The effect of selected lactic acid bacterial strains on the technological and microbiological quality of mechanically separated poultry meat cured with a reduced amount of sodium nitrite

Beata Łaszkiewicz,*[,1] Piotr Szymański,* and Danuta Kołożyn-Krajewska[†]

*Department of Meat and Fat Technology, Prof. Waclaw Dabrowski Institute of Agricultural and Food Biotechnology, 02-532 Warsaw, Poland; and [†]Institute of Human Nutrition Sciences, Warsaw University of Life Sciences - SGGW, 02-787 Warsaw, Poland

ABSTRACT The aim of the research was to estimate the effect of selected lactic acid bacterial strains on the technological quality and microbiological stability of mechanically separated poultry meat (**MSPM**) cured with a reduced amount of sodium nitrite. The 5 different treatments of MSPM batters were prepared: C150 – control cured with sodium nitrite at 150 mg/kg, C50 – control cured with sodium nitrite at 50 mg/kg, PL1 – cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus plantarum* SCH1 at about 10^7 cfu/g, PL2 – cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus brevis* KL5 at about 10^7 cfu/g, and PL3 – cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g. The MSPM batters were tested at 1, 4 and 7 d of being in refrigerated storage. The scope of the research was as follows – physicochemical determinations: pH and redox, nitrates and nitrites as well as nitrosyl pigments levels, color estimation with a Comission Internationale de l'Eclairage Lab system and microbiological determinations: the total viable counts, the mesophilic lactic acid bacteria counts, *Escherichia coli* and *Enterobacteriaceae* counts. The inhibitory effect of *L. plantarum* SCH1 isolated from the ecological raw fermented meat product on *E. coli* in cured MSPM batters during refrigerated storage was proved ($P < 0.05$). The use of lactic acid bacterial strains in cured batters that were prepared and based on mechanically separated poultry meat did not have a negative effect on their technological quality. The positive effect of *L. brevis* KL5 on the level of nitrosyl pigments in the cured MSPM batters was observed ($P < 0.05$). The conducted research suggested the possibility of using the selected bacterial strains of the *Lactobacillus* genus to improve the microbiological quality of MSPM cured with a reduced amount of sodium nitrite.

Key words: mechanically separated poultry meat, curing, *Lactobacillus*, bioprotection

2021 Poultry Science 100:263–272
https://doi.org/10.1016/j.psj.2020.09.066

INTRODUCTION

In recent years, higher poultry meat consumption can be observed all over the world. It is forecasted that in 2020, global poultry meat production will reach a record level of 103.5 million tonnes and thus exceeding pork production (USDA, 2019). In Poland, the poultry slaughter market is currently the biggest of the remaining markets (e.g., pork, beef) (GUS, 2019). This increase in poultry meat production is accompanied by increased mechanically deboned poultry meat production and its use thereof in the meat industry (Froning and McKee, 2000). To obtain mechanically separated poultry meat (**MSPM**), high-pressure separators are used to destroy bone structure. As a result, such a raw material is of worse technological quality and lower stability compared with hand-deboned poultry meat (Stiebing, 2002; Viuda-Martos et al., 2012).

Mechanically separated meat is a cheaper product than hand-deboned meat and is commonly used in meat processing in Poland and worldwide. MSPM is mainly used in cooked or roasted meat products, canned meat, homogenized sausages and ready-to-eat products (Botka-Petrak et al., 2011). The MSPM chemical content is different from muscle tissue content. The raw

© 2020 Published by Elsevier Inc. on behalf of Poultry Science Association Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

Received April 24, 2020.

Accepted September 23, 2020.

[1]Corresponding author: beata.laszkiewicz@ibprs.pl

material obtained in the process of deboning has a high fat content (including phospholipids), high calcium, phosphorus, iron and heme pigments content (Daros et al., 2005; Botka-Petrak et al., 2011). Moreover, the bones used for MSPM production may contain a high number of microorganisms. The mechanically separated meat microflora may contain pathogenic bacteria, for example *Salmonella* spp., *Campylobacter* spp., *Escherichia coli*, *Listeria monocytogenes*, *Yersinia enterocolitica*, *Staphylococcus aureus*, as well as saprophytic bacteria, mainly the *Pseudomonas*, that accelerate meat spoiling (Gill, 2004; Daros et al., 2005; Ozkececi et al., 2008).

A lot of research has indicated some problems with microbiological MSPM quality. A total of 46 MSPM batches were tested within the studies performed in Poland, and *Salmonella* spp. was found in each batch of 25 g. In 59% of the MSPM samples, anaerobic spore bacteria were found in 0.01 g, whereas in 87% of the samples, *E. coli* bacteria were confirmed in 0.001 g. The coagulase-positive *Staphylococci* found in 0.1 g were confirmed in 76% of the meat samples (Pomykała and Michalski, 2008). In New Zealand, 145 MSPM samples from 3 meat plants were tested. The average amounts of *E. coli* in MSPM were 3.64 log cfu/g, average amounts of *Campylobacter* were 2.87 log cfu/g, and the coagulase-positive *Staphylococci* average were 2.72 log cfu/g (On et al., 2011).

To stabilize MSPM in the curing process, sodium nitrite is used in industrial practice. This method is used to stabilize fresh or defrosted MSPM. Curing plays an important role in forming the color and also contributes to the taste and flavor of products containing MSPM (Cammak et al., 1999; Majou and Christieans, 2018). Mechanically separated poultry meat is stabilized because of the bacteriostatic effect of nitrites added to MSPM at a certain level together with other substances, mainly with sodium chloride (Lücke, 2008; Sindelar and Milkowski, 2011). Most of all, sodium nitrite is an inhibiting factor to *Clostridium botulinum* growth and its toxin production (Sebranek and Bacus, 2007; Lücke, 2008; Sindelar and Milkowski, 2011). Nitrite has also a negative physiological effect on other bacteria such as *Salmonella enterica* serovar Typhimurium and *Listeria* spp. (Hospital et al., 2012; Majou and Christieans, 2018). An important nitrite function is also its antioxidative effect (Pegg and Shahidi, 2000).

The aforementioned facts legitimate the use of sodium nitrite as a preservative in the meat industry, but at the same time, its application has been raising concern for years. Sodium nitrite may be the precursor of nitrosamines, and many nitrosamines are considered to be carcinogenic (Pegg and Shahidi, 2000). European Union (**EU**) legislative solutions are aimed at limiting this ingredient in meat products (Commission Regulation (EU) No 257/2010). Some countries for example Denmark already have their own individual stricter regulations concerning the maximum level of sodium nitrite that is 60 mg/kg in some meat products, whereas in the EU, it is 150 mg/kg (Commission Decision (EU) 2018/702). Moreover, a significantly lower addition of sodium nitrite to MSPM batters may limit its stability. Thus, it is recommended and legitimate to look for new technological ways of enabling MSPM stabilization.

The lactic acid bacteria (**LAB**) are commonly used in meat processing to produce fermented sausages (Rubio et al., 2013). Lactic acid bacteria may be widely used in bioprotection because they may naturally dominate the microflora of many food products during their storage (Balciunas et al., 2013). Furthermore, the antimicroorganism effect of LAB is possible owing to its extracellular protein substances. To provide proper conditions for its growth, the bacteria produce many antimicroorganism substances released outside the cell. Apart from organic acids, hydrogen peroxide, diacetyl, and carbon dioxide, bacteria produce a wide variety of protein substances called bacteriocins that have a significant bactericidal and/or bacteriostatic effect (Rzepkowska et al., 2017a).

The LAB such as *Lactobacillus sakei, Pediococcus acidilactici,* and *Lactobacillus curvatus* are used to improve the stability and health security of raw meat products (Ammor and Mayo, 2007). In addition, there has been research performed on the use of various lactic acid bacterial strains for the bioprotection of steamed cured meat and poultry cutup carcass parts during storage (Bredholt et al., 2001; Enan, 2006; Perez-Chabela et al., 2008; Martinez-Romero et al., 2016). In addition, there were trials to use selected *Pediococcus* and *Lactobacillus* strains to improve the microbiological quality of uncured MSPM (Raccach and Baker, 1979; Łaszkiewicz et al., 2019). The authors did not find research on LAB use in cured MSPM produced with reduced amounts of sodium nitrite in the available bibliography.

The use of LAB in cured MSPM production with reduced amount of sodium nitrite may be an additional hurdle in the "hurdle technology" improving MSPM microbiological quality. However, an important aspect in the practical use of LAB as cured MSPM bioprotection may be also the bacteria effect on the technological quality that is color, pH, redox, and nitrosyl pigments concentration in MSPM. The aim of this research was to estimate the effect of selected lactic acid bacterial strains on the technological and microbiological quality of MSPM cured with a reduced amount of sodium nitrite.

MATERIAL AND METHODS

Lactic Acid Bacteria Strains and Culture Conditions

Three lactic acid bacterial strains were used within this research that is: *Lactobacillus plantarum* SCH1 isolated from the ecological raw fermented pork roast, *Lactobacillus brevis* KL5 isolated from ecological raw fermented sausage, and *L. plantarum* S21 isolated from organic whey. The ecological raw fermented meat products were produced by the Meat Processing Plant "Jasiołka" in Dukla in Poland, in which meat from local

organic farms is being processed. Whey was derived from milk from an organic farm in Podkarpackie region in Poland. Bacterial strains originated from microorganism collection owned by the Chair of the Food Hygiene and Quality Management at the Warsaw University of Life Sciences were selected and based on the research of Rzepkowska et al. (2017a,b). To properly revive and prepare bacterial strains for the study each time, the LAB culture was defrosted from stocks containing 20% of glycerol with storage at −80°C. Each bacteria culture was mixed, and 20 μL of each strain was added to the sterile test tubes with 5 mL of sterile MRS broth (Merck, Darmstadt, Germany). Test tubes were incubated for 24 h at a temperature of 37°C. Then, 1 mL of bacterial culture was taken after 24 h and moved to 9 mL of fresh sterile MRS broth (Merck, Darmstadt, Germany) and was subjected to reincubation in the same conditions. After that, the bacterial cultures were centrifuged (J2-21; Beckman, Birkerød, Denmark) (4,500 rpm, 2,313 × *g*), supernatant was removed, and bacteria were suspended in 0.9% NaCl solution. The bacterial biomass in this form was applied to MSPM batters. Finally, all of the procedures were performed in sterile conditions with the use of sterile equipment.

Preparing MSPM Batters

High-pressure MSPM was obtained by the deboning of unfrozen chicken carcasses in a separator (AM2C, Quimper, France) (whole diameter was 1 mm) in the conditions of the meat plant. The MSPM was divided into 10-kg blocks, frozen to −18°C, and stored at this temperature for 2 to 4 d. To produce batters, the MSPM blocks were defrosted in refrigerator conditions (4°C–6°C) for approximately 24 h.

The 5 different treatments of MSPM batters were prepared (Table 1): C150 – control cured with sodium nitrite at 150 mg/kg, C50 – control cured with sodium nitrite at 50 mg/kg, PL1 – cured with sodium nitrite at 50 mg/kg and inoculated *L. plantarum* SCH1 at about 10^7 cfu/g, PL2 - cured with sodium nitrite at 50 mg/kg and inoculated *L. brevis* KL5 at about 10^7 cfu/g, and PL3 – cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g. The batter ingredients were mixed for 3 min until they reached uniform consistency in the Hobart mixer (N-50G; Hobart Corporation, Troy, OH). The MSPM batters were canned in 190-g cans and kept for 7 d at a temperature of 4°C to 6°C to reduce microbiological pollution. All of the samples were tested at 24 h, 4 d, and 7 d of being stored. The experimental production of MSPM batters was performed in the half-technical hall of the Meat and Fat Technology Department in the Prof. Wacław Dąbrowski Institute of Agriculture and Food Biotechnology in Warsaw. The entire experiment was repeated 3 times.

Physical and Chemical Analyses

pH and Oxidative Reduction Potential Measurement Ten grams of MSPM batters was homogenized with 50 mL distilled water to determine the pH and oxidative reduction potential (**ORP**) using an 600-W blender (MSM 66120; BSH Hausgeräte GmbH, Munich, Germany) for 1 min at a speed equal to 14,000 rpm. Then, the digital pH-meter (Mettler Delta 350; Mettler Toledo, Schwerzenbach, Switzerland) was used to measure the pH value with an automatic compensation temperature, a glass-calomel electrode In Lab Cool (Mettler Toledo, Greifensee, Switzerland), and ORP value with an electrode In Lab Redox Pro (Mettler Toledo, Greifensee, Switzerland). The obtained result ORP value (mV) was calculated into the redox potential value in relation to the standard hydrogen electrode E_H (mv). To this end, the potential value of the reference electrode at a temperature of 20°C (207 mV) was added to the readout value obtained with the equipment.

Sodium Nitrate and Nitrite Content The nitrate and nitrite level was determined as per PN-EN 120414:2006 changed by Siu and Henshall (1998). To perform the test, a liquid chromatograph (Agilent Technologies, Waldbronn, Germany) with a UV detector with an IonPac AS11-HC 4 × 250 mm analytical column (Thermo Fisher Scientific, Sunnyvale, CA) and precolumn AG11-HC 4 × 50 mm (Thermo Fisher Scientific, Sunnyvale, CA) was used. The nitrate and nitrite content in the tested samples was expressed as $NaNO_3$ and $NaNO_2$ salts content in mg/kg.

Color Determination The spherical spectrophotometer Minolta (CR-300; Konica Minolta, Tokyo, Japan) with a measuring hole diameter of 25.4 mm was used to determine the color parameters. The trio-chromatic

Table 1. The composition of model MSPM cured batters.

Ingredients/experimental treatment	C150	C50	PL1	PL2	PL3
Mechanically separated poultry meat (kg)	10	10	10	10	10
Salt (kg)	0.2	0.2	0.2	0.2	0.2
Sodium nitrite (kg)	0.0016	0.00053	0.00053	0.00053	0.00053
Bacterial biomass in NaCl solution 0.9% (kg)	-	-	0.476	0.476	0.476
NaCl solution 0.9% (kg)	0.476	0.476	-	-	-

Abbreviations: C150, control cured with sodium nitrite at 150 mg/kg; C50, control cured with sodium nitrite at 50 mg/kg; MSPM, mechanically separated poultry meat; PL1, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus plantarum* SCH1 at about 10^7 cfu/g; PL2, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus brevis* KL5 at about 10^7 cfu/g; PL3, cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g.

coordinates were settled in a Comission Internationale de l'Eclairage system L* a* b*, where L* is for color brightness, a* for chromaticity in the range of red and green, and b* chromaticity in the range of yellow and blue. The standard Comission Internationale de l'Eclairage observatory was used at measurements: 2°, illuminant D65, 8 mm measuring area. The reference source was the white standard (L* = 95.87, a* = −0.49, b* = 2.39). For each of the 3 repeats of the treatment (C150, C50, PL1, PL2, PL3), 5 measurements were carried out.

Nitrosyl Pigments Content Analysis The nitrosyl pigment content was determined with the Hornsey Method (1956). The absorbance of filtrate values was measured using a spectrophotometer (U-2900; Hitachi, Tokyo, Japan), and the nitrosyl pigment content was measured in hematin ppm.

Microbiological Analysis The scope of the microbiological studies of cured MSPM batters was determined based on the preliminary tests. The preliminary tests included a microbiological analysis of an averaged sample of 3 batches of MSPM used in experiment. The range and methodology of the microbiological tests are described in the following text.

Ten grams of samples were taken for quantity laboratory measurements, and 25 g samples were taken for quality laboratory measurements. The sample after mixing was suspended in 100 mL of peptone water, then diluted many times and placed for growing on different culture media.

The presence of *Salmonella* spp. in 25 g of the product was determined using Müller-Kauffman's medium with tetrathionate and novobiocin (Oxoid Ltd., Basingstoke, Hampshire, England), RVS (medium in accordance with Rappaport-Vassiliadis with soya) (Oxoid Ltd., Basingstoke, Hampshire, England), xylose lysine deoxycholate medium (Oxoid Ltd., Basingstoke, Hampshire, England), and chromogenic medium Rambach (37°C for 24 h) (Merck KGaA, Darmstadt, Germany).

The presence of *Campylobacter* spp. in 25 g of the product was determined using a rapid serological test Singlepath Campylobacter (Merck KGaA, Darmstadt, Germany). Incubation was carried out on Bolton broth medium (Oxoid Ltd., Basingstoke, Hampshire, England) in a microaerophilic atmosphere (5% O_2, 10% CO_2, and 85% N_2) initially at 32°C for 4 h and then at 41.5°C for 44 h.

The number of the total viable counts (**TVC**) (30°C for 48 h) was determined on plate count agar medium (Oxoid Ltd., Basingstoke, Hampshire, England).

The mesophilic LAB counts (30°C for 48 h) was determined on MRS medium (Merck KGaA, Darmstadt, Germany).

E. coli counts (44°C for 18–24 h) was determined using agar TBX medium (Oxoid Ltd, Basingstoke, Hampshire, England).

Enterobacteriaceae counts (37°C for 24 h) were determined on VRBD medium (Merck KGaA, Darmstadt, Germany).

The coagulase-positive *Staphylococci* counts (37°C for 18–24 h) were determined on RPF medium (Oxoid Ltd., Basingstoke, Hampshire, England).

The number of bacteria was expressed as log10 of cfu per gram of MSPM (log cfu/g). If the presence of the given microorganisms was not detected in the MSPM, no further tests were taken during storage. Microbiological tests were performed on MSPM batters after the first, fourth, and seventh day of storage at the temperature of 4°C.

Statistical Analysis The experiment was carried out in 3 replications (n = 3) at different times, and a completely randomized design was used. All observations composing the experiment (5 treatments × 3 batches × 3 storage periods) were included in the statistical analysis. The results obtained in the research were statistically analyzed using the two-way ANOVA. The model included the treatment effect (LAB addition) of the time of storage (1, 4, 7 d) and their interaction (LAB addition x time of storage). The Bonferroni post hoc test was used to determine the significance of the mean values for a multiple comparison at $P < 0.05$. The Statistica package, version 13 (StatSoft Polska Sp. z o.o, Cracov, Poland), was used for the calculations.

RESULTS AND DISCUSSION

pH and ORP

The LAB treatment and storage time affected ($P < 0.001$) the pH value. Interaction between LAB addition and storage time for pH also was found (Table 2). The addition of LAB to the MSPM batters resulted in little but significant ($P < 0.05$) differences in the batter acidity and were observed between experimental treatment after the first day of storage (Table 2). The highest pH value was reported after the first day of storage in the PL2 treatment with the addition of *L. brevis* KL5 ($pH_1 = 6.99$). In the remaining experimental treatments, the pH value was at a similar level (6.91–6.94). The acidity of the MSPM batters was higher with a longer refrigerated storage time ($P < 0.05$). The pH changes dynamics, which was similar in all of the experimental treatment (Table 2). The increase of the acidity was probably related to the metabolic activity of the added LAB or wild bacterial cultures present in MSPM (Ha et al., 2003). The LAB may ferment sugars into lactic acid or other organic acids (Balciunas et al., 2013). After 7 d of storing, the pH value of the MSPM batters did not differ significantly ($P > 0.05$) (Table 2). Taking into consideration the small differences between the pH values of the different treatment in all of the 3 storing periods (0.02–0.08), it can be assumed they had no effect on the water-holding capacity of the meat.

The chemical content of MSPM is different from hand-deboned meat. Mechanically separated poultry meat has a higher fat and collagen content and also lower water activity than hand-boned meat (Mayer et al., 2007). It can be assumed that the LAB environment

Table 2. The effect of lactic acid bacteria and refrigerated storage time on the pH and oxidative reduction potential of MSPM cured batters (average value ± SE).

Treatment	Storage time (day) 1	4	7	LAB treatment P	Time P	LAB treatment x time P
pH						
C150	6.94 ± 0.01^{c,d}	6.77 ± 0.01^{b}	6.66 ± 0.02^{a}	**	**	*
C50	6.92 ± 0.01^{c}	6.76 ± 0.01^{b}	6.64 ± 0.01^{a}			
PL1	6.92 ± 0.01^{c}	6.76 ± 0.01^{b}	6.65 ± 0.01^{a}			
PL2	6.99 ± 0.01^{d}	6.78 ± 0.02^{b}	6.68 ± 0.01^{a}			
PL3	6.91 ± 0.01^{c}	6.76 ± 0.01^{b}	6.70 ± 0.01^{a}			
ORP [mV]						
C150	311.8 ± 2.3^{a,b,c}	326.6 ± 0.8^{d,e}	305.6 ± 1.0^{a}	**	**	**
C50	319.7 ± 1.9^{b,c,d,e}	328.1 ± 3.0^{d,e}	321.3 ± 5.6^{b,c,d,e}			
PL1	320.2 ± 2.2^{b,c,d,e}	323.6 ± 1.6^{c,d,e}	332.9 ± 3.2^{e}			
PL2	308.9 ± 0.9^{a,b}	315.2 ± 1.6^{a,b,c,d}	327.5 ± 1.8^{d,e}			
PL3	318.3 ± 2.9^{a,b,c,d}	318.4 ± 1.0^{a,b,c,d}	327.2 ± 1.7^{d,e}			

[a–e]Means with different superscript small letters differ significantly ($P < 0.05$).
n = 3.
P: significance of effects; LAB treatment; time; LAB treatment-time interaction.
*$P < 0.01$; **$P < 0.001$.
Abbreviations: C150, control cured with sodium nitrite at 150 mg/kg; C50, control cured with sodium nitrite at 50 mg/kg; MSPM, mechanically separated poultry meat; PL1, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus plantarum* SCH1 at about 10^7 cfu/g; PL2, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus brevis* KL5 at about 10^7 cfu/g; PL3, cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g.

was unfavorable for its growth. In addition, a relatively low sugar content in MSPM could affect the limited production of some metabolites including lactic acid by applied LAB (Ha et al., 2003).

The significant ($P < 0.001$) influence of LAB treatment and storage time on the redox potential value was observed. In addition, interaction between LAB addition and storage time for redox potential was found (Table 2). There were no significant differences ($P > 0.05$) in ORP values between treatment at the first and fourth day of storage time. The significantly ($P < 0.05$) lowest ORP value was observed in C150 treatment after 7 d of being stored.

In the control treatment C50 ($NaNO_2$ 50 mg/kg), the redox potential value oscillated within 319.7–328.1 mV. In the control treatment C150 ($NaNO_2$ 150 mg/kg), the redox potential after 4 d of storage increased from 311.8 mV to 326.6 mV and then decreased by 21.0 mV after 7 d of being stored, reaching the lowest value of all of the treatments. Sodium nitrite is highly antioxidative (Sebranek, 2009), so it could be assumed that adding more $NaNO_2$ caused a decrease of the redox potential of the MSPM batters after 7 d of storage.

In the treatments with the addition of LAB (PL1, PL2, PL3), an increase in ORP value during storage was observed. However, significant ($P < 0.05$) differences in ORP values during storage were found only for the PL2 treatment (Table 2).

In the research by Libera et al. (2015), the addition of *Bifidobacterium* BB12 did not affect the redox potential of dry-cured pork necks. It could be assumed that metabolites produced by the probiotic strains protect lipids from oxidation during refrigerated storage (Libera et al., 2015). In the case of MSPM in which the muscle tissue was crushed during deboning and the lipids were partially oxidized, damaged tissues were much more prone to oxidation (Stiebing, 2002). Moreover, MSPM is of higher heme pigment content than hand-deboned meat (Daros et al., 2005). Thus, heme pigments may initiate lipid oxidation processes, and lipid oxidation products contribute to pigment oxidation (Skibsted, 1996; Faustman et al., 1999).

Sodium Nitrate and Nitrite Content

The LAB treatment and storage time affected ($P < 0.001$) $NaNO_2$ content. Interaction between LAB addition and storage time for $NaNO_2$ content was found (Table 3). It was confirmed that $NaNO_2$ content in the experimental treatments decreased during storage (Table 3), and this fact indicated the reaction of added nitrites with heme pigments and other MSPM ingredients (Honikel, 2008). The sodium nitrite content in MSPM treatments cured at 50 mg/kg (C50, PL1, PL2, PL3) was similar after the first and fourth day of storage (Table 3). After 1 d of storage, sodium nitrite in the experimental treatments varied from 35.6 to 40.4 mg/kg, whereas after 4 d of storage, it ranged from 28.2 to 30.1 mg/kg. After 7 d of storage, the significantly ($P < 0.05$) lowest $NaNO_2$ content (18.8 mg/kg) was reported in MSPM with *L. brevis* KL5 (PL2). The nitrites may be reduced by some bacterial strains of the *Lactobacillus* genus in the process called fermentation nitrate reduction (Hammes, 2012). In the control treatment C150, it was reported that after 4 d of being stored, the sodium nitrite content was significantly lower and reached 112.6 mg/kg, whereas after 7 d, it increased up to 122.0 mg/kg ($P < 0.05$). The higher nitrites content after 7 d may be caused by the reduction of nitrates by bacteria in the dismutation reaction (Honikel, 2008; Hammes, 2012). The effectiveness of the meat curing process depends on many factors including meat

Table 3. The effect of lactic acid bacteria and refrigerated storage time on $NaNO_2$ and $NaNO_3$ as well as nitrosyl pigment levels in MSPM cured batters (average value ± SE).

	Storage time (day)			LAB treatment	Time	LAB treatment x time
Treatment	1	4	7	P	P	P
$NaNO_2$ [mg/kg]						
C150	131.2 ± 1.7^{i}	112.6 ± 2.1^{g}	122.0 ± 0.4^{h}	**	**	**
C50	35.6 ± 1.4^{e,f}	28.2 ± 0.9^{b,c,d}	22.7 ± 1.2^{b,c}			
PL1	40.4 ± 1.3^{f}	28.4 ± 0.2^{c,d}	25.2 ± 0.3^{b,c,d}			
PL2	38.1 ± 0.4^{f}	30.1 ± 1.6^{d,e}	18.8 ± 0.6^{a}			
PL3	36.2 ± 1.2^{e,f}	29.1 ± 1.5^{d}	22.0 ± 0.2^{b}			
$NaNO_3$ [mg/kg]						
C150	15.5 ± 0.7^{b,c,d}	27.8 ± 0.7^{e}	15.4 ± 0.3^{b,c,d}	**	**	**
C50	14.7 ± 0.4^{b,c}	18.9 ± 0.4^{d}	7.3 ± 0.7^{a}			
PL1	14.6 ± 1.0^{b,c}	17.5 ± 0.5^{c,d}	9.0 ± 1.4^{a}			
PL2	14.9 ± 0.5^{b,c}	19.1 ± 0.4^{d}	7.7 ± 1.0^{a}			
PL3	13.4 ± 0.5^{b}	15.1 ± 0.9^{b,c,d}	7.7 ± 0.6^{a}			
Nitrosyl pigments [ppm hematin]						
C150	59.45 ± 3.70^{a,b}	n.a.	82.94 ± 3.46^{b,c,d}	**	**	**
C50	62.21 ± 0.12^{a,b}	n.a.	85.98 ± 2.72^{b,c,d}			
PL1	78.49 ± 5.7^{b}	n.a.	103.82 ± 3.31^{c}			
PL2	48.29 ± 1.54^{a}	n.a.	127.31 ± 4.74^{e}			
PL3	108.46 ± 3.79^{d,e}	n.a.	126.44 ± 8.52^{e}			

$^{a–i}$Means with different superscript small letters differ significantly ($P < 0.05$).
n = 3.
P: significance of effects; LAB treatment; time; LAB treatment-time interaction.
$^{**}P < 0.001$.
Abbreviations: C150, control cured with sodium nitrite at 150 mg/kg; C50, control cured with sodium nitrite at 50 mg/kg; MSPM, mechanically separated poultry meat; n.a., not applicable; PL1, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus plantarum* SCH1 at about 10^7 cfu/g; PL2, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus brevis* KL5 at about 10^7 cfu/g; PL3, cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g.

composition (Honikel, 2008). High-fat and collagen protein content in MSPM (Botka-Petrak et al., 2011) may obstruct the nitrogen oxide access to heme pigments and affect the final curing result (Mancini and Hunt, 2005).

The significant ($P < 0.001$) influence of LAB treatment and storage time on $NaNO_3$ content in MSPM batters was observed. Interaction between LAB addition and storage time for $NaNO_3$ content was found (Table 3). After 1 d of storage, the nitrate content in

Table 4. The effect of lactic acid bacteria and refrigerated storage time on the colour parameters L* a* b* of MSPM cured batters (average value ± SE).

	Storage time (day)			LAB treatment	Time	LAB treatment x time
Treatment	1	4	7	P	P	P
L*						
C150	52.56 ± 0.16^{d,e,f}	51.45 ± 0.34^{c,d}	49.84 ± 0.29^{a,b}	**	**	**
C50	49.65 ± 0.28^{a}	51.88 ± 0.26^{c,d,e}	50.40 ± 0.33^{a,b,c}			
PL1	53.95 ± 0.33^{f}	50.86 ± 0.39^{a,b,c}	51.25 ± 0.31^{b,c,d}			
PL2	50.59 ± 0.25^{a,b,c}	49.54 ± 0.46^{a}	50.39 ± 0.29^{a,b,c}			
PL3	53.29 ± 0.23^{e,f}	50.74 ± 0.34^{a,b,c}	49.68 ± 0.17^{a,b,}			
a*						
C150	13.78 ± 0.44^{b,c}	13.86 ± 0.63^{b,c}	22.00 ± 1.17^{e,f}	*	**	**
C50	12.90 ± 1.23^{a,b}	14.47 ± 0.69^{c}	21.18 ± 1.15^{d,e,f}			
PL1	12.61 ± 0.37^{a,b}	14.51 ± 0.75^{c}	20.43 ± 2.34^{d}			
PL2	12.79 ± 0.67^{a,b}	14.33 ± 1.32^{c}	22.51 ± 1.30^{f}			
PL3	12.24 ± 0.34^{a}	14.65 ± 0.48^{c}	20.93 ± 1.07^{d,e}			
b*						
C150	8.88 ± 0.81^{b,c,d}	8.53 ± 0.58^{a,b,c}	8.40 ± 0.46^{a,b,c}	N.S.	**	*
C50	8.85 ± 0.82^{b,c,d}	8.34 ± 0.60^{a,b,c}	8.29 ± 0.40^{a,b}			
PL1	9.48 ± 0.56^{d}	8.20 ± 0.67^{a,b}	8.04 ± 0.47^{a,b}			
PL2	9.18 ± 0.85^{c,d}	8.22 ± 0.82^{a,b}	8.63 ± 0.49^{a,b,c}			
PL3	9.52 ± 0.47^{d}	8.26 ± 0.53^{a,b}	7.96 ± 0.71^{a}			

$^{a–f}$ Means with different superscript small letters differ significantly ($P < 0.05$).
n = 3.
P: significance of effects; LAB treatment; time; LAB treatment-time interaction.
$^{*}P < 0.01$; $^{**}P < 0.001$.
Abbreviations: C150, control cured with sodium nitrite at 150 mg/kg; C50, control cured with sodium nitrite at 50 mg/kg; MSPM, mechanically separated poultry meat; N.S., not significant; PL1, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus plantarum* SCH1 at about 10^7 cfu/g; PL2, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus brevis* KL5 at about 10^7 cfu/g; PL3, cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g.

all of the experimental treatments was similar (13.4–15.5 mg/kg). After 4 d, an increase in $NaNO_3$ content in all treatments was found; however, significant ($P < 0.05$) differences were observed in C150, C50, and PL2 treatments (Table 3). The significantly ($P < 0.05$) highest nitrate content confirmed in the C150 (27.8 mg/kg) and the lowest content in the PL3 (15.1 mg/kg). The nitrate increase in the treatments was caused by the dismutation of nitric acid produced from nitrites added to the MSPM and the secondary responses of nitric oxide produced in the reaction (Honikel, 2008). The $NaNO_3$ content in each treatment significantly ($P < 0.05$) diminished after 7 d of being stored. The highest nitrate level was confirmed in the C150 treatment (15.4 mg/kg). In other treatments, nitrate content was at a similar level (7.3–9.0 mg/kg). Nitrate reduction in MSPM could run by the involvement of bacterial enzymes (Honikel, 2008). Furthermore, some bacterial strains of the *Lactobacillus* genus are able to biochemically transform nitrogen into nitric oxide with the use of nitrite reductase in both anaerobic and aerobic conditions (Xu and Verstraete, 2001).

Determination of Color

The LAB addition and storage time affected ($P < 0.001$) lightness (L*) in the tested MSPM batters. Interaction between LAB treatment and storage time was found for L* parameter (Table 4). The obtained results point out that the addition of LAB has a significant ($P < 0.05$) effect on the lightness of the MSPM batters at the beginning of the experiment (1 d). After 7 d of refrigerated storage, the increase of the L* parameter compared with day 4 was reported in the PL1 and PL2 treatments. In the research of Zhang et al. (2018) also, the influence of *L. sakei* and *L. curvatus* on the color brightness (L*) increases in vacuum-packed raw beef after cold storage was observed.

The LAB addition did not significantly affect the b* parameter value. The storage time affected ($P < 0.001$) the b* parameter. Interaction between LAB treatment and storage time for the b* parameter was found (Table 4). After 4 d, the significant ($P < 0.05$) decrease of the b* parameter was observed in all treatments with the LAB addition. After 7 d of storage, decrease of the b* parameter was observed in all treatments, except for the PL2 treatment with *L. brevis* KL5, which presented an increase of the b* parameter (8.63). In the research of Kim et al. (2014), the increase of L* and b* values was observed in chicken breast with LAB added.

The significant influence of LAB treatment ($P < 0.01$) and storage time ($P < 0.001$) on redness (a*) was observed. Interaction between LAB treatment and storage time was found for the a* parameter (Table 4). At the beginning of storage (1 d), the highest a* value was observed in the C150 treatment. The highest red color share in the color tone after 7 d of storage was observed in the PL2 treatment. The LAB effect on the a* parameter increase was also reported by Zhang et al. (2018) in raw beef after 38 d of being stored ($P < 0.05$). The a* value increased significantly ($P < 0.05$) in all of the experimental treatments during storing. The higher share of red color was caused by the overcuring of meat and the growing amount of nitrosyl derivatives of heme pigments in the MSPM batters (Tables 3 and 4).

Nitrosyl Pigments Content

The LAB treatment and storage time affected ($P < 0.001$) nitrosyl pigment content. Interaction between LAB addition and storage time for nitrosyl pigments content was also found (Table 3). One of the factors determining the speed and efficiency of the curing process is the concentration of hydrogen ions. Lower pH influenced the reaction process between the heme pigments (Mancini and Hunt, 2005; Faustman et al., 2010). After 7 d of storage, the nitrosyl pigment levels increased in all of the experimental treatments ($P < 0.05$). It was confirmed that nitrosyl pigment content in the MSPM batters after storage was the highest ($P < 0.05$) in treatments PL2 and PL3 with the addition of LAB (Table 3). In the case of the PL2 treatment, the high nitrosyl pigment level could be caused by a low $NaNO_2$ level after 7 d of storage. This fact indicated the intensive reaction of heme pigments with sodium nitrite (Sebranek and Bacus, 2007; Sindelar and Milkowski, 2011. The treatment with *L. brevis* KL5 showed the lowest ORP value after 1 and 4 d of storage, among all of the experimental treatments (Table 2). The higher reduction potential of the MSPM environment could affect sodium nitrite reduction and thus produces more nitrogen oxide. Nitrogen oxide may react with MSPM heme proteins resulting in producing a complex NO myoglobin (Honikel, 2008).

The PL3 treatment was a similar ORP value to the control treatment (C50). This fact indicated the similar reduction potential of the MSPM batters environment (Table 2). It suggested that the mechanism behind the higher amount of nitrosyl pigments in the PL3 treatment was different (Table 3). Some lactic acid bacterial strains may produce nitrogen oxide in the L-arginine synthesis reaction (Zhang et al., 2007; Li et al., 2016). Nitrogen oxide produced in this way was observed in both environments with and without nitrites (Morita et al., 1997; Christensen et al., 1999).

Microbiological Analysis

Microbiological Analysis of MSPM In the preliminary tests, the TVC in MSPM was determined reaching 6.30 log cfu/g. A similar TVC level of 5.86 log cfu/g in MSPM was reported by Hać-Szymańczuk et al. (2014). In the research of On et al. (2011), the TVC in MSPM was observed at a higher level reaching 7.26 log cfu/g. Relatively high MSPM microbiological pollution is caused by fine meat grinding, decomposition of tissue structure, and aeration during the separation process,

Table 5. The effect of lactic acid bacteria and refrigerated storage time on the microbiological quality of MSPM cured batters (average value ± SE).

Treatment	Storage time (day) 1	4	7	LAB treatment P	Time P	LAB treatment x time P
Total viable counts, [log cfu/g]						
C150	6.91 ± 5.57[a,b]	7.19 ± 6.16[a,b,c]	8.42 ± 7.34[i]	**	**	**
C50	6.61 ± 5.45[a]	7.40 ± 6.32[a,b,c]	8.12 ± 7.22[g,h]			
PL1	7.80 ± 6.08[c,d,e]	7.91 ± 6.16[d,e,f]	8.20 ± 7.00[h]			
PL2	7.71 ± 7.20[b,c,d,e]	7.68 ± 6.16[a,b,c,d,e]	8.07 ± 6.52[f,g,h]			
PL3	7.36 ± 5.76[a,b,c]	7.62 ± 5.95[a,b,c,d]	7.97 ± 6.70[e,f,g]			
Mesophilic lactic acid bacteria counts, [log cfu/g]						
C150	4.26 ± 2.52[a]	4.26 ± 2.52[a]	4.10 ± 2.52[a]	**	**	**
C50	4.20 ± 2.76[a]	3.82 ± 2.53[a]	4.10 ± 2.95[a]			
PL1	7.71 ± 6.37[d]	7.65 ± 6.31[d]	7.87 ± 6.76[e]			
PL2	7.48 ± 5.52[c]	7.33 ± 5.82[b,c]	7.30 ± 5.76[b]			
PL3	7.19 ± 5.52[b]	7.17 ± 5.52[b]	7.16 ± 5.95[b]			
Escherichia coli counts, [log cfu/g]						
C150	2.07 ± 0.52[d]	<1.00[a]	<1.00[a]	**	**	**
C50	2.14 ± 0.82[d]	1.67 ± 0.52[b,c]	<1.00[a]			
PL1	<1.00[a]	<1.00[a]	<1.00[a]			
PL2	1.82 ± 0.95[c]	1.80 ± 0.52[c]	<1.00[a]			
PL3	<1.00[a]	1.65 ± 1.18[b]	<1.00[a]			
Enterobacteriaceae counts, [log cfu/g]						
C150	3.68 ± 2.40[a]	4.62 ± 3.58[a]	5.39 ± 4.46[a]	**	**	**
C50	3.78 ± 2.16[a]	5.14 ± 3.95[a]	6.65 ± 5.16[d]			
PL1	4.19 ± 2.82[a]	5.23 ± 3.76[a]	6.48 ± 5.54[c]			
PL2	3.79 ± 2.71[a]	5.23 ± 3.76[a]	6.50 ± 5.16[c]			
PL3	3.63 ± 3.13[a]	5.32 ± 4.08[a]	6.33 ± 5.25[b]			

[a–i]Means with different superscript small letters differ significantly ($P < 0.05$).

n = 3.

P: significance of effects; LAB treatment; time; LAB treatment-time interaction.

** $P < 0.001$.

Abbreviations: C150, control cured with sodium nitrite at 150 mg/kg; C50, control cured with sodium nitrite at 50 mg/kg; MSPM, mechanically separated poultry meat; PL1, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus plantarum* SCH1 at about 10^7 cfu/g; PL2, cured with sodium nitrite at 50 mg/kg and inoculated *Lactobacillus brevis* KL5 at about 10^7 cfu/g; PL3, cured sodium nitrite at 50 mg/kg and inoculated *L. plantarum* S21 at about 10^7 cfu/g.

which contributes to microorganism increase (Pomykała and Michalski, 2008).

In the tested MSPM, *E. coli* was at the 2.04 log cfu/g level, whereas *Enterobacteriaceae* reached 3.83 log cfu/g. *E. coli* counts observed in the MSPM crossed the limit of 1.6 log cfu/g settled as a criterium for a hygienic MSPM production process in EU Regulation 2073/2005. However, this parameter was settled for MSPM produced with a "low pressure" technique. In the research of other authors, *E. coli* in MSPM varied from 3.54 to 3.72 log cfu/g (On et al., 2011). *Enterobacteriaceae* counts in the MSPM ranged between 3.3 and 5.6 log cfu/g (Bijker et al., 1987; Hać-Szymańczuk et al., 2014).

The number of coagulase-positive *Staphylococci* in the MSPM was <10 log cfu/g. No *Salmonella* sp. or *Campylobacter* spp. in 25 g samples was detected (data are not presented in the table). The research of Hać-Szymańczuk et al. (2014) also did not confirm the presence of *Salmonella* spp. in 25 g MSPM samples. Other authors relatively commonly reported the presence of *Salmonella* sp. and *Campylobacter* spp. in MSPM (Pomykała and Michalski, 2008; On et al., 2011).

Microbiological Analysis of Cured MSPM Batters During Refrigerated Storage The LAB treatment and storage time affected ($P < 0.001$) the number of TVC, LAB, *E. coli*, and *Enterobacteriaceae* in the tested MSPM batters. Interaction between LAB addition and storage time for all microbiological analyses was found (Table 5). The significant ($P < 0.05$) increase of the TVC in MSPM batters was observed with the storage time. At the beginning of storage, the TVC of the treatments with LAB was higher because of bacteria addition, but after 7 d of storage, the TVC in treatments with LAB (PL2 and PL3) was lower than that in the control treatments C150 and C50 (Table 5). It may prove the inhibitory effect of LAB on other bacteria present in the MSPM batters.

The number of mesophilic LAB during the whole storage time was at a similar level in all of the experimental treatments with LAB addition (7.19–7.71 log cfu/g). The significant ($P < 0.05$) higher number of LAB in whole storage period was observed in treatments with LAB addition (Table 5). After 7 d of storage, it was significant ($P < 0.05$) that the highest number of LAB in the PL1 treatment was observed.

The significant ($P < 0.05$) inhibitory effect of *L. plantarum* SCH1 (PL1) on *E. coli* in the MSPM batters during the whole time of being stored was confirmed (Table 5). In the model research of Rzepkowska et al. (2017a), the inhibitory effect of *L. plantarum* SCH1 and *L. brevis* KL5 on *E. coli, Salmonella* Enteritidis, *L. monocytogenes, and Pseudomonas fluorescens* was proved. It can be assumed that LAB produced metabolites that hindered *E. coli* growth. Gong et al. (2010)

reported the inhibiting effect of bacteriocin (plantaricin MG) produced by *L. plantarum* on *E. coli*, *S. aureus*, *L. monocytogenes,* and *Salmonella* Typhimurium growth. The antagonistic LAB influence on gram-negative pathogens may be also caused by organic acids and hydrogen peroxide production (Laslo et al., 2019). In the C50 treatment, the *E. coli* counts after 1 and 4 d of storage was 2.14 and 1.67 log cfu/g, respectively. It proved that the $NaNO_2$ dose (50 mg/kg) was not sufficient to hinder the growth of this bacteria. The inhibiting effect of *E. coli* growth after 4 and 7 d of storage was observed in the C150 treatment with the maximum $NaNO_2$ content (150 mg/kg). In the previous research performed on uncured MSPM batters, the inhibiting effect of *L. plantarum* SCH1 on *E. Coli* was also observed. Nevertheless, the *E. coli* inhibiting effect was not as strong. A gradual reduction of *E. coli* counts from 2.28 log cfu/g (after 1 d of storage) to 1.94 log cfu/g (7 d of storage) was observed (Łaszkiewicz et al., 2019). The reported results indicate the synergy of a reduced amount of sodium nitrite (50 mg/kg) with *L. plantarum* SCH1 on *E. coli* in MSPM.

After 7 d of cold storage, the TVC in all of the experimental variants varied from 7.97 to 8.42 log cfu/g. The MSPM batters were already spoiled. After this duration, the *E. coli* counts in all of the treatments was lower than 1 log cfu/g. In all of the experimental treatments, the *Enterobacteriaceae* count increase was observed. It could be assumed that the reason for a lower *E. coli* count was the domination of the meat environment by other bacteria (including other bacteria from the *Enterobacteriaceae* family). Bacteria growth strictly depended on environmental conditions and nutrient availability that is essential for their growth (Teusink and Molenaar, 2017). The significant growth of *Enterobacteriaceae* after 7 d of storage was also observed in uncured MSPM with LAB (Łaszkiewicz et al., 2019). Hać-Szymańczuk et al. (2014) observed the increase of *Enterobacteriaceae* counts regardless of the MSPM stabilization method.

CONCLUSIONS

The application of the selected lactic acid bacterial strains did not have a negative effect on MSPM technological quality. The addition of LAB could be an effective alternative to the use of high amounts of sodium nitrite (150 mg/kg) for MSPM batters production. The inclusion of LAB improved the microbiological quality of MSPM batters. A significant inhibitory effect in terms of *E. coli* counts reduced by *L. plantarum* SCH1 was observed throughout the storage period. The conducted research suggests the possibility of using the selected bacterial strains of the *Lactobacillus* genus to improve the microbiological quality of MSPM cured with a reduced amount of sodium nitrite. However, research on the sensory quality and physicochemical parameters of products being produced with MSPM inoculated *L. plantarum* SCH1 should be carried out.

ACKNOWLEDGMENTS

This work was financially supported by the prof. Waclaw Dabrowski Institute of Agricultural and Food Biotechnology in Poland. This research was performed as part of the employment of the authors.

Compliance With Ethics Requirements: This article does not contain any studies with human participants or animal performed by any of authors. No ethical approval was required.

DISCLOSURES

The authors declare no conflicts of interest.

REFERENCES

Ammor, M. S., and B. Mayo. 2007. Selection criteria for lactic acid bacteria to Be used as functional starter cultures in dry sausage production: an Update. Meat Sci. 76:138–146.

Balciunas, E. M., F. A. C. Martinez, S. D. Todorov, B. D. Gombossy de Melo Franco, A. Converti, and R. Pinheiro de Souza Oliveira. 2013. Novel biotechnological applications of bacteriocins: a review. Food Control 32:134–142.

Bijker, P. G. H., van J. G. Logtestijn, and D. A. A. Mossel. 1987. Bacteriological quality assurance (BQA) of mechanically deboned meat (MDM). Meat Sci. 20:237–252.

Botka-Petrak, K., A. Hraste, H. Lucić, Ž. Gottstein, M. ⊠uras Gomerčić, S. Jakšić, and T. Petrak. 2011. Histological and chemical characteristics of mechanically deboned meat of broiler chickens. Vet. Arh. 81:273–283.

Bredholt, S., T. Nesbakken, and A. Holck. 2001. Industrial application of an antilisterial strain of *Lactobacillus sakei* as a protective culture and its effect on the sensory acceptability of cooked, sliced, vacuum-packaged meats. Int. J. Food Microbiol. 66:191–196.

Cammack, R., C. L. Joannou, X. Y. Cui, C. Torres Martinez, S. R. Maraj, and M. N. Hughes. 1999. Nitrite and nitrosyl compounds in food preservation. Biochim. Biophys. Acta. 1411:475–488.

Christensen, J. E., E. G. Dudley, J. A. Pederson, and J. L. Steele. 1999. Peptidases and amino acid catabolism in lactic acid bacteria. Anton. Leeuw. 76:217–246.

Commission Decision (EU) 2018/702 of 8 May 2018 concerning national provisions notified by Denmark on the addition of nitrite to certain meat products (notified under document C(2018) 2721). Off. J. Euro. Uni, L 118, 2018 7–15.

Commission Regulation (EU) No 257/2010 of 25 March 2010 setting up a programme for the re-evaluation of approved food additives in accordance with Regulation (EC) No 1333/2008 of the European Parliament and of the Council on food additives. Off. J. Eur. Uni. L 80 2, 2020:19–27.

Daros, F. G., M. L. Masson, and S. C. Amico. 2005. The influence of the addition of mechanically deboned poultry meat on the rheological properties of sausage. J. Food Process. Eng. 68:185–189.

Enan, G. 2006. Behaviour of *Listeria monocytogenes* LMG 10470 in poultry meat and its control by the bacteriocin Plantaricin UG 1. Int. J. Poult. Sci. 5:355–359.

Faustman, C., D. C. Liebler, T. D. McClure, and Q. Sun. 1999. α,β-unsaturated aldehydes accelerate oxymyoglobin oxidation. J. Agric. Food Chem. 47:3140–3144.

Faustman, C., Q. Sun, R. Mancini, and S. P. Suman. 2010. Myoglobin and lipid oxidation interactions: Mechanistic bases and control. Meat Sci. 86:86–94.

Froning, S. M., and G. F. McKee. 2000. Mechanical separation of poultry meat and its use in products. Pages 243–254 in Poultry Meat Processing. A. R. Sams, ed. CRC Press, Boca Raton, FL.

Gill, C. O. 2004. Visible contamination on animals and carcasses and the microbiological condition of meat. J. Food Prot. 67:413–419.

Gong, H., X. Meng, and H. Wang. 2010. Mode of action of plantaricin MG, a bacteriocin active against *Salmonella* Typhimurium. J. Basic Microbiol. 50:37–45.

GUS-Główny Urząd Statystyczny [Statistics Poland]. 2019. Chapter 1: Economic and social aspects. Pages 54–66 in Statistical Analyses, Agriculture in 2018. A. Łączyński and B. Domaszewicz, eds. Statistics Poland, Agriculture Department, Warsaw, Poland.

Ha, M. Y., S. W. Kim, Y. W. Lee, M. J. Kim, and S. J. Kim. 2003. Kinetics analysis of growth and lactic acid production in pH-controlled batch cultures of *Lactobacillus casei* KH-1 using yeast extract/corn steep liquor/glucose medium. J. Biosci. Bioeng. 96:134–140.

Hać-Szymańczuk, E., A. Cegiełka, E. Lipińska, and P. Ilczuk. 2014. Effect of sage on the microbial quality and TBARS value of mechanically deboned poultry meat. Med. Weter. 70:704–708.

Hammes, W. P. 2012. Metabolism of nitrate in fermented meats: the characteristic feature of a specific group of fermented foods. Food Microbiol. 29:151–156.

Honikel, K. O. 2008. The use and control of nitrate and nitrite for the processing of meat products. Meat Sci. 78:68–76.

Hornsey, M. 1956. The colour of cooked cured pork. I.-estimation of the nitric oxide-Haem pigments. J. Sci. Food Agric. 8:534–540.

Hospital, X. F., E. Hierro, and M. Fernández. 2012. Survival of *Listeria innocua* in dry fermented sausages and changes in the typical microbiota and volatile profile as affected by the concentration of nitrate and nitrite. Int. J. Food Microbiol. 153:395–401.

Kim, S. H., D. D. Jayasena, H. J. Kim, Ch. Jo, and S. Jung. 2014. Effect of adding Lactobacillus-fermented solution on characteristics of chicken breast meat. Korean J. Poult. Sci. 41:127–133.

Laslo, É., É. György, and A. Czikó. 2019. Meat starter cultures: Isolation and characterization of lactic acid bacteria from traditional sausages. Acta Univ. Sapientiae Aliment. 12:54–69.

Łaszkiewicz, B., P. Szymański, and D. Kołożyn-Krajewska. 2019. Impact of selected lactic acid bacteria strains on technological usability and microbiological quality of mechanically separated poultry meat. Żywn-Nauk Technol. Ja 26:122–134.

Li, P., H. Luo, B. Kong, Q. Liub, and C. Chen. 2016. Formation of red myoglobin derivatives and inhibition of spoilage bacteria in raw meat batters by lactic acid bacteria and *Staphylococcus xylosus*. Lwt-Food Sci. Technol. 68:251–257.

Libera, J., M. Karwowska, D. Stasiak, and Z. J. Dolatowski. 2015. Microbiological and physicochemical properties of dry-cured neck inoculated with probiotic of *Bifidobacterium animalis* ssp. lactis BB-12. Int. J. Food Sci. Technol. 50:1560–1566.

Lücke, F. K. 2008. Effect of the use of nitrite on safety and shelf life of cooked meats. Fleischwirtschaft 143:91–94.

Majou, D., and S. Christieans. 2018. Mechanisms of the bactericidal effects of nitrate and nitrite in cured meats. Meat Sci. 145:273–284.

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121.

Martinez-Romero, R., R. M. Romero-Orozco, H. Martinez-Romero, S. R. Trejo-Estrada, and O. Lazo-Zamalloa. 2016. Biopreservation composition based on facultative heterofermentative lactobacteria for preventing and controlling the spoilage of fresh and cooked meat products. Can. Inellectual Property Off. CA 2971392:1–39.

Mayer, A. L., J. S. Smith, D. H. Kropf, J. L. Marsden, and G. A. Milliken. 2007. A comparison in the composition of recovered meat produced from beef neckbones processed using hand boning, a traditional Advanced Meat Recovery (AMR) system, and a Desinewated Minced Meat system. Meat Sci. 77:602–607.

Morita, H., H. Yoshikawa, R. Sakata, Y. Nagata, and H. Tanaka. 1997. Synthesis of nitric oxide from the two equivalent guanidinonitrogens of L-arginine by *Lactobacillus fermentum*. J. Bacteriol. 179:7812–7815.

On, S., T. L. Wong, B. Hom, Ch. Graham, and S. Paulin. 2011. Pages 26–28 in Bacterial Concentrations of Poultry Offal and in Mechanically Separated Meat Products at the Processing Plant. MAF Technical Paper No: 2011/59. MAF Information Bureau, Wellington, New Zeland.

Ozkececi, R. B., M. Karakaya, M. T. Yilmaz, C. Saricoban, and H. W. Ockerman. 2008. The effect of carcass part and packaging method on the storage stability of mechanically deboned chicken meat. J. Muscle Foods 19:288–301.

Pegg, R. B., and F. Shahidi. 2000. The color of meat. Pages 23–66 in Nitrite Curing of Meat: The N-Nitrosamine Problem and Nitrite Alternatives. Food & Nutrition Press Inc., Trumbull, CT.

Perez-Chabela, M. L., A. Totosaus, and I. Guerrero. 2008. Evaluation of thermotolerant capacity of lactic acid bacteria isolated from commercial sausages and the effects of their addition on the quality of cooked sausages. Food Sci. Technol. 28:132–138.

Pomykała, R., and M. Michalski. 2008. Microbiological quality of mechanically separated poultry meat. Acta Sci. Pol. 7:43–49.

Raccach, M., and R. C. Baker. 1979. The effect of lactic acid bacteria on some properties of mechanically deboned poultry meat. Poult. Sci. 58:144–147.

Rubio, R., T. Aymerich, S. Bover-Cid, M. D. Guardia, J. Arnau, and M. Garriga. 2013. Probiotic strains *Lactobacillus plantarum* 299V and *Lactobacillus rhamnosus* GG as starter cultures for fermented sausages. LWT - Food Sci. Technol. 54:51–56.

Rzepkowska, A., D. Zielińska, A. Ołdak, and D. Kołożyn-Krajewska. 2017a. Organic whey as a source of *Lactobacillus* strains with selected technological and antimicrobial properties. Int. J. Food Sci. Technol. 52:1983–1994.

Rzepkowska, A., D. Zielińska, A. Ołdak, and D. Kołożyn-Krajewska. 2017b. Safety assessment and antimicrobial properties of the lactic acid bacteria strains isolated from polish raw fermented meat products. Int. J. Food Prop. 20:2736–2747.

Sebranek, G. J. 2009. Basic curing ingredients. Pages 1–23 in Ingredients in Meat Products: Properties, Functionality, and Applications. R. Tarte, ed. Springer., New York, NY.

Sebranek, G. J., and J. N. Bacus. 2007. Cured meat products without direct addition of nitrate or nitrite: what are the issues? Meat Sci. 77:136–147.

Sindelar, J. J., and A. L. Milkowski. 2011. Sodium nitrite in processed meat and poultry meats: a review of curing and Examining the Risk/Benefit of its Use. American meat Science Association. AMSA White Paper Ser. 3:1–14.

Siu, D., and A. Henshall. 1998. Ion chromatographic determination of nitrate and nitrite in meat products. J. Chromatogr. 804:156–160.

Skibsted, L. H. 1996. Chemical changes in meat and meat products during storage, transportation and retail display-theoretical considerations. Pages 169–181 in Meat Quality and Meat Packaging. S. A Taylor, A. Raimundo, M. Severini, and F. J. M. Smulders, eds. ECCEAMST, Utrecht, The Netherlands.

Stiebing, A. 2002. Separatorenfleisch im Kreuzfeuer der Kritik. Fleischwirtsch 82:8.

Teusink, B., and D. Molenaar. 2017. Systems biology of lactic acid bacteria: for food and thought. Curr. Opin. Syst. Biol. 6:7–13.

United States Department of Agriculture 2019. Livestock and Poultry: World Markets and Trade, *USDA Foreign Agricultural Service*, *Office of Global Analysis*, Washington, DC. 10:18-20.

Viuda-Martos, M., J. Fernández-López, and J. A. Pérez-Álvarez. 2012. Mechanical deboning. Pages 457–468 in Handbook of Meat and Meat Processing. Y. H. Hui, ed. 2nd ed. CRC Press, Boca Raton, FL.

Xu, J., and W. Verstraete. 2001. Evaluation of nitric oxide production by lactobacilli. Appl. Microbiol. Biotechnol. 56:504–507.

Zhang, X., B. Kong, and Y. Xiong. 2007. Production of cured meat color in nitrite-free Harbin red sausage by *Lactobacillus fermentum* fermentation. Meat Sci. 77:593–598.

Zhang, Y., L. Zhu, P. Dong, R. Liang, Y. Mao, S. Qiu, and X. Luo. 2018. Bio-protective potential of lactic acid bacteria: effect of *Lactobacillus sakei* and *Lactobacillus curvatus* on changes of the microbial community in vacuum-packaged chilled beef. 31:585–594.