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Optimization of additives in the curing of meat and meat products

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Abstract

This study investigates the efficacy of nitrite salts and inorganic phosphates in meat products. First, the focus was on optimizing nitrite salt addition in meat emulsion coagulates and cooked pork loins. Nitrite salt from a test producer was compared with that from a standard producer by analysing nitrite residues, instrumentally measured colour parameters, and sensory attributes. Secondly, the optimal addition of inorganic phosphates from standard and test producers in meat emulsion coagulates and coarse-ground-meat coagulates were evaluated by analysing phosphate content, instrumentally measured texture parameters, and sensory attributes. The findings indicate that the optimal addition of nitrite salt from the test producer is 1.6 % for meat emulsion coagulates and 2.5 % for cooked pork loins. For meat emulsion coagulates, both 0.3 % and 0.4 % phosphate additions from the test producer are suitable, while for coarse-ground-meat coagulates, a slight advantage is observed for the 0.4 % addition due to lower adhesiveness. The importance of continuous evaluation and optimization of food additives to ensure consumer safety, product quality, and regulatory compliance is emphasized.

Keywords: meat emulsion coagulates, cooked and cured meat, coarse-ground meat coagulates, nitrite, phosphate

Introduction

Meat and meat products are an important part of the human diet, but there are concerns about their quality and safety (Xie et al., 2023). The discovery of carcinogenic and genotoxic N-nitroso compounds (NOCs) in processed meat products has had a negative impact on the meat industry. Researchers continue to investigate the safety of nitrites and nitrates and are looking for ways to replace their functions with other food additives. They are also investigating nitrite residues in meat and meat products and developing alternative additives (Zhang et al., 2023).

One of the concerns associated with the consumption of processed meat products is the use of synthetic additives such as inorganic phosphates. Their intake is associated with hyperphosphataemia in patients with chronic kidney disease and reduced absorption of certain minerals (Molina et al., 2023). Inorganic phosphates are functional food additives used to improve water holding capacity, emulsion stability, yield during thermal processing, sensory properties (Santhi et al., 2017), antioxidant and antimicrobial properties (Barbut and Mittal, 1991). In most countries, meat product formula-

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tions are allowed to contain up to 0.5 % inorganic phosphates (as P_2O_5) in the final product to ensure consumer acceptance and safety (Regulation (EC) No 1333/2008; Balestra and Petracci, 2019).

Additive producers are often faced with the dilemma of comparing the efficacy of their additives in different meat products (based on meat emulsion, cured meat or coarse mosaic sausages) with that of additives from other producers on the market. This was the basis for our study, in which the addition of nitrite salt from the test producer was optimised compared to the nitrite salt from the standard producer (control) in the production of meat emulsion coagulates and cooked pork loins. Based on the analysis of the nitrite residues, the instrumental colour measurement and the sensory analysis, the optimum addition of nitrite salt was determined for both products.

In the second part of the study, the meat emulsion coagulates and the coarse-ground-meat coagulates were produced with different additions of inorganic phosphate from two producers, the standard producer and the tested producer. The optimum addition of inorganic phosphate for both products was determined by analysing the phosphate content, instrumental texture measurement and sensory analysis.

Material and methods

Material

In the first part of the experiment, two products were made, meat emulsion coagulates and cooked pork loins with nitrite salt from two producers in different concentrations (2 products × 3 amount of nitrite salt originated from two producers × 2 production replicates = 12 products), and in the second part of the experiment, meat emulsion coagulates and coarse-ground-meat coagulates with inorganic phosphate in different concentrations (2 products × 3 amount of phosphate originated from two producers × 2 production replicates = 12 products).

Raw material (pork leg, beef top round, back fat) was obtained from local store and was stored at 2 °C. The further materials used included:

- nitrite salt (0.5 % sodium nitrite; P1 – producer 1: Prava Aroma, Zrkovci, Slovenia),
- nitrite salt (0.3 % sodium nitrite; P2 – producer 2: TKI, Hrastnik, Slovenia),
- seasoning mixture for frankfurter (Aroma mix; Prava Aroma, Zrkovci, Slovenia),
- phosphate CARNAL® (P1 – producer 1: Budenheim, Geschwister Oetker Beteiligungen KG; combination of sodium pyro-, sodium tripoly-, and sodium hexametaphosphates up to 50.0 % expressed as P_2O_5),
- phosphate SOFOS 4X (P2 – producer 2: TKI, Hrastnik, Slovenia; combination of sodium di-, sodium poly-, and sodium tripolyphosphates up to 50.0 % expressed as P_2O_5),
- sodium ascorbate (Aroma mix, Prava Aroma, Zrkovci, Slovenia),
- garlic granulate (Aroma mix, Prava Aroma, Zrkovci, Slovenia).

Production of meat emulsion coagulates

A total of six experimental groups of meat emulsion coagulates were produced based on nitrite salt and phosphate addition; each additive was added to provide three levels, as detailed in Table 1.

Conditioned beef, pork meat and pork back fat (-5 °C) were ground separately in a meat grinder (MADO GmbH, Germany). In the first part of the experiment ground meat and phosphate from producer 1 (P1) were homogenized with half of the ice in the Stephan UMC 5 electronic (double-layer vacuum cutter Stephan Nahrungsmittel und Verfahrenstechnik, Germany) at a speed of 2400 × rpm until the temperature of the meat batter was 8 °C. Then nitrite salt, fat, sodium ascorbate, seasoning mixture for frankfurter, garlic granulate and the remaining ice were added and homogenization continued under vacuum until the temperature reached 12 °C. The emulsion was filled into vacuum PA/PE bags (120 mm × 550 mm, thickness 0.09 mm, TE-CO d.o.o., Slovenia), formed into a cylinder (diameter 38 mm) and one hour after production (stabilisation of colour) thermally treated in a steam-convection oven (Rational FRIMA SCC61, Germany) at moist heat up to a core temperature of 72 °C. The meat emulsion coagulates were vacuum packed and stored in a refrigerator at 4 °C until analysis. Three experimental groups of meat emulsion coagulate were produced with different addition of nitrite salt (1.4 % (P1), 1.6 % (P2) and 2.0 % (P2)) in two production replicates. In order to achieve the same effect as with the control nitrite salt (P1), we had to add larger quantities of test nitrite salt (P2) to the meat emulsion coagulates and the cooked pork loins. The curing salt P2 contained 0.3

Table 1 Formulations for the production of meat emulsion coagulates, cooked pork loins and coarse-ground-meat coagulates

Additive added in three levels	**Nitrite salt**		**Phosphate**	
Ingredients (wt. %)	Meat emulsion coagulates	Pork loins	Meat emulsion coagulates	Coarse-ground-meat coagulates
Beef	30		30	11
Pork	16	100	16	70
Pork back fat	24		24	14
Ice/water	30		30	5
Calculated per kg of	**upper sum**	**injected meat**	**upper sum**	**upper sum**
Nitrite salt	1.4 (P1)	2.0 (P1)	1.4 (P1)	2.0 (P1)
	1.6 (P2)	2.5 (P2)		
	2.0 (P2)	3.0 (P2)		
Phosphate	0.3 (P1)	0.5 (P1)	0.3 (P1)	0.3 (P1)
			0.3 (P2)	0.3 (P2)
			0.4 (P2)	0.4 (P2)
+ water		7.5		
		7.0		
		6.5		
Na ascorbate	0.1		0.1	0.1
Aroma mix frankfurter	0.2		0.2	
Garlic granulate	0.2		0.2	0.3
Pepper				0.2

P1 – producer 1; P2 – producer 2.

% nitrite, while in the producer's curing salt P1 nitrite content was higher, 0.5 %.

In the second part of the experiment, meat emulsion coagulates were made following the same protocol, with the exception of phosphate additions (0.3 % (P1), 0.3 % (P2), and 0.4 % (P2)). In this part of experiment, additive from producer P1 served as a control due to their routine and verified use in the past. To achieve the same effect as with the control phosphate (P1), equal amounts of phosphate mixture (0.3 %) both producers (P1 and P2) was added to meat emulsion coagulates and coarse-ground-meat coagulates. The phosphate mixture P2 contained the same amount of phosphate as the mixture from producer P1. By adding phosphate mixture P2 at higher levels (0.4 %), we tested the acceptability of the samples produced in this way.

Production of the cooked pork loins

A three experimental groups of cooked pork loins were produced based on nitrite salt addition to provided three levels, as detailed in Table 1. Two-kilogram pieces of pork loins were manually injected with 20 wt. % of brine, in which was previously dissolved phosphate (P1) and nitrite salt at different levels, 2 % (P1), 2.5 % (P2), or 3 % (P2). After injection, the pork loins were vacuum packed and stored in cold (2 °C) for 5 days for proper brine distribution, solubilizing of intramuscular proteins and to create texture. Then the injected pork loins were hung with a string on the oven racks and thermally treated in a steam-convection oven (Rational FRIMA SCC61, Germany) using moist heat (80 °C, 100 % RH) to a core temperature of 72 °C.

Production of the coarse-ground-meat coagulates

Samples of coarse-ground-meat coagulates were produced from medium/coarse ground pork (meat grinder plate hole, 13 mm) of the highest quality, combined with solid back fat (meat grinder plate hole, 10 mm), twice ground beef (meat grinder plate hole, 3 mm), small amount of water and phosphate (Table 1). The meat-fat mixture has to be cured (nitrite salt P1 and ascorbate), seasoned with pepper and dehydrated garlic and mixed (Bosch mum mixer, Slovenia). Mixture was used to fill into vacuum PA/PE bags (120 mm × 550 mm, thickness 0.09 mm, TE-CO d.o.o., Slovenia), formed into a cylinder (diameter 38 mm), and twelve hours after formation (stabilisation of colour) thermally treated in steam-convection oven (Rational FRIMA SCC61, Germany) at moist heat until the core temperature of 72 °C. The coarse-ground-meat coagulates were vacuum packed and stored in a refrigerator at 4 °C until analysis. Three experimental groups of coarse-ground-meat coagulates were produced with different addition of phosphate (0.3 % (P1), 0.3 % (P2) and 0.4 % (P2)), in two production replicates.

For the chemical analysis, the samples used were initially homogenized (Grindomix GM 200; Retch, Germany), then vacuum packed into polythene bags and stored until analysis in a freezer at −18 °C. For the evaluation of the sensory properties, instrumental measurements of texture and colour fresh samples were used. All of the parameters were measured twice, with the colour values measured five times and sensory attributes assessed by five panellists.

Methods

Determination of the chemical composition: The water content of products was determined on 5 g minced samples, dried in an oven at 105 °C (according to Association of Official Analytical Chemists [AOAC] 950.46; AOAC, 1997), and the total protein content (crude protein, N × 6.25) by the Kjeldahl method (according to AOAC 928.08; AOAC, 1997). The fat content was determined on SoxtecTM 2050 Automatic System (Foss) based on hydrolysis with 4M HCl and hot extraction with petroleum ether as a solvent. NaCl was determined by the Volhard method (according to AOAC 941.18; AOAC, 1997), nitrite by the method described as AOAC Official Method 973.31 for Nitrite in Cured Meats. Phosphate was determined by the AOAC Official Method 991.27 Phosphorus in Meat and Meat Products (AOAC, 1997). Data from the chemical analyses were expressed on a wet matter basis.

Determination of textural parameters: For instrumental measurements of texture, two 25 mm thick slices were taken from each sample. Using a scalpel, squares measuring 25×25×25 mm were carefully cut, covered with plastic wrap to prevent drying, and conditioned at a temperature of 4 °C for 2 h. TPA (Texture Profile Analysis) was performed as described previously by Morales et al. (2007) on four samples using the XT Plus texture analyser (Stable Micro Systems Ltd., Surrey, UK) for each product. The specimens were compressed twice to 50 % vertical to the muscle fibres (with an interval of 5 s between these compression cycles) and at a crosshead speed of 5 mm/s. The force-time curves were recorded, and the following parameters were calculated: hardness (expressed as maximum force of the first compression), adhesiveness (expressed as the negative work between the two cycles), cohesiveness (ratio between the positive force area during the second compression cycle and that during the first compression cycle), springiness (expressed as a ratio or percentage of the original downstroke compression), chewiness (expresses as the product of hardness, cohesiveness and springiness), and resilience (expressed by dividing the upstroke energy of the first compression by the downstroke energy of the first compression) (Bourne, 1978; Novaković and Tomašević, 2017).

Determination of colour: A CR-400 Chroma Meter (Konica Minolta Optics, Inc., Osaka, Japan; Illuminant C, 0° viewing angle) was used to determine Commission Internationale de l'Eclairage (CIE; International Commission on Illumination) *L** (lightness), *a** (±, red to green) and *b** (±, yellow to blue) values on the surface of a 3-4 cm slice. A white ceramic tile with the specifications Y = 84.6, x = 0.3176, y = 0.3245 was used to standardise the colorimeter. The colour values CIE *L**, *a**, *b** were measured at five different points on the surface and the total difference, ΔE* calculated:

$$\Delta E^*_{cx} = [(L^*_c - L^*_x)^2 + (a^*_c - a^*_x)^2 + (b^*_c - b^*_x)^2]^{½},$$

where c means control sample, x tested sample.

Sensory evaluation: To evaluate the sensory qualities, a panel of five qualified and experienced panellists in the field of meat products was appointed (Gašperlin et al., 2014), with the sensory properties of coded (blinded) samples tasted. The panel has been trained and has participated in the sensory profiling of meat products for at least 8 years. All samples were assessed by the same panel. The evaluation was carried out under defined, precisely prescribed, controlled and reproducible operating conditions (ISO 8589:2007; ISO 8586:2023). The analysis was performed by scoring the sensory attributes on an unstructured scale of 1 to 7 points, with a higher score indicated greater expression of a given attribute. The panel could also use half values. The exceptions to this were texture and saltiness, which were rated on a structured scale of 1 to 4 to 7 (1-4-7). Here, a score of 4 points was considered optimal, with a score of 4.5 or more indicating greater expression of an attribute and a score of 3.5 or less indicating an insufficient expression of an attribute. These sensory profiles of the products were assessed using 12 descriptors divided into five blocks. The first block related to the visual attributes of the cross-section of a slice: uniformity and intensity of colour and mosaic. The second block related to texture: stability, drip loss, general texture and juiciness. The third block related to the olfactory attributes: smell intensity and off-smell. The fourth block related to the aroma attributes: saltiness, aroma intensity and off-aroma.

For the sensory evaluation of the slice cross-section, the samples were cold (not thermally regenerated). For each sample, slice (10 mm) at room temperature (20 °C) was served to the panellists on a white plate. For the sensory evaluation of the other attributes, such as texture, smell and aroma, the samples were heated in hot water at approximately 90 °C for 5 minutes (meat emulsion coagulates) or 10 minutes (coarse-ground-meat coagulates) and then cut into 2 mm thick slices for the panellists to evaluate. The cooked pork loins were conditioned to room temperature and evaluated. The panel evaluated the sensory attributes in the order in which they were perceived. To neutralise the taste, the panel used the middle dough of white bread and water. The panel evaluated the samples separately in four sessions (days) with 6 samples each.

Data analysis: Data were analysed using the SPSS statistical program (version 29.0, IBM SPSS Statistics Inc., Chicago, USA). The normality of distribution and homogeneity of variance were tested using the Shapiro-Wilk test ($\alpha<0.05$) and Levene's test ($P<0.05$). Since the data were not normally distributed, the non-parametric Kruskal-Wallis test was used for data processing, and the differences between the three experimental groups were tested with the Bonferroni correction. Since the non-parametric ANOVA test gave results similar to those obtained with the parametric tests, the data were presented as least squares means (LSM, i.e. estimates of the mean values that are adjusted for all data and consider possible dependencies between the variables in the model) and their corresponding standard errors (SE), which were obtained based on the parametric ANOVA procedure and Tukey's post-hoc test at 5 % risk. Model for physicochemical and instrumental parameters and sensory properties included fixed effects of additive and additive producer (P1 and P2 were two different producers, amount of additive varied from product to product). The effect of replication (two production batches) was insignificant and therefore excluded from the model.

Results and discussion

Nitrite salt in meat emulsion coagulates

The basic statistical parameters for the chemical composition of meat emulsion coagulates, made with different producer and the amount of nitrite salt added, demonstrated the homogeneity of the samples. On average, these samples contained water at 69.1 ±1.9 g/100 g, protein at 13.4 ±0.3 g/100 g, fat at 14.3 ±2.2 g/100 g, salt at 1.88 ±0.20 g/100 g and phosphate expressed as P_2O_5 at 3.12 ±0.27 g/100 g (not presented in tables). These data are not precisely in agreement with those of Golob et al. (2006), who reported for frankfurters, a type of meat emulsion sausage, almost identical protein (12.9 g/100 g, range 11.5-13.9 g/100 g) and salt content (1.78 g/100 g, range 1.63-1.88 g/100 g), but significantly lower water content (59.2 g/100 g, range 54.5-64.2 g/100 g) and higher fat content (26.2 g/100 g, range 20.8-30.5 g/100 g) due to less fat used in this study. Cooked sausage made from pork meat, backfat and 150 mg nitrite/kg of batter (another type of meat emulsion) in study of Gao et al. (2022) showed similar colour L^* and b^* values and lower a^* values compared to meat emulsions in this study. This difference is attributed to the significant share of beef used in our samples.

Based on the analysis of the nitrite residues, the instrumental colour measurement and the sensory analysis of colour and saltiness, the optimum addition of nitrite salt P2 for meat emulsion coagulates was set at 1.6 % (Table 2). The reason for this was that the residual nitrite content in the P2_1.6 % group was significantly lower than in the P1_1.4 % (control) and P2_2.0 % groups. Secondly, no differences in the red colour (value a^*) were found between the emulsion groups. Although the coagulates P2_1.6 % differed more from the control in the total colour difference (ΔE^* value) than P2_2.0 %, the latter coagulates were slightly darker and less yellow. Sensory analysis also found no significant differences between the additions of nitrite salt P2 at 1.6 % and 2.0 %, the panellists found no differences between the experimental groups of coagulates in terms of colour stability and intensity; both attributes were optimally expressed. The nitrite salt content also had no significant effect on the aroma intensity and the occurrence of off-aroma and off-smells. The panellists assessed an increased saltiness in all three groups, whereby the saltiness was more pronounced with both nitrite salt additions from the producer P2 compared to the control.

Most cooked sausages (meat emulsions) contain between 14 and 18 g of salt per kilogramme, and local eating habits primarily determine the level of salt accepted by consumers. Worldwide food standards limit the maximum level of nitrite permissible in cooked sausages to 80-125 ppm, regardless of the amount added during the production process (Feiner, 2006). The results on the addition and residual nitrite in this part of the study agree with Feiner (2006). The optimum addition of nitrite salt P2 at 1.6 % was to be expected, as the nitrite salt P2 contained less nitrite than P1 (0.3 % vs. 0.5 %). The residual nitrite content in the 1.6 % group was also significantly lower than in the standard and P2_2.0 % groups and was well below the maximum level of nitrite permissible and below content (44 ppm) in conventionally cured Bologna sausage (Crop et al. 2024) and below content (89 ppm) in cured sausages (Gao et al., 2022).

Nitrite salt in cooked pork loins

The basic statistical parameters for the chemical composition of the cooked pork loins, made with different producer and the amount of nitrite salt added, are as follows: on average, these samples contained water at 69.1 ±0.9 g/100 g, protein at 25.8 ±1.4 g/100 g, fat at 2.9 ±0.9 g/100 g, salt at 1.48 ±0.19 g/100 g and phosphate expressed as P_2O_5 at 5.27 ±0.28 g/100 g (not presented in tables). These data slightly contradict those reported of Golob et al. (2006) for cooked pork loin, who found a lower protein content (20.9 g/100 g, g), an almost equal water content (68.2 g/100 g), a higher fat content (7.5 g/100 g), salt (2.34 g/100 g,) and a lower content of phosphate expressed as P_2O_5 (3.7 g/100 g).

The optimal addition of nitrite salt P2 at 2.5 % was confirmed by sensory analysis, namely pork loins P2_2.5 % were evaluated as closest to P1_2.0 % in terms of colour intensity and significantly better in terms of aroma intensity and off-aroma (Table 2, right). The residual nitrite content was higher in the P2_2.5 % group than in the P2_3.0 % and P1_2.0 % (control) groups, but the differences was not significant. No differences were found in colour values between the group of loins. The other differences in the parameters between 2.5 % and 3.0 % added nitrite salt P2 were also less unimportant (Δ*E** value, saltiness, smell and aroma intensity and off-aromas) or statistically insignificant (e.g. residual nitrite and salt content, *a** value and colour uniformity).

In this study the residual nitrite content in pork loins was in range 5.44–11.98 ppm, which is significantly less than in the study of Kim et al. (2019), where samples of pork loins (cured with 120 ppm nitrite) contained 16 ppm of residual nitrite, and in the study on the thermally treated cured goat loins (cured with 150 ppm nitrite; Dzudie et al., 2000), where in the range 99 ppm to 117 ppm were determined, differences could be attributed to the difference in the loss of moisture and to some extent to the loss of minerals. Acquired colour values for cooked pork loins can be compared with some Slovenian canned meat product (Polak et al., 2020) where measured values are very similar (shoulder and ham, *L**: 71.34 and 66.94, *a**: 5.71 and 9.76, *b**: 9.80 and 8.64).

Phosphate in meat emulsion coagulates

The basic statistical parameters for the chemical composition of the meat emulsion coagulates, with different producer and the amount of phosphate added, are as follows: on average, these samples contained water at 68.1 ±1.4 g/100 g, protein at 13.7 ±0.3 g/100 g, fat at 15.4 ±1.8 g/100 g, salt at 1.84 ±0.07 g/100 g and residual nitrite at 25.4 ±5.6 mg/100 g (not shown in the tables). The meat emulsion coagulates formulated from beef in the study by Morela (2019) differs from our data, except for the protein content, i.e. they contain 55.9 % water, 27.4 % fat and 13.5 % protein, due to the less fat used and the exclusive use of beef.

The optimum addition of phosphate P2 in meat emulsion coagulates cannot be clearly determined (Table 3). The two phosphate additions from the producer P2 (0.3 % and 0.4 %) proved to be suitable, as they do not differ significantly from the control (P1_0.3 %) in terms of quality parameters or there are differences in some parameters that are not relevant for the function of the phosphates (residual nitrite or *b** value). More phosphate could have been added to the meat emulsions (e.g. 0.5 %), but the products would most likely exceed the legal limit for phosphates (5 g phosphate expressed as P_2O_5/kg of finished product, Regulation (EC) No 1333/2008; Balestra and Petracci, 2019). The authors reported different amounts of added phosphate in relation to the type of mixture and the proportion of phosphate in the mixture: 0.25 % in cooked sausage (Puolanne et al, 2001), 0.4 % in Bologna-style chicken sausage

(Çelebi and Erge, 2024), 0.5 % in conventionally cured Bologna sausage (Crop et al., 2024) or 0.7 % in meat emulsions (264 ppm phosphate expressed as P P_2O_5; Polak et al., 2018; Morela, 2019).

Phosphate in coarse-ground-meat coagulates

The basic statistical parameters for the chemical composition of the coagulates for coarsely ground meat, made with different producer and the amount of phosphate added, demonstrate the homogeneity of the samples. On average, these samples contained 64.5 ±0.5 g/100 g, protein at 20.3 ±0.4 g/100 g, fat at 11.6 ±0.7 g/100 g, salt at 1.90 ±0.07 g/100 g and residual

Table 2 Least squares mean (LSM) and standard error (SE) values for physicochemical and instrumental parameters and sensory properties of meat emulsion coagulates and cooked pork loins made with different producer and the amount of nitrite salt added (n = 6)

	Parameter value depending on the producer and the amount of nitrite salt added									
Product	**Meat emulsion coagulates**					**Cooked pork loins**				
Parameter/Attribute	**P1_1.4 %**	**P2_1.6 %**	**P2_2.0 %**	**SE**	**KW**	**P1 2.0 %**	**P2_2.5 %**	**P2_3.0 %**	**SE**	**KW**
Physicochemical parameters and nutrient composition										
Protein (g/100 g)	13.41	13.60	13.12	0.05	Ns	26.37	26.24	23.21	1.24	Ns
Fat (g/100 g)	17.07	13.00	12.75	0.16	Ns	2.01	2.82	2.91	0.46	Ns
Water (g/100 g)	66.63	70.18	70.36	0.01	Ns	69.92	68.76	70.04	<0.01	Ns
Salt (g/100 g)	1.67	1.87	2.12	0.02	Ns	1.33	1.47	1.83	0.10	Ns
Residual nitrite (mg/kg)	20.43^a	9.79^b	19.15^a	0.51	*	8.83	9.43	8.26	1.35	Ns
P_2O_5 (g/kg)	3.06	3.15	3.23	0.16	Ns	5.57	5.13	5.54	0.02	Ns
Colour parameters										
*L** value	72.52^a	71.98^b	72.13^a	0.14	*	72.71	72.93	73.00	0.54	Ns
*a** value	13.52	13.64	13.53	0.06	Ns	9.79	9.46	8.85	0.42	Ns
*b** value	9.37^a	9.08^b	9.00^c	0.05	***	5.37	5.82	5.48	0.34	Ns
ΔE* value	-	0.62	0.13	-	-	-	0.60	0.96	-	-
Texture parameters										
Hardness (N)	129.33	128.15	131.66	3.93	Ns	158.40	170.20	166.55	12.56	Ns
Adhesiveness (N.s)	-0.22	-0.24	-0.99	0.15	Ns	-0.07	-0.05	-0.06	0.01	Ns
Springiness	0.87	0.90	0.88	0.01	Ns	0.69	0.67	0.68	0.02	Ns
Cohesiveness	0.67	0.68	0.68	0.01	Ns	0.53	0.52	0.50	0.01	Ns
Chewiness (N)	75.39	78.41	78.42	2.87	Ns	59.19	58.75	55.61	4.94	Ns
Resilience	0.35	0.36	0.36	0.01	Ns	0.23	0.22	0.22	0.01	Ns
Sensory attributes										
Colour uniformity (1-7)	7.0	7.0	7.0	<0.1	-	5.9	6.1	5.8	0.1	Ns
Colour intensity (1-7)	7.0	7.0	7.0	<0.1	-	4.4^b	4.3^b	4.8^a	0.1	*
Stability (1-7)	6.5	6.5	6.6	<0.1	Ns					
Texture (1-4-7)	4.0	4.1	4.1	0.1	Ns	3.9	3.8	4.1	0.1	Ns
Juiciness (1-7)	6.4	6.5	6.5	0.1	Ns	5.3	5.0	5.3	0.2	Ns
Saltiness (1-4-7)	4.4^b	5.1^a	5.4^a	0.1	***	4.3^b	4.4^b	4.6^a	0.1	Ns
Smell intensity (1-7)	6.9	7.0	7.0	0.1	Ns	5.9^b	6.6^a	5.9^b	0.1	***
Aroma intensity (1-7)	7.0	7.0	7.0	<0.1	Ns	5.7^c	6.3^a	6.0^b	0.1	**
Off-aroma (1-7)	1.1	1.0	1.0	<0.1	Ns	2.1^a	1.1^c	1.4^b	0.1	***
Off-smell (1-7)	1.8	1.7	1.8	0.1	Ns					

*n: number of each products; P1, P2: producer 1, producer 2; KW: Kruskal-Wallis test; sign.: ***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$, Ns $p > 0.05$; for each parameter and product, values with different superscript letters (a-c) are statistically significantly different ($p \leq 0.05$, differences between groups formed according to producer and amount of nitrite salt added; significance between groups were calculated with an adjusted Bonferroni correction for multiple testing).*

nitrite at 4.20 ±1.24 mg/100 g (not listed in the tables). These data are comparable with those reported by Polak et al. (2017) for Kranjska klobasa PGI (cooked, cured and smoked sausage made from coarse pork meat similar to this samples), who found a protein content at 19.6 g/100 g, a water content at 55.5 g/100 g, a fat content at 22.0 g/100 g, a salt content at 2.14 g/100 g and a residual nitrite content at 1.96 mg/kg. The proximate composition of fully-cooked coarse-ground sausages formulated mainly from pork trimmings in study of Kibler et al. (2022) differs from our data. Their samples contained 47.6 % water, 31.3 % fat and 12.7 % protein. Consequently, their colour values, except for the *L** value (*L** 62.46, *a** 9.39 and *b** 10.92), and TPA parameters (lower hardness, springiness and higher resilience) also differed from our data.

As the phosphate mixture from producers P1 and P2 had the same phosphate content, we decided to add 0.3 % for both producers and a higher content of 0.4 % for P2 (Table 3). The group of coarse-ground-meat coagulates P2_0.4 % differed significantly from the control group (P1_0.3 %) in only three parameters, namely in two colour values (lower *a** and *b** values) and in adhesiveness, the textural property; the P2_0.3 % group was significantly less adhesive than the control and P2_0.4 % groups. Nevertheless, both phosphate additions from the producer P2 proved to be suitable, with a slight advantage for P2_0.4 % due to its lower adhesiveness. Authors reported different amount of added phosphate regard to type of blend and share of phosphate in blend expressed as P2O5 for cooked coarse-ground sausage, e.g. 0.3 % tripolyphosphate (Choe et al., 2015) or 0.25 % (Kibler et al., 2022).

Linear discriminant analysis

To classify each of the meat products in the experiment into subgroups with similar properties based on additive used during production (different types and amount added nitrite salt and/or phosphate), Linear Discriminant Analysis (LDA) was used.

Nitrite salt in meat emulsion coagulates

When analysing the selected 15 parameters (six sensory properties, nine instrumental parameters – three colour, five texture, and residual nitrite) with LDA, a 100 % correct classification of the experimental groups based on the producer and the amount of added nitrite salt (P1_1.4 %, P2_1.6 % and P2_2.0 %) could be explained (F1 85 % and F2 15 %). In the lower left part of Figure 1A, the group of emulsions P1_1.4 % is clearly recognisable, while the group P2_2.0 % is located at the upper edge and the group P2_1.6 % at the lower right edge of the graph. Figure 1A shows the variables defined by function 1, which are far from the origin on the negative side, namely the concentration of residual nitrite and the *b** value. Function 2 defines variables such as resilience on the positive side and the cohesiveness on the negative side of the origin. Properties that are close to each other show a high positive correlation (i.e. off-aromas and off-smells). The P1_1.4 % group is defined by a high content of residual nitrite and a yellow colour (*b** value), the P2_1.6 % group by springiness and adhesiveness (less adhesive than the other two groups) and the P2_2.0 % group by a high content of residual nitrite and phosphate as well as stability and resilience.

It can be concluded that groups P2_1.6 % and P2_2.0 % are too salty compared to the control group – both groups lie on the left side of Figure 1A, which is defined by the sensory rating of saltiness. This was also confirmed by the non-parametric analysis of variance and the Mann-Whitney U test, as these two groups were significantly too salty compared to the control group (Table 2). Based on the instrumentally measured and sensorially evaluated colour, it is difficult to determine the optimal addition of nitrite salt P2, as all colour variables are close to the starting point of the graph and have no effect on the differentiation between the experimental groups of emulsions or show no similarities with the colour of the control emulsion. Finally, the variable residual nitrite was decisive for determining the optimum amount of nitrite salt P2 to be added, which was lowest when 1.6 % nitrite salt P2 was added.

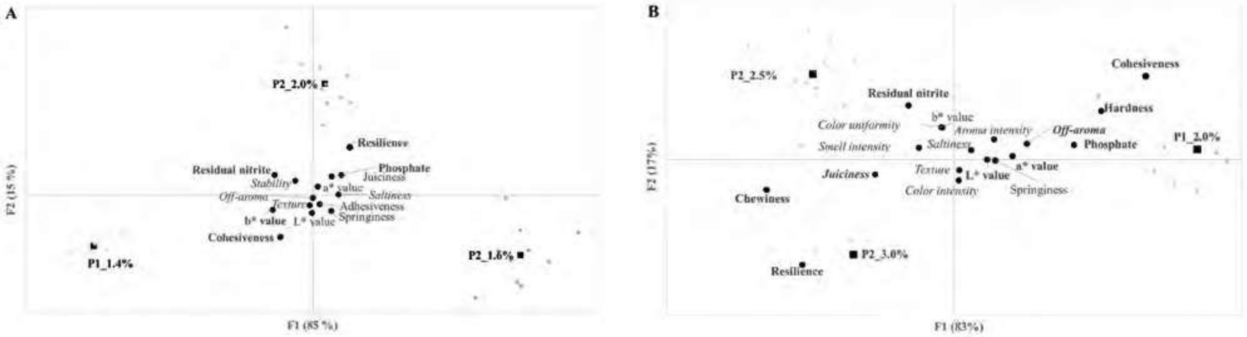
Nitrite salt in cooked pork loins

When analysing the selected 18 parameters (eight sensory properties, eight instrumental parameters – three colour and five texture, and residual nitrite and phosphate contents) with LDA, a 100 % correct classification of the experimental groups of cooked pork loins based on the producer and the amount of added nitrite salt (P1_2.0 %, P2_2.5 % and P2_3.0 %) could be explained (F1 83 % and F2 17 %). Separate groups of cooked pork loins (P2_2.5 % and P2_3.0 %) are clearly visible on the left side of Figure 1B, while the P1_2.0 % group is distributed on the right side of the origin. The variables defined by function 1 are far away from the origin on the negative side, namely the instrumentally measured chewiness and resilience as well as the sensory evaluated juiciness, and the instrumentally measured cohesiveness, hardness, phosphate content, sensory evaluated off-aroma

Table 3 Least squares mean (LSM) and standard error (SE) values for physicochemical and instrumental parameters and sensory properties of meat emulsion coagulates and coarse-ground-meat coagulates made with different producer and the amount of phosphate added (n = 6)

	Parameter value depending on the producer and the amount of phosphate added									
Product	**Meat emulsion coagulates**					**Coarse-ground-meat coagulates**				
Parameter/Attribute	**P1_0.3 %**	**P2_0.3 %**	**P2_0.4 %**	**SE**	**KW**	**P1_0.3 %**	**P2_0.3 %**	**P2_0.4 %**	**SE**	**KW**
Physicochemical parameters and nutrient composition										
Protein (g/100 g)	13.89	13.35	13.76	0.07	Ns	20.24	20.41	20.37	0.40	Ns
Fat (g/100 g)	13.13	16.63	16.52	0.09	Ns	11.64	11.04	12.20	0.44	Ns
Water (g/100 g)	69.95	67.43	67.02	0.13	Ns	64.76	64.87	63.91	0.19	Ns
Salt (g/100 g)	1.91	1.84	1.78	0.04	Ns	1.94	1.94	1.84	0.04	Ns
Residual nitrite (mg/kg)	19.87^{b}	23.27^{b}	32.03^{a}	1.04	*	4.67	5.33	2.51	0.88	Ns
P_2O_5 (g/kg)	3.38^{b}	3.55a^{b}	3.89^{a}	0.28	*	4.49	4.94	4.87	0.31	Ns
Colour parameters										
L^* value	72.23	72.26	72.55	0.13	Ns	62.58	62.10	62.48	0.16	Ns
a^* value	13.55	13.58	13.63	0.06	Ns	13.15^{a}	12.97^{ab}	12.51^{b}	0.11	**
b^* value	9.02^{b}	9.22^{b}	9.41^{a}	0.08	*	7.76^{a}	7.49^{ab}	7.16^{b}	0.09	***
ΔE* value	-	0.20	0.14	-	-	-	0.58	0.88	-	-
Texture parameters										
Hardness (N)	118.52	125.58	126.43	3.09	Ns	198.13	198.35	208.41	9.19	Ns
Adhesiveness (N.s)	-0.30	-0.27	-0.30	0.03	Ns	-0.04^{a}	-0.34^{c}	-0.12^{b}	0.08	*
Springiness	0.89	0.86	0.88	0.01	Ns	0.89	0.90	0.91	0.01	Ns
Cohesiveness	0.67	0.68	0.68	<0.01	Ns	0.63	0.63	0.65	0.01	Ns
Chewiness (N)	70.24	73.76	75.86	2.17	Ns	111.64	113.20	123.03	7.34	Ns
Resilience	0.35	0.36	0.36	<0.01	Ns	0.30	0.30	0.32	0.01	Ns
Sensory attributes										
Colour uniformity (1-7)	7.0	7.0	7.0	<0.1	-					
Colour intensity (1-7)	7.0	7.0	7.0	<0.1	-	7.0	7.0	7.0	<0.1	-
Mosaic (1-7)						6.1	5.9	5.9	0.2	Ns
Stability (1-7)	6.3	6.3	6.5	0.1	Ns					
Drip loss (1-7)						1.1	1.1	1.1	0.1	Ns
Texture (1-4-7)	4.1^{a}	3.8^{b}	3.7^{b}	0.1	*	4.9	5.0	4.9	0.1	Ns
Juiciness (1-7)	6.5	6.4	6.6	0.1	Ns	5.6	5.6	5.7	0.1	Ns
Saltiness (1-4-7)	4.5	4.3	4.3	0.1	Ns	4.3	4.3	4.2	0.1	Ns
Smell intensity (1-7)	7.0	6.9	6.9	0.1	Ns	5.8	5.7	5.7	0.1	Ns
Aroma intensity (1-7)	7.0	7.0	7.0	<0.1	-	6.0	5.9	5.9	0.1	Ns
Off-aroma (1-7)	1.0	1.0	1.0	<0.1	-	1.0	1.0	1.0	<0.1	Ns
Off-smell (1-7)	2.2^{a}	1.4^{b}	1.7^{b}	0.1	***					

*n: number of each products; P1, P2: producer 1, producer 2; KW: Kruskal-Wallis test; sign.: ***p≤0.001, **p≤0.01, *p≤0.05, Ns p>0.05; for each parameter and product, values with different superscript letters (a-c) are statistically significantly different (p≤0.05, differences between groups formed according to producer and amount of phosphate added; significance between groups were calculated with an adjusted Bonferroni correction for multiple testing).*



Legend: P1: Producer 1; P2: Producer 2; A: 1.4 %, 1.6 % and 2.0 %: Nitrite salt addition based on the weight of the meat emulsion; B: 2.0 %, 2.5 % and 3.0 %: Nitrite salt addition based on the weight of the pork loin. Italic are mark sensorially evaluated variables. Bold are marked the most discriminant variables. ■ group centroid.

Figure 1: Distribution of the three groups of meat emulsion coagulates (A) and cooked pork loins (B) with different producer and amounts of added nitrite salt and associated variables analysed by linear discriminant analysis

and colour value *a** on the positive side of the origin. Function 2 defines variables such as cohesiveness and residual nitrite on the positive side of the origin. The control group P1_2.0 % is defined by a higher phosphate value, *a** value, cohesiveness and off-aroma, lower residual nitrite (opposite quadrant) and hardness (negative attribute). The P2_2.5 % group is defined by the residual nitrite, the highest *b** value, the uniformity of the colour and the intensity of the aroma. The P2_3.0 % group is defined by the high residual nitrite content and the *L** value as well as the lowest *a** value, juiciness, chewiness and resilience.

On the basis of colour and aroma variables it can be concluded that LDA confirmed the optimal addition of nitrite salt P2 at 2.5 %.

Phosphate in meat emulsion coagulates

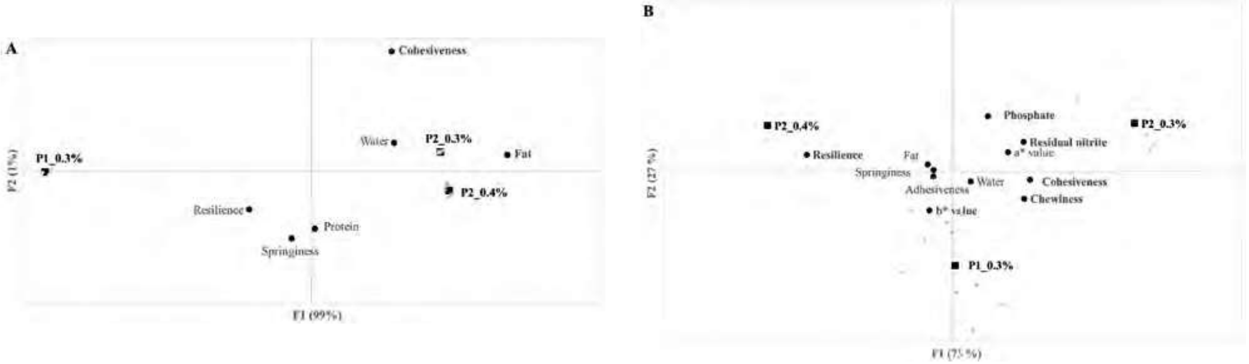
When analysing six selected parameters (springiness, cohesiveness, resilience, water, protein and fat content) of the meat emulsion coagulates with different producers and amount of phosphate added with LDA, they explained 100 % (function 1 99 % and function 2 1 %) of the variability between the three experimental groups (P1_0.3 %, P2_0.3 % and P2_0.4 %). On the right side of Figure 2A, the separate groups of meat emulsion coagulate P2_0.3 % and P2_0.4 % are clearly visible, while the group P1_0.3 % is located on the left side of the origin. The variables protein and fat defined by function 1 are far from the baseline on the positive side of the abscise. Function 2 defines cohesiveness on the positive side and springiness on the negative side of the ordinate. The group P1_0.3 % is described by the lowest fat content and cohesiveness, the group P2_0.3 % by the lowest springiness (via the origin of the opposite quadrant), the highest cohesiveness and fat content (same quadrant). The P2_0.4 % group is defined by the lowest water content (to the left of the centroid for this group).

It can be concluded that the LDA showed differences between the two producers of phosphate, but no clear answer was given to the question of the optimal amount of phosphate from producer 2 added to meat emulsion coagulates.

Phosphate in coarse-ground-meat coagulates

When analysing with LDA (with a test of equality of the means of the groups) 11 selected variables (nine texture and colour instrumental parameters, fat, water, phosphate and residual nitrite content) of the coarse-ground-meat coagulates made with different producers and amount of phosphate added, they explained 100 % (function 1 73 % and function 2 27 %) of the variability between the three experimental groups (P1_0.3 %, P2_0.3 % and P2_0.4 %).

In the upper part of the graph (Figure 2B), two distinct groups of cured meat pieces P2_0.3 % and P2_0.4 % (bottom) are clearly recognisable, while the control group P1_0.3 % is distributed in the lower part of the graph. The figure shows that the instrumentally measured resilience variable, defined by function 1, lies far from the baseline on the negative side and the instrumentally measured chewiness and cohesiveness as well as the residual nitrite content lie on the positive side of the baseline. Function 2 defines the variable *b** value on the negative side and the phosphate content on the positive side of the baseline. The P1_0.3 % control group is described by variables such as the highest water content and low cohesive-



Legend: P1: Producer 1; P2: Producer 2; A: 0.3 % and 0.4 %: Phosphate addition based on the weight of the meat emulsion; A and B: 0.3 % and 0.4 %: Phosphate addition based on the weight of the pork loins or coarse-ground-meat coagulates. Italic are mark sensorially evaluated variables. Bold are marked the most discriminant variables. ■ group centroid.

Figure 2: Distribution of three groups of meat emulsion coagulates (A) and coarse-ground-meat coagulates (B) with different producer and amounts of added phosphate and associated variables analysed by linear discriminant analysis.

ness and chewiness, the P2_0.3 % group by a high *a** value, high residual nitrite and phosphate values and the P2_0.4 % group by a high resilience and fat content.

Even with this product, it is difficult to determine by LDA the optimal amount of phosphate from producer 2 added, as the differences between groups of coarse-ground-meat coagulates are rarely.

Conclusion

Present study provides valuable insights into the optimization of nitrite salts and inorganic phosphates in meat products, with significant practical implications for the meat industry. The findings indicate that the optimal addition of nitrite salt for meat emulsion coagulates is 1.6 %, while for cooked pork loins, it is 2.5 %. These results suggest that nitrite salts from the test producer can achieve comparable or superior outcomes in terms of residual nitrite content, colour values, and sensory properties compared to the standard producer. However, determining the optimal addition of inorganic phosphates is more complex due to legal restrictions and product-specific differences. Actually, the optimal addition of inorganic phosphates varies depending on the type of meat product and the producer. For meat emulsion coagulates, the study suggests that both 0.3 % and 0.4 % additions from the test producer are suitable, while for coarse-ground-meat coagulates, a slight advantage is observed for the 0.4 % addition due to lower adhesiveness.

Overall, this research underscores the importance of continuous evaluation and optimization of food additives to ensure consumer safety, product quality, and regulatory compliance. By optimizing the addition of nitrite salts, meat producers can reduce the residual nitrite content in their products, thereby enhancing food safety, build the expected colour as well as overall sensory quality. On the other hand, the right amount of phosphate can enhance the sensory attributes of meat products, such as texture and juiciness, and ensuring that products are safe and meet regulatory standards. The practical applications of these findings can lead to significant improvements in the meat industry, benefiting both producers and consumers.

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Optimizacija aditiva u sušenju mesa i mesnih proizvoda

Sažetak

Ovaj rad istražuje učinkovitost nitritnih soli i anorganskih fosfata u mesnim proizvodima. Prvo, fokus je bio na optimizaciji dodavanja nitritne soli u koagulate mesnih emulzijsa i kuhane svinjske kotlete. Nitritna sol testnog proizvođača uspoređena je s onom standardnog proizvođača analizom ostataka nitrita, instrumentalno mjerenih parametara boje i senzorskih svojstava. Drugo, optimalni dodatak anorganskih fosfata standardnog i testnog proizvođača u mesnim emulzijskim koagulatima i krupno mljevenim mesnim koagulatima procijenjen je analizom sadržaja fosfata, instrumentalno mjerenih parametara teksture i senzorskih svojstava. Rezultati pokazuju da je optimalan dodatak nitritne soli od ispitivanog proizvođača 1,6 % za koagulate mesnih emulzija i 2,5 % za kuhane svinjske kotlete. Za koagulate mesnih emulzija prikladni su dodaci fosfata od 0,3 % i 0,4 % ispitivanog proizvođača, dok se za koagulate krupno mljevenog mesa uočava mala prednost dodatka od 0,4 % zbog manje ljepljivosti. Naglašena je važnost kontinuirane evaluacije i optimizacije prehrambenih aditiva kako bi se osigurala sigurnost potrošača, kvaliteta proizvoda i usklađenost s propisima.

Ključne riječi: mesni emulzijski koagulati, kuhano i sušeno meso, krupno mljeveni mesni koagulati, nitrit, fosfat

Optimierung von Zusatzstoffen bei der Pökelung von Fleisch und Fleischprodukten

Zusammenfassung

In dieser Studie wird die Wirksamkeit von Nitritsalzen und anorganischen Phosphaten in Fleischerzeugnissen untersucht. Der Schwerpunkt lag zunächst auf der Optimierung der Nitritsalzzugabe in Fleischemulsionskoagulaten und gekochten Schweinelenden. Nitritsalz eines Testproduzenten wurde mit dem eines Standardproduzenten verglichen, indem Nitritrückstände, instrumentell gemessene Farbparameter und sensorische Eigenschaften analysiert wurden. Zweitens wurde die optimale Zugabe von anorganischen Phosphaten von Standard- und Testherstellern in Fleischemulsionskoagulaten und grob gemahlenen Fleischkoagulaten durch Analyse des Phosphatgehalts, instrumentell gemessener Texturparameter und sensorischer Eigenschaften bewertet. Die Ergebnisse zeigen, dass die optimale Zugabe von Nitritsalz des Testherstellers bei Fleischemulsionskoagulaten 1,6 % und bei gekochten Schweinelenden 2,5 % beträgt. Bei Fleischemulsionskoagulaten sind sowohl 0,3 % als auch 0,4 % Phosphatzusatz des Testherstellers geeignet, während bei grob gemahlenen Fleischkoagulaten ein leichter Vorteil für den 0,4 %-Zusatz aufgrund der geringeren Klebrigkeit zu beobachten ist. Es wird hervorgehoben, wie wichtig eine kontinuierliche Bewertung und Optimierung von Lebensmittelzusatzstoffen ist, um die Sicherheit der Verbraucher, die Produktqualität und die Einhaltung von Vorschriften zu gewährleisten.

Schlüsselwörter: Fleischemulsionskoagulat, gekochtes und gepökeltes Fleisch, grob gemahlenes Fleischkoagulat, Nitrit, Phosphat

Optimización de aditivos en el curado de carne y productos cárnicos

Resumen

Este estudio analiza la eficacia de las sales de nitrito y los fosfatos inorgánicos en los productos cárnicos. En primer lugar, se optimizó la adición de sales de nitrito en coagulados de emulsión cárnica y lomos de cerdo cocidos. Se compararon las sales de nitrito de un productor de prueba con las de un productor estándar mediante el análisis de residuos de nitrito, parámetros de color medidos instrumentalmente y atributos sensoriales. En segundo lugar, se evaluó la adición óptima de fosfatos inorgánicos de productores estándar y de prueba en coagulados de emulsión cárnica y en coagulados de carne de molienda gruesa, analizando el contenido de fosfato, parámetros de textura medidos instrumentalmente y atributos sensoriales. Los resultados indican que la adición óptima de sal de nitrito del productor de prueba es del 1,6 % para coagulados de emulsión cárnica y del 2,5 % para lomos de cerdo cocidos. Para los coagulados de emulsión cárnica, son adecuadas tanto la adición de 0,3 % como de 0,4 % de fosfato del productor de prueba, mientras que para los coagulados de carne de molienda gruesa, se observa una ligera ventaja con la adición del 0,4 % debido a una menor adhesividad. Se destaca la importancia de la evaluación y optimización continua de los aditivos alimentarios para garantizar la seguridad del consumidor, la calidad del producto y el cumplimiento de la normativa vigente.

Palabras claves: coagulados de emulsión cárnica, carne cocida y curada, coagulados de carne de molienda gruesa, nitrito, fosfato

Ottimizzazione degli additivi nel processo di essiccazione della carne e dei prodotti a base di carne

Riassunto

Questo studio esplora l'efficacia dei sali di nitrito e dei fosfati inorganici nei prodotti a base di carne. In primo luogo, l'attenzione si è concentrata sull'ottimizzazione dell'aggiunta di sale nitrito nei coaguli di emulsioni di carne e nelle cotolette di maiale cotte. Il sale nitrito del produttore testato è stato confrontato con quello del produttore standard tramite l'analisi dei residui di nitriti, dei parametri strumentali del colore e delle proprietà sensoriali. In secondo luogo, è stata valutata l'aggiunta ottimale di fosfati inorganici dei produttori standard e testato nei coaguli di emulsioni di carne e nei coaguli di carne grossolanamente macinata attraverso l'analisi del contenuto di fosfati, dei parametri strumentali della texture e delle proprietà sensoriali. I risultati mostrano che l'apporto ottimale di sale nitrito del produttore testato è del 1,6 % per i coaguli di emulsioni di carne e del 2,5 % per le cotolette di maiale cotte. Per i coaguli di emulsioni di carne, invece, gli apporti ottimali di fosfato sono dello 0,3 % e dello 0,4 % per il produttore testato, mentre per i coaguli di carne grossolanamente macinata si osserva un piccolo vantaggio nell'aggiunta dello 0,4 % a causa di una minore appiccicosità (adesività). È stata sottolineata l'importanza della valutazione continua e dell'ottimizzazione degli additivi alimentari per garantire la sicurezza dei consumatori, la qualità del prodotto e la conformità alle normative.

Parole chiave: coaguli di emulsioni di carne, carne cotta e essiccata, coaguli di carne grossolanamente macinata, nitrito, fosfato