 ± 0.05	0.12 ± 0.05	0.15B ± 0.06	0.24B ± 0.07	0.09 ± 0.03	0.38 ± 0.51
n-Nonanal	AP	0.32a ± 0.07	0.98bB ± 0.03	0.44aA ± 0.16	0.26aA ± 0.07	0.29aA ± 0.23	0.32 ± 0.07	0.73AB ± 0.37	0.65 ± 0.38	0.42 ± 0.15	0.58 ± 0.31
	Hi-O_2-MAP	1.77 ± 2.31	0.43A ± 0.03	0.37A ± 0.03	0.29A ± 0.11	0.39A ± 0.06	1.77 ± 2.31	0.33A ± 0.11	0.38 ± 0.17	0.42 ± 0.08	0.72 ± 0.28
	VP	0.74 ± 0.30	1.26B ± 0.32	0.78B ± 0.15	0.54B ± 0.11	0.72B ± 0.07	0.74 ± 0.30	1.01B ± 0.17	1.21 ± 0.41	0.52 ± 0.24	1.40 ± 0.74
2,4-Decadienal	AP	0.02 ± 0.02	0.04 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.03	0.02 ± 0.02	0.03 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.06 ± 0.03
	Hi-O_2-MAP	0.11 ± 0.15	0.02 ± 0.01	0.09 ± 0.04	0.02 ± 0.04	0.03 ± 0.04	0.11 ± 0.15	0.01 ± 0.01	0.05 ± 0.04	0.05 ± 0.01	0.03 ± 0.04
	VP	0.03 ± 0.01	0.04 ± 0.03	0.03 ± 0.02	0.05 ± 0.03	0.06 ± 0.04	0.03 ± 0.01	0.05 ± 0.03	0.04 ± 0.01	0.05 ± 0.02	0.07 ± 0.04
2-Heptanal	AP	0.22 ± 0.25	0.19 ± 0.04	0.13 ± 0.04	0.14 ± 0.13	0.04 ± 0.03	0.22 ± 0.25	0.31 ± 0.49	0.19 ± 0.14	0.07 ± 0.03	0.09 ± 0.02
	Hi-O_2-MAP	0.12 ± 0.19	0.10 ± 0.04	0.04 ± 0.01	0.07 ± 0.11	0.06 ± 0.05	0.12 ± 0.19	0.06 ± 0.03	0.15 ± 0.05	0.11 ± 0.03	0.19 ± 0.12
	VP	0.11 ± 0.1	0.15 ± 0.13	0.19 ± 0.18	0.17 ± 0.12	0.11 ± 0.04	0.11 ± 0.1	0.12 ± 0.04	0.23 ± 0.09	0.16 ± 0.10	0.17 ± 0.15
Hexadecanal	AP	0.03 ± 0.03	0.07 ± 0.02	0.05 ± 0.03	0.06 ± 0.06	0.03 ± 0.02	0.03 ± 0.03	0.12 ± 0.12	0.06 ± 0.05	0.02 ± 0.01	0.04 ± 0.02
	Hi-O_2-MAP	0.31 ± 0.26	0.06 ± 0.01	0.05 ± 0.01	0.03 ± 0.04	0.05 ± 0.01	0.31 ± 0.26	0.03 ± 0.03	0.05 ± 0.03	0.08 ± 0.06	0.07 ± 0.02
	VP	0.17 ± 0.19	0.15 ± 0.07	0.07 ± 0.04	0.07 ± 0.04	0.07 ± 0.02	0.17 ± 0.19	0.09 ± 0.03	0.14 ± 0.06	0.07 ± 0.04	0.08 ± 0.06

Meaning of letters in result qualificators as in Table 1. Left: the cold-stored meat. Right: meat exposed in a display case (mean ± standard deviation).
[1]The results for the initial day 1 were included in both analyses for cold-stored and exposed meat.

Table 3. Evolution of alcohols in differently packaged chicken breasts stored for 8 D.

Alcohols	Packaging technique	Cold room, day					Display case, day				
		1 (initial)[1]	3	6	7	8	1 (initial)[1]	3	6	7	8
n-Pentanol	AP	0.66a ± 0.33	1.29b ± 0.07	0.73a ± 0.09	0.30aA ± 0.10	0.24aA ± 0.14	0.66 ± 0.33	0.79 ± 0.67	0.46 ± 0.47	0.49 ± 0.25	0.76 ± 0.43
	Hi-O_2-MAP	0.47 ± 0.70	0.79 ± 0.19	1.09 ± 0.04	0.28A ± 0.12	0.40A ± 0.10	0.47 ± 0.70	0.59 ± 0.43	0.67 ± 0.45	0.59 ± 0.27	1.07 ± 0.72
	VP	1.34 ± 0.81	0.96 ± 0.49	0.91 ± 0.34	0.79B ± 0.08	0.75B ± 0.08	1.34 ± 0.81	0.84 ± 0.47	1.00 ± 0.06	0.95 ± 0.38	2.04 ± 2.43
Isopentyl alcohol	AP	nd	nd	0.11 ± 0.14	0.02 ± 0.02	0.09 ± 0.07	nd	0.01a ± 0.02	0.01a ± 0.01	0.19bB ± 0.09	0.11ab ± 0.05
	Hi-O_2-MAP	nd	0.01 ± 0.01	0.14 ± 0.10	0.05 ± 0.05	0.03* ± 0.03	nd	0.01 ± 0.02	0.04 ± 0.02	0.02A ± 0.01	0.36* ± 0.30
	VP	0.06 ± 0.11	0.08 ± 0.13	0.06 ± 0.10	0.02 ± 0.02	0.02 ± 0.02	0.06 ± 0.11	nd	0.01 ± 0.02	0.02A ± 0.04	0.13 ± 0.06
n-Octanol	AP	0.18 ± 0.12	0.22 ± 0.14	0.14 ± 0.11	0.07 ± 0.08	0.09 ± 0.06	0.18 ± 0.12	0.22 ± 0.19	0.14 ± 0.09	0.04 ± 0.05	0.17 ± 0.11
	Hi-O_2-MAP	0.08 ± 0.09	0.11a ± 0.01	0.02 ± 0.01	0.04 ± 0.02	0.05 ± 0.03	0.08 ± 0.09	0.07 ± 0.05	0.10 ± 0.05	0.07 ± 0.09	0.10 ± 0.02
	VP	0.14a ± 0.1	0.36b ± 0.08	0.09a ± 0.09	0.08a ± 0.07	0.13a ± 0.06	0.14 ± 0.1	0.16 ± 0.13	0.25 ± 0.13	0.07 ± 0.07	0.16 ± 0.12
Ethylhexanol	AP	1.76 ± 2.56	2.36 ± 1.10	2.39 ± 2.27	2.31B ± 0.93	1.43 ± 0.69	1.76 ± 2.56	2.12B ± 1.14	0.91 ± 0.27	2.09 ± 0.82	1.63 ± 0.48
	Hi-O_2-MAP	2.33 ± 3.60	1.30 ± 1.54	0.69 ± 0.07	0.53A ± 0.47	0.77 ± 0.73	2.33 ± 3.60	0.17A ± 0.13	0.57 ± 0.19	0.65 ± 0.03	0.61 ± 0.45
	VP	0.48 ± 0.49	4.06 ± 5.23	0.93 ± 0.37	0.87AB ± 0.20	1.41 ± 0.45	0.48 ± 0.49	0.63AB ± 0.58	0.62 ± 0.11	0.92 ± 0.81	1.98 ± 1.18
Oct-1-en-3-ol	AP	0.57ab ± 0.33	1.50b ± 0.69	0.61ab ± 0.15	0.29a ± 0.03	0.24A* ± 0.19	0.57 ± 0.33	1.05 ± 0.77	0.66 ± 0.35	1.02 ± 0.72	1.54* ± 1.07
	Hi-O_2-MAP	1.14 ± 0.99	0.43 ± 0.06	1.31* ± 0.05	0.43 ± 0.44	0.35A ± 0.18	1.14 ± 0.99	0.29 ± 0.09	0.59* ± 0.32	0.74 ± 0.06	0.81 ± 0.50
	VP	1.12 ± 0.54	0.99 ± 0.50	0.70 ± 0.53	0.68 ± 0.36	0.77B ± 0.15	1.12 ± 0.54	0.94 ± 0.58	0.81 ± 0.71	0.63 ± 0.28	1.40 ± 1.38
n-Hexan-1-ol	AP	0.17 ± 0.04	0.32B ± 0.06	0.26 ± 0.20	0.15 ± 0.06	0.14 ± 0.11	0.17 ± 0.04	0.34B ± 0.09	0.20 ± 0.10	0.37 ± 0.26	0.29 ± 0.04
	Hi-O_2-MAP	0.45 ± 0.49	0.17A ± 0.03	0.54 ± 0.01	0.13 ± 0.23	0.20 ± 0.18	0.45 ± 0.49	0.11A ± 0.06	0.23 ± 0.21	0.26 ± 0.05	0.38 ± 0.37
	VP	0.28 ± 0.12	0.24AB ± 0.07	0.24 ± 0.17	0.23 ± 0.09	0.27 ± 0.10	0.28 ± 0.12	0.22AB ± 0.03	0.23 ± 0.11	0.21 ± 0.07	0.68 ± 0.92
Butoxyethoxyethanol	AP	0.24 ± 0.25	0.19 ± 0.07	0.20 ± 0.06	0.15 ± 0.03	0.23 ± 0.11	0.24 ± 0.25	0.22 ± 0.05	0.15 ± 0.09	0.30 ± 0.17	0.34 ± 0.15
	Hi-O_2-MAP	6.39 ± 4.82	0.36 ± 0.02	0.14 ± 0.02	0.18 ± 0.14	0.16 ± 0.12	6.39 ± 4.82	0.22 ± 0.21	0.27 ± 0.13	0.33 ± 0.09	0.56 ± 0.33
	VP	0.16 ± 0.13	0.40 ± 0.32	0.19 ± 0.05	0.22 ± 0.08	0.28 ± 0.09	0.16 ± 0.13	0.31 ± 0.24	0.21 ± 0.10	0.15 ± 0.13	0.61 ± 0.71

Meaning of letters in result qualificators as in Table 1. Left: the cold-stored meat. Right: meat exposed in a display case (mean ± standard deviation).
[1]The results for the initial day 1 were included in both analyses for cold-stored and exposed meat.

Table 4. Evolution of acids and other volatile compounds in differently packed chicken breasts stored for 8 D.

Compound	Packaging technique	Cold room, day									Display case, day									
		1 (initial)[1]		3		6		7		8	1 (initial)[1]		3		6		7		8	
Acids																				
Pentanoic acid	AP	0.93	± 1.25	2.59	± 2.17	1.20	± 1.20	0.24	± 0.39	0.49	± 0.33	0.93	± 1.25	1.57	± 1.31	0.57	± 0.65	0.13	± 0.18	1.50	± 1.28
	Hi-O_2-MAP	2.99	± 2.70	1.53	± 1.28	0.03	± 0.01	0.07	± 0.08	0.11	± 0.11	2.99	± 2.70	0.58	± 0.68	0.65	± 0.64	0.34	± 0.53	0.52	± 0.72
	VP	1.05	± 1.14	1.89	± 1.55	0.39	± 0.58	0.45	± 0.71	0.43	± 0.6	1.05	± 1.14	1.81	± 1.50	0.85	± 0.70	0.16	± 0.20	0.33	± 0.48
n-Heptanoic acid	AP	0.03	± 0.04	0.10	± 0.05	0.13	± 0.09	0.04	± 0.03	0.07	± 0.06	0.03	± 0.04	0.12	± 0.05	0.05	± 0.03	0.06	± 0.04	0.09	± 0.05
	Hi-O_2-MAP	0.25	± 0.24	0.06	± 0.05	0.11	± 0.06	0.10	± 0.08	0.03	± 0.02	0.25	± 0.24	0.05	± 0.06	0.06	± 0.01	0.05	± 0.01	0.12	± 0.12
	VP	0.07	± 0.04	0.08	± 0.04	0.04	± 0.040	0.04	± 0.04	0.04	± 0.04	0.07	± 0.04	0.07	± 0.06	0.06	± 0.01	0.05	± 0.06	0.06	± 0.07
n-Octanoic acid	AP	0.15	± 0.06	0.33B	± 0.05	0.51	± 0.43	0.17	± 0.14	0.34	± 0.27	0.15	± 0.06	0.34	± 0.13	0.13	± 0.07	0.26	± 0.11	0.51	± 0.38
	Hi-O_2-MAP	0.58	± 0.41	0.16A	± 0.03	0.30	± 0.01	0.18	± 0.09	0.09	± 0.05	0.58	± 0.41	0.27	± 0.34	0.18	± 0.09	0.17	± 0.02	0.45	± 0.15
	VP	0.25	± 0.14	0.23AB	± 0.06	0.14	± 0.06	0.22	± 0.14	0.14	± 0.19	0.25	± 0.14	0.24	± 0.10	0.17	± 0.02	0.19	± 0.25	0.22	± 0.15
n-Nonanoic acid	AP	0.14	± 0.10	0.48	± 0.34	0.93	± 0.84	0.14	± 0.12	0.53B	± 0.24	0.14	± 0.10	0.56	± 0.36	0.16	± 0.09	0.37	± 0.20	0.32	± 0.17
	Hi-O_2-MAP	1.19	± 1.08	0.24	± 0.15	0.57*	± 0.08	0.32	± 0.15	0.08A*	± 0.05	1.19	± 1.08	0.58	± 0.81	0.30*	± 0.12	0.29	± 0.01	0.72*	± 0.49
	VP	0.53	± 0.37	0.45	± 0.28	0.26	± 0.12	0.29	± 0.20	0.18A	± 0.24	0.53	± 0.37	0.26	± 0.13	0.26	± 0.11	0.35	± 0.47	0.50	± 0.36
n-Dodecanoic acid	AP	0.20	± 0.14	0.17	± 0.04	0.14	± 0.08	0.19	± 0.15	0.48	± 0.29	0.20	± 0.14	0.28	± 0.31	0.09	± 0.01	0.34B	± 0.08	0.50	± 0.35
	Hi-O_2-MAP	0.12	± 0.06	0.15	± 0.06	0.04	± 0.01	0.17	± 0.16	0.17	± 0.11	0.12	± 0.06	0.14	± 0.08	0.22	± 0.17	0.17A	± 0.04	0.16	± 0.06
	VP	0.10	± 0.02	0.13	± 0.04	0.12	± 0.04	0.28	± 0.15	0.08	± 0.09	0.10	± 0.02	0.27	± 0.16	0.13	± 0.05	0.05A	± 0.03	0.21ab	± 0.15
Propanoic acid	AP	0.39	± 0.37	0.04	± 0.02	0.10	± 0.11	0.03*	± 0.01	0.51B	± 0.29	0.39ab	± 0.37	0.13a	± 0.13	0.09a	± 0.04	0.19a*	± 0.07	1.77b	± 1.24
	Hi-O_2-MAP	0.21	± 0.17	0.05	± 0.02	0.04	± 0.01	0.03	± 0.02	0.02A	± 0.02	0.21	± 0.17	0.02	± 0.02	0.03	± 0.03	0.11	± 0.07	0.11	± 0.09
	VP	0.11	± 0.12	0.05a	± 0.01	0.07	± 0.06	0.04	± 0.01	0.09A	± 0.03	0.11	± 0.12	0.03	± 0.05	0.10	± 0.01	0.17	± 0.14	0.07	± 0.04
Butanoic acid	AP	0.13	± 0.13	0.20*	± 0.02	0.12	± 0.05	0.08	± 0.04	0.05	± 0.03	0.13	± 0.11	0.07*	± 0.06	0.04	± 0.03	0.07	± 0.03	0.09	± 0.04
	Hi-O_2-MAP	0.32	± 0.43	0.16	± 0.04	0.07	± 0.01	0.06	± 0.09	0.06	± 0.05	0.32	± 0.23	0.11	± 0.12	0.06	± 0.01	0.03	± 0.03	0.20	± 0.11
	VP	0.05	± 0.06	0.16	± 0.02	0.12	± 0.10	0.09	± 0.05	0.26	± 0.18	0.05	± 0.06	0.16	± 0.02	0.06	± 0.01	0.08	± 0.06	0.12	± 0.05
Isovaleric acid	AP	0.03	± 0.02	0.07	± 0.02	0.22	± 0.12	0.05	± 0.05	0.23	± 0.06	0.03	± 0.02	0.04	± 0.03	0.14	± 0.11	0.06	± 0.05	0.43	± 0.35
	Hi-O_2-MAP	0.03	± 0.02	0.06	± 0.03	0.13	± 0.09	0.02	± 0.02	0.01	± 0.01	0.03	± 0.02	0.02	± 0.01	0.10	± 0.04	0.03	± 0.01	0.13	± 0.12
	VP	0.07	± 0.05	0.14	± 0.14	0.18	± 0.26	0.05	± 0.02	0.15	± 0.08	0.07	± 0.05	0.08	± 0.03	0.11	± 0.10	0.05	± 0.06	0.19	± 0.22
Hexanoic acid	AP	1.12	± 1.35	0.71	± 0.07	0.59	± 0.10	0.31	± 0.14	0.24	± 0.09	1.12	± 1.05	0.55	± 0.13	0.65	± 0.38	0.32	± 0.12	1.73	± 1.21
	Hi-O_2-MAP	1.11	± 0.8	0.56*	± 0.07	0.74	± 0.03	0.24	± 0.23	0.38	± 0.23	1.11	± 0.80	0.27*	± 0.16	0.83	± 0.73	0.43	± 0.28	0.84	± 0.68
	VP	0.67	± 0.23	3.15	± 2.53	0.50	± 0.33	0.60	± 0.30	0.66	± 0.35	0.67	± 0.23	0.38	± 0.20	1.16	± 0.49	0.66	± 0.30	0.72	± 0.66
Others																				
2.3-Octanedion	AP	0.05	± 0.06	0.16	± 0.04	0.22	± 0.28	0.06	± 0.02	0.08	± 0.07	0.05	± 0.06	0.14B	± 0.06	0.08	± 0.11	0.13	± 0.09	0.33	± 0.20
	Hi-O_2-MAP	0.23	± 0.22	0.06	± 0.04	0.05	± 0.01	0.24	± 0.39	0.09	± 0.10	0.23	± 0.22	0.01A	± 0.01	0.16	± 0.16	0.09	± 0.05	0.15	± 0.10
	VP	0.09	± 0.04	0.13	± 0.08	0.09	± 0.04	0.20	± 0.22	0.13	± 0.07	0.09	± 0.04	0.12B	± 0.03	0.10	± 0.02	0.07	± 0.05	0.22	± 0.19
Methanethiol caproate	AP	0.26	± 0.30	0.50	± 0.36	0.27	± 0.12	0.10	± 0.05	0.10	± 0.08	0.26	± 0.30	0.38	± 0.30	0.24	± 0.19	0.08A	± 0.02	0.44	± 0.30
	Hi-O_2-MAP	0.30	± 0.29	0.33	± 0.21	0.43	± 0.03	0.06	± 0.08	0.15	± 0.09	0.30	± 0.29	0.07	± 0.02	0.32	± 0.19	0.20AB	± 0.09	0.28	± 0.18
	VP	0.34	± 0.3	0.61	± 0.53	0.26	± 0.25	0.20	± 0.11	0.20	± 0.09	0.34	± 0.30	0.39	± 0.25	0.64	± 0.28	0.24B	± 0.06	0.62	± 0.64
n-Pentylfuran	AP	0.02	± 0.02	0.06	± 0.05	0.06	± 0.03	0.06	± 0.08	0.02	± 0.01	0.02	± 0.01	0.13B	± 0.10	0.03	± 0.02	0.09	± 0.07	0.11	± 0.07
	Hi-O_2-MAP	0.01	± 0.01	0.03	± 0.03	0.04	± 0.01	0.04	± 0.07	0.03	± 0.04	0.01	± 0.01	0.02A	± 0.02	0.04	± 0.02	0.05	± 0.01	0.04	± 0.04
	VP	0.05	± 0.04	0.08	± 0.07	0.08	± 0.02	0.02	± 0.03	0.03	± 0.03	0.05	± 0.04	0.07AB	± 0.06	0.08	± 0.03	0.03	± 0.03	0.13	± 0.11

Meaning of letters in result qualificators as in Table 1. Left: the cold-stored meat. Right: meat exposed in a display case (mean ± standard deviation).
[1]The results for the initial day 1 were included in both analyses for cold-stored and exposed meat.

quality stored under refrigeration (Saraiva et al., 2015). Hexanal and nonanal are 2 aldehydes associated with lipid oxidation (Ross and Smith, 2006; Lytou et al., 2018). Chicken meat contains relatively high levels of polyunsaturated fatty acids susceptible to oxidation (Kawahara et al., 2009; Brenes and Roura, 2010). Composition of fatty acids determines also the profile of aldehydes formed through oxidation of lipids. Hexanal is mainly a product of linoleic acid oxidation (Ayseli et al., 2014). It provides green and fatty character/aroma to different meat species, including chicken meat. Octanal and nonanal are associated with pleasant notes described as "floral" and "sweet" or "soapy" and "waxy" odor; however, these molecules are very undesirable above certain concentration threshold (Silva et al., 2017). According to Jayasen et al. (2013), 2,4-decadienal is a more essential odorant in chicken meat than hexanal because of its much lower odor threshold. Shares of that compound in the volatile compounds profiles found in this study were low regardless of the packaging technique and storage conditions, nevertheless it was detected in all our samples (Table 2).

N-pentanol, ethylhexanol, and oct-1-en-3-ol were the dominant alcohols identified in our samples (Table 3). Content of n-pentanol and oct-1-en-3-ol significantly ($P \leq 0.05$) changed during cold-storage of AP-packed meat; the highest content was found on day 3 of the storage. Changes ($P \leq 0.05$) of n-octanol were observed in VP-packed cold-stored packages. No isopentyl alcohol was found in the AP-packed meat on the first 3 days of cold-storage or exposition. However, isopentyl alcohol content reached its maximum on day 7 of exposure in the display case. Considerable fluctuations in the share of some alcohols in volatile compounds profile during meat storage period observed in this study were similar to results obtained by other authors. According to Casaburi et al. (2015) alcohols may produce off-odor in meat. In particular, 2-ethyl-1-hexanol is associated with resin, flower, and green odor. In turn, 1-octen-3-ol (unsaturated alcohol derived from linoleic acid oxidation) is regarded a key odorant because of its low odor threshold at the level of 0.001 mg/kg (Song et al., 2014). It is associated with mushroom, earthy, green, oily, vegetative, and/or fungal aroma of meat (Casaburi et al., 2015). These alcohols may produce dairy and/or mozzarella fermented cheese off-odors of meat stored in air and/or under vacuum (Casaburi et al., 2011). Jääskeläinen et al. (2016) reported that content of 1-octen-3-ol in MAP- and VP-packed beef meat was considerably fluctuating during 14- or 26-day-long storage period, respectively. According to Silva et al. (2017), short-chain alcohols can play a role of a meat microbial spoilage index. Casaburi et al. (2015) suggest that alcohols in chicken meat are most probably produced by *Pseudomonas* spp. Alcohols most commonly reported in spoiled meat include 3-methyl-1-butanol; 1-octen-3-ol; 2-ethyl-1-hexanol; 2,3-butanediol; butanol; 1-heptanol; 1-hexanol; and 3-phenoxy-1-propanol. These compounds have been found mainly in VP- and AP-packed meat, whereas 1-octen-3-ol was found also in MAP-packed meat. Some of these alcohols produce meat off-odor (Pothakos et al., 2015). On the other hand, Tait et al. (2014) claim that long-chain aliphatic alcohols are commonly associated with growth of *Enterobacteriaceae* family bacteria. Other compounds in meat stored under aerobic conditions such as aldehydes, ketones, and volatile fatty acids are reportedly associated with growth of both *Enterobacteriaceae* and *Pseudomonas* spp. (Casaburi et al., 2015). Compounds of the same types were also reported in VP-packed meat; however, in that case, their presence was associated with the growth of Enterobacteria (Casaburi et al., 2011).

Pentanoic acid, n-octanoic acid, and n-nonanoic acid were the dominant organic acids identified in our samples (Table 4). In general, no clear trend in evolution of their share in the volatile compounds profile was observed regardless of the storage conditions and meat packaging technique. Two exceptions were stated: content of propanoic/hexanoic acid in AP-packed and exposed meat sharply/moderately rose on day 8 of the storage, respectively. Volatile acids generally originate from lipolysis of triglycerides and phospholipids (del Olmo et al., 2014). They give rise to off-flavors such as rancid, sour, and woody odor, decreasing consumer interest in the product (Summo et al., 2010). Jääskeläinen et al. (2016) found that acetic and hexanoic acid dominated among acids produced in beef, and their content systematically increased in MAP- or VP-packed meat during 14 and 26 D of storage, respectively. Ayseli et al. (2014) found oleic acid as the major acid produced in chicken breast meat. According to authors, other acids encountered in different meat species include acetic acid (in raw chicken meat) and butanoic acid (in duck meat). Acetic acid, nonanoic acid, pentanoic acid, and octanoic acid were found in heat-treated chicken meat: cooked, fried, toasted, and roasted, respectively.

In general, no significant trend in time evolution of volatile compounds profiles and rather high variability of results regardless of the storage conditions and packaging technique (Tables 2–4) might reflect diversity of the research material.

Data in Tables 2–4 may be also used to compare the three tested meat packaging methods from the point of view of volatile compounds.

No effect ($P > 0.05$) of the used packaging technique (AP/Hi-O_2-MAP/VP) on the content of majority of aldehydes was found. A few exceptions have been found: higher content of hept-2-enal (day 7), n-heptanal (day 3), n-hexanal (day 7 and 8), and n-pentanal (day 7 and 8) was observed (respectively) in VP-packed meat than in AP- or Hi-O_2-MAP-packed meat; higher content of n-nonanal on day 6–8 in VP-packed and cold-stored meat than in AP- or Hi-O_2-MAP-packed meat; higher amounts of decanal in AP-packed meat on day 3 than in VP-packed meat; higher content of n-pentanal and n-hexanal on day 6 in VP-packed and exposed meat than in AP- or Hi-O_2-MAP-packed meat; higher content of 2-octen-1-al (day 3 and 6) and n-nonanal (day 3), in VP-packed and exposed meat than in Hi-O_2-MAP-

packed meat (Table 2). The obtained results confirm the thesis that hexanal, nonanal, decanal, tetradecanal, and benzaldehyde are aldehydes commonly found in naturally spoiled VP-packed meat (Casaburi et al., 2011).

Lower ($P \leq 0.05$) content of n-pentanol (day 7 and 8) and oct-1-en-3-ol (day 8) was found in AP- or Hi-O_2-MAP–packed and cold-stored meat than in VP-packed meat (Table 3). Higher ($P \leq 0.05$) content of n-hexan-1-ol (day 3) and ethylhexanol (day 7) was observed in AP-packed meat than in Hi-O_2-MAP–packed meat. Higher content of isopentyl alcohol (day 7), ethylhexanol (day 3), and n-hexan-1-ol (day 3) was found in AP-packed and exposed meat than in Hi-O_2-MAP–packed and exposed meat. Casaburi et al. (2015) reported 1-octen-3-ol as the most common alcohol found in naturally spoiled MAP-packed meat.

Higher content of n-octanoic acid (day 3), n-nonanoic acid (day 8), and propanoic acid (day 8) were found in AP-packed and cold-stored meat than in Hi-O_2-MAP–packed and cold-stored meat. For the exposed meat, one significant difference was observed on day 7: n-dodecanoic acid content was higher in AP-packed meat than in Hi-O_2-MAP- and VP-packed meat (Table 4). Jääskeläinen et al. (2016) found several volatile compounds (diacetyl, 1-octen-3-ol, hexanoic acid) in higher amounts in high oxygen MAP-packed beef than in VP-packed beef.

Within the given meat-packaging techniques (AP/Hi-O_2-MAP/VP), differences between content of majority of the identified volatile compounds for particular day of cold room storage vs. the same day of exposition in the display case were insignificant ($P > 0.05$) or equivocal (Tables 2–4).

CONCLUSIONS

Food spoilage results from complex processes combining metabolism of numerous microorganisms and numerous purely chemical reactions. At the beginning of the chicken fillets storage, bacteria of all major groups were growing at similar rates regardless of the used packaging technique (AP/Hi-O_2-MAP/VP). However, at the end of 8-D storage, the growth dynamic was different. The Hi-O_2-MAP packaging technique delayed growth of microflora in display case exposed meat above 7 log cfu/g by at least 1 D compared with the AP and/or VP technique. Profile of the volatile compounds most likely depends on fatty acid composition of the meat. Mainly aldehydes, alcohols, and organic acids were identified in the profile of volatile compounds isolated from the meat headspace. N-hexanal and n-nonanal were the dominating aldehydes; they result from lipid oxidation and some chemical processes catalyzed by the growing bacterial microflora. N-pentanol, ethylhexanol, and oct-1-en-3-ol were the dominating alcohols, whereas pentanoic acid, n-octanoic acid, and n-nonanoic acid were the dominating organic acids. Content of majority of the identified volatile compounds did not clearly depend on storage time, storage conditions, or packaging technique. No clear relation was identified probably because of a too large diversity of the research material. Future research scoped to identify correlations between meat spoilage and volatile compounds have to be based on standardized material with similar bacterial load and microbiome composition. In addition, further research in the chicken meat microbiome evolution during meat storage have to be performed to identify bacteria responsible for particular off-odor generation.

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