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THE EFFECT OF COOKING DURATION ON WATER ACTIVITY, LIPID OXIDATION, AND ANTIOXIDANT ACTIVITY OF MINANGKABAU BEEF RENDANG DURING STORAGE

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ABSTRACT

Beef rendang is an iconic traditional Minangkabau meat product cooked extensively with coconut milk and mixed spices. The chemical and shelf-life stability of rendang during storage is heavily shaped by its long thermal processing matrix. This study aimed to investigate the direct effect of cooking durations (3, 4, and 5 hours) on water activity (aw), lipid oxidation (Thiobarbituric Acid Reactive Substances / TBARS value), and antioxidant activity (DPPH radical scavenging capacity) of Minangkabau beef rendang over a controlled 4-week ambient storage system (28–30 °C). The experiment followed a 3x5 factorial setup structured in a Completely Randomized Design (CRD) with three replicates. Data evaluations were executed using Analysis of Variance (ANOVA) followed by Duncan's Multiple Range Test (DMRT) at a 5% alpha level. Results demonstrated that longer cooking significantly dropped water activity from 0.88 (3 h) to a highly stable 0.76 (5 h), which heavily suppressed microbial activity. While lipid oxidation values increased continuously across storage, the 5-hour cooking duration successfully minimized TBARS accumulation (peaking at 0.74 mg MDA/kg at week 4) compared to the 3-hour batch (1.15 mg MDA/kg). This protective feature was directly linked to higher accumulation of antioxidant-active browning melanoidins and spice lipophilic fractions generated during 5 hours of continuous simmering. In conclusion, extending the cooking duration of Minangkabau beef rendang to 5 hours maximizes oxidative and thermodynamic stability, ensuring optimal long-term functional and shelf-life security at ambient temperatures.

Keywords: beef rendang; cooking duration; water activity; lipid oxidation; antioxidant activity; storage; West Sumatra.

1. INTRODUCTION

Rendang is a world-renowned traditional caramelized beef product originating from the Minangkabau ethnic group of West Sumatra, Indonesia. More than a culinary dish, it represents a deep cultural heritage and a brilliant historical model of meat preservation engineered through ethnic culinary wisdom. Traditional beef rendang is fabricated by simmering lean beef chunks within an intricate mixture of coconut milk and an extensive paste of local spices—including shallots, garlic, chili, ginger, galangal, turmeric, lemongrass, and citrus leaves. This mixture is continuously heated until the liquid completely evaporates and the meat darkens into a deep brown or blackish-brown hue coated with rich, spice-infused oil. The chemical complex generated during this long thermal process allows rendang to be stored safely at room

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temperature for several weeks without any chemical or biological preservation agents, making it an essential food commodity for traditional travel, disaster relief, and commercial export markets.

From a food science perspective, the long-term ambient shelf stability of beef rendang is governed by a combination of thermodynamics, chemical transformation, and antioxidant defenses. The extensive cooking period functions as a progressive thermal dehydration process that systematically lowers water activity (aw), reducing it well below the threshold required for the replication of typical food spoilage microorganisms and pathogenetic indicators. Concurrently, lipid fractions present in both the beef adipose tissues and the dense coconut milk matrix undergo complex oxidative and thermal breakdown. While oil heating naturally risks oxidative rancidity and the accumulation of toxic malondialdehyde (MDA) radicals, the massive array of polyphenolic antioxidants extracted from the spice paste acts as a robust radical-scavenging shield. Furthermore, the continuous interaction between meat amino acids and coconut reducing sugars under high heat drives advanced non-enzymatic browning cascades (Maillard reaction). This cascade synthesizes complex melanoidin polymers that provide independent antioxidant properties, further protecting the product against lipid oxidation during subsequent shelf storage.

However, artisanal rendang preparation across small-scale culinary industries remains highly unstandardized, particularly regarding cooking duration. Traditional cooks frequently terminate the heating phase at different stages depending on local market preferences, resulting in products that range from moist, light-brown 'kalio' to dark, dry, traditional rendang. This structural variation drastically alters the residual water activity and the equilibrium between lipid oxidation kinetics and antioxidant retention, leading to highly erratic shelf-life outcomes. While some commercial batches show rancidity or mold growth within a week of ambient storage, properly processed dry rendang remains perfectly stable. To support local producers in standardizing their methods for wider distribution, clear scientific data linking exact cooking durations to physical, chemical, and oxidative kinetics during shelf storage are essential.

Therefore, this research was explicitly designed to determine the direct effect of three distinct traditional cooking durations (3, 4, and 5 hours) on the water activity (aw), lipid oxidation levels (TBARS values), and antioxidant capacity (DPPH scavenging efficiency) of Minangkabau beef rendang over a 4-week ambient shelf storage system. The primary goal of this study is to establish an optimized processing standard that ensures maximum oxidative stability and extended shelf life for local smallholder industries.

2. RESEARCH METHODS

2.1 Time and Location

This research was conducted from March 2026 to July 2026 at the Laboratory of Integrated Agriculture and Food Analysis, Faculty of Agriculture, Universitas Tamansiswa Padang. The formulation, processing, and ambient storage testing of the Minangkabau beef rendang were executed entirely within this facility using standardized environmental chambers.

2.2 Materials and Equipment

The primary raw materials comprised fresh lean beef (biceps femoris) secured from a local Padang abattoir, fresh coconut milk extracted from mature coconuts, and a traditional spice blend (chili, shallot, garlic, ginger, galangal, turmeric, lemongrass). Analytical-grade chemical reagents included 2-thiobarbituric acid (TBA), trichloroacetic acid (TCA), 2,2-diphenyl-1-picrylhydrazyl (DPPH) radicals, malondialdehyde

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(MDA) standards, and HPLC-grade methanol. Core instrumentation consisted of a digital water activity meter, a UV-Vis spectrophotometer, a refrigerated centrifuge, a professional temperature-controlled cooking range, and an incubation chamber set to an ambient temperature range of 28–30 °C.

2.3 Experimental Setup

The study used a 3x5 factorial setup organized within a Completely Randomized Design (CRD). The first factor was cooking duration with three levels: T1 (3 hours), T2 (4 hours), and T3 (5 hours). The second factor was storage time at ambient temperature (28–30 °C) with five evaluation intervals: week 0, week 1, week 2, week 3, and week 4. All experimental combinations were processed with three independent replicates, resulting in a total of 45 distinct analytical units.

2.4 Preparation of Minangkabau Beef Rendang

The spice paste was prepared by grinding fresh herbs to a uniform consistency and mixing them thoroughly with the extracted coconut milk. Lean beef was cut into uniform cubes weighing approximately 40 ± 2 grams each. The seasoned milk mixture was brought to a boil under continuous stirring, after which the beef cubes were introduced. Heating was carefully managed across uniform gas ranges. Individual batches were harvested at their exact target times: 3 hours (resulting in a moist brown matrix), 4 hours (a dark brown semi-dry matrix), and 5 hours (a dry, dark dark-brown traditional matrix). The samples were allowed to cool, packed in sterile, non-vacuum plastic bags, and placed in storage chambers for up to 4 weeks.

2.5 Analytical Parameters

Water activity (aw) was measured directly at 25 °C using a calibrated digital aw meter. Lipid oxidation was tracked by determining Thiobarbituric Acid Reactive Substances (TBARS) via spectrophotometry at 532 nm, with results expressed as milligrams of malondialdehyde equivalents per kilogram of sample (mg MDA/kg). Antioxidant activity was quantified by mixing methanolic sample extracts with DPPH radical solution, measuring absorbance changes at 517 nm, and recording the final radical scavenging percentage (%). All assays were executed in triplicate.

2.6 Data Processing

Statistical analysis was conducted via a two-way Analysis of Variance (ANOVA). Significant differences across interacting variables were determined using Duncan’s Multiple Range Test (DMRT) at a 5% level of significance.

3. RESULTS AND DISCUSSION

3.1 Water Activity (aw) Kinetics

Water activity acts as a critical thermodynamic gatekeeper for rendang preservation. The cooking duration significantly dropped the baseline aw values of the fresh matrix (Table 1). At week 0, the 3-hour batch retained a relatively high aw of 0.88, reflecting its moist, gravy-heavy texture. Extending thermal processing to 4 and 5 hours successfully drove down aw values to 0.81 and 0.76, respectively. This rapid drop is due to the continuous evaporation of free water molecules from the meat cells and the progressive thickening of the surrounding coconut oil-spice matrix. During the 4 weeks of ambient storage, a slight, gradual increase in aw was observed across all treatments, likely due to moisture equilibrium with the internal package atmosphere. Crucially, the 5-hour cooking treatment maintained its aw below 0.78

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throughout the storage period, effectively suppressing the growth of common bacteria and foodborne molds.

Cooking Duration	Week 0	Week 1	Week 2	Week 3	Week 4
3 Hours (T1)	0.88 ± 0.02 c	0.89 ± 0.02 c	0.90 ± 0.01 c	0.91 ± 0.03 d	0.92 ± 0.02 d
4 Hours (T2)	0.81 ± 0.01 b	0.82 ± 0.01 b	0.83 ± 0.02 b	0.84 ± 0.02 b	0.85 ± 0.01 b
5 Hours (T3)	0.76 ± 0.01 a	0.76 ± 0.02 a	0.77 ± 0.01 a	0.77 ± 0.02 a	0.78 ± 0.01 a

Table 1. Water Activity (aw) of Beef Rendang at Different Cooking Durations during Ambient Storage

3.2 Lipid Oxidation (TBARS Accumulation)

Lipid oxidation is a major chemical pathway driving quality decline and off-flavors in fat-rich meat products. TBARS values increased across all three cooking treatments over the course of storage (Table 2). Interestingly, at week 0, the 5-hour batch showed a higher baseline TBARS value (0.38 mg MDA/kg) compared to the 3-hour batch (0.22 mg MDA/kg). This initial increase reflects thermal lipid degradation stimulated by the extended heating phase. However, during the subsequent storage weeks, the oxidation rate reversed dramatically. By week 4, the 3-hour batch showed a sharp increase in TBARS, peaking at 1.15 mg MDA/kg, whereas the 5-hour batch demonstrated strong oxidative stability, limiting its final TBARS value to 0.74 mg MDA/kg. This defensive profile indicates that while extended cooking causes minor initial oxidation, it also builds a robust chemical shield that effectively protects the meat matrix during long-term storage.

Cooking Duration	Week 0	Week 1	Week 2	Week 3	Week 4
3 Hours (T1)	0.22 ± 0.01 a	0.45 ± 0.03 b	0.68 ± 0.04 c	0.92 ± 0.05 d	1.15 ± 0.06 d
4 Hours (T2)	0.31 ± 0.02 b	0.48 ± 0.02 b	0.59 ± 0.03 b	0.74 ± 0.03 b	0.88 ± 0.04 c
5 Hours (T3)	0.38 ± 0.02 c	0.42 ± 0.01 a	0.51 ± 0.02 a	0.62 ± 0.04 a	0.74 ± 0.03 a

Table 2. TBARS Values (mg MDA/kg) of Beef Rendang at Different Cooking Durations during Ambient Storage

3.3 Antioxidant Activity (DPPH Radical Scavenging Kinetics)

The impressive oxidative resistance observed in the 5-hour cooking treatment is directly explained by its stable antioxidant performance (Table 3). At week 0, the 5-hour cooked rendang exhibited the highest DPPH radical scavenging capacity (74.2%), outperforming both the 4-hour (65.8%) and 3-hour (58.4%)

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batches. This robust antioxidant performance stems from two primary mechanisms: first, the extensive 5-hour thermal processing extracts maximum lipophilic polyphenols and essential oils from the ground spice paste into the fat layer; second, the advanced heat drives the Maillard reaction to its final stages, synthesizing dark melanoidin compounds that provide independent free-radical scavenging activity. Over the 4 weeks of storage, antioxidant activity decreased across all batches due to the continuous consumption of primary antioxidants as they neutralized incoming lipid peroxy radicals. Notably, the 5-hour treatment maintained an active scavenging level of 52.1% at week 4, while the 3-hour batch dropped to 31.4%, leaving it vulnerable to rapid chemical decline.

Cooking Duration	Week 0	Week 1	Week 2	Week 3	Week 4
3 Hours (T1)	58.4 ± 1.1 a	50.2 ± 1.5 a	44.1 ± 1.8 a	36.5 ± 2.1 a	31.4 ± 1.9 a
4 Hours (T2)	65.8 ± 1.4 b	58.4 ± 1.2 b	52.3 ± 1.1 b	45.2 ± 1.6 b	40.8 ± 1.5 b
5 Hours (T3)	74.2 ± 1.2 c	69.5 ± 1.1 c	63.4 ± 1.5 c	57.1 ± 1.3 c	52.1 ± 1.2 c

Table 3. DPPH Radical Scavenging Activity (%) of Beef Rendang at Different Cooking Durations during Ambient Storage

4. CONCLUSION AND SUGGESTIONS

4.1 Conclusion

Cooking duration exerts a decisive effect on the thermodynamic and chemical shelf stability of traditional Minangkabau beef rendang stored at ambient temperature. Extending the cooking time to 5 hours significantly reduces water activity to a stable baseline of 0.76, while maximizing the extraction of spice polyphenols and the synthesis of antioxidant-active Maillard melanoidins. This robust chemical profile provides long-term protection, limiting TBARS accumulation to a safe 0.74 mg MDA/kg and maintaining a high radical scavenging capacity of 52.1% through 4 weeks of storage. In contrast, shorter cooking times (3 hours) leave the product with a higher water activity and lower antioxidant defense, making it vulnerable to rapid lipid oxidation and shelf-life decline. Therefore, a 5-hour cooking duration is highly recommended as the operational standard for producing shelf-stable, high-quality traditional rendang.

4.2 Suggestions

Future studies should evaluate the impact of these cooking durations on specific vitamin retention and individual fatty acid profiles, particularly changes in unsaturated fatty acid fractions. Additionally, exploring the integration of vacuum-sealed barrier packaging with these optimized cooking standards would help establish parameters for broader commercial export distribution.

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