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Optimizing Granulated Palm Sugar (*Arenga pinnata* (Wurmb) Merr.) And Sodium Chloride Formulation to Improve Physicochemical Quality and Sensory Acceptance of Pork Dendeng .

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Abstract. This study evaluated the effects of different combinations of granulated palm sugar (gula semut) and sodium chloride (NaCl) on the physicochemical and sensory quality of pork dendeng. A completely randomized design (CRD) with three treatments and five replications (3×5) was applied. Treatments were formulated on a meat-weight basis (w/w): A1 (2.5% gula semut + 7.5% NaCl), A2 (5.0% gula semut + 5.0% NaCl), and A3 (7.5% gula semut + 2.5% NaCl). For each replication, 200 g pork ham was ground (5 mm plate), mixed with the assigned ingredients, rested at 4 °C for 12–24 h, and dried in a cabinet oven at 80 °C for 11 h. Moisture content (AOAC 950.46), pH, water-holding capacity (WHC; press method), and cooking loss were measured. Sensory acceptance (color, aroma, texture, and taste) was evaluated by 25 untrained panelists using a five-point hedonic scale. Data were analyzed using one-way ANOVA followed by BNJ (Tukey's HSD) at $P < 0.05$. The formulation significantly affected WHC and cooking loss. Treatment A2 produced the highest WHC (19.51%) and the lowest cooking loss (40.90%), indicating improved water retention and thermal yield compared with A1 and A3 ($P < 0.05$). pH values (6.61–6.69) and hedonic scores for all sensory attributes did not differ significantly among treatments ($P > 0.05$). Overall, a balanced gula semut–NaCl formulation (5%:5%) is recommended to enhance pork dendeng processing performance while maintaining acceptable sensory quality.

Keywords: cooking loss; gula semut; pork dendeng; sodium chloride; water-holding capacity

INTRODUCTION

Sugar palm (Arenga pinnata (Wurmb) Merr.) is widely distributed in Indonesia and provides multiple economically important products, particularly palm sap that can be processed into palm sugar. Granulated palm sugar ("gula semut") has attracted increasing attention because it is easy to dissolve, convenient to package, and generally has a longer shelf life than molded palm sugar, while also contributing a distinctive caramel-like aroma and flavor in foods (Rahayu et al., 2025; Sarkar et al., 2023).

In meat processing, sweeteners and salt are not only added for taste but also influence product quality. Salt (primarily NaCl) contributes to preservation by lowering water activity and plays key functional roles in meat matrices, including improving protein solubility and water binding, which can affect water-holding capacity and cooking loss. At the same time, there is growing scientific and public-health interest in controlling salt levels in processed meats, which makes formulation optimization increasingly relevant (Fang & Zhu, 2025; Wang et al., 2023; Xiang et al., 2025).

Jerky-type products including Indonesian "*dendeng*" are valued for convenience and extended shelf life, but their quality depends strongly on controlling moisture removal and water activity during processing (Han et al., 2021; Kim et al., 2021). Commercial jerky commonly targets low water activity (often around 0.7–0.85), which supports room-temperature stability; however, food-safety literature emphasizes that pathogens may still survive for prolonged periods in low-moisture foods, underscoring the need for robust process control and quality assurance (Acuff et al., 2023; Htet Aung & Nam, 2024). Recent reviews further highlight that drying conditions and the use of humectant-type ingredients can influence moisture retention, texture, and overall acceptability in jerky products (Mediani et al., 2022; Veselá et al., 2025).

Pork dendeng is consumed as a snack or as a side dish, and its acceptability is commonly linked to a balanced sweet–savory profile and a desirable texture. Because palm sugar can contribute both sweetness and characteristic flavor notes, and NaCl can affect both sensory perception and physicochemical properties, their combined use is technically plausible for producing pork dendeng with improved quality consistency (Sarkar et al., 2023; Wang et al., 2023).

Although palm sugar products are increasingly studied as alternative sweeteners and jerky processing has been widely investigated, evidence remains limited on how granulated sugar-palm (gula semut) specifically combined with NaCl influences the physicochemical properties and sensory acceptance of pork dendeng, particularly regarding moisture-related traits (water-holding capacity and cooking loss) that strongly shape texture and yield. Therefore, this study evaluates different formulations of granulated sugar palm and NaCl in pork dendeng and examines key quality attributes (moisture content, pH, water-holding capacity, cooking loss, and organoleptic properties) to identify a formulation that provides desirable physical and sensory characteristics and supports value-added utilization of sugar palm products.

MATERIALS AND METHODS

The study was conducted using a completely randomized design (CRD; RAL) with three treatments and five independent replications (3×5). Treatments were defined by different combinations of granulated palm sugar (gula semut) and sodium chloride (NaCl), expressed as percentage (w/w) of meat. The treatment levels were: A1 (2.5% gula semut + 7.5% NaCl), A2 (5.0% gula semut + 5.0% NaCl), and A3 (7.5% gula semut + 2.5% NaCl).

Each replication used 200 g pork, therefore the ingredient quantities per replication were calculated as: A1: 5 g gula semut + 15 g NaCl; A2: 10 g gula semut + 10 g NaCl; A3: 15 g gula semut + 5 g NaCl. Physicochemical variables (moisture content, pH, water-holding capacity, and cooking loss) were measured from the five replications per treatment. Sensory evaluation was performed using 25 untrained panelists.

Table 1. Treatment formulations (percent w/w of meat) and corresponding ingredient weights per 200 g pork

Treatment	Gula semut (% w/w)	NaCl (% w/w)	Gula semut (g)	NaCl (g)
A1	2.5	7.5	5	15
A2	5	5	10	10
A3	7.5	2.5	15	5

Table 1 summarizes the three formulation treatments evaluated in this study, expressed as percentages relative to meat weight (w/w) and converted into ingredient weights for a 200 g pork batch to support reproducibility. The treatment set represents a systematic shift in the gula semut–NaCl balance, with A1 being salt-dominant (7.5% NaCl; 2.5% gula semut), A2 representing an equal ratio (5%:5%), and A3 being sugar-dominant (7.5% gula semut; 2.5% NaCl). This formulation gradient enables direct comparison of how increasing gula semut while decreasing NaCl influences product quality.

The rationale for using these combinations is that NaCl is known to contribute to water binding and processing yield through its effects on myofibrillar proteins, whereas gula semut can contribute sweetness and may influence moisture retention and drying-related characteristics. Therefore, the treatment structure in Table 1 provides a practical basis for assessing formulation-driven changes in moisture-related physicochemical traits (e.g., WHC and cooking loss) as well as consumer acceptance attributes such as taste, aroma, texture, and color.

Raw materials

Pork ham (hindquarter) was used as the main raw material. Pork was purchased from a traditional market (e.g., Pinasungkulan Karombasan, Manado) and processed within 2–3 h after purchase. During transport to the laboratory, pork was kept in a cool box at approximately 4 °C. Gula semut was obtained from local sugar palm sap (North Sulawesi), described as 100% pure, food grade, fine granules. NaCl was a commercial iodized, food-grade fine salt (manufacturer specification >99% purity).

Preparation of pork dendeng

For each replication, pork was washed, filleted, cut into small pieces, and weighed to 200 g. Meat was ground using a meat grinder fitted with a 5 mm plate. Treatment-specific amounts of gula semut and NaCl (Table 1) were added, and the mixture was manually mixed (food-grade gloves) for 5–10 min until uniform. The seasoned mixture was then rested (marinated) in a closed container at 4 °C for 12–24 h.

After resting, the mixture was spread in a thin layer (approximately 3–5 mm) on trays lined with baking paper or aluminum foil, ensuring samples were not stacked. Drying was performed in an electric cabinet drying oven with the fan turned on at 80 °C for 11 h. The drying endpoint was time-based (drying was stopped at 11 h). Because dried-meat quality is sensitive to drying conditions, consistent tray loading and airflow control were maintained across treatments (Mediani et al., 2022). After drying, samples were cooled to room temperature prior to analysis and sensory testing.

Physicochemical analyses

All physicochemical measurements were performed on five independent replications per treatment, unless otherwise specified.

Moisture content

Moisture content was determined by a gravimetric method (AOAC 950.46) using oven drying at 105 °C for 16–18 h until constant weight.

pH

pH was measured using a digital benchtop pH meter equipped with a glass electrode. The pH meter was calibrated using buffer solutions at pH 9 and pH 4. A 5 g sample was homogenized and mixed with 5 mL distilled water (1:1, w/v). The electrode was immersed in the homogenate, and the pH value was recorded after the reading stabilized. Measurements were conducted at room temperature (25 ± 2 °C) and performed in triplicate technical readings per replication; the mean value was used for statistical analysis.

Water-holding capacity (WHC)

WHC was measured using a press method (Hamm approach as cited by Soeparno). A 0.3 g sample was placed on Whatman filter paper (No. 1 or 41) and pressed under a 35 kg load for 5 min using a hydraulic press apparatus or precision thick glass plate press. The wet area was quantified using a planimeter. WHC determination was performed in duplicate technical measurements per replication and averaged.

Released water was calculated as:

$$\text{mg } H_2O = (\textit{wet area}\ (\text{cm}^2) \times 8.0) / 0.094$$

Free water (%) was calculated as:

$$\textit{Free water}\ (\%) = (\text{mg } H_2O / 300 \text{ mg}) \times 100$$

WHC was calculated as:

$$\textit{WHC}\ (\%) = \textit{total moisture}\ (\%) - \textit{free water}\ (\%)$$

Clear reporting of WHC procedures is important because press-based WHC can be sensitive to sample geometry and pressing conditions (Szmańko et al., 2021).

Cooking loss

Cooking loss was measured using sample cubes (2 × 2 × 2 cm). Samples were weighed, placed in polyethylene (PE) bags, and sealed watertight using an impulse sealer. Heating was performed in a thermostatic water bath at 80 °C for 1 h. Samples were then cooled in 10 °C water for 15 min, blotted dry with filter paper, and reweighed.

Cooking loss was calculated as:

$$\textit{Cooking loss}\ (\%) = ((W_1 - W_2) / W_1) \times 100$$

Sensory (organoleptic) evaluation

A hedonic test was conducted using 25 untrained panelists (students of the Faculty of Animal Science, Sam Ratulangi University). Oral informed consent was obtained, and panelists were screened to ensure no pork-related dietary restrictions or allergies. Samples were cut into bite-size portions (approximately 2 × 2 cm) and served at room temperature. Each sample was labeled with a randomized three-digit code, and serving order was randomized across panelists. Drinking water at neutral temperature was provided as a palate cleanser between samples.

Panelists evaluated color, aroma, texture, and taste using a 5-point hedonic scale: 1 (strongly dislike), 2 (dislike), 3 (neutral), 4 (like), and 5 (strongly like). Standardization of coding, randomization, and serving conditions is consistent with current methodological guidance for sensory testing (Tura et al., 2024).

Statistical analysis

Data were analyzed using SPSS (version 25 or 26). Physicochemical and sensory scores were evaluated by one-way ANOVA according to the CRD design. When significant differences were detected, means were compared using BNJ (Tukey's HSD) at a significance level of $P < 0.05$.

RESULTS AND DISCUSSION

In this study, pork dendeng was produced using three gula semut–NaCl formulations expressed as % (w/w) of meat, corresponding to the following ingredient additions per 200 g pork batch: A1 (5 g gula semut + 15 g NaCl), A2 (10 g gula semut + 10 g NaCl), and A3 (15 g gula semut + 5 g NaCl). Physicochemical variables were evaluated using five independent replications per treatment (n = 5), while sensory acceptance was assessed by 25 untrained panelists.

Physicochemical quality

The physicochemical responses (pH, water-holding capacity/WHC, and cooking loss) are presented in Table 2 to support comparison of formulation effects on water-related properties and thermal yield.

Table 3. Hedonic sensory scores of pork dendeng produced with different gula semut–NaCl formulations

Variable	A1 (2.5% sugar + 7.5% NaCl)	A2 (5% sugar + 5% NaCl)	A3 (7.5% sugar + 2.5% NaCl)
pH	6.63 ± 0.10	6.61 ± 0.05	6.69 ± 0.06
WHC (%)	$11.30^a \pm 2.56$	$19.51^b \pm 1.64$	$13.58^a \pm 1.80$
Cooking loss (%)	$45.32^b \pm 1.63$	$40.90^a \pm 2.37$	$44.64^b \pm 2.80$

As reported in the study, differences among treatments for sensory attributes were not significant ($P > 0.05$). Nevertheless, the mean trends provide useful interpretation of how formulation might shape consumer perception.

Color scores were numerically highest in A3 (4.50), which had the highest gula semut level. This pattern is plausible because higher sugar availability can intensify non-enzymatic browning during heating/drying, contributing to darker or more desirable brown coloration (El Hosry et al., 2025; Kathuria et al., 2023). Aroma scores were slightly higher for A2 and A3 than A1, consistent with the idea that sugar–amino acid reactions and heat-driven pathways can contribute to volatile aroma formation in dried meat products.

Texture scores were numerically highest in A2 (3.66), aligning with its superior WHC and lower cooking loss. In jerky-type products, moisture-related traits and humectant-like formulation strategies can influence perceived tenderness and palatability, and overall processing conditions strongly shape texture outcomes. Taste scores were numerically highest in A1 (4.66), which contained the highest salt level; this trend is consistent with the role of salt in enhancing perceived savory intensity and overall flavor impact in meat products. When physicochemical and sensory outcomes are considered together, A2 (5% gula semut + 5% NaCl) appears most advantageous as a formulation that improves water retention and reduces cooking loss while maintaining generally high consumer acceptance across sensory attributes.

CONCLUSION

This study demonstrated that varying the gula semut–NaCl ratio (w/w of meat) significantly influenced the water-related quality of pork dendeng. The balanced formulation A2 (5% gula semut + 5% NaCl) produced the highest water-holding capacity and the lowest cooking loss ($P < 0.05$), indicating superior water retention and improved thermal yield. In contrast, pH was not significantly affected by formulation differences, suggesting that the treatments mainly modified functional water–protein interactions rather than the product’s acid–base status. Sensory acceptance scores for color, aroma, texture, and taste did not differ significantly among treatments ($P > 0.05$), indicating that the tested formulation adjustments remained within an acceptable sensory range. Considering both physicochemical performance and consumer acceptance, A2 is recommended as the most suitable formulation for producing pork dendeng using gula semut and NaCl. These results align with established knowledge that salt plays a major role in meat-product functionality and yield, while formulation strategies involving humectant-type ingredients can influence moisture-related characteristics in jerky-type products.

Further studies should (i) quantify water activity (aw) and conduct shelf-life assessments under defined packaging and storage conditions to strengthen claims about product stability and safety; (ii) expand formulation optimization by testing a wider range of gula semut–NaCl levels and integrating additional quality indicators such as instrumental texture and color; and (iii) evaluate sodium-reduction strategies that maintain sensory quality, supported by more comprehensive statistical reporting (effect sizes and assumption checks) to improve comparability and robustness across studies.

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