

INVESTIGATING THE INFLUENCE OF SODIUM NITRATE ADDITIVES ON COLOR CHANGES IN RAW AND COOKED MEAT PRODUCTS USING CIE LAB COLOR SPACE AND MYOGLOBIN LEVEL MEASUREMENT VIA UV SPECTROPHOTOMETRY

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Abstract. This study investigates the influence of sodium nitrate additives on color changes and myoglobin levels in raw and cooked meat products using CIE Lab color space and UV spectrophotometry. Sausage samples from beef, lamb, and chicken were prepared with varying sodium nitrate concentrations (0 mg/g, 40 mg/g, 80 mg/g, and 120 mg/g), resulting in twelve distinct formulations. Results indicated that beef sausages, which inherently possess a higher myoglobin content (8 mg/g), exhibited the most pronounced increase in redness values, rising from 3.05 (0 mg/g) to 7.21 (40 mg/g) in uncooked samples. Cooked sausages showed similar trends, with beef redness values increasing to 3.60 (40 mg/g). Conversely, lamb and chicken sausages demonstrated more complex and less pronounced responses. Nitrosylmyoglobin concentrations also showed notable increases with sodium nitrate addition, reaching 13.85 ppm in beef sausages at 40 mg/g. These findings highlight the significant impact of sodium nitrate on meat coloration and myoglobin stability, providing valuable insights for optimizing sausage formulations.

Keywords: sodium nitrate, color changes, CIE Lab color space, myoglobin, UV spectrophotometry, meat products.

INTRODUCTION

In the realm of food science and technology, the utilization of additives such as sodium nitrate plays a pivotal role not only in enhancing food safety and shelf life but also in influencing the sensory attributes of meat products [1,2]. Among these attributes, color stands as a critical determinant of consumer acceptance and quality perception in processed meats, particularly sausages [3]. The incorporation of sodium nitrate into sausage formulations is known to exert significant effects on color stability and myoglobin content, thereby shaping both the visual appeal and the chemical composition of the final product [4,5].

Traditionally, sodium nitrate has been employed in meat processing primarily for its antimicrobial properties, which contribute to extending shelf life by inhibiting the growth of pathogenic bacteria [2]. However, beyond its preservative function, sodium nitrate interacts with myoglobin—a protein responsible for the characteristic red color of meat—to form nitrosylmyoglobin. This compound not only enhances the red coloration of meat products but also contributes to their overall visual appeal and consumer preference [6,7]. Understanding the nuanced relationship between sodium nitrate concentration and the resulting color attributes of sausages is therefore crucial for optimizing product formulations and ensuring consistency in quality across different meat types [1,5].

Despite the extensive use of sodium nitrate in the meat industry, there remains a notable research gap regarding its precise impact on color changes and myoglobin stability in different types of sausages [8]. Existing studies often focus on general effects without delving into specific meat types or comprehensive quantitative analyses using advanced colorimetric and spectrophotometric methods [9]. This research aims to fill this gap by systematically investigating the influence of varying sodium nitrate levels on the color characteristics and myoglobin levels of sausages made from beef, lamb, and chicken [1,10].

The novelty of this research lies in its comprehensive approach, combining precise color measurement using the CIE Lab color space and quantitative myoglobin analysis via UV spectrophotometry [3,11]. By meticulously controlling sodium nitrate concentrations (ranging from 0 mg/g to 120 mg/g) and meticulously preparing sausage samples under controlled conditions, this study aims to provide detailed insights into how different meat types respond to sodium nitrate supplementation [12]. Such insights are crucial not only for enhancing the aesthetic appeal of sausage products but also for optimizing processing methods to meet consumer expectations and regulatory standards in the food industry [4,13].

Moreover, the findings from this research hold significant implications for food manufacturers and processors seeking to improve the visual appeal, nutritional value, and safety of meat products [14,15]. By elucidating the intricate relationship between sodium nitrate concentration, meat type, and color attributes, this study will contribute valuable data-driven insights that can inform industry practices, regulatory guidelines, and consumer education initiatives. Ultimately, this research strives to advance the understanding and application of sodium nitrate in meat processing, paving the way for enhanced product innovation and quality assurance in the global food market [16,17].

MATERIALS AND METHODS

This research investigates the influence of sodium nitrate additives on color changes in raw and cooked meat products using CIE Lab color space and myoglobin level measurement via UV spectrophotometry [9]. Sausage samples will be prepared from three types of meat: chicken, beef, and lamb. For each meat type, four levels of sodium nitrate will be added, resulting in twelve distinct sausage samples. Each sample will weigh 5 kg [9,18].

Materials

According to this study, various sausage samples were prepared to analyze the impact of sodium nitrate addition on different types of sausages. Three types of sausages were selected for the experiment: beef, lamb, and chicken. For each type of sausage, four different formulations were prepared to represent varying levels of sodium nitrate content. The formulations included sausages without any added sodium nitrate (denoted as T(B0), T(L0), and T(C0) for beef, lamb, and chicken sausages respectively), as well as sausages with added sodium nitrate at concentrations of 40 mg/g, 80 mg/g, and 120 mg/g (denoted as T(B40), T(B80), T(B120), T(L40), T(L80), T(L120), T(C40), T(C80), and T(C120) respectively) [19,20,21].

For each formulation, the sausages were prepared following standard procedures for sausage production. High-quality meat cuts were selected for each type of sausage, and appropriate fat content was incorporated to achieve the desired texture and flavor profile. The meat and fat were finely ground and mixed thoroughly with seasonings and spices to enhance taste and aroma.

In formulations where sodium nitrate was added, it was carefully weighed and mixed uniformly with the meat mixture to ensure even distribution throughout the sausage. The sausages

were then stuffed into casings and shaped according to the desired size and dimensions. Finally, the sausages were cooked or cured using appropriate methods, depending on the intended final product [19].

Throughout the preparation process, strict hygiene and sanitation practices were observed to prevent any contamination and ensure the safety of the sausage samples. Once prepared, the sausages were labeled accordingly and stored under appropriate conditions until further analysis [18,19].

Sample Preparation

1.1 Meat Preparation

Fifteen kilograms each of beef, lamb, and chicken meat will be sourced from a reliable supplier. Excess fat and connective tissue will be trimmed from the meat, which will then be cut into small cubes suitable for grinding [19,20].

1.2 Grinding

The cubed meat will undergo a two-step grinding process. Initially, the meat will be passed through a meat grinder using a coarse plate (8-10 mm). Subsequently, the coarsely ground meat will be passed through a finer plate (4-6 mm) to achieve a uniform texture [1,19].

1.3 Mixing and Seasoning

The sausage mixtures will be prepared for each meat type in 5 kg batches: T(B0), T(B40), T(B80), T(B120) for beef; T(L0), T(L40), T(L80), T(L120) for lamb; and T(C0), T(C40), T(C80), T(C120) for chicken. The amount of sodium nitrate needed for each treatment will be calculated as follows: T(X0) with 0 mg/g (no sodium nitrate), T(X40) with 40 mg/g (200 g for 5 kg meat), T(X80) with 80 mg/g (400 g for 5 kg meat), and T(X120) with 120 mg/g (600 g for 5 kg meat) [19].

A standard seasoning mix for each 5 kg batch of sausage will include 100 g of salt, 20 g of pepper, 15 g of garlic powder, and 15 g of onion powder. The ground meat will be mixed with the seasonings and the appropriate amount of sodium nitrate in a mixer until thoroughly combined [19,21].

1.4 Stuffing

The sausage casings will be soaked in warm water to make them pliable. Using a sausage stuffer, the meat mixture will be filled into the casings, ensuring consistent stuffing pressure to avoid air pockets. The sausages will be twisted into uniform links [7,19].

1.5 Cooking

A portion of each sausage batch will be set aside for raw sample analysis. The remaining sausages will be cooked in a water bath at 75°C until the internal temperature reaches 72°C. After cooking, the sausages will be allowed to cool to room temperature [17,19].

Color Measurement

Ensure that the sausage samples are properly prepared according to the formulations described in the study. This involves selecting high-quality meat cuts, incorporating appropriate fat content, grinding the meat and fat finely, and thoroughly mixing with seasonings and spices [7].

Calibrate the color measurement device according to standard procedures to ensure accurate and consistent results. This involves checking and adjusting settings such as light source, observer angle, and calibration standards [7,11].

Prior to cooking or curing, measure the color of the raw meat samples using the color measurement device. Place the device in contact with the meat surface or hold it close enough to obtain accurate readings [7,8].

After cooking or curing the sausages using appropriate methods, measure the color of the cooked sausage samples using the same color measurement device. Ensure that the sausages have cooled down to room temperature before taking measurements [8,9].

Record the color values obtained for each sample in the CIE Lab* color space. These values include luminosity (L^*), red-green chromaticity (a^*), and yellow-blue chromaticity (b^*) were measured on a spectrophotometer with the illuminant D65 (CM-3500d, Konica Minolta Inc., Tokyo, Japan). Repeat the measurement process for each formulation of sausage samples, including those with varying levels of sodium nitrate content. The results were analyzed in the Spectra Magic software (Spectramagic TM NX, Konica Minolta Inc., Tokyo, Japan) [21-23].

Analyze the color data collected to evaluate the impact of sodium nitrate addition on the color attributes of the sausages. Compare the color values of sausages with different sodium nitrate concentrations to assess any noticeable differences in color [12].

2.5 Myoglobin Analysis

Myoglobin analysis was conducted to quantify the levels of myoglobin present in the meat samples used for sausage preparation. UV spectrophotometry was employed, following established protocols to ensure accurate and reproducible results [8,10].

Raw meat samples from each formulation were carefully prepared and processed according to the study's specifications. These samples were homogenized to ensure uniformity and consistency before undergoing spectrophotometric analysis. The samples were then subjected to UV light at specific wavelengths, allowing for the quantification of myoglobin levels based on the absorption of light by the heme pigment [8,10].

2.5.1 Measure Absorbance

Measure the absorbance of the meat sample at specific wavelengths. Myoglobin has characteristic absorption peaks at different wavelengths. Deoxymyoglobin absorbs strongly at around 555 nm, Oxymyoglobin absorbs strongly at around 577 nm, and Metmyoglobin absorbs strongly at around 630 nm [24,25].

Every type of myoglobin has a specific extinction coefficient, which determines the amount of light at a certain wavelength it is able to absorb. The extinction coefficients for myoglobin forms are typically provided in scientific literature or can be experimentally determined [24].

2.5.2 Calculate Concentrations of myoglobin in meat sample.

The Beer-Lambert Law to calculate the concentration of each form of myoglobin based on their absorbance and extinction coefficients [24].

Table 1 formula for calculating myoglobin concentration in meat by using spectrophotometer absorbance

Beer-Lambert Law	Rearranging for concentration
$A = \epsilon \times c \times l$	$c = \frac{A}{\epsilon \times l}$

The terms A stands for absorbance, ϵ for molar absorptivity/extinction coefficient, c for myoglobin content, and l for the spectrophotometer cuvette's path length [12,26].

Measuring Nitrosylmyoglobin Content in Cooked Sausage Products Using UV Spectrophotometry

2.6.1 Sample Homogenization

The first step in the procedure involves homogenizing the sausage samples to create a uniform paste. A representative portion of the cooked sausage from each treatment group, such as T(B40), T(L80), T(C120), etc., is selected. Using a mortar and pestle or a food processor, the sausage samples are homogenized thoroughly. This homogenization ensures that the myoglobin is evenly distributed throughout the sample, providing consistent results in subsequent analysis [24,27].

2.6.2 Extraction of Myoglobin

After homogenization, the extraction of myoglobin from the sausage matrix is carried out. A 10 g portion of the homogenized sausage sample is weighed and placed in a test tube. Subsequently, 50 mL of phosphate buffer solution (pH 6.8) is added to the test tube. The mixture is vortexed for 2 minutes to ensure thorough mixing. This step facilitates the release of myoglobin from the sausage tissue into the buffer solution. The mixture is then allowed to sit at room temperature for 30 minutes, with occasional shaking to enhance the extraction process [27,28].

2.6.3 Filtration

Following the extraction, the mixture is filtered to remove solid particles. This can be accomplished using either filter paper or centrifuge tubes with filters. If using a centrifuge, the mixture is centrifuged at 4,000 rpm for 10 minutes. The supernatant is carefully decanted into a clean test tube, ensuring that only the liquid portion, which contains the extracted myoglobin, is used for further analysis [28,29].

2.6.4 Spectrophotometer Calibration

Before measuring the absorbance of the extract, the UV spectrophotometer must be calibrated. The instrument is turned on and allowed to warm up according to the manufacturer's instructions. Calibration is performed using a blank sample, which is the phosphate buffer solution. This sets the baseline absorbance to zero, ensuring accurate measurements of the sample absorbance [27,29].

2.6.5 Absorbance Measurement

A portion of the filtered extract is transferred into a cuvette. The absorbance of the extract is measured at 540 nm, corresponding to the peak absorbance of nitrosylmyoglobin. The absorbance value is recorded for further analysis. This measurement step is crucial as it directly correlates with the concentration of nitrosylmyoglobin in the sample [30].

2.6.6 Calculation

The concentration of nitrosylmyoglobin in the sample is calculated using the Beer-Lambert Law: By comparing the absorbance values with a standard curve generated using known concentrations of nitrosylmyoglobin, the exact concentration in the sausage samples can be determined [24,26].

2.6.7 Repeat Measurements

To ensure accuracy and reproducibility, the measurement process is repeated for each treatment group (T(B0), T(B40), T(B80), T(B120), T(L0), T(L40), T(L80), T(L120), T(C0), T(C40), T(C80), T(C120)) in triplicate. Performing multiple measurements allows for the identification of any anomalies and provides more reliable data for analysis [19,27].

2.7 Statistical Analysis

Statistical analysis, such as ANOVA or t-tests, can be performed on the myoglobin data to determine if there are significant differences in myoglobin levels among the various sausage formulations. This analysis helps to elucidate the relationship between sodium nitrate

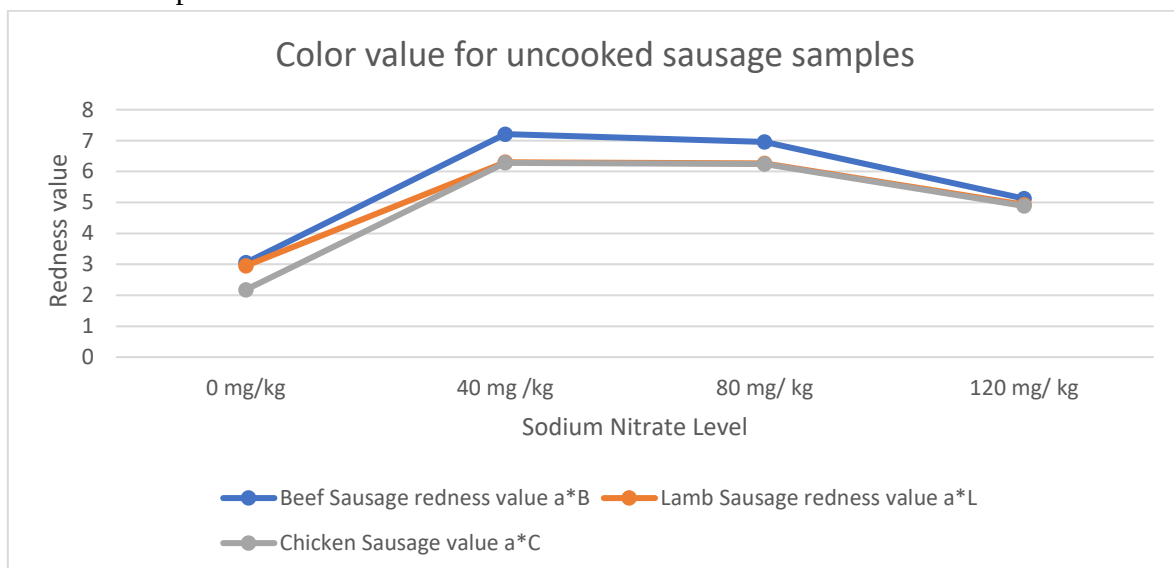
concentration and myoglobin content, providing valuable information for optimizing sausage formulations and ensuring product consistency and quality.

RESULTS

Color value for uncooked sausage samples

Sausage type		Sodium Nitrate content			
		0 mg/kg	40 mg /kg	80 mg/ kg	120 mg/ kg
Beef Sausage	L*	63.69 ± 3. 16	59.38 ± 2.41	52.19 ± 2.34	44.68 ± 2.66
	a*	3.05 ± 0.77	7.21 ± 0.59	6.96 ± 0.72	5.13 ± 0.86
	b*	9.34 ± 1.55	8.41 ± 0.85	7.89 ± 0.78	7.08 ± 1.54
Lamb Sausage	L*	54.79 ± 3. 96	48.28 ± 2.11	45.89 ± 2.94	39.68 ± 2.56
	a*	2.95 ± 0.85	6.30 ± 0.51	6.26 ± 0.90	4.93 ± 0.78
	b*	9.03 ± 1.24	8.07 ± 0.73	7.87 ± 0.80	6.88 ± 1.36
Chicken Sausage	L*	52.49 ± 4.09	46.16 ± 2.38	44.89 ± 2.71	40.42 ± 2.46
	a*	2.18 ± 0.85	6.28 ± 0.49	6.24 ± 0.87	4.89 ± 0.71
	b*	8.27 ± 1.14	7.19 ± 0.85	7.29 ± 0.73	5.87 ± 1.12

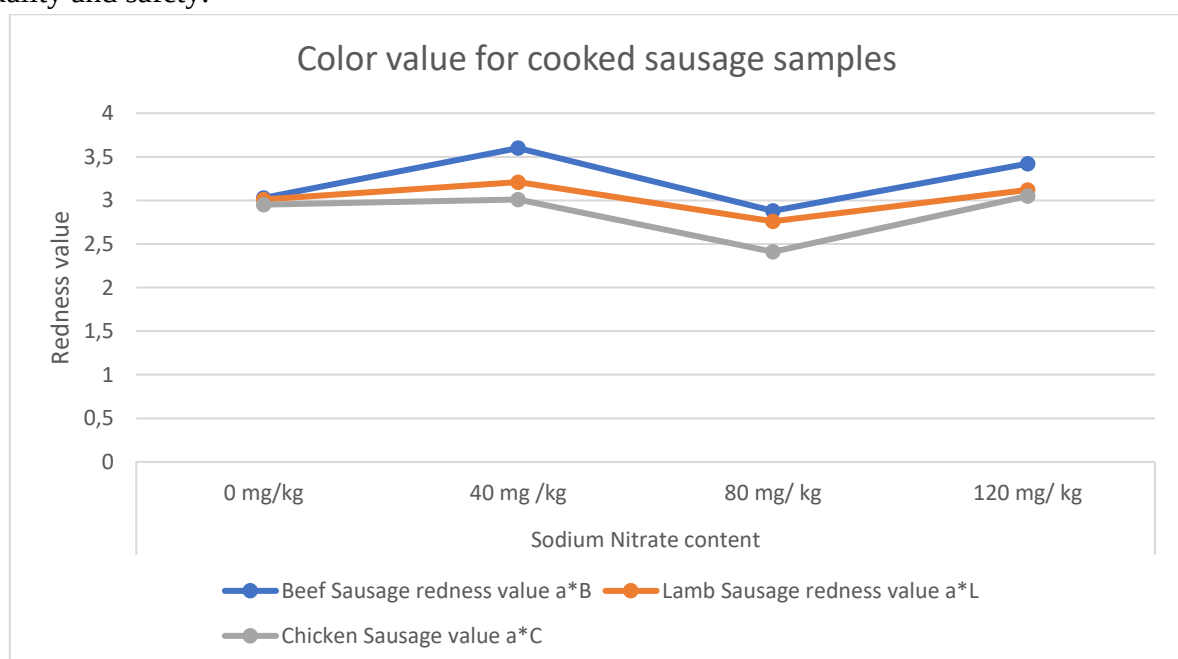
The uncooked sausage samples of beef, lamb, and chicken exhibit distinct redness values, reflecting variations in their inherent coloration. Without the addition of sodium nitrate, the beef sausage demonstrates the highest redness value at 3.05, followed closely by lamb at 2.95, while chicken lags at 2.18. This suggests that beef inherently possesses a richer red hue compared to lamb and chicken. Upon introducing sodium nitrate at 40 mg/kg, a substantial increase in redness is observed across all meat types, with beef exhibiting the most significant increase at 7.21, lamb at 6.30, and chicken at 6.28. This escalation in redness indicates the potent effect of sodium nitrate in enhancing the coloration of sausages, with the beef variant responding most prominently. However, as the sodium nitrate level escalates further to 80 mg/kg and 120 mg/kg, a diminishing return in redness is evident for all meat types. Despite this, beef consistently maintains a higher redness value compared to lamb and chicken across all sodium nitrate levels. This analysis underscores the intricate relationship between meat type, sodium nitrate concentration, and the resultant redness of uncooked sausages, highlighting beef's predisposition towards a deeper red hue and its heightened responsiveness to sodium nitrate supplementation compared to lamb and chicken counterparts.



CIB LAB Color value for cooked sausage samples

Sausage type		Sodium Nitrate content			
		0 mg/kg	40 mg /kg	80 mg/ kg	120 mg/ kg
Beef Sausage	L*	78.04 ± 2.10	73.30 ± 1.76	75.35 ± 2.77	76.22 ± 1.85
	a*	3.03 ± 0.47	3.60 ± 0.27	2.88 ± 0.28	3.42 ± 0.22
	b*	13.11 ± 0.53	13.21 ± 0.47	12.59 ± 0.28	12.95 ± 1.08
Lamb Sausage	L*	72.23 ± 2.10	66.21 ± 1.52	69.64 ± 2.71	70.43 ± 1.79
	a*	3.01 ± 0.29	3.21 ± 0.17	2.76 ± 0.23	3.12 ± 0.14
	b*	12.08 ± 0.57	12.90 ± 0.47	11.58 ± 0.23	11.95 ± 1.12
Chicken Sausage	L*	63.13 ± 2.05	56.11 ± 1.12	59.23 ± 2.22	61.32 ± 1.26
	a*	2.95 ± 0.11	3.01 ± 0.06	2.41 ± 0.18	3.05 ± 0.18
	b*	11.98 ± 0.41	12.79 ± 0.25	11.46 ± 0.24	11.83 ± 1.14

Valuable facts about the function of sodium nitrate in meat processing can be gained from the correlation between redness values and sodium nitrate levels in cooked sausage samples made from beef, lamb, and chicken. Results find a steady trend in beef sausages where redness values rise in proportion to rising sodium nitrate levels. For example, the redness value improved dramatically to 3.60 at 40 mg/kg of sodium nitrate, demonstrating a strong effect on color growth. This pattern indicates that sodium nitrate is an important factor in enhancing the red color of beef sausages. On the other hand, sausages made of lamb exhibit a less uniform reaction to amounts of sodium nitrate. After an additional administration of sodium nitrate at a dose of 80 mg/kg, the redness value decreases to 2.76 after first increasing to 3.21 at 40 mg/kg. This variation points to a complex relationship between lamb meat and sodium nitrate that may be impacted by natural color or fat content. However, chicken sausages react to sodium nitrate levels in a more controlled method. The redness values exhibit little changes within a small range, suggesting a less noticeable effect in comparison to their counterparts in the beef and lamb categories. This research shows the complex relationship between sodium nitrate levels and the type of meat, showing the value of custom formulas in sausage production to obtain desired color results while ensuring product quality and safety.



Myoglobin level of meat

Sausage type	Beef meat	Lamb meat	Chicken meat
Myoglobin level	8 mg/g	3.4 mg/g	1.4 mg/g

The myoglobin content of various meat samples was examined by measuring absorbance at the appropriate wavelength with a spectrophotometer. Determining the concentration of red meat is made possible by the way the protein called myoglobin absorbs light at a particular wavelength.

The spectrophotometer detected a significant absorbance for beef meat (8 mg/g myoglobin content), which suggests a higher myoglobin concentration than other meat types. This is consistent with what is typical of beef, which can be identified by its deeper red color and higher myoglobin content. Lamb meat, with a myoglobin content of 3.4 mg/g, showed a lower absorbance compared to beef. This corresponds to the slightly lighter red color typically associated with lamb compared to beef, reflecting its lower myoglobin concentration. Chicken sausage, with a myoglobin content of 1.4 mg/g, exhibited the lowest absorbance among the samples. This is consistent with the lighter color of poultry compared to red meat, as chicken has a lower myoglobin content.

Effect of Sodium Nitrate Content on Nitrosylmyoglobin Concentration in Cooked Sausages

The concentration of nitrosylmyoglobin in cooked beef, lamb, and chicken sausages was affected by varying sodium nitrate contents. The initial measurements of nitrosylmyoglobin concentrations for beef, lamb, and chicken sausages were 12.61 ppm, 11.71 ppm, and 11.41 ppm, respectively, prior to add sodium nitrate.

Table 3. Nitrosylmyoglobin content in cooked sausage products

	Nitrosylmyoglobins (ppm)			
Sodium Nitrate content	0 mg/kg	40 mg /kg	80 mg/ kg	120 mg/ kg
Beef Sausage	12.61 ± 0.48	13.85 ± 0.58	12.79 ± 0.41	13.98 ± 0.61
Lamb Sausage	11.71 ± 0.36	12.41 ± 0.69	11.93 ± 0.65	12.97 ± 0.58
Chicken Sausage	11.41 ± 0.24	11.91 ± 0.72	11.81 ± 0.55	12.05 ± 0.62

Distinct variations in the amounts of nitrosylmyoglobin were observed when sodium nitrate (40 mg/kg, 80 mg/kg, and 120 mg/kg) was added. The addition of 40 mg/kg to the beef sausage caused a significant increase to 13.85 ppm, suggesting that the concentrations of nitrosylmyoglobin and sodium nitrate are positively correlated. The results indicate a decreasing effect at higher concentrations since subsequent rises to 80 mg/kg and 120 mg/kg resulted in slight increases to 12.79 ppm and 13.98 ppm.

Lamb sausage also showed a similar pattern, increasing to 12.41 ppm after the first addition of 40 mg/kg. A similar pattern of diminishing returns was seen with subsequent administrations of 80 mg/kg and 120 mg/kg, which led to small enhancements to 11.93 ppm and 12.97 ppm.

Chicken sausage displayed a relatively stable nitrosylmyoglobin concentration across the different sodium nitrate content levels, with slight variations observed. The initial addition of 40

mg/kg led to a modest increase to 11.91 ppm, followed by marginal changes to 11.81 ppm and 12.05 ppm at 80 mg/kg and 120 mg/kg.

Table 3. Physical and chemical criteria of cooked sausage products

Sausage type		Sodium Nitrate content			
		0 mg/kg	40 mg /kg	80 mg/ kg	120 mg/ kg
Beef Sausage	a _w	0.976 ± 0.01	0.977 ± 0.00	0.976 ± 0.00	0.979 ± 0.01
	pH	5.78 ± 0.01	5.69 ± 0.02	5.70 ± 0.01	5.73 ± 0.09
Lamb Sausage	a _w	0.963 ± 0.01	0.964 ± 0.01	0.963 ± 0.01	0.966 ± 0.01
	pH	6.62± 0.01	6.57± 0.01	6.58± 0.01	6.61± 0.01
Chicken Sausage	a _w	0.971± 0.01	0.970± 0.01	0.969± 0.01	0.972± 0.01
	pH	6.43± 0.01	6.41± 0.01	6.44± 0.01	6.51± 0.01

The impact of sodium nitrate additives on the water activity of beef, lamb, and chicken sausages across varying concentrations. Water activity, a crucial parameter in food preservation, influences microbial growth and stability. Initially, without sodium nitrate, the water activities for beef, lamb, and chicken sausages are 0.976, 0.963, and 0.971, respectively. As 40mg/kg of sodium nitrate is introduced, slight increases in water activity are observed: 0.977 for beef, 0.964 for lamb, and 0.970 for chicken sausage. This suggests sodium nitrate's ability to retain moisture, albeit marginally. Doubling the sodium nitrate content to 80mg/kg maintains stability in water activity for beef (0.976), lamb (0.963), and chicken (0.969) sausages, indicating a plateau effect. However, at 120mg/kg, water activity rises significantly: beef (0.979), lamb (0.966), and chicken (0.972). This escalation likely arises from sodium nitrate's hygroscopic nature, absorbing more moisture as concentration increases. Consequently, while sodium nitrate aids in preserving meat products by inhibiting microbial growth, its dosage must be carefully calibrated to prevent excessive water activity, which can compromise product quality and safety. The pH value of the sodium nitrate concentrate added to the sausage sample shows no significant changes or influence.

Conclusion

The study demonstrated that sodium nitrate significantly impacts the color and myoglobin content of sausages made from beef, lamb, and chicken. Beef sausages, with the highest initial myoglobin content (8 mg/g), showed the most substantial increase in redness, from 3.05 to 7.21 in uncooked samples and 3.60 in cooked samples at 40 mg/g sodium nitrate. Lamb and chicken sausages exhibited less pronounced and more variable responses, reflecting their lower myoglobin levels (3.4 mg/g for lamb and 1.4 mg/g for chicken). The concentration of nitrosylmyoglobin in cooked sausages also increased with sodium nitrate addition, peaking at 13.85 ppm for beef at 40 mg/g, while lamb and chicken showed more modest increases. These results underscore the importance of sodium nitrate in enhancing meat coloration and preserving myoglobin stability, particularly in beef products. This research provides valuable guidance for meat processors in optimizing sausage formulations to achieve desired color outcomes and product consistency.

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