

The influence of broiler transport length on safety parameters of chicken breasts

Effect of quality parameters of raw and smoked chicken breasts

By Vesna Radovic, Dragan Vasilev, Nedjeljko Karabasil, Mirjana Dimitrijevic, Vladimir Tomovic, Branko Suvajdzic, Milijana Sindjic, and Silvana Stajkovic

The aim of the study was to investigate the influence of broiler transport length on safety and quality parameters of raw and smoked chicken breasts. The study was carried out on Ross 308 broiler chickens reared and transported under similar commercial conditions, while the only varying factor was the length of transport. Transport was categorized as short (20 km) and long (170 km) and from meat (*m. pectoralis major*) obtained from such transported broilers, two experimental groups were formed: short transport (ST) and long transport (LT) group, respectively. Each of these groups had a raw chicken breasts and further processed smoked chicken breasts variant. At the beginning of storage, raw chicken breasts from ST group showed higher pH value, water holding capacity (WHC) and shear force and lower TBARS and L* value, but during storage, TBARS and L* value increased, and pH value and shear force decreased. On the contrary, in LT group WHC, L*, and a* increased and TBARS, b*, and shear force decreased. At the beginning of the storage of smoked chicken breasts, only color (L*, a*, b*) significantly changed in both groups. At the end of the storage period, samples from ST group showed higher b* and lower pH value, whereas samples from LT group showed higher b* and shear force values. Higher bacterial counts were observed in all raw LT samples at the beginning of the storage period, except for *Micrococci*. During storage, bacterial counts increased in ST samples, but in LT samples *Micrococci* increased, and total count of psychrophiles decreased. Bacterial counts in smoked chicken breasts were distinctly lower than in raw meat. Cross-section appearance, showed higher scores throughout the entire storage period in the smoked chicken breast from ST group in comparison to LT group, color and color stability, odor and taste, texture and juiciness had a higher score on 1st and 15th day of storage, and external appearance on the 30th day of storage.

Global meat production has been on the rise, with poultry meat showing the most significant increase (Wóciak et al., 2022). This growth is largely due to the fact that poultry is easier and less costly to produce compared to other types of meat, such as pork, beef, and lamb (Kim et al., 2020). Chicken meat is widely accepted across various countries and cultures, contributing to its global popularity (Salinas et al., 2012). Chicken meat is highly valued by consumers for its rich nutritional profile, characterized by high protein content and low levels of fat and cholesterol. However, chicken meat also presents certain disadvantages, such as a short shelf-life caused by the presence of bacteria from the broiler's natural microbiota and conditions during meat processing. Additionally, its high content of unsaturated fatty acids makes it prone to oxidation (Sudjono et al., 2018). The oxidation process impairs sensory properties, decreases the nutritional value of the product, and adversely affects consumer health (Esposito et al., 2022).

In recent times, chicken meat has been increasingly processed into products intended as home meal replacements, allowing consumers to enjoy them conveniently anytime and anywhere (Ellsworth et al., 2023). Common examples of such products include smoked chicken, chicken sausage, and fried chicken (Ellsworth et al., 2023). Smoked chicken is favored due to its recognizable mild smoky flavor, increased tenderness, juiciness and extended shelf-life. The production of smoked chicken

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- >> Broiler transport
- >> Chicken breasts
- >> Raw meat
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- >> Quality

involves wet curing, smoking, and heat treatment as preservation methods, which provide adequate shelf-life and safety of the product while contributing to the development of its sensory properties. Curing typically involves the addition of nitrites, which inhibit the growth of spoilage and pathogenic microorganisms, particularly *Clostridium* spp. as well as stabilizing double bonds of cell membrane lipids achieving antioxidant action. Moreover, nitrites play a key role in developing the product's characteristic pink color and distinct aroma (Choi et al., 2017). On the other hand, as smoking provides a more pronounced surface-preserving effect, additional heat treatment (pasteurization) is required to ensure product safety. Furthermore, smoking imparts distinctive sensory characteristics to meat, enhancing its acceptability among consumers (Samant et al., 2016; Corioan et al., 2023).

Transportation is an essential component of the poultry industry and can cause different degrees of stress to birds (Schwartzkopf-Genswein et al., 2012). The influence of transport stress does not stop at slaughter but also continues to affect conversion of muscle to meat and the resultant meat quality parameters such as color, texture, and related protein functionality (Fu et al., 2022). These changes in meat quality parameters could have negative effects on consumer acceptability and processing functionality of the further processed products (Schwartzkopf-Genswein et al., 2012). Duration of transport is a major animal welfare concern. Studies that have considered the effect of transportation duration and distance on animal welfare and resultant meat quality of broiler chickens are not consistent. Zhang et al. (2009) reported no effect of transportation (up to 3 h) on meat quality traits in broilers. Also, Gou et al. (2021) showed that transporting broiler chickens for 0, 0.5, 1, 2, or 3 h showed only a negligible influence on meat quality, as the meat color and shear force, were not affected. Different studies have reported that an increase in transportation distance has been associated with higher pH, lower lightness, shear force, and drip loss (Hussain et al., 2020). However, some studies have indicated that short-term transportation could be more stressful to the birds (Vosmerova et al., 2010; Schwartzkopf-Genswein et al., 2012). Transportation stress can also increase endogenous microbial contamination of broilers, and this aggravates the microbial risk (Zheng et al., 2020).

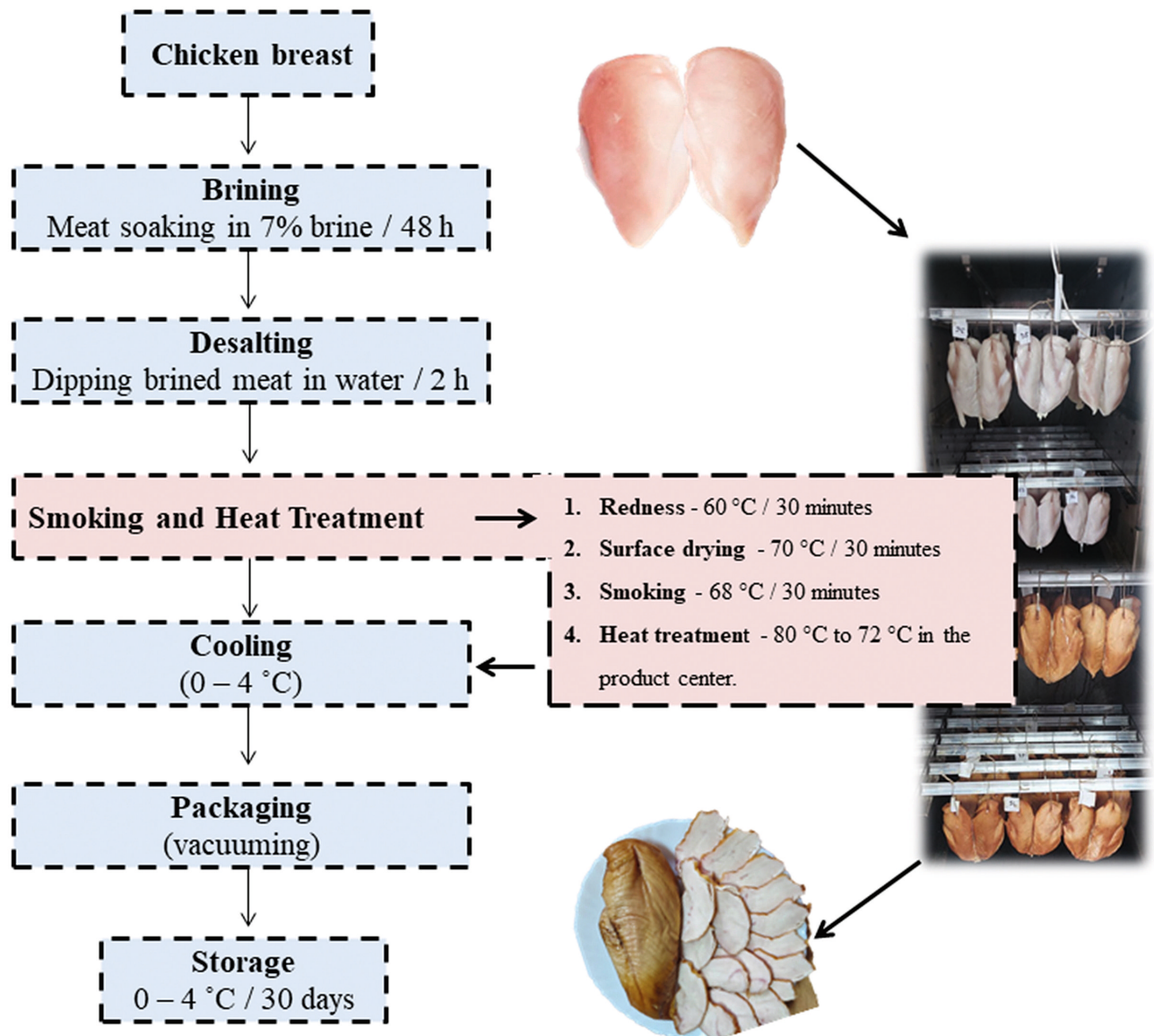


Fig.: Flow diagram of the production of experimental groups of smoked chicken breasts. Photo: RADOVIC et al.

Abb.: Flussdiagramm der Produktion von Versuchsgruppen geräucherter Hähnchenbrust. Foto: RADOVIC et al.

The evaluation of chicken meat quality is mainly based on its microbiological and sensory characteristics in relation to the length of storage (CHIMEL et al., 2022).

In the light of these considerations and bearing in mind that the meat product quality is highly influenced by the raw material characteristics, the present study aimed to investigate the influence of broiler transport length on safety and quality parameters of raw and smoked chicken breasts, with the special emphasis on the physicochemical, oxidative, colorimetric, textural, microbiological and sensory properties.

Materials and methods

Experimental birds and meat samples

ROSS-308 broilers (age: 38 days) were transported in specialized trucks from a commercial farm to industrial slaughterhouses. Transport distance was categorized as short (20 km) and long (170 km). Upon reaching the slaughtering facility, birds were slaughtered, defeathered, eviscerated and chilled below 4 °C. After deboning, chicken breasts (m. *pectoralis*

major) were collected randomly from the abattoir (54 per transport group) and were placed into sterile plastic sampling bags, labeled and transported immediately to the laboratory in enclosed polystyrene mobile refrigerator with ice blocks (4 °C), under aerobic condition. Breast meat samples obtained after short transport (ST) and long transport (LT) were further divided into two separate groups. The first group consisted of ST and LT samples that were raw vacuum packed and stored in the refrigerator at 4 °C in the dark over a period of four days for further examinations, which were conducted after 1st, 2nd and 4th day of storage. The second group consisted also of ST and LT samples, was used to produce smoked chicken breasts.

Smoked chicken breasts production and sampling

Smoked chicken breasts were processed based on the flow diagram outlined in the Figure. Chicken breasts were brined by dipping in a 7% solution of nitrite curing salt (NaCl + 0.5% NaNO₂). The process of bringing lasted for 48 h, followed by desalting (2 h), i.e. immersing the salted meat in water to remove excess salt. After that, the brined chicken

breasts were properly marked and hung on the rods of the chamber for smoking and heat treatment of meat (UKM Junior 04, Mauting, Valtice, Czech Republic). Beech wood shavings were used to produce smoke. Hot smoking with simultaneous pasteurization was applied, which lasted until a temperature of 72 °C reached in the center of the product (Fig.). After finishing the heat treatment, the products were cooled (0 – 4 °C) and then packed in a separate vacuum packaging. Packed smoked chicken breasts were stored in the refrigerator (0 – 4 °C) in the dark for next 30 days, and were analyzed on 1st, 15th and 30th day of storage.

Physicochemical examination

The pH value of raw and smoked chicken breasts was determined by a pH-meter (Testo 205, Testo AG, Lenzkirch, Germany). Before measuring, the pH meter was calibrated using standard phosphate buffers.

Water activity (a_w value) of smoked chicken breasts was determined with a a_w -meter (LabMaster- a_w , Novasina, Switzerland), according to a standard method (ISO 18787:2017).

Water holding capacity (WHC) of raw chicken breasts was determined by the filter paper press method (GRAU and HAMM, 1952). On filter paper (Whatman No. 2, 7x7 cm), samples of 0.3 g were weighed and pressed between 2 Plexiglass plates for 5 min. The areas of pressed sample and squeezed out water were measured using a planimeter (Robotron, Reiss Precision, Germany). WHC was calculated using the formula:

$$\text{WHC (\%)} = \text{area of pressed sample} / \text{area of squeezed out water} \times 100.$$

Oxidative changes examination

Thiobarbituric acid reactive substances (TBARS) value was determined in raw and smoked chicken breasts samples according to the combined

method of TARLADGIS et al. (1964) and HOLLAND (1971). Briefly, malondialdehyde was separated by steam distillation. Thiobarbituric acid was added, and in reaction with malondialdehyde, caused the solution to turn red. Color intensity was measured at 532 nm using a spectrophotometer (Perkin Elmer Lambda 365 UV-Vis, USA). The TBARS content was expressed as milligrams of malondialdehyde per kilogram of sample (mg MDA/kg).

Microbiological examination

Microbial analyses were carried out on raw and smoked chicken breast samples. 25 g of each sample was weighed and transferred aseptically to stomacher bags and homogenized with 225 ml of sterile 0.1% (w/v) saline peptone water. Serial decimal dilutions were made from the primary solution and inoculated on appropriate agar plates. Lactic acid bacteria (LAB) were enumerated on de Man, Rogosa, and Sharpe agar (Merck, Darmstadt, Germany) incubated at 30 °C for 72 h under anaerobic conditions; micrococci count on Mannitol Salt Agar (Merck, Darmstadt, Germany) at 37 °C for 48 h; *Enterobacteriaceae* count on violet red bile glucose (VRBG, OXOID) agar at 37 °C for 24 h. Determination of the total number of mesophilic bacteria were conducted according to standard method SRPS EN ISO 4833-2:2017. Determination of the presence of *L. monocytogenes* and *Salmonella spp.* were conducted according to standard methods SRPS EN ISO 11290-1:2017 and ISO 6579-1:2017, respectively, and determination of the number of colonies of *Clostridium spp.*, according to SRPS EN ISO 15213-2:2023. Results of microbial counts were expressed as log cfu/g means.

Colorimetric and texture examination

Instrumental color determination of raw and smoked chicken breasts samples was measured using a colorimeter (Chroma Meter CR-400, Mi-

Results of analysis of variance

Tab. 1: Effect of broiler transport length on raw chicken breasts quality during storage

Tab. 1: Einfluss der Transportdauer von Masthähnchen auf die Qualität roher Hähnchenbrustfilets während der Lagerung

Items	Storage (day)	Length of transportation (km) ¹		Effect ²		
		ST	LT	Transport	Storage	Transport x Storage
³ pH60 min	1	6.13±0.08 ^{Aa}	5.93±0.08 ^{Ab}	0.4326	0.7702	0.0892
⁴ pH24h	2	6.01±0.15 ^{ABa}	5.94±0.10 ^{Aa}			
⁵ pH4day / Tag	4	5.93±0.08 ^{Ba}	6.06±0.38 ^{Aa}			
WHC	1	67.92±1.47 ^{Aa}	64.34±2.87 ^{Ab}	0.0212	0.0435	0.1304
	4	68.81±2.14 ^{Aa}	68.25±2.68 ^{Ba}			
TBARS	1	0.01±0.01 ^{Aa}	0.04±0.01 ^{Ab}	0.3776	0.2467	< 0.0001
	4	0.04±0.02 ^{Ba}	0.02±0.01 ^{Ba}			
L *	1	52.59±2.70 ^{Aa}	54.15±3.06 ^{Ab}	< 0.0001	0.1369	0.0010
	4	56.25±3.76 ^{Ba}	55.63±2.68 ^{Ba}			
a *	1	1.49±0.80 ^{Aa}	1.26±0.96 ^{Aa}	< 0.0001	0.0073	< 0.0001
	4	1.40±0.79 ^{Aa}	2.17±1.11 ^{Bb}			
b *	1	7.34±1.59 ^{Aa}	7.41±1.57 ^{Aa}	< 0.0001	< 0.0001	< 0.0001
	4	7.57±1.55 ^{Aa}	5.61±1.51 ^{Bb}			
Shear force	1	189.70±43.83 ^{Aa}	142.30±37.30 ^{Ab}	< 0.0001	< 0.0001	< 0.0001
	4	99.40±26.14 ^{Ba}	90.56±17.84 ^{Bb}			

¹Results of one-factor analysis of variance; ²Results of two-factor analysis of variance. ^{ab} Significant difference in a row (p < 0.05); ^{A*} Significant difference in a column (p < 0.05).

³pH60 min, pH at 60 min post mortem; ⁴pH24h, pH at 24 h post mortem; ⁵pH4day, pH after 4 day of slaughter.

WHC, water holding capacity; TBARS, Thiobarbituric acid reactive substances; L *, lightness; a *, redness; b *, yellowness;

ST, short transport (20 km), LT, long transport (170 km). Values are means ± SE (n = 6).

Source: RADOVIC et al.

nolta Co., Osaka, Japan), calibrated according to the manufacturer's standard instructions. Color values of L* (lightness), a* (redness), and b* (yellowness) were repeatedly measured using the same method and process.

Shear force value determination (N/cm²) of raw and smoked chicken breasts samples was performed on the Instron 4301 device, on a sample 2 cm thick and 2.54 cm in diameter, at 50% compression and a speed of 1 mm/s.

Sensory analysis

Descriptive sensory analysis (external appearance, cross-section appearance, color and color stability, odor and taste, texture and juiciness) of all smoked chicken breasts samples was performed by six trained and experienced panelists in a sensory analysis room compliant with ISO 6658:2017. All the panelists were allowed into the room together and had unlimited time to complete the testing. Sensory evaluations were conducted using a 5-point scale (0–5), where a score of 5 was defined as excellent, while 0 was defined as very bad.

Statistical analysis

For statistical analysis of results software GraphPad Prism version 7.00 for Windows (GraphPad Software, San Diego, CA, USA, www.graphpad.com) was used. Data obtained from experiments were tested for normality using Shapiro-Wilk test ($p > 0.05$). General linear model was used with length of transportation and storage time as fixed factors. Bonferroni post hoc test was applied for estimation of differences between defined groups within factors. Differences were considered significant at $p < 0.05$.

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Results and discussion

Raw chicken breasts quality parameters

Transport stress alters both psychological state and the metabolism of animals, which can lead to undesirable changes in meat quality (ZHANG et al., 2009). Postmortem pH decline is one of the most important factors affecting meat quality attributes, due to its impact on meat color, WHC, texture and microbial growth (SUJAWA et al., 2018). During rigor mortis development, substrates such as glycogen and glucose are converted into lactate, which accumulates and acidifies the meat. The rate of pH decline during postmortem period depends on activity of glycolytic enzymes at slaughter, while the extent of pH decline depends on muscle glycogen reserves (ZHENG et al., 2020; HUSSNAIN et al., 2020). In the present study, pH60min, pH24h and pH4day were not affected by transport time, storage time, or their interaction (Tab. 1). The recorded pH60min values

Smoked chicken breasts

Tab. 2: Effect of broiler transport length on smoked chicken breasts quality during storage

Tab. 2: Einfluss der Transportdauer von Masthähnchen auf die Qualität geräucherter Hähnchenbrustfilets während der Lagerung

Items	Storage (day)	Length of transportation (km) ¹		Effect ²		
		ST	LT	Transport	Storage	Transport x Storage
pH	1	6.24±0.01 ^{Aa}	6.18±0.07 ^{Aa}	< 0.0001	0.0616	0.3660
	15	6.08±0.04 ^{Ba}	6.09±0.06 ^{Aa}			
	30	6.15±0.07 ^{Ba}	6.08±0.08 ^{Aa}			
a _w	1	0.969±0.001 ^{Aa}	0.964±0.001 ^{Aa}	0.0041	< 0.0001	0.6879
	15	0.972±0.000 ^{Aa}	0.966±0.002 ^{Ab}			
	30	0.970±0.001 ^{Aa}	0.965±0.000 ^{Ab}			
TBARS	1	0.06±0.01 ^{Aa}	0.05±0.01 ^{Aa}	0.0001	0.4754	0.1242
	15	0.06±0.02 ^{Aa}	0.07±0.01 ^{Ba}			
	30	0.05±0.01 ^{Aa}	0.05±0.01 ^{Aa}			
L*	1	79.52±2.30 ^{Aa}	80.34±1.80 ^{Ab}	< 0.0001	0.0085	0.0040
	15	77.96±2.22 ^{Ba}	78.81±1.67 ^{Bb}			
	30	79.30±1.67 ^{Aa}	78.95±1.87 ^{Ba}			
a*	1	5.34±1.08 ^{Aa}	6.06±1.25 ^{Ab}	< 0.0001	< 0.0001	0.4505
	15	6.21±0.90 ^{Ba}	6.82±1.03 ^{Bb}			
	30	5.96±1.22 ^{Ba}	6.34±0.87 ^{Ab}			
b*	1	10.96±1.12 ^{Aa}	10.02±0.62 ^{Ab}	< 0.0001	< 0.0001	0.0003
	15	12.03±0.75 ^{Ba}	11.67±1.03 ^{Bb}			
	30	11.63±0.94 ^{Ca}	11.35±0.50 ^{Cb}			
Shear force	1	89.02±24.78 ^{Aa}	90.95±22.77 ^{Aa}	0.0001	0.7513	< 0.0001
	15	112.9±47.93 ^{Ba}	82.93±17.44 ^{Ab}			
	30	94.96±29.72 ^{Aa}	125.8±76.73 ^{Bb}			

¹Results of one-factor analysis of variance; ²Results of two-factor analysis of variance. ^{a,b} Significant difference in a row ($p < 0.05$); ^{A, B, C} Significant difference in a column ($p < 0.05$).

TBARS, Thiobarbituric acid reactive substances; a_w, water activity; L*, lightness; a*, redness; b*, yellowness; ST, short transport (20 km); LT, long transport (170 km). Values are means ± SE (n = 6).

Source: RADOVIC et al.

ranged from 5.93 (LT) to 6.13 (ST) which is considered usual for chicken breasts that generally range from 5.8 to 6.3 (LIU et al., 2004; LESIOW et al. 2009; Sampaio et al., 2012). However, pH_{60min} was significantly higher ($p < 0.05$) in samples from ST group than those of pH_{60min} from LT group. Shorter transportation might be more stressful to the birds, because they do not have enough time to recover from the stress induced during handling and crating (VOSMERDOVA et al., 2010). Short-term sudden stress immediately before slaughter may have accelerated glycolytic rate, and depletion of glycogen stores during the animal's lifetime, resulting in higher initial postmortem muscle pH_{60min}. During storage, pH values were also in the range usual for the chicken breasts, but the opposing changes were observed between two groups till the 4th day. Namely, samples from ST group showed decrease and samples from LT group an increase of pH value. As the glycolysis has been finished at the beginning of the storage, further pH decrease in ST group could be attributed to the activity of LAB (AUGUSTYŃSKA-PREJSNAR et al., 2023), which are detected by microbiological examination (Tab. 3). On the contrary, pH increase during storage of LT samples could be a consequence of proteolytic microorganisms as well as tissue enzymes activity, which leads to the accumulation of alkaline compounds (AUGUSTYŃSKA-PREJSNAR et al., 2023). As the higher number of *Enterobacteriaceae*, mesophylic and psychrophylic bacteria was detected in LT group at the beginning of the storage (Tab. 3), this could be the possible explanation of pH value increase in this group. Even more, chicken breasts with lower initial pH values, which was the case in LT group, tend to show more intense tissue proteolytic enzyme activity also leading to the pH value increase (LI et al., 2012).

An important meat quality attribute is WHC as it influences the yield and the quality of fresh and processed meat products. Postmortem changes including rate and extent of pH value decrease as well as proteolysis highly influence the WHC (HUFF-LONERGAN and LONERGAN, 2005). Rapid pH decline coupled with high muscle temperature early post-mortem causes the denaturation of muscle proteins (HUFF-LONERGAN and LONERGAN, 2005) which leads to the decreased protein hydrophilicity and consequently, decline of meat WHC (Fu et al., 2022). Accordingly, samples from LT group in our study showed significantly lower WHC after first day of storage then the ST group (Tab. 1), which could be attributed to

the lower pH value in LT group that was observed at the beginning of the storage. Till the end of storage, WHC increased significantly only in LT group, which could be attributed to the increase in pH value in this group, which was already described in previous section. Such results are in accordance with the findings of ZHANG et al. (2009) who state that increase in the pH value of broiler breast meat is associated with an increase in WHC. HUFF-LONERGAN and LONERGAN, (2005) also described that the increase of pH value as a result proteolysis is associated with the mobilization of water in meat.

Enhanced lipid oxidation processes in meat contribute to deterioration of meat quality, hence lipid oxidation is another factor used as an indicator of quality deterioration in chicken meat (SUJOWO et al., 2018). Many factors are associated with lipid oxidation in meat, including oxygen content and types of oxygen, heat and light, catalysts, unsaturated fatty acids, phospholipids, processes that destroy muscle membranes, pH and pre-slaughter conditions including transportation (CHENG, 2016), which can induce stress in broilers, and consequently release reactive oxygen species (ROS), followed by enhanced lipid peroxidation. The TBARS values of the chicken breast meat samples in this study were higher in samples from LT group on the first day of storage. During storage, TBARS value increased significantly in the ST group (Tab. 1). Also, significant interaction effect of transport and storage time for TBARS was determined ($p < 0.05$). Obtained TBARS values were in accordance with those reported by SUJOWO et al. (2018), who measured TBARS at 0.01 mg MDA/kg on day 1 to 0.04 mg MDA/kg on day 5 of storage at 4 °C. The TBARS values observed in this study indicate that the meat should still be acceptable to consumers after 4 days of storage, as CHANDRA MOHAN et al. (2017) reported that the off-odors and off-flavors can be detected by inexperienced consumers at TBARS values in the range of 0.6 to 2.0 mg MDA/kg, and O'NEILL et al. (1998) reported that TBARS values ≥ 0.8 mg MDA/kg are indicative of perceptible rancidity. Also, BREWER et al. (1992) reported that TBARS values below 0.2 mg MDA/kg should be acceptable for consumers and indicate fresh meat.

Color is considered the most important sensory attribute influencing the acceptability or rejection of meat by consumers, as well as a useful tool for the assessment of meat quality intended for further processing. Factors that affect the color the amount and distribution of myoglobin

Raw chicken breasts

Tab. 3: Effect of broiler transport length on raw chicken breasts microbiota during storage

Tab. 3: Einfluss der Transportdauer von Masthähnchen auf die Mikrobiota roher Hähnchenbrustfilets während der Lagerung

Bacterial counts	Storage (day)	Length of transportation (km) ¹		Effect ²		
		ST	LT	Transport	Storage	Transport x Storage
LAB	1	2.91±0.07 ^{Ab}	3.89±0.22 ^{Ab}	< 0.0001	< 0.0001	< 0.0001
	4	4.15±0.29 ^{Ba}	4.18±0.33 ^{Aa}			
<i>Enterobacteriaceae</i>	1	2.26±0.36 ^{Ab}	4.04±0.19 ^{Ab}	< 0.0001	< 0.0001	< 0.0001
	4	3.86 ±0.31 ^{Ba}	3.97±0.46 ^{Aa}			
Micrococci	1	3.50±0.18 ^{Ab}	3.40±0.18 ^{Ab}	< 0.0001	< 0.0001	< 0.0001
	4	4.58±0.33 ^{Ba}	4.01±0.27 ^{Bb}			
TCM	1	3.63±0.13 ^{Ab}	5.72±0.10 ^{Ab}	< 0.0001	< 0.0001	< 0.0001
	4	6.55±0.08 ^{Ba}	6.04±0.40 ^{Ab}			
TCP	1	4.43±0.14 ^{Ab}	6.01±0.17 ^{Ab}	0.0009	0.7970	< 0.0001
	4	6.43±0.20 ^{Ba}	4.79±0.38 ^{Bb}			

¹Results of one-factor analysis of variance; ²Results of two-factor analysis of variance. ^{ab} Significant difference in a row ($p < 0.05$); ^{A*} Significant difference in a column ($p < 0.05$).

LAB, Lactic Acid Bacteria; TCM, Total Count of Mesophiles; TCP, Total Count of Psychrophiles. ST, short transport (20 km); LT, long transport (170 km). Values are means $\pm$ SE (n = 6).

Source: RADOVIC et al.

species, together with internal reflectance, are closely impacted by the products of transport stress. Those products (such as reactive oxygen species, and lactic acid) can damage muscle cell membranes, resulting in myoglobin infiltration into the blood and an increase in L^* (Fu et al., 2022). In our study, L^* , a^* and b^* values were affected by interaction of transport and storage time (Tab. 1). On the first day of storage, samples from the LT group showed significantly higher L^* value ($p < 0.05$) than the samples from the ST group, while there was no significant difference concerning a^* and b^* values. Higher L^* value in LT group could be attributed to greater light reflection from the wet meat surface due to lower WHC and pH value. HUSSNAIN et al. (2020) also describe that ultimate pH lower than 6.0 results in greater meat lightness due to an increase in scattering of light from the meat surface. Concerning the chicken transport time, Fu et al. (2022) also found that L^* value significantly increases with longer transport. During storage, L^* values increased in both experimental groups, showing no statistical difference between them after 4th day. Such increase raised a suspicion on pale, soft and exudative (PSE) meat, as literature data (Fu et al., 2022) indicate that L^* value higher than 50 is considered as PSE meat indicator. Despite that, another important PSE indicator such as pH value, which was in usual range in both groups (Liu et al., 2004; LESIOW et al. 2009; SAMPAIO et al., 2012) yet did not indicate this undesirable quality issue. In addition, BOULIANNE and KING (1995) reported that L^* value for PSE chicken breasts was 59.2, and for normal meat 52.3 in average.

Concerning a^* and b^* values, on the first day of storage there were no significant changes related to the transportation length, and such results were in accordance to the findings of DEBUT et al. (2003) who registered no differences in breast meat color between transported and non-transported broiler chickens. Compared to the findings of BOULIANNE and KING (1995), who reported that in normal chicken breasts a^* value is

3.2 and b^* value 8.4 in average, the results in our study were much lower for redness and similar for yellowness. During the storage, a^* value significantly increased and b^* value decreased in samples from LT group, while in ST group remained unchanged. The red value (a^*) of meat is usually influenced by pigment state and structure, but also the variation of moisture on the meat surface could lead to dilution or concentration of the pigments on the surface causing the red color to decrease or increase during storage (BOULIANNE and KING, 1995). Fu et al. (2022) state that the fresh muscle color favored by consumers mainly comes from the red oxygenated myoglobin which can reversibly convert to the brown metmyoglobin, and this process is affected by temperature, pH, but also cellular oxidative stress caused by transport and emotional stress.

Our results for b^* value were like those of QIAO et al. (2002) who reported b^* values ranged from 6 to 9. Variations in meat color could be related to different factors such as chicken breeds, management, housing, diet, colorimeter calibration, location of measurement, etc.

Shear force is a critical factor in determining the tenderness of broiler meat, which is an important organoleptic characteristic that mostly affects consumer acceptance (SUJAWO et al., 2018). In our study, shear force was affected by interaction of transport and storage time (Tab. 1). Lower shear force was observed in LT compared to the ST group, after 1 day and after 4 days of storage. HUSSNAIN et al. (2020) also reported a significant decrease in shear force with the increase in transportation distance of broilers. For 4 days storage, shear force decreased significantly in both groups, and such findings were also consistent with the results reported by YOUNG and LYON (1997), who found that the shear force values of chicken breast meat decreased with prolonged storage time. This decrease may be attributed to the degradation of meat protein during storage, which can be caused by either enzymatic or bacterial processes (KRUK et al., 2011; LI et al., 2012).

Microbiota

Tab. 4: Effect of broiler transport length on smoked chicken breasts microbiota during storage

Tab. 4: Einfluss der Transportdauer von Masthähnchen auf die Mikrobiota geräucherter Hähnchenbrustfilets während der Lagerung

Bacterial counts	Storage (day)	Length of transportation (km) ¹		Effect ²		
		ST	LT	Transport	Storage	Transport x Storage
LAB	1	< 1	< 1	0.160	0.0011	< 0.0001
	15	1.78±0.65 ^{Aa}	1.77±1.00 ^{Aa}			
	30	3.91±1.58 ^{Ba}	2.69±1.96 ^{Aa}			
<i>Enterobacteriaceae</i>	1	3.20±0.34	< 1			
	15	< 1	< 1	–	–	–
	30	< 1	< 1			
Micrococci	1	2.96±0.34 ^{Aa}	1.54±0.48 ^{Ab}	0.0125	0.1217	0.0012
	15	1.38±0.40 ^{Ba}	1.61±0.42 ^{Aa}			
	30	1.75±0.73 ^{Ba}	2.03±0.88 ^{Aa}			
TCM	1	3.25±0.24 ^{Aa}	2.10±0.24 ^{Ab}	< 0.0001	0.0064	< 0.0001
	15	1.23±0.35 ^{Ba}	2.86±0.91 ^{Ab}			
	30	2.96±1.40 ^{Aa}	4.62±0.46 ^{Bb}			
TCP	1	1.61±0.53 ^a	4.16±0.26 ^{Ab}	< 0.0001	< 0.0001	< 0.0001
	15	< 1	1.00±0.00 ^{Ba}			
	30	< 1	4.18±1.25 ^{Ab}			

¹Results of one-factor analysis of variance; ²Results of two-factor analysis of variance. ^{a,b} Significant difference in a row ($p < 0.05$); ^{A, B} Significant difference in a column ($p < 0.05$).

LAB, Lactic Acid Bacteria; TCM, Total Count of Mesophiles; TCP, Total Count of Psychrophiles. ST, short transport (20 km); LT, long transport (170 km). Values are means ± SE (n = 6).

Source: RADOVIC et al.

Smoked chicken breasts quality parameters

Smoked chicken breasts is a pasteurized meat product that is perishable due to its high pH (> 6.4) and a_w (> 0.95) values, which favors the growth of microorganisms [FU and KERR, 2020]. In our study, pH value of samples from the ST group was slightly higher than the LT group at the beginning of the storage (Tab. 2), which could be a consequence of the higher pH values in raw meat from ST group (Tab. 1), but the difference was not statistically significant. During storage, pH value in both groups decreased, which could be attributed to the LAB growth (Tab. 4), but was still in range usual for the type of product.

Water activity values of both the ST and LT experimental groups were in range usual for smoked chicken breasts [FU and KERR, 2020], but it was higher in samples from ST group compared to the LT group (Tab. 2), which might be due to higher WHC that was recorded in raw meat from ST group (Tab. 1).

TBARS values were similar in both experimental groups and didn't change significantly during storage (Tab. 2). The determined values ranged from 0.05 to 0.07 which was far below the rancidity threshold of 0.6 mg MDA/kg [CHANDRA MOHAN et al., 2017]. Instrumental color analysis showed that samples from the ST group had weaker redness, but more pronounced yellowness, while the lightness was similar in both groups (Tab. 2). L^* and b^* values were affected by interaction of transport and storage time (Tab. 2). It is known that color of cured meats depends on nitrosyl-myoglobin formation, a pigment created by the reaction of nitrite from curing salt with myoglobin from meat [BAJČIĆ et al., 2023; HAN et al., 2024]. As these reactions are influenced by meat pH value [SOLTANI-ZADEH et al., 2012], the differences in pH value between the experimental groups could be the explanation for the difference in redness. During the storage, redness increased in both groups, which could be attributed to continuation of nitrosyl-myoglobin formation through the reaction of

residual nitrite with myoglobin. Yellowness of cured meat products could increase due to microbial decomposition of moieties such as H_2O_2 or H_2S that react with myoglobin giving bilirubin or sulfur-myoglobin [HAN et al., 2024]. As samples from the ST group showed higher microbial counts, this could be the potential cause of their higher yellowness. Despite all differences, the L^* , a^* and b^* values were usual for smoked chicken breasts [FU and KERR, 2020].

Shear force in both the ST and LT groups was similar at the first day of storage (Tab. 2). But it changed during the storage, so samples from the ST group got harder texture after 15 days, while LT group remained unchanged. Shear force values were affected by interaction of transport and storage time. In heat treated meat products, a characteristic texture is formed due to protein denaturation, aggregation and gel formation, as well as connective tissue shrinkage and solubilisation. In addition, these changes are influenced by meat WHC and pH value [TORNBORG, 2005]. Accordingly, as raw meat in ST group had higher WHC, higher pH value, higher shear force (Tab. 1), as well as lower pH and higher a_w in smoked product (Tab. 2), all these factors could have contributed to higher shear force in ST group after 15 days. On the contrary, after 30 days, samples from ST group got softer, while LT group got harder texture. Texture softening happens during meat product ripening, where changes in proteins occur, including proteolysis [LOVEDEEP et al., 2021]. Obviously, such changes developed earlier in samples from the ST then in LT group.

Microbiota of raw chicken breasts

Fresh chicken meat is an excellent substrate for microbial growth as it is rich in moisture and valuable nutrients. Although meat originating from healthy chicken is sterile in the depth microbiological contamination is inevitable due to handling after slaughter where bacteria are transferred from equipment and workers to carcasses and meat cuts [ROUGER et al.,

Sensory

Tab. 5: Effect of broiler transport length on smoked chicken breasts sensory properties during storage

Tab. 5: Einfluss der Transportdauer von Masthähnchen auf die sensorischen Eigenschaften geräucherter Hähnchenbrustfilets während der Lagerung

Sensory attributes	Storage (days)	Length of transportation (km) ¹		Effect ²		
		ST	LT	Transport	Storage	Transport x Storage
External appearance	1	4,9±0,2 ^{Aa}	4,9±0,2 ^{Aa}	< 0.0001	0.1802	< 0.0001
	15	4,5±0,5 ^{Ba}	5,0±0,0 ^{Ab}			
	30	4,6±0,2 ^{ABa}	4,4±0,4 ^{Bb}			
Cross-section appearance	1	4,8±0,3 ^{Aa}	4,4±0,2 ^{Ab}	0.0084	0.0001	0.0183
	15	4,7±0,4 ^{Aa}	3,8±0,6 ^{Bb}			
	30	4,6±0,4 ^{Aa}	4,3±0,5 ^{Ab}			
Colour and colour stability	1	4,9±0,2 ^{Aa}	4,7±0,2 ^{Ab}	0.0001	0.0067	0.1606
	15	4,7±0,4 ^{ABa}	4,4±0,3 ^{Bb}			
	30	4,5±0,4 ^{Ba}	4,4±0,2 ^{Ba}			
Odor and taste	1	4,9±0,2 ^{Aa}	4,5±0,2 ^{ABb}	0.0078	0.1252	0.0052
	15	4,7±0,4 ^{ABa}	4,4±0,2 ^{Ab}			
	30	4,5±0,5 ^{Ba}	4,6±0,2 ^{Ba}			
Texture and juiciness	1	4,7±0,3 ^{Aa}	4,2±0,6 ^{Ab}	0.0002	0.0001	0.0077
	15	4,4±0,3 ^{Ba}	3,7±0,5 ^{Bb}			
	30	4,4±0,4 ^{Ba}	4,3±0,4 ^{Aa}			

¹Results of one-factor analysis of variance; ²Results of two-factor analysis of variance. ^{ab} Significant difference in a row ($p < 0.05$); ^{A*} Significant difference in a column ($p < 0.05$).

ST, short transport (20 km); LT, long transport (170 km). Values are means $\pm$ SE (n = 6).

Source: RADović et al.

2017). In the present study, all bacterial counts were affected by transport length, storage time, and their interaction, except total count of psychrophilic bacteria, which were not affected by the storage time (Tab. 3). Results in our study showed that at the 1st day samples from LT group contained significantly higher number of LAB *Enterobacteriaceae*, as well as total count of mesophilic and psychrophilic bacteria, while the number of *Micrococci* was similar. On the contrary, after the 4th day of storage, samples from the ST group contained higher numbers of *Micrococci*, and total count of mesophilic and psychrophilic bacteria, while the number of LAB and *Enterobacteriaceae* was similar. None of all examined samples from both groups contained clostridia, *Salmonella* spp nor *Listeria monocytogenes*. All isolated microorganisms were usual microbiota of fresh chicken meat (DOUROU et al., 2021). Higher bacterial counts in LT group could be attributed to longer exposure of birds to their own excrements in the cages during longer transportation, and stressful surroundings as well (COX and PAVIC, 2010), which is all described as important source of microbial contamination in broilers (ROUGER et al., 2017). During storage, all bacterial counts significantly increased in ST group, while in LT group counts remained unchanged (LAB, *Enterobacteriaceae*, total count of mesophilic bacteria) or even decreased (*Micrococci*, total count of psychrophilic bacteria). Higher bacterial counts in ST group could be attributed to the higher initial meat pH value (Tab. 1), which is suitable for the bacterial growth in meat. However, the bacterial counts in both ST and LT groups were in range usual for raw chicken meat stored at 4 °C as reported by other authors (ROUGER et al., 2017; DOUROU et al., 2021).

Microbiota of smoked chicken breasts

Different processing methods influence significantly chicken meat microbiota in various ways, depending on the techniques used (AL-MAAQR et al., 2024). Smoked chicken meat production is based on curing, smoking and heat treatment, where the very heat treatment provides a significant reduction in the number of microorganisms, especially when the core temperature exceeds 60 °C (AKAKPO et al., 2022). In the present study, all bacterial counts in smoked chicken breasts were affected by the interaction of transport and storage time (Tab. 4). Bacterial counts in smoked chicken breasts (Tab. 4) were distinctly lower than in raw meat (Tab. 3), which could be attributed to the applied heat treatment at 72 °C. At the beginning of the storage, LAB in both experimental groups as well as *Enterobacteriaceae* in LT group throughout the storage were below the detection limit (< 1.00 log cfu/g), which is usual as these bacteria are not heat resistant. The presence of *Enterobacteriaceae* on the 1st day of storage in ST group could be attributed to the usual surface contamination of smoked products (AKAKPO et al., 2022), and their count was however below the detection limit after 15th and 30th day of storage. Although being below the detection limit, LAB count showed up and increased gradually during the storage, which is usual for the vacuum-packed products, as LAB are microaerophilic microorganisms and also could be found in pasteurized foods (BINTSIS, 2018). *Micrococci* and total count of mesophilic bacteria were detected throughout the whole period of storage, being significantly higher in the ST group. *Micrococci* are known as thermophilic bacteria that are capable to survive 63 °C for 30 min (CORTEZ et al., 2022), so they could survive the heat treatment used in our experiment, but as they are aerobic microorganisms, their count decreased during the storage in vacuum-packaging. Psychrophilic bacteria were detected in both experimental groups, but in ST group their count was significantly lower than in the LT group at the beginning and lowered below the detection limit till the end of the storage, while in LT group they persisted to the 30th day.

Sensory properties of smoked chicken breasts

Sensory properties of smoked chicken breasts are influenced by various factors, starting from the raw meat quality, processing techniques including way of brining, smoking process, heat treatment, chilling and storage (FU and KERR, 2020). In the present study, only color and color stability were not affected by interaction of transport and storage time (Tab. 5). The results of sensory analysis showed that samples from both the ST

and LT groups were highly evaluated, since most of the properties got scores of at least 4.5, and the lowest ratings were found in the LT group only for cross-section appearance (3.8), and texture and juiciness (3.7), both after 15 days of storage.

External appearance was almost the same in both groups at the first day of storage, without any defects, while after 15 days, samples from ST group got 0.5 lower score because of light wrinkles on the surface (Tab. 5). This could be due to the protein shrinkage (TORNBERG, 2005) which gave higher shear force in ST products (Tab. 2) at the 15th day of storage. After 30 days, wrinkles are noticed also in samples from LT group, that had higher shear force at this stage, resulting in even lower score (4.4) compared to ST group (4.6).

Cross section appearance of samples from ST group was significantly better evaluated than LT group during the whole storage period (Tab. 5), being more compact and with more uniform color. Color and color stability was also better evaluated in ST group, being more uniform and stable, but only after 1st and 15th day, while there was no difference between groups after 30 days of storage. As described in previous sections, instrumental color analysis (Tab. 2) showed that samples from ST group were somewhat darker, with less redness and more pronounced yellowness. According to FU and KERR (2020) pink color in cooked white poultry meat is not favored and usually is considered as an indicator of unsafe and undercooked meat, which is described as "pink defect".

Odor and taste were better evaluated in ST group, also only after 1st and 15th day, while there was no difference between groups after 30 days of storage (Tab. 5). Other authors also reported that there is no off-odor in chicken breasts with bacterial counts below 4.5 log cfu/g (BALAMATSI et al., 2006) similar to values obtained in our study (Tab. 4). Even more, such findings are usual as aroma of smoked meat is much complex being based on different volatile aromatic compounds, mainly including phenols, aldehydes, and nitrogenous moieties (GAO et al., 2024).

Texture and juiciness were better evaluated in ST group, also only after 1st and 15th day (Tab. 5). Better texture could be due to higher shear force in ST products (Tab. 2) at the 15th day of storage, and better juiciness could be attributed to higher WHC of meat from ST group (Tab. 1). After 30 days, there was no significant difference in texture and juiciness between experimental groups.

Significance for the practice

The results of this study demonstrate that broiler transport length showed significant effects on several key quality parameters of both raw and smoked chicken breasts. Raw chicken breasts obtained from short transported broilers (ST) showed higher early post-mortem pH value and water-holding capacity, weaker redness and more pronounced yellowness, less intense oxidative changes (TBARS value) and mostly lower bacterial loads, compared to meat from long transported birds (LT). Smoked chicken breasts from the ST group showed higher initial pH and *a_w* values, as well as higher yellowness, higher textural instability and higher lactic acid bacteria counts during storage. Sensory properties of smoked chicken breasts from the both groups were highly evaluated, but products from the ST group got a slightly better scores almost for all examined attributes. Despite better sensory scores in ST group, bearing in mind that physico-chemical, oxidative and microbiological parameters change during storage, further investigation during prolonged storage should be conducted in order to determine the final stability and overall quality of these products over time. Although all investigated quality parameters in this study were within usual ranges, significant differences that were observed between the experimental groups indicate that optimizing broiler transport length and duration can help maintain meat quality, improve shelf-life, and enhance consumer acceptance in poultry meat production.

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vergleichbaren kommerziellen Bedingungen aufgezogen und transportiert wurden. Der einzige untersuchte Variationsfaktor war die Transportdauer, wobei zwei Gruppen gebildet wurden: Kurztransport (20 km) und Langtransport (170 km). Aus dem Brustmuskel (*M. pectoralis major*) der Tiere wurden zwei Versuchsgruppen gebildet – die Kurztransportgruppe (ST) und die Langtransportgruppe (LT) – jeweils mit rohen und geräucherten Hähnchenbrustfilets als Varianten. Zu Beginn der Lagerung zeigten die rohen Filets der ST-Gruppe einen höheren pH-Wert, eine höhere Wasserhaltekapazität (WHC) und Scherkraft sowie niedrigere TBARS- und L*-Werte. Im Verlauf der Lagerung stiegen in dieser Gruppe die TBARS- und L*-Werte, während pH-Wert und Scherkraft sanken. Im Gegensatz dazu wurden in der LT-Gruppe während der Lagerung ein Anstieg von WHC, L*- und a*-Werte sowie ein Rückgang von TBARS, b*-Wert und Scherkraft beobachtet. Bei den geräucherten Filets zeigten sich zu Beginn der Lagerung signifikante Unterschiede ausschließlich in den Farbwerten (L*, a*, b*) beider Gruppen. Am Ende der Lagerzeit wiesen die ST-Proben höhere b*- und niedrigere pH-Werte auf, während die LT-Proben durch höhere a*- und Scherkraftwerte gekennzeichnet waren. Zu Beginn der Lagerung zeigten die rohen LT-Proben im Allgemeinen höhere Keimzahlen, mit Ausnahme der Mikrokokken. Während der Lagerung stiegen die Gesamtkeimzahlen in den ST-Proben an, während in den LT-Proben die Mikrokokkenzahlen zunahmen und die Gesamtzahl psychrophiler Keime abnahm. Die mikrobielle Belastung war bei den geräucherten Proben deutlich geringer als bei den rohen Filets. Das Schnittbild der geräucherten Filets zeigte während der gesamten Lagerdauer höhere Werte in der ST-Gruppe im Vergleich zur LT-Gruppe. Hinsichtlich Farbe und Farbstabilität, Geruch, Geschmack, Textur und Saftigkeit erzielten die ST-Proben sowohl am ersten als auch am fünfzehnten Lagertag bessere Bewertungen, ebenso wie das äußere Erscheinungsbild am dreißigsten Lagertag.

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Contacts

Vesna Radovic, Prof. Dr. Dragan Vasilev (corresponding author: vasilevd@vet.bg.ac.rs),
Nedjeljko Karabasil, Mirjana Dimitrijevic, Branko Suvajdzic, Milijana Sindjic, Silvana Stajkovic,
Faculty of Veterinary Medicine, University of Belgrade, Bulevar oslobodjenja 18, 11000 Belgrade,
Serbia;
Prof. Dr. Vladimir Tomovic, Faculty of Technology, University of Novi Sad, Bulevar cara Lazara 1,
21000 Novi Sad, Serbia

Zusammenfassung

Der Einfluss der Transportdauer von Masthühnern auf die Sicherheitsparameter von Hähnchenbrustfilets

Auswirkung auf die Qualitätsparameter von rohen und geräucherten Hähnchenbrustfilets

Vesna Radovic, Dragan Vasilev, Nedjeljko Karabasil, Mirjana Dimitrijevic, Branko Suvajdzic, Milijana Sindjic, Silvana Stajkovic – Belgrad, Serbien; Vladimir Tomovic – Novi Sad, Serbien

Broilertransport | Hähnchenbrust | Rohes Fleisch | Geräuchertes Fleisch | Sicherheit | Qualität

Ziel der vorliegenden Studie war es, den Einfluss der Transportdauer von Masthühnern auf sicherheits- und qualitätsrelevante Parameter von rohen und geräucherten Hähnchenbrustfilets zu untersuchen. Die Untersuchung wurde an Ross 308-Broilern durchgeführt, die unter