

## PHYSICOCHEMICAL AND SENSORY CHARACTERISTICS OF SMOKED PORK LOIN PRODUCED WITH AN ALTERNATIVE CURING SYSTEM

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### ABSTRACT

This study extends previous research on colour development in industrially produced semi-dry smoked pork loin by evaluating additional physicochemical characteristics and sensory quality of the same experimental batches. Four groups of smoked pork loin were produced in three production replicates under industrial conditions: group I with table salt, dextrose and ascorbic acid; group II with nitrite salt, dextrose and ascorbic acid; group III with nitrite salt, dextrose, ascorbic acid and starter culture BactoFerm Rosa; and group IV with table salt, Swiss chard powder, dextrose, acerola powder and starter culture BactoFerm Rosa. Samples were analysed during salting and after thermal processing, while sensory evaluation of the finished products was performed by 10 assessors using descriptive sensory scoring scales. During processing, water activity and moisture content decreased in all groups, whereas dry matter-related components increased, reflecting dehydration and salt diffusion during salting and thermal processing. In the final product, pH values remained within a narrow range, indicating that the starter culture did not cause a marked pH change in smoked pork loin as a non-fermented whole-muscle product. Group III showed the most favourable sensory profile, particularly for cut-surface colour, odour, taste, aroma and overall impression. Group IV had favourable texture and aroma scores, but poor cut-surface colour development, which negatively affected the overall impression. The results indicate that nitrite salt combined with starter culture provided the most balanced quality profile, whereas direct application of Swiss chard powder with acerola powder and starter culture requires further technological optimization to achieve uniform colour development.

**Key words:** smoked pork loin, Swiss chard powder, acerola, starter culture, sensory quality, physicochemical properties.

### INTRODUCTION

Semi-dry smoked pork loin is a whole-muscle product, most commonly produced from *m. longissimus dorsi*, using curing, drying, smoking and heat treatment (Carnero-Hernández et al., 2023). The quality of this product depends on the properties of the raw material, the composition of the curing mixture, the curing duration, and the smoking and heat-treatment conditions (Carnero-Hernández et al., 2023; Kim & Chin, 2022). These factors directly affect the physicochemical properties, colour, texture, flavour and overall sensory acceptability of the final product (Carnero-Hernández et al., 2023).

Nitrites have an important technological role in the production of cured meat products (Yong et al., 2021; Shakil et al., 2022; Zhang et al., 2023). They contribute to the development and stabilisation of the characteristic pink-red colour, the formation of specific flavour and aroma, the reduction of oxidative changes, and the improvement of the product's

microbiological stability (Yong et al., 2021; Zhang et al., 2023). However, their use has attracted increasing scientific and regulatory attention due to the potential formation of *N*-nitroso compounds, particularly *N*-nitrosamines, which are associated with health risks (Shakil et al., 2022). Therefore, current trends in the meat industry are directed towards reducing the use of synthetic nitrites and adopting clean-label approaches (Yong et al., 2021). In this context, natural sources of nitrates, such as Swiss chard powder, celery, spinach or beetroot, in combination with starter cultures, possessing nitrate-reducing activity, are being considered as a possible approach for the partial replacement of synthetic nitrites in cured meat products (Bhusal & Muriana, 2021; Silovska Nikolova & Belichovska, 2021).

A previous study on industrially produced smoked pork loin showed that the application of Swiss chard powder, acerola powder and a starter culture with nitrate-reducing activity affected colour formation, with colour development being more pronounced in the peripheral part and limited in the central part of the product (Silovska Nikolova et al., 2022). This finding indicates that, in addition to colour, a broader assessment of quality is required, including physicochemical properties and sensory characteristics. Therefore, the present study builds on previous research and examines the effect of this natural curing system on the physicochemical properties and sensory quality of semi-dry smoked pork loin produced under industrial conditions.

## MATERIAL AND METHODS

### Material

This study builds on previously published research on smoked pork loin, produced under industrial conditions (Silovska Nikolova et al., 2022). The production protocol and formulation of the experimental groups were described in detail in the previous publication. Briefly, four groups of smoked pork loin were produced: group I with table salt, dextrose and ascorbic acid; group II with nitrite salt, dextrose and ascorbic acid; group III with nitrite salt, dextrose, ascorbic acid and starter culture; and group IV with table salt, Swiss chard powder, acerola powder, dextrose and starter culture. Each experimental group was produced in three independent production replicates under industrial conditions, following the protocol described by Silovska Nikolova et al. (2022). The same experimental batches were used in the present study to evaluate physicochemical properties and sensory quality, which had not been previously reported.

### Methods

Physicochemical and sensory analyses were performed on semi-dry smoked pork loin produced under industrial conditions, using the same experimental batches previously described by Silovska Nikolova et al. (2022). In the present study, additional quality parameters not reported in the previous publication, were investigated.

The samples were analysed at the following production stages: day 0 (12 hours after salting), day 7 of salting, day 14 of salting, and after heat treatment in the finished product. At these stages, pH, water activity (*a<sub>w</sub>*), salt, moisture, protein, fat, and ash contents were determined. The pH value was measured using a portable pH meter (Ebro PHT 810 pH) with a penetration glass electrode, after previous calibration with standard buffer solutions at pH 4.00 and 7.00. Water activity was determined according to ISO 21807:2004, salt content according to the Volhard method (ISO 1841-1:1996), moisture, protein and fat contents by near-infrared spectroscopy using a FoodScan™ Lab analyser according to AOAC 2007.04, and ash content according to ISO 936:1998.

Sensory analysis was performed on the finished product by a panel of ten assessors. A descriptive sensory test using 1–7 and 1–4–7 scoring scales was applied, depending on the evaluated sensory attribute (SEG, 1989). External appearance and colour profile were evaluated on whole pieces of smoked pork loin, while the remaining sensory attributes were

evaluated on slices approximately 1.5 mm thick. The samples were coded, and the evaluation was carried out under organised guidance after prior harmonisation of the assessors. Appearance, colour, texture, odour, taste, saltiness, the presence of off-odours, and overall sensory acceptability were evaluated.

The data were statistically processed using the STATISTICA software package, version 8.0 (StatSoft, Inc., 2007). The experiment was arranged as a  $4 \times 4$  factorial design, comprising four experimental groups of smoked pork loin (I–IV) and four production stages: day 0, day 7, day 14 and after heat treatment. For each group and production stage, three samples were analysed. Analytical replicates were averaged for each sample, and the sample means were included in the statistical analysis. The production replicate was considered the experimental unit.

To evaluate the effects of experimental group, production stage and their interaction on the examined physicochemical parameters, two-way analysis of variance (two-way ANOVA) was applied. The following statistical model was used for each physicochemical parameter:

$$Y_{ijk} = \mu + G_i + F_j + (G \times F)_{ij} + e_{ijk}$$

where  $Y_{ijk}$  is the value of the examined parameter,  $\mu$  is the overall mean,  $G_i$  is the fixed effect of experimental group,  $F_j$  is the fixed effect of production stage,  $(G \times F)_{ij}$  is the interaction between experimental group and production stage, and  $e_{ijk}$  is the random error. Before applying two-way ANOVA, the normality of residuals was assessed using the Shapiro–Wilk test, while homogeneity of variances was evaluated using Levene’s test. No significant deviations from normality or homogeneity of variances were observed for the analysed physicochemical parameters. Differences among mean values were assessed using Tukey’s HSD post hoc test at a significance level of  $p \leq 0.05$ . Results are presented as mean  $\pm$  standard deviation ( $\bar{x} \pm SD$ ).

Sensory data were analysed separately for the finished product using a general linear model. Experimental group (I–IV) was considered as the main fixed factor, while the assessor–production replicate combination was included as a blocking factor to account for variability among assessors and production replicates. The following statistical model was used for each sensory attribute:

$$Y_{ij} = \mu + G_i + B_j + e_{ij}$$

where  $Y_{ij}$  is the sensory score,  $\mu$  is the overall mean,  $G_i$  is the effect of experimental group,  $B_j$  is the effect of the assessor–production replicate block, and  $e_{ij}$  is the random error. Differences among group means were assessed using Tukey’s HSD test at a significance level of  $p \leq 0.05$ . Results are presented as mean  $\pm$  standard deviation ( $\bar{x} \pm SD$ ). For the attribute “off-odours”, statistical testing was not performed because no variability was observed among the scores.

## **RESULTS AND DISCUSSION**

In the finished product, the groups containing starter culture showed slightly higher pH values: group III ( $5.85 \pm 0.01$ ) and group IV ( $5.84 \pm 0.01$ ), compared with group I ( $5.78 \pm 0.01$ ) and group II ( $5.77 \pm 0.01$ ) (Table 1). Although the differences were statistically significant, they were small, ranging from 0.06 to 0.08 pH units. This indicates that, under the applied production model, the starter culture was not associated with a decrease in pH in the finished product. These values are consistent with the nature of smoked pork loin as a non-fermented, dry-salted whole-muscle product, unlike fermented meat products in which acidification is related to the activity of starter cultures (Hwang et al., 2023).

**Table 1. Changes in pH value in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	5.73 ± 0.00 <sup>ab</sup>	5.73 ± 0.02 <sup>ab</sup>	5.71 ± 0.01 <sup>ab</sup>	5.73 ± 0.02 <sup>aC</sup>
<b>Day 7 (salting)</b>	5.63 ± 0.03 <sup>cC</sup>	5.71 ± 0.01 <sup>bBC</sup>	5.65 ± 0.00 <sup>cC</sup>	5.78 ± 0.01 <sup>ab</sup>
<b>Day 14 (salting)</b>	5.63 ± 0.02 <sup>bC</sup>	5.70 ± 0.01 <sup>aC</sup>	5.73 ± 0.03 <sup>ab</sup>	5.74 ± 0.01 <sup>aC</sup>
<b>After heat treatment</b>	5.78 ± 0.01 <sup>bA</sup>	5.77 ± 0.01 <sup>bA</sup>	5.85 ± 0.01 <sup>aA</sup>	5.84 ± 0.01 <sup>aA</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

As expected, water activity ( $a_w$ ) decreased in all groups during the production process, which is related to salting, moisture loss and NaCl uptake during curing and heat treatment (Carnero-Hernández et al., 2023; Kim et al., 2021). In the finished product, the lowest  $a_w$  value was determined in group III ( $0.931 \pm 0.001$ ), whereas the highest value was found in group I ( $0.939 \pm 0.000$ ) (Table 2).

**Table 2. Changes in water activity ( $a_w$ ) in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	0.975 ± 0.000 <sup>aA</sup>	0.970 ± 0.001 <sup>bA</sup>	0.971 ± 0.001 <sup>bA</sup>	0.971 ± 0.001 <sup>bA</sup>
<b>Day 7 (salting)</b>	0.971 ± 0.000 <sup>aB</sup>	0.969 ± 0.002 <sup>abA</sup>	0.968 ± 0.001 <sup>bB</sup>	0.969 ± 0.001 <sup>abA</sup>
<b>Day 14 (salting)</b>	0.967 ± 0.000 <sup>aC</sup>	0.949 ± 0.001 <sup>bB</sup>	0.942 ± 0.000 <sup>cC</sup>	0.948 ± 0.001 <sup>bB</sup>
<b>After heat treatment</b>	0.939 ± 0.000 <sup>aD</sup>	0.936 ± 0.001 <sup>bC</sup>	0.931 ± 0.001 <sup>cD</sup>	0.936 ± 0.002 <sup>bC</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

Moisture content decreased in all groups during the production process. At the beginning, values ranged from 70.99% in group III to 73.27% in group I, whereas in the finished product moisture content decreased to 62.21% in group III, 63.34% in group IV, 64.21% in group II and 64.61% in group I (Table 3). The lowest moisture content in the finished product was determined in group III, which is consistent with the lowest  $a_w$  value recorded in the same group. A decrease in moisture content is expected in a salted and heat-treated meat product, since curing and heat treatment promote changes in NaCl content, moisture loss and dry matter concentration. In smoked pork loin, changes in NaCl concentration, water-holding capacity, colour and sensory properties have been reported after curing and smoking, confirming the close relationship between curing conditions and physicochemical quality (Carnero-Hernández et al., 2023).

**Table 3. Changes in moisture content (%) in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	73.27 ± 0.03 <sup>aA</sup>	71.34 ± 0.03 <sup>cA</sup>	70.99 ± 0.02 <sup>dA</sup>	72.06 ± 0.01 <sup>bA</sup>
<b>Day 7 (salting)</b>	72.25 ± 0.05 <sup>aB</sup>	70.47 ± 0.05 <sup>bB</sup>	70.17 ± 0.04 <sup>cB</sup>	70.08 ± 0.05 <sup>cB</sup>
<b>Day 14 (salting)</b>	71.05 ± 0.06 <sup>aC</sup>	69.64 ± 0.02 <sup>bC</sup>	69.71 ± 0.05 <sup>bC</sup>	69.70 ± 0.03 <sup>bC</sup>
<b>After heat treatment</b>	64.61 ± 0.03 <sup>aD</sup>	64.21 ± 0.04 <sup>bD</sup>	62.21 ± 0.04 <sup>dD</sup>	63.34 ± 0.04 <sup>cD</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

Protein content increased in all groups after heat treatment, mainly due to a concentration effect caused by moisture loss. Initial values ranged from 22.26% in group IV to 23.06% in group III, whereas in the finished product they ranged from 28.07% in group IV to 29.42% in group III (Table 4). This increase is expected, because the reduction in moisture during salting and heat treatment leads to a relative increase in the proportion of protein in the finished product. The increase in protein content in heat-treated smoked pork loin may also be associated with protein denaturation and mass loss, which result in a higher relative proportion of dry matter and protein in the finished product (Szpicer et al., 2023; Carnero-Hernández et al., 2023).

**Table 4. Changes in protein content (%) in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	22.34 ± 0.04 <sup>cB</sup>	22.54 ± 0.03 <sup>bD</sup>	23.06 ± 0.02 <sup>aD</sup>	22.26 ± 0.03 <sup>dC</sup>
<b>Day 7 (salting)</b>	22.36 ± 0.01 <sup>cB</sup>	22.75 ± 0.04 <sup>bC</sup>	23.16 ± 0.01 <sup>aC</sup>	22.36 ± 0.03 <sup>cC</sup>
<b>Day 14 (salting)</b>	22.37 ± 0.02 <sup>cB</sup>	23.35 ± 0.02 <sup>aB</sup>	23.28 ± 0.02 <sup>aB</sup>	22.70 ± 0.06 <sup>bB</sup>
<b>After heat treatment</b>	28.83 ± 0.05 <sup>bA</sup>	29.41 ± 0.04 <sup>aA</sup>	29.42 ± 0.03 <sup>aA</sup>	28.07 ± 0.03 <sup>cA</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

Fat content in the finished product was low in all groups, as expected for pork loin as a relatively lean whole-muscle product. The lowest value was determined in group III (2.04 ± 0.01%), and the highest in group IV (3.21 ± 0.03%) (Table 5). The low fat content may be associated with the natural variability of intramuscular fat in pork loin (Daszkiewicz et al., 2005). In addition, in the present study the raw material had been prepared by removing visible adipose tissue, fascia and irregular parts.

**Table 5. Changes in fat content (%) in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	2.55 ± 0.03 <sup>cA</sup>	3.14 ± 0.04 <sup>aA</sup>	2.87 ± 0.02 <sup>bA</sup>	2.82 ± 0.03 <sup>bB</sup>
<b>Day 7 (salting)</b>	2.30 ± 0.03 <sup>cB</sup>	2.62 ± 0.03 <sup>aC</sup>	2.45 ± 0.04 <sup>bB</sup>	2.63 ± 0.01 <sup>aC</sup>
<b>Day 14 (salting)</b>	2.08 ± 0.03 <sup>bcC</sup>	2.16 ± 0.01 <sup>bD</sup>	2.03 ± 0.03 <sup>cC</sup>	2.56 ± 0.05 <sup>aC</sup>
<b>After heat treatment</b>	2.54 ± 0.03 <sup>cA</sup>	2.70 ± 0.03 <sup>bB</sup>	2.04 ± 0.01 <sup>dC</sup>	3.21 ± 0.03 <sup>aA</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

Ash content increased in all groups during the production process. In the finished product, the highest value was determined in group II ( $4.90 \pm 0.06\%$ ), and the lowest in group IV ( $4.30 \pm 0.04\%$ ) (Table 6). This increase is expected in a dry-salted and heat-treated product, because NaCl uptake and moisture loss lead to a higher relative proportion of mineral matter in the finished product (Carnero-Hernández et al., 2023; Desmond, 2006).

**Table 6. Changes in ash content (%) in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	2.17 ± 0.04 <sup>dD</sup>	2.60 ± 0.02 <sup>bD</sup>	2.90 ± 0.03 <sup>aC</sup>	2.52 ± 0.03 <sup>cC</sup>
<b>Day 7 (salting)</b>	2.93 ± 0.04 <sup>dC</sup>	3.61 ± 0.03 <sup>bC</sup>	3.90 ± 0.06 <sup>aB</sup>	3.39 ± 0.03 <sup>cB</sup>
<b>Day 14 (salting)</b>	3.75 ± 0.02 <sup>cB</sup>	4.25 ± 0.10 <sup>bB</sup>	4.46 ± 0.02 <sup>aA</sup>	3.39 ± 0.08 <sup>dB</sup>
<b>After heat treatment</b>	4.62 ± 0.03 <sup>bA</sup>	4.90 ± 0.06 <sup>aA</sup>	4.41 ± 0.03 <sup>cA</sup>	4.30 ± 0.04 <sup>cA</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

Sodium chloride content increased in all groups during the production process. In the finished product, the lowest value was determined in group I ( $3.45 \pm 0.03\%$ ), and the highest in group IV ( $3.81 \pm 0.02\%$ ) (Table 7). This increase is expected because, during dry salting, NaCl penetrates the muscle tissue, while moisture loss increases its relative concentration in the finished product (Carnero-Hernández et al., 2023; Desmond, 2006). From a technological perspective, these salt values are relevant because sodium chloride affects flavour, texture, water-binding capacity and product stability in meat products (Desmond, 2006).

Regarding external appearance, significant differences among groups were observed for all evaluated attributes ( $p < 0.001$ ). The highest scores were recorded in group III for colour typicality ( $5.08 \pm 0.82$ ), colour intensity ( $4.55 \pm 0.27$ ), colour homogeneity ( $4.32 \pm 0.25$ ) and adipose tissue colour ( $4.38 \pm 0.22$ ), indicating the most favourable external appearance of the product. Group II also showed high scores for these parameters, whereas group I generally had the lowest values. Group IV showed intermediate scores for most external appearance attributes, suggesting partial improvement compared with the negative control.

**Table 7. Changes in sodium chloride content (%) in smoked pork loin during the production process**

Production stage	Groups of smoked pork loin			
	I	II	III	IV
	$\bar{x} \pm SD$			
<b>Day 0</b> (12 hours after salting)	2.45 ± 0.04 <sup>bd</sup>	2.55 ± 0.02 <sup>ad</sup>	2.55 ± 0.01 <sup>ad</sup>	2.57 ± 0.01 <sup>ad</sup>
<b>Day 7 (salting)</b>	2.61 ± 0.02 <sup>bc</sup>	2.73 ± 0.06 <sup>abc</sup>	2.79 ± 0.06 <sup>ac</sup>	2.84 ± 0.04 <sup>ac</sup>
<b>Day 14 (salting)</b>	2.83 ± 0.04 <sup>bb</sup>	2.90 ± 0.01 <sup>abB</sup>	2.95 ± 0.03 <sup>ab</sup>	2.98 ± 0.06 <sup>ab</sup>
<b>After heat treatment</b>	3.45 ± 0.03 <sup>ca</sup>	3.73 ± 0.05 <sup>ba</sup>	3.76 ± 0.02 <sup>abA</sup>	3.81 ± 0.02 <sup>aA</sup>

$\bar{x}$  – mean value; SD – standard deviation. Mean values marked with different lower-case letters within the same row differ significantly among experimental groups, whereas mean values marked with different upper-case letters within the same column differ significantly among production stages (Tukey HSD,  $p \leq 0.05$ ).

**Table 8. Sensory scores of finished smoked pork loin produced with different curing formulations**

Attribute	I	II	III	IV	p
	$\bar{x} \pm SD$				
<b>EXTERNAL APPEARANCE</b>					
Colour typicality (1–7)	2	3	5	3	<
Colour intensity (1–4–7)	2	4	4	3	<
Colour homogeneity (1–7)	2	4	4	3	<
Adipose tissue colour (1–7)	2	4	4	3	<
<b>COLOUR PROFILE</b>					
Cut-surface colour typicality (1–4–7)	1	4	5	1	<
Cut-surface colour intensity (1–4–7)	1	3	4	1	<
Cut-surface colour homogeneity (1–7)	1	5	6	1	<
<b>TEXTURE PROFILE</b>					
Firmness–hardness (1–7)	5	5	4	4	<
Adhesiveness (1–7)	2	2	3	3	<
Disintegration/fragmentation (1–7)	3	4	6	6	<
Moisture absorption (1–7)	3	4	6	6	<
Bite resistance/grip (1–7)	3	4	6	6	<
<b>AROMA PROFILE</b>					
Odour typicality (1–7)	3	5	6	6	<
Off-odours (1–7)	1	1	1	1	
Taste typicality (1–7)	3	5	6	6	<
Aroma typicality (1–7)	3	5	6	6	<
<b>SALTINESS (1–4–7)</b>	3	4	4	4	<
<b>OVERALL IMPRESSION (1–7)</b>	2	5	6	3	<

$\bar{x}$  – mean value; SD – standard deviation; p – significance level for the effect of experimental group in the GLM model. Mean values marked with different lower-case letters within the same row differ significantly among groups (Tukey HSD,  $p \leq 0.05$ ). For the attribute “off-odours”, statistical testing was not performed because no variability was observed among the scores.

Significant differences among experimental groups were found for all evaluated sensory attributes, except for off-odours, for which all groups had an identical value of  $1.00 \pm 0.00$ . The most pronounced and most typical cut-surface colour profile was determined in group III, which had the highest scores for cut-surface colour typicality ( $5.13 \pm 0.29$ ), cut-surface colour intensity ( $4.17 \pm 0.24$ ) and cut-surface colour homogeneity ( $6.77 \pm 0.25$ ). In contrast,

group IV had the lowest scores for cut-surface colour, particularly for intensity and homogeneity, both of which were  $1.00 \pm 0.00$ . This indicates that the direct application of Swiss chard powder in combination with starter culture did not provide uniform development of the characteristic colour in the central part of the product. This result is consistent with the previous study on smoked pork loin, in which the formulation containing Swiss chard powder, acerola and starter culture developed colour mainly at the periphery, due to the limited availability of formed nitrites for reaction with myoglobin in the central part of the product (Silovska Nikolova et al., 2022).

In the texture profile, groups III and IV had lower firmness–hardness scores ( $4.18 \pm 0.25$ ) compared with group I ( $5.87 \pm 0.32$ ) and group II ( $5.37 \pm 0.32$ ). The same groups showed higher scores for disintegration, moisture absorption and grip/bite resistance, indicating a different texture profile in the formulations containing starter culture. These changes may be related to the influence of starter cultures on the structural and sensory properties of meat products; however, this interpretation should remain cautious, since the available evidence mainly concerns fermented meat products rather than non-fermented smoked pork loin (Hwang et al., 2023).

In the aroma profile, the highest scores were determined in group III for odour typicality ( $6.58 \pm 0.32$ ), taste typicality ( $6.58 \pm 0.30$ ) and aroma typicality ( $6.57 \pm 0.34$ ). Group IV also showed high scores for odour, taste and aroma, indicating that the application of starter culture and Swiss chard powder did not impair the aroma profile of the product. Overall impression was highest in group III ( $6.37 \pm 0.29$ ), followed by group II ( $5.30 \pm 0.34$ ), whereas groups IV and I had lower scores,  $3.43 \pm 0.43$  and  $2.47 \pm 0.37$ , respectively. In group IV, the favourable texture and aroma profile was not sufficient to achieve a high overall score, most probably due to the poor development and homogeneity of cut-surface colour.

Kim et al. (2019), using pre-fermented Swiss chard solution in semi-dry pork loin, obtained better sensory scores for colour without significantly impairing taste, off-odours, chewiness, juiciness or overall acceptability. This indicates that prior conversion of nitrates from Swiss chard into nitrites may have a more favourable effect on colour development. However, that approach is not directly comparable with dry-salted smoked pork loin with directly added Swiss chard powder, due to the different mode of application of the plant-based nitrate source.

## CONCLUSIONS

Based on the obtained results, several conclusions can be drawn. During the production process, water activity and moisture content decreased in all groups, whereas protein, ash and sodium chloride contents increased. These changes are expected in dry-salted and heat-treated smoked pork loin. The starter culture did not reduce the pH value of the finished product, indicating that the examined product did not behave as a fermented product with pronounced acidification. The most favourable sensory profile was determined in group III, which received the highest scores for cut-surface colour, odour typicality, taste typicality, aroma typicality and overall impression. Group IV showed a favourable texture and aroma profile; however, the poor development of cut-surface colour negatively affected the overall impression. The direct application of Swiss chard powder in combination with acerola powder and starter culture did not ensure sufficient and uniform red-pink colour development in the central part of the product. For more effective use of Swiss chard powder as a natural nitrate source, further technological optimisation of the process is required, particularly to improve the conversion of nitrates into nitrites before heat treatment.

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