Jurnal Ilmu Produksi dan Teknologi Hasil Peternakan
ISSN 2303-2227 eISSN 2615-594X
Accredited by National Journal Accreditation No. 105/E/KPT/2022

Vol. 14 No. 2 June 2026, Page: 55-60
DOI: https://doi.org/10.29244/jipthp.14.2.55-60
Available online at https://journal.ipb.ac.id/index.php/ipthp/index

The Optimal Sugar-Salt Formulation and Its Effect on Crispy Dried Chicken Meat

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(Received 15-04-2026; Revised 25-05-2026; Accepted 29-06-2026)

ABSTRACT

This study evaluated the effects of sugar and salt levels on the physicochemical properties and sensory attributes of crispy dried chicken meat and determined the optimal formulation. A 3 x 3 factorial design was applied using three salt levels (1.5, 3.0, and 4.5%) and three sugar levels (1.5, 3.0, and 4.5%). Data were analyzed using analysis of variance, and principal component analysis was used to integrate physicochemical and sensory parameters for formulation optimization. Increasing salt and sugar levels significantly reduced moisture content (1.67–1.85%) and water activity (0.49–0.54), while hardness increased from 4.60 to 5.73 N, contributing to the development of a crispy texture. Sensory evaluation showed that the formulation containing 1.5% salt and 3.0% sugar achieved the highest scores for colour, aroma, taste, and texture. Principal component analysis explained 93.4% of the total variance, revealing strong positive correlations among sensory attributes, whereas hardness was negatively associated with overall acceptability. The optimal formulation (1.5% salt and 3.0% sugar) provided a balance between product stability, texture, and sensory quality. These findings demonstrate that moderate sugar-salt levels are critical for optimizing crispy dried chicken meat and provide a scientific basis for further product development.

Keywords: Crispy dried chicken meat, multivariate analysis, sensory evaluation, sugar-salt interaction, texture hardness

ABSTRAK

Penelitian ini mengevaluasi pengaruh tingkat gula dan garam terhadap sifat fisikokimia dan atribut sensori daging ayam kering renyah serta menentukan formulasi yang optimal. Rancangan faktorial 3 × 3 diterapkan dengan menggunakan tiga tingkat garam (1,5; 3,0; dan 4,5%) dan tiga tingkat gula (1,5; 3,0; dan 4,5%). Data dianalisis menggunakan analisis ragam, sedangkan analisis komponen utama digunakan untuk mengintegrasikan parameter fisikokimia dan sensori dalam optimasi formulasi. Peningkatan kadar garam dan gula secara signifikan menurunkan kadar air (1,67–1,85%) dan aktivitas air (0,49–0,54), sementara kekerasan meningkat dari 4,60 menjadi 5,73 N, yang berkontribusi terhadap terbentuknya tekstur renyah. Evaluasi sensori menunjukkan bahwa formulasi yang mengandung 1,5% garam dan 3,0% gula memperoleh skor tertinggi untuk warna, aroma, rasa, dan tekstur. Analisis komponen utama menjelaskan 93,4% dari total varians, yang menunjukkan adanya korelasi positif yang kuat antar atribut sensori, sedangkan kekerasan berasosiasi negatif dengan tingkat penerimaan keseluruhan. Formulasi optimal (1,5% garam dan 3,0% gula) memberikan keseimbangan antara stabilitas produk, tekstur, dan kualitas sensori. Temuan ini menunjukkan bahwa tingkat gula-garam yang moderat sangat penting dalam mengoptimalkan daging ayam kering renyah dan memberikan dasar ilmiah bagi pengembangan produk lebih lanjut.

Kata kunci: Analisis multivariat, daging ayam kering renyah, evaluasi sensori, interaksi gula–garam, kekerasan tekstur

INTRODUCTION

Chicken meat is widely consumed due to its high nutritional value and versatility (FAO 2023; Connolly and Campbell 2023). Increasing demand for convenient and shelf-stable foods has promoted the development of dried meat products such as jerky and crispy dried chicken (Rodrigues *et al.* 2023; Domínguez *et al.* 2022). Drying preserves meat by reducing moisture and water activity, which are essential for microbial stability (Fellows 2017; Barbosa-Cánovas *et al.* 2020). However, excessive moisture removal can cause shrinkage of the muscle matrix, formation of a denser protein structure, and increased hardness, which may reduce eating quality and consumer acceptance. In such systems, formulation plays a key role. Salt and sugar not only enhance flavor but also influence water status, structure, and texture (Mediani *et al.* 2022; Zou 2024).

Higher salt and sugar levels can reduce moisture content and water activity through osmotic effects and water-binding capacity, thereby decreasing the amount and mobility of free water in the meat matrix and improving product stability (Barbosa-Cánovas *et al.* 2020; Zou 2024). However, excessive solute levels may intensify dehydration, increase total solids, promote structural contraction and the formation of a denser protein network, resulting in greater hardness and reduced sensory quality (Petričević *et al.* 2018; Fan *et al.* 2024; Vidal *et al.* 2025). Therefore, an integrated evaluation of physicochemical and sensory properties is needed for sugar-salt formulation optimization in crispy dried chicken meat. Multivariate statistical techniques, such as principal component analysis (PCA), provide an effective tool for analyzing complex relationships among multiple quality variables and supporting product optimization (Jolliffe and Cadima 2016). By combining instrumental and sensory data, PCA enables the identification of key factors influencing product quality and facilitates the selection of balanced formulations.

Therefore, the aim of this study was to evaluate the effects of different sugar and salt levels on moisture content, water activity, texture, and sensory attributes of crispy dried chicken meat, and to determine the optimal formulation using principal component analysis.

MATERIALS AND METHODS

Raw Materials and Sample Preparation

The ingredients used were chicken breast fillet (CP, Vietnam), sugar (Bien Hoa, Vietnam), salt (Visaco, Vietnam), and monosodium glutamate (MSG; Ajinomoto, Japan). Chicken meat was washed, cut into 2-cm-thick pieces along the muscle fibers, and steamed at 120 °C for 15 min. The cooked meat was shredded into 0.2 cm fibers and mixed with MSG (0.2%), salt, and sugar according to the experimental levels.

Experimental Design and Drying Process

A two-factor experimental design was applied with three salt levels (1.5, 3.0 and 4.5 %) and three sugar levels (1.5, 3.0 and 4.5 %). After marination, samples were arranged in a single layer and dried in a hot-air dryer (MSD100-160, Mactech, Vietnam) at 80 °C for 6 h (Xuan *et al.* 2025). All treatments were performed in triplicate.

Determination of Moisture Content and Water Activity

Moisture content was determined by the thermogravimetric loss-on-drying method using a rapid moisture analyzer (KERN DBS 60-3, Kern & Sohn GmbH, Balingen-Frommern, Germany), according to the manufacturer's instructions (Kern & Sohn GmbH 2011). Approximately 2 g of sample was analyzed at 105 °C until the endpoint was reached.

Texture Analysis

Texture (hardness, N) was measured using Texture Lab Pro (Force) software (version 1.18-408) with a TMS Pro texture analyzer (China) under a single-cycle compression test using a pointed probe. Hardness was defined as the peak force during the first compression cycle, corresponding to the maximum resistance of the sample to deformation (Jonkers *et al.* 2022).

Sensory Evaluation

Sensory attributes (colour, aroma, taste, texture) were evaluated by a trained panel using a 5-point intensity scale (0¬5) based on QDA (Lawless and Heymann 2010). Samples were coded, randomized, and tested in triplicate; mean scores were used for radar plots.

Statistical Analysis

Data were analyzed by ANOVA to assess the effects of sugar and salt levels, with mean comparisons at $p<0.05$. Principal component analysis (PCA) was conducted to evaluate relationships among physicochemical and sensory parameters and to identify the optimal formulation. The first two principal components (PC1 and PC2) were used for interpretation. All statistical analyses were performed using Minitab software (version 18, Minitab Inc., State College, PA, USA).

RESULTS AND DISCUSSION

Effects of Sugar and Salt Levels on Moisture Content and Water Activity

Moisture content ranged from 1.67% to 1.85% and was significantly affected by sugar-salt combinations ($p=0.042$), decreasing with increasing salt and/or sugar. Water activity (a_w) ranged from 0.49 to 0.54 and was highly significantly affected ($p=0.002$), showing a consistent decline with increasing sugar or salt levels (Table 1).

The reduction in moisture content and aw can be explained by the osmotic effect and water-binding capacity of solutes. Both salt and sugar reduce free water through osmotic pressure, promoting water migration from muscle tissue, and by increasing the proportion of bound water within the protein–carbohydrate matrix (Barbosa-Cánovas *et al.* 2020; Zou 2024). Salt also affects myofibrillar protein solubility and water-holding capacity, while sugar acts as a humectant, limiting water mobility.

These findings are consistent with previous studies on dried meat products, where increasing salt or sugar levels reduces residual moisture and water activity (Petričević *et*

Table 1. Effects of salt and sugar levels on moisture content and water activity of crispy dried chicken meat (means±standard error)

Salt (%)	Sugar (%)	Moisture (%)	a_w
1.5	1.5	1.85 ±0.04a	0.54 ±0.01a
1.5	3	1.79 ±0.04abcd	0.53 ±0.01ab
1.5	4.5	1.72 ±0.03cde	0.51 ±0.01bcd
3	1.5	1.83 ±0.04ab	0.53 ±0.01ab
3	3	1.77 ±0.04abcde	0.52 ±0.01abc
3	4.5	1.69 ±0.03de	0.50 ±0.01cd
4.5	1.5	1.81 ±0.04abc	0.52 ±0.01abc
4.5	3	1.74 ±0.03bcde	0.51 ±0.01bcd
4.5	4.5	1.67 ±0.03e	0.49 ±0.01d
	P	0.042	0.002

Means in the same column with different superscript differ significantly (P<0.05). P-values refer to the effect of salt-sugar interaction.

al. 2018; Fan *et al.* 2024). Similar mechanisms have been reported in other food systems, indicating that combined solute effects play a key role in controlling water status and product stability. Although the formulation containing 4.5% salt and 4.5% sugar resulted in the lowest moisture content and aw, excessive dehydration may negatively affect product quality. Therefore, optimization should consider not only water stability but also textural and sensory properties.

Effects of Sugar and Salt Levels on Textural Properties (Hardness)

Hardness of crispy dried chicken meat ranged from 4.60 to 5.73 N and was significantly affected by the sugar-salt combination (p=0.001) (Figure 1). The lowest value was observed at 1.5% salt and 1.5% sugar, whereas the highest was recorded at 4.5% salt and 4.5% sugar. In general, hardness increased with increasing levels of salt and/or sugar. This trend can be explained by structural changes occurring during drying. Increasing salt and sugar levels reduces free water and water activity, leading to a denser protein network and greater resistance to deformation. Salt affects protein hydration and interactions within myofibrillar structures, while sugar increases total solids and contributes to the formation of a firmer matrix (Barbosa-Cánovas *et al.* 2020; Zou 2024).

Similar trends were reported in dried meat products, where increased dehydration resulting a higher hardness and altered texture (Fan *et al.* 2024; Liang *et al.* 2024). These findings confirm the close relationship between water loss, microstructural changes, and mechanical properties in dried meat systems. However, excessive hardness may negatively affect sensory acceptance. Although the formulation containing 4.5% salt and 4.5% sugar produced the highest hardness, the treatment with 1.5% salt and 3.0% sugar (4.97 N) provided a more balanced texture, maintaining structural integrity without becoming overly firm. These results indicate that textural optimization should consider not only structural firmness but also its impact on sensory perception, which is further discussed in the following section.

Effects of Sugar and Salt Levels on sensory Attributes

Sensory attributes (colour, aroma, taste, texture) were significantly affected by sugar-salt combinations (p=0.001) (Table 2 and Figure 2). The 1.5 % salt–3.0 %

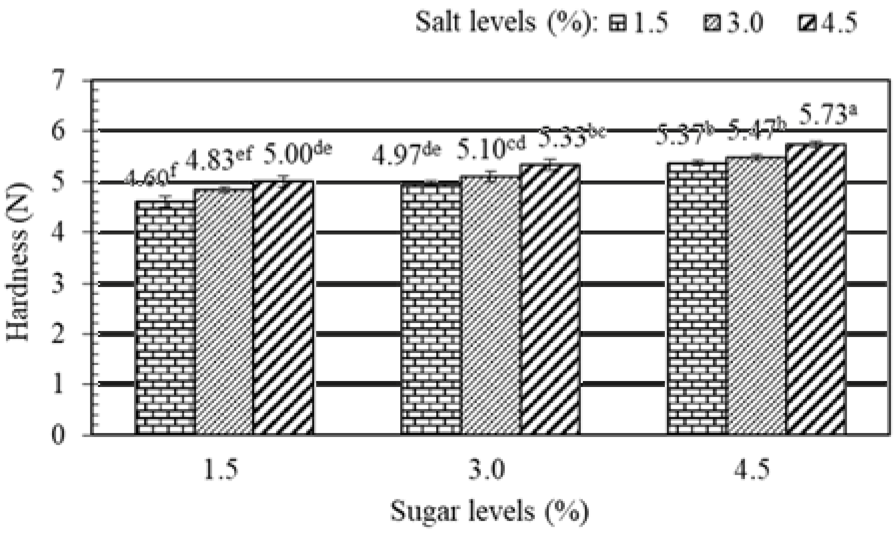

Figure 1. Effects of salt and sugar levels on hardness of crispy dried chicken meat. Values are expressed as mean. Means in the figure with different superscript differ significantly (P<0.05).

Table 2. Effects of salt and sugar levels on sensory attributes of crispy dried chicken meat (means±standard error)

Salt (%)	Sugar (%)	Color	Aroma	Taste	Texture
1.5	1.5	4.30±0.48abc	4.10±0.57ab	3.50±0.53b	3.60±0.52bc
1.5	3	4.80±0.42a	4.40±0.52a	4.40±0.52a	4.80±0.42a
1.5	4.5	4.60±0.52ab	4.00±0.47ab	3.20±0.42bc	3.80±0.42b
3	1.5	4.20±0.42abc	3.80±0.42abc	2.80±0.42cd	3.20±0.42bcd
3	3	3.90±0.57cd	3.60±0.52bc	2.90±0.32bcd	3.10±0.32cd
3	4.5	3.50±0.53d	3.50±0.53bc	2.50±0.53d	2.90±0.57d
4.5	1.5	2.80±0.42e	3.20±0.42c	2.80±0.42cd	2.60±0.52d
4.5	3	4.10±0.57bcd	3.50±0.53bc	2.90±0.57bcd	2.80±0.42d
4.5	4.5	3.80±0.42cd	3.70±0.48abc	3.00±0.00 bcd	2.60±0.52d
	P	0.001	0.001	0.001	0.001

Means in the same column with different superscript differ significantly ($P<0.05$). P-values refer to the effect of salt-sugar interaction.

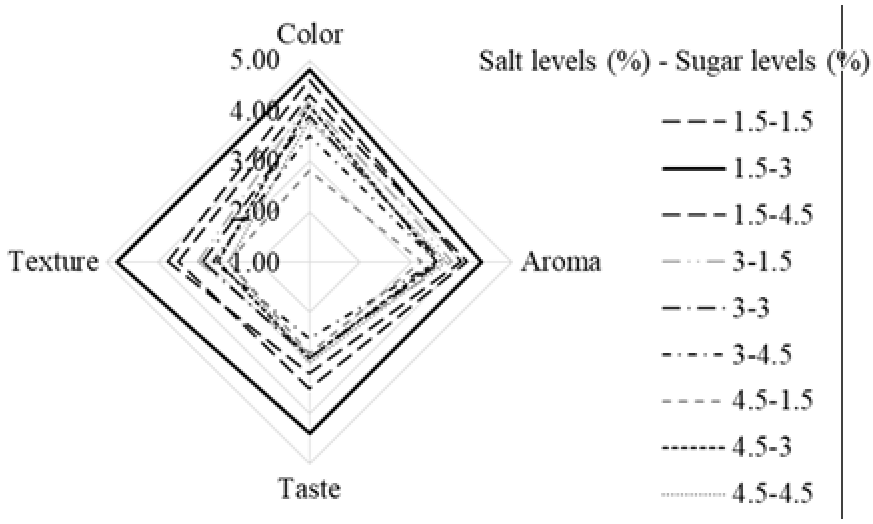

Figure 2. Effects of salt and sugar levels on sensory attributes of crispy dried chicken meat.

sugar treatment showed the highest scores, while higher salt (4.5 %) or high sugar combinations reduced sensory quality, especially taste and texture.

The superior sensory performance of the 1.5% salt and 3.0% sugar formulation can be attributed to a balanced interaction between flavour and structural properties. Moderate sugar levels promote desirable colour and aroma development through Maillard reactions and mild caramelization, while excessive salt may disrupt surface appearance and flavor balance (Zhou *et al.* 2024; Jiang *et al.* 2024). In addition, taste perception depends on the interaction between saltiness, sweetness, and umami, where balanced formulations enhance overall palatability, whereas excessive salt or sugar may mask characteristic meat flavors (Liu *et al.* 2024).

Texture also played an important role in sensory acceptance. As discussed in Sections 3.1 and 3.2, increasing salt and sugar levels reduced moisture and water activity while increasing hardness, resulting in a drier and firmer product. However, excessive firmness negatively affected chewability and overall acceptability, as previously reported in dried meat products (Heymann and Lawless 2013). Overall, the results indicate that optimal sensory quality is achieved not at the lowest moisture or water activity levels, but at an intermediate formulation that balances flavor, texture, and structural stability. Therefore, the formulation containing 1.5% salt and 3.0% sugar was identified as the most suitable condition for producing high-quality crispy dried chicken meat.

Optimization of Sugar-Salt Formulation and Principal Component Analysis (PCA)

Principal component analysis (PCA) revealed that the first two principal components explained 93.4% of the total variance (PC1: 63.8%; PC2: 29.6%), indicating a strong representation of the relationships among variables (Figure 3). Sensory attributes (color, aroma, taste, and texture) were closely grouped and positively correlated, whereas hardness was positioned in the opposite direction, confirming its negative effect on sensory acceptability (Heymann and Lawless 2013). In contrast, moisture content and aw were clustered together but separated from the sensory axis, indicating their primary association with water status and product stability rather than direct sensory perception (Barbosa-Cánovas *et al.* 2020).

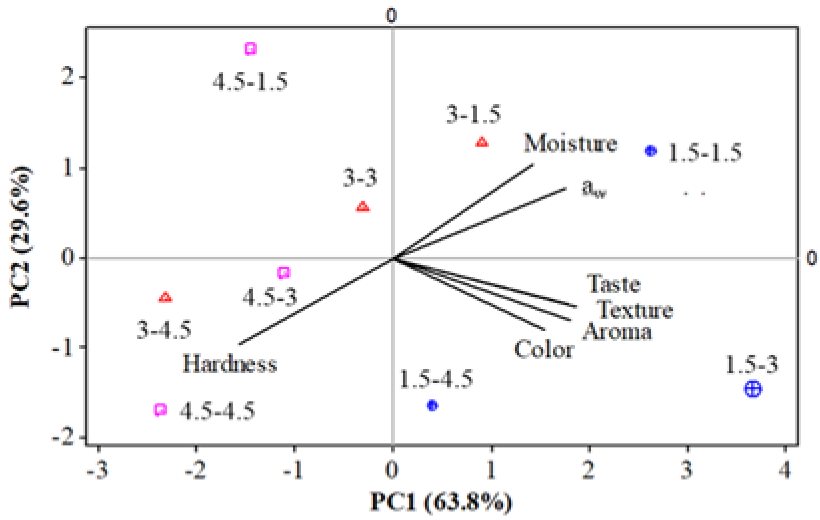

Figure 3. Principal component analysis (PCA) biplot showing relationships among physicochemical and sensory attributes. PC1 and PC2 represent the first and second principal components, explaining 63.8% and 29.6% of the total variance, respectively.

The formulation containing 1.5% salt and 3.0% sugar was located closest to the sensory attribute vectors, indicating a strong association with desirable sensory quality. In contrast, treatments with higher salt and sugar levels (particularly 4.5%-4.5%) were positioned towards the hardness vector, reflecting increased product firmness and reduced acceptability. Treatments with lower solute concentrations were associated with higher moisture and aw, indicating softer but less stable products.

These results confirm the trade-off between water stability, structural firmness, and sensory quality in dried meat systems. Increasing salt and sugar levels enhances dehydration and structural rigidity, but excessive levels negatively affect sensory properties. Similar trends have been reported in dried meat products, where optimal quality is achieved at intermediate formulation levels (Fan *et al.* 2024; Liang *et al.* 2024). Overall, PCA provided an effective integrative approach to evaluate multiple quality attributes simultaneously. The formulation containing 1.5% salt and 3.0% sugar was identified as the optimal condition, achieving the best balance between moisture content, water activity, texture, and sensory quality.

CONCLUSION

The sugar-salt formulation significantly affected the physicochemical and sensory quality of crispy dried chicken meat. Increasing salt and sugar levels reduced moisture content and water activity, while increasing hardness. Among the tested formulations, 1.5% salt and 3.0% sugar produced the best sensory scores for color, aroma, taste, and texture. Principal component analysis confirmed this formulation as the optimal condition, providing the most suitable balance between water control, texture, and sensory acceptability. Therefore, the formulation containing 1.5% salt and 3.0% sugar is recommended for producing crispy dried chicken meat. These findings provide a scientific basis for further product development and quality improvement.

ACKNOWLEDGMENTS

This paper is derived from a university-level research project (Grant No. DTCS 2026-20) of Can Tho University of Technology. The authors gratefully acknowledge Can Tho University and Can Tho University of Technology for theirs support and for providing the facilities necessary for this study. The authors also thank V. T. Hieu and T. T. H. Gam for their assistance in analyzing the product evaluation parameters.

CONFLICT OF INTEREST

The authors have stated that they have no competing interests.

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