2025, Scienceline Publication
World's Veterinary Journal
World Vet J, 15(4): 1024-1033.
ISSN 2322-4568
DOI: https://dx.doi.org/10.54203/scil.2025.wvj104
PII: S232245682500104-15

Effects of Fresh Celery as a Natural Curing Agent on Physicochemical Characteristics and Sensory Quality of Beef Jerky

Nurafni Mallu[1], Wahniyathi Hatta[2]*, and Fatma Maruddin[2]

[1]*Graduate Student of Animal Science and Technology, Faculty of Animal Science, Hasanuddin University, Makassar, 90245, Indonesia*
[2]*Department of Animal Productions, Faculty of Animal Science, Hasanuddin University, Makassar, 90245, Indonesia*

*Corresponding author's Email: wahnihatta@gmail.com

ORIGINAL ARTICLE
Received: September 20, 2025
Revised: October 23, 2025
Accepted: November 19, 2025
Published: December 31, 2025

ABSTRACT

Beef jerky is a processed meat product. Nitrite or nitrate salts are usually used as curing agents for beef jerky processing. However, excessive nitrite intake can pose health risks and raise public concern, so natural alternatives such as celery can be used. This study evaluated fresh celery as a natural curing agent for beef jerky based on its physicochemical and sensory qualities. The study was conducted in two stages. In the first stage, beef was treated with celery at three levels (2%, 4%, and 6%) and saltpeter as a control, combined with three incubation periods (1, 2, and 3 hours) to identify the optimal treatment for the subsequent stage based on color characteristics and nitrite residue. In the second stage, the selected curing treatments (saltpeter, 4% celery, and 6% celery) were applied to beef jerky and evaluated over different storage periods (0, 2, and 4 weeks). The parameters analyzed included color values, lightness (L*), redness (a*), yellowness (b*), nitrite content, and lipid oxidation, as well as sensory attributes. The results of the first stage showed that the use of saltpeter produced the highest nitrite content (0.54 mg/kg), while the highest b* value was obtained in the treatment of 4% and 6% celery. The incubation length had no significant effect on all parameters, but there was a significant interaction between the type of curing material and the length of incubation on the value of a*. In the second stage, neither curing material treatment nor storage time had a significant impact on organoleptic characteristics, and Thiobarbituric acid reactive substances values were relatively low (< 0.5 mg MDA/kg) up to 4 weeks of storage. A 6% celery treatment yielded the highest L* value, while the highest a* value was indicated by saltpeter, followed by 6% and 4% celery. Overall, the 6% celery treatment showed comparable performance to saltpeter, especially in retaining redness, suppressing lipid oxidation, and maintaining the sensory qualities of ground beef jerky.

Keywords: Beef jerky, Celery leaf, Meat quality, Natural curing, Residual nitrite

INTRODUCTION

Beef jerky is one of the oldest processed meat products that is traditionally processed through a preservation process. The curing process usually uses synthetic nitrites from sodium nitrite or potassium nitrate (commonly called saltpeter), which plays a role in forming a simple, antibacterial, red color and produces the distinctive taste and aroma of preserved meat products (Kim et al., 2014). However, excessive nitrite intake has been reported to negatively affect human health due to the formation of carcinogenic N-nitroso compounds (Ferysiuk and Wójciak, 2020). These health concerns, along with growing consumer demand for clean-labeled meat products, have encouraged researchers to investigate natural alternatives to synthetic nitrites. Several natural ingredients have shown potential as nitrite substitutes in meat products, including celery (Li et al., 2011), parsley (Riel et al., 2017), cranberry (Karwowska et al., 2017), and beet root (Sucu and Turp, 2018).

Celery is one of the alternative natural ingredients to replace synthetic nitrites because of its high nitrate content, especially in the leaves. The nitrate content in celery can be converted to nitrite through controlled incubation (Sebranek, 2007; Saputro, 2017). Celery powder and juice have been reported to improve the redness of processed meat without compromising overall consumer acceptability compared to conventionally cured products (Ramachandraiah and Chin, 2022).

Despite being of natural origin, the use of celery as a curing agent also presents challenges, including the potential formation of nitrosamines, especially in meat products processed at high temperatures, such as beef jerky (Oral et al., 2024). During storage, lipid oxidation in beef jerky can produce Malondialdehyde (MDA), a major secondary oxidation product of polyunsaturated fatty acids. MDA is widely used as an indicator of lipid oxidation in meat because even at low concentrations, it can lead to rancid odor development (Domínguez et al., 2019). The antioxidant properties of celery may help mitigate such oxidative degradation (Hassanen et al., 2015).

To cite this paper: Mallu N, Hatta W, and Maruddin F (2025). Effects of Fresh Celery as a Natural Curing Agent on Physicochemical Characteristics and Sensory Quality of Beef Jerky. *World Vet. J.*, 15(4): 1024-1033. DOI: https://dx.doi.org/10.54203/scil.2025.wvj104

Several previous studies have used celery as a curing ingredient in various processed meat products, such as ham slices, pork patties, pork sausage, and cold-smoked sausage (Horch et al., 2014; Sucu et al., 2018; Eisinaitė et al., 2020). Specific investigations on the use of fresh celery leaves in ground beef jerky remain limited. Beef jerky has unique processing characteristics and oxidative susceptibility during storage, thus requiring further study. Therefore, the present study aimed to evaluate the potential of fresh celery leaves (*Apium graveolens*) as a natural source of nitrite to replace synthetic nitrites in ground beef jerky, and to assess their effects on physicochemical properties (color, nitrite residue, lipid oxidation) and sensory attributes as indicators of animal product quality.

MATERIALS AND METHODS

Ethical approval

This study involved sensory evaluation by human panelists who assessed non-edible attributes of beef jerky samples. No tasting or ingestion was performed. All panelists participated voluntarily after being informed about the procedure. This study did not involve live animals; beef samples were obtained from halal-certified Antang slaughterhouses in Makassar, South Sulawesi, Indonesia. This study has been carried out in accordance with the applicable ethical guidelines at Hasanuddin University, Indonesia.

Time and place of study

This study was conducted from July to September 2024. Nitrite residue testing was carried out at the Health Laboratory Center in Makassar in August 2024, Makassar, Indonesia. Color testing (L,a,b*), Thiobarbituric acid reactive substances (TBARS) value analysis, and organoleptic evaluation were conducted from July to September 2024 at the Meat and Egg Product Processing Laboratory, Faculty of Animal Science, Hasanuddin University, Makassar, Indonesia.

Study design

The study was conducted in two phases**.** Phase 1 focused on optimizing the celery leaf level and incubation time to determine the optimal concentration of celery leaves and the incubation time required to generate sufficient nitrite levels and achieve the desired meat color prior to jerky processing. The study employed a complete randomized design (CRD) in a factorial arrangement consisting of two factors. The first factor, the curing ingredient, consists of four treatment groups, including control (C0) with 0.03% saltpeter and celery leaves at 2% (C1), 4% (C2), and 6% (C3). The second factor was incubation time, consisting of 1, 2, and 3 hours. Each treatment combination was replicated three times, yielding a total of 36 experimental units. The parameters observed at this stage included color (Fadlilah et al., 2022) and nitrite content (SNI, 1992).

Phase 2 focused on evaluating the quality of ground beef jerky during storage. This phase assessed the effects of celery leaf application, under the optimal conditions determined in Phase 1, on the quality and stability of ground beef jerky during storage. A completely randomized design (CRD) in a factorial arrangement with two factors was employed. The first factor was the curing ingredient, consisting of three treatment groups, including Control (C0), 4% celery (C2), and 6% celery (C3), selected based on the result of phase 1. The second factor was storage duration, consisting of 0, 2, and 4 weeks. Each combination was replicated three times, resulting in a total of 27 experimental units. The parameters observed in this phase included color (Fadlilah et al., 2022), lipid oxidation (Apriyantono et al., 1989), and sensory attributes (Sugiarto and Marfuah, 2023).

Celery leaf preparation and incubation

The preparation of celery leaves as a curing agent is carried out based on the method of Saputro et al. (2016a) with several modifications. Fresh celery leaves (Apium graveolens) are obtained from Pasar Daya, Makassar, Indonesia, and are selected based on their ripeness level and uniform quality. Celery leaves are then washed using running water to remove dirt and dust, drained, and then weighed according to the predetermined treatment levels (2%, 4%, and 6%). Weighing was carried out by the ratio of celery weight to beef weight (weight/weight [w/w]). The weighed celery leaves are added with clean water in a ratio of 5:1, then mashed using a blender (Cosmos, Indonesia) until a homogeneous paste is formed.

The celery paste is applied evenly to the surface of the beef according to the treatment. Four treatments were used in this stage, namely control with saltpeter (potassium nitrate; brand Koepoe-Koepoe sourced from the local supermarket) and three celery treatments (2%, 4%, and 6%). All samples were then incubated at room temperature (± 32°C) for 1, 2, or 3 hours, depending on the treatment group. The incubation process aims to activate the natural nitrate reductase enzyme contained in celery, thereby facilitating the conversion of nitrate into nitrite through microbial activity.

Jerky preparation

The production of beef jerky in this study refers to the modified method of Saputro et al. (2016b), with the formulation of ingredients following the study of Suryati et al. (2014) as shown in Table 1. The beef that has been cut to a uniform size is treated with curing ingredients (0%, 4%, and 6%), and each treatment is made three times to produce 9 sample units, then incubated for 2 hours at room temperature (± 32°C). After incubation, the meat is ground using a food processor (Cosmos, India) with spices until a homogeneous dough is obtained. The dough is then shaped into sheets with a thickness of about 2.2 mm and dried using a food dehydrator (Getra, China) at 75 °C for 4 hours on each side.

Table 1. Formulation of ground beef jerky

Treatment / Ingredient	C0		C1		C2		C3	
	(%)	Weight (g)	(%)	Weight (g)	(%)	Weight (g)	(%)	Weight (g)
Beef		1000		1000		1000		1000
Salt	2.5	25	2.5	25	2.5	25	2.5	25
Galangal	8.5	85	8.5	85	8.5	85	8.5	85
Coriander	2.0	10	2.0	10	2.0	10	2.0	10
sGarlic	10	50	10	50	10	50	10	50
Palm sugar	16.5	165	16.5	165	16.5	165	16.5	165
White sugar	16.5	165	16.5	165	16.5	165	16.5	165
Tamarind	0.3	3	0.3	3	0.3	3	0.3	3
Pepper	0.3	3	0.3	3	0.3	3	0.3	3
Saltpeter	0.03	0.3	-	-	-	-	-	-
Celery leaves	-	-	2	20	4	40	6	60

C0: 0.03% saltpeter, C1: 2% celery leaves, C2: 4% celery leaves, C3: 6% celery leaves.

Physicochemical analysis

Nitrite content

Nitrite content analysis was conducted at the Central Public Health Laboratory (BBLK), Makassar, in August 2024, following the Indonesian National Standard method for nitrite determination in food products (SNI 01-2894-1992). Samples were extracted using hot water, followed by protein precipitation, after which the nitrite was reacted with sulfanilamide and the reagent N-1-naphthyl ethylenediamine dihydrochloride (NED) to form a pink azo dye, and the absorbance was measured spectrophotometrically to quantify nitrite concentration using a standard calibration curve as specified in the SNI method.

Lipid oxidation

Lipid oxidation in the samples was assessed by measuring malondialdehyde (MDA) levels using the (thiobarbituric acid) TBA assay, as described by Apriyantono et al. (1989). For this analysis, 10 g of homogenized ground beef jerky sample was transferred into a 300 mL Kjeldahl flask, the pH was adjusted, and the mixture was distilled. An aliquot of the distillate was reacted with TBA reagent and heated in a water bath (Memmert, Germany) at 75°C for 35 minutes to form a red chromogen. The absorbance was measured at 528 nm using a spectrophotometer UV-1800 (Shimadzu, Japan) against a blank. The TBA value was expressed as milligrams of malondialdehyde per kilogram of sample (mg MDA/kg).

Color measurement

Color measurements were performed objectively using a color meter (TES 135, Taiwan) based on the International Commission on Illumination (CIE) Lab* color space system (Fadlilah et al., 2022).

Sensory evaluation

Sensory evaluation was conducted using a modified method based on Sugiarto and Marfuah (2023). Fifteen semi-trained panelists participated in three separate sessions to assess the color, aroma, tenderness, texture, and overall acceptability of the jerky samples. All attributes were assessed using a 5 point hedonic scale, in which color ranged from 1 (very brown) to 5 (reddish brown), aroma from 1 (no meat aroma), tenderness from 1 (very fragile) to 5 (very hard), texture from 1 (very smooth) to 5 (very coarse) and overall acceptability from 1 (dislike very much) to 5 (like very much).

Statistical analysis

All data were subjected to one-way analysis of variance (ANOVA) to evaluate the significance of differences among treatment groups. When significant differences were detected ($p < 0.05$), Duncan's multiple range test was conducted for post hoc comparisons of means. Results are presented as mean ± standard deviation (SD). Statistical analyses were performed using SPSS software, version 16.0 (IBM Corp., Armonk, NY, USA).

RESULT AND DISCUSSION

Optimization of celery concentration and incubation time (Phase 1)

Nitrite content

One of the main objectives of this study is to evaluate the ability of fresh celery leaves to produce sufficient nitrite levels for natural preservation. Curing material has a significant effect on the nitrite content in beef, as shown in Table 2 the highest nitrite concentration was observed in the burp treatment (C0) with an average nitrite content of 0.54 mg/kg, while the celery concentration (C1-C3) resulted in a much lower average nitrite content value of 0.11-0.13 mg/kg ($p < 0.05$). However, these levels are still within an acceptable range and are functionally comparable for preservation purposes. According to Indonesian Food and Drug Authority (BPOM, 2019), the limit for nitrite use in beef is 30mg/kg, while according to the Joint Expert Committee of the Food and Agriculture Organization (JEFCA) and the World Health Organization (WHO), the acceptable daily intake is 0.07 mg nitrite per kg of body weight (Shakil et al., 2022). This confirms that celery can be used as an alternative source of natural nitrites. These findings are in line with previous research that showed that celery powder can effectively replace synthetic nitrites without compromising product quality (Meawad Ahmed et al., 2022).

Although incubation time did not significantly affect nitrite concentration ($p > 0.05$), there was a tendency for nitrite levels to increase with longer incubation periods. Incubation for 1 hour yielded nitrite levels of 0.12 mg/kg, then increased to 0.24 mg/kg at 2-hour incubation, and continued to increase to 0.29 mg/kg at 3-hour incubation. This trend may be attributed to the activity of endogenous nitrate reductase enzymes present in celery, which facilitate the conversion of nitrate to nitrite during incubation (Saputro et al., 2016a).

Color attributes

In addition to its role as a preservative, nitrite also plays a crucial role in producing the characteristic and appealing color of cured meat products (Sorour et al., 2023). The measurements of color parameters L* (lightness) and b* (yellowness) in this study are presented in Table 3. The results for a* values (redness) are presented separately in Figure 1, as this parameter exhibited a significant interaction between curing agent treatments and incubation duration ($p < 0.05$).

Table 2. Nitrite content of beef samples (mg/kg) in the present study

Curing agent (%) \ Incubation time (hours)	1	2	3	Mean ± SD
C0	0.16±0.15	0.63±0.74	0.84±0.31	$0.54±0.40^{b}$
C1	0.11±0.05	0.11±0.03	0.10±0.04	$0.11±0.04^{a}$
C2	0.08±0.06	0.08±0.06	0.09±0.06	$0.08±0.06^{a}$
C3	0.12±0.02	0.13±0.01	0.13±0.02	$0.13±0.02^{a}$
Average	0.12±0.07	0.24±0.21	0.29±0.11	

Note: C0: 0.03% saltpeter; C1: 2% celery leaves; C2: 4% celery leaves; C3: 6% celery leaves. [a,b] Different superscript letters in the same column indicate significant differences ($p < 0.05$).

Table 3. L* (lightness) and b* values (yellowness) of beef samples treated with different curing agents and incubation time

Color	Curing agent (%)	Incubation time (hours)			Mean ± SD
		1	2	3	
L	C0	39.64±7.83	40.63±4.12	39.75 ±5.30	40.01±5.75
	C1	39.96±3.44	40.32 ±6.55	39.88±6.64	40.05±5.54
	C2	38.93±6.55	40.43±3.37	38.35±3.26	39.24±4.39
	C3	44.06±5.34	37.91±5.00	41.88±5.94	41.28±5.43
	Average	40.65±5.79	39.82±4.76	39.97± 5.29	
b	C0	4.68±0.07	6.19±0.82	6.34±2.43	$5.73±1.11^{a}$
	C1	7.56±0.53	5.81±0.89	7.60±1.51	$6.99±0.98^{ab}$
	C2	8.01±1.93	8.41±2.26	6.50±1.83	$7.64±2.01^{b}$
	C3	9.37±1.33	8.09±2.71	8.56±1.30	$8.67±1.78^{b}$
	Average	7.405±0.97	7.125±1.67	7.25±1.77	

Note: C0: 0.03% saltpeter; C1: 2% celery leaves; C2: 4% celery leaves; C3: 6% celery leaves. [ab] Different superscript letters in the same column indicate significant differences ($p < 0.05$).

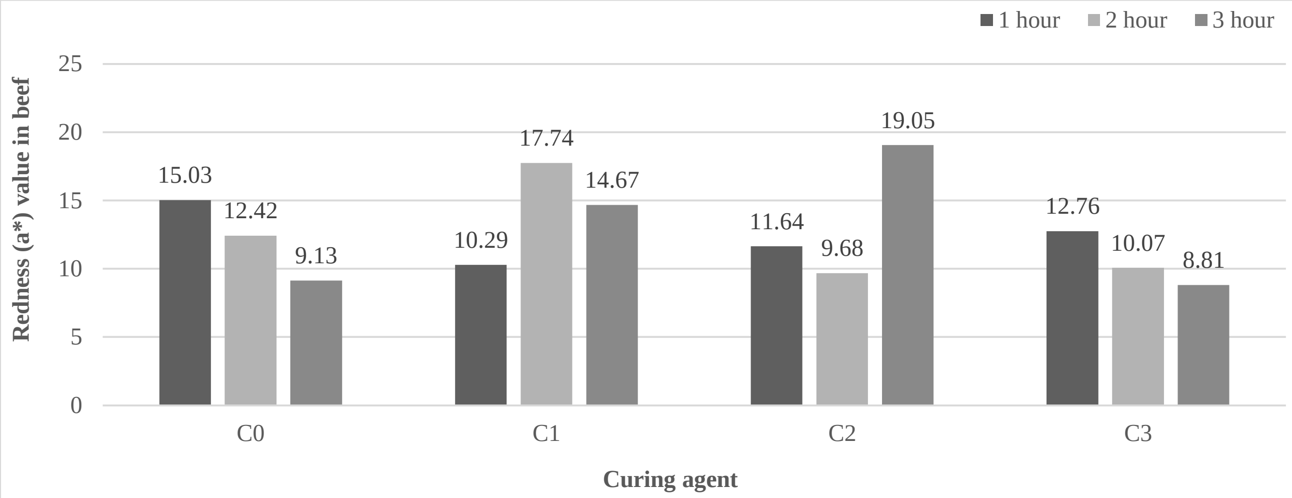

Figure 1. The a* value (redness) of beef as affected by different curing agents (C0: 0.03% saltpeter; C1: 2% celery leaves; C2: 4% celery leaves; C3: 6% celery leaves) and incubation times (1, 2, and 3 hours)

L* value in Beef

The curing agents, incubation time, and their interaction did not significantly affect the brightness value (L*) in beef jerky, as shown in Table 3 ($p > 0.05$). Interestingly, the highest L* value was found in the treatment with 6% celery (C3), which indicates that natural curing using celery can achieve a level of brightness comparable to or even better than conventional curing methods. These findings were in agreement with Policarpio (2024), who reported that celery juice powder acts as an effective natural color stabilizer in meat products.

b* value in Beef

The concentration of celery had a significant effect on b* values ($p < 0.05$), with higher concentrations (4% and 6%) resulting in increased yellowness compared to the saltpeter treatment, as shown in Table 3. This increase may be attributed to the presence of natural pigments and antioxidant compounds in celery, such as flavonoids (Horsch et al., 2014). In contrast, incubation time did not significantly affect b* values ($p > 0.05$). The observed increase in yellowness is likely associated with pigment interactions during the curing process, including the formation of nitrosomyoglobin and the reduction of oxymyoglobin facilitated by nitrite activity (Keszler et al., 2008).

a* value in Beef

A significant interaction between the curing agent and incubation time on the a* value of beef was observed ($p < 0.05$), as presented in Figure 2. The highest a* value was recorded in the treatment with 4% celery and 3 hours of incubation (19.05), followed by 2% celery with 2 hours of incubation (17.74), both of which were significantly higher than all treatments using 0.03% saltpeter ($p < 0.05$). This increase in redness indicated that the nitrate present in celery was successfully converted into nitrite during incubation, which then reacted with myoglobin in the meat to form the characteristic cured meat color. These findings further demonstrate that successful nitrate to nitrite conversion under optimal conditions allows active nitrite to preserve or improve a* value in beef. This finding was consistent with the report of Sindelar and Milkowski (2012), who emphasized nitrite's dual role in both color stabilization and microbial inhibition. The results confirmed that celery, when properly applied, can replicate the color development effects of synthetic nitrite. Based on the best results of Phase 1 of the present study, treatment C2 (4% celery) and C3 (6% celery), demonstrated strong potential as natural curing agents. Both treatments produce redness (value a*) comparable to or higher than C0 (synthetic nitrites), while resulting in substantially lower nitrite residues. The selection of the 2-hour incubation period was supported by the study results, as the a* value obtained at 2 hours did not differ significantly from that at 3 hours, whereas the L* value (lightness) was higher at 2 hours. The higher L* value contributes positively to the visual appearance of jerky products, while also offering improved time efficiency.

C0 C2 C3

Figure 2. Color evaluation of ground beef jerky treated with different curing agents during 4 weeks of storage. **C0**: 0.03% saltpeter (synthetic nitrite); **C2**: 4% celery leaves; **C3**: 6% celery.

Storage stability – Lipid oxidation (TBA values, Phase 2)

Lipid oxidation

As shown in Table 4, the thiobarbituric acid reactive substances (TBARS) analysis revealed no significant differences in lipid oxidation levels between curing agents or across storage durations ($p > 0.05$). All TBARS values remained low (< 0.5 mg MDA/kg), indicating that lipid oxidation was effectively controlled throughout the 4-week storage period. The presence of nitrite from both saltpeter and celery likely contributed to this oxidative stability, as nitrite is known to function as an antioxidant. According to Jo et al. (2020), nitrite could neutralize reactive oxygen species such as hydroxyl radicals, thereby delaying lipid oxidation.

In this study, the antioxidant compounds present in celery also contributed to inhibiting lipid oxidation during storage. Wulandari et al. (2015) reported that celery contains flavonoids, saponins, and essential oils, all of which contribute to the preservation of meat quality during storage. This is in line with the findings of Kisworo et al. (2020), who stated that celery leaf powder can be used as a source of antioxidants that can prevent and inhibit fat breakdown in sausages. These findings are consistent with the previous study of Bolognesi et al. (2015), who noted that significant lipid oxidation in commercial jerky products typically occurs after 120 days of storage, substantially longer than the duration of this study.

Table 4. Thiobarbituric acid reactive substances values in ground beef jerky

Curing agent (%) \ Storage period (week)	1	2	3	Mean ± SD
C0	0.29±0.08	0.38±0.39	0.26±0.41	0.31±0.29
C2	0.23±0.13	0.39±0.23	0.33±0.35	0.32±0.23
C3	0.32±0.14	0.33±0.25	0.44±0.67	0.36±0.37
Average	0.28±0.11	0.37±0.26	0.34±0.44	

Note: C0: 0.03% saltpeter; C2: 4% celery leaves; C3: 6% celery leaves

Color stability during storage

Color is a key quality attribute in processed meat products, as it directly influences consumer perception and marketability (Sorour et al., 2023). In cured meats, long-term color stability is primarily affected by pigment development and oxidative processes. The results of the effects of celery leaf and storage duration on the lightness (L*), redness (a*), and yellowness (b*) of ground beef jerky, presented in Figure 2.

Color values in beef jerky

Lightness in beef jerky

The lightness (L*) is one of the main visual attributes in processed meat products (do Santos et al., 2019). As presented in Table 5, the storage time had no significant effect on the L* value ($p > 0.05$) in beef jerky, while the type of curing material had a significant effect on the brightness level ($p < 0.05$) of jerky. The C3 treatment produced the highest L* value, while the C0 and C2 treatments produced lower L* did not differ significantly between the two. This indicates that C3 can increase the brightness level in beef jerky compared to other treatments.

Overall, L* values ranged from 30.22 to 34.40, reflecting relatively dark surface tones. This darkness may be attributed to Maillard browning reactions during the drying process (Hosry et al., 2025). According to Han et al. (2024), the interaction between reducing sugars and amino acids at elevated temperatures promotes the formation of melanoidins, contributing to the characteristic brown color of jerky products. These findings are consistent with those reported by Saputro et al. (2016b), who observed no significant changes in L* values in naturally cured meat stored for up to 28 days, which suggests that pigment stability can be maintained using plant-based curing agents such as celery

Redness values in beef jerky

One of the objectives of this study was to evaluate the effect of curing agent concentration, particularly celery, and storage duration on the redness (a*) of beef jerky. As shown in Table 5, curing ingredients, both from synthetic nitrites and celery, had a very significant influence on the value of a* ($p < 0.01$) on beef jerky, while storage time had a significant influence on beef jerky ($p < 0.05$).

The highest redness value was observed in the synthetic nitrite treatment (C0), followed by 6% celery (C3) and 4% celery (C2). While the 6% celery treatment produced results comparable to synthetic nitrite, lower concentrations may have yielded insufficient nitrite for optimal pigment formation and stabilization. Despite slight fluctuations during storage, all treatments consistently maintained the characteristic cured red color of meat for up to 4 weeks. This finding is in agreement with Govari and Pexara (2015), who reported that nitrite compounds are able to stabilize red color by participating in color fixation processes, through interactions with heme proteins and scavenging free radicals, thereby preventing pigment oxidation during storage.

Yellowness values in beef jerky

The results of the analysis showed that variations in curing ingredients and storage duration did not have a significant effect on the b* value of beef jerky (p > 0.05), with values ranging from 8 to 12.46. According to the CIE Lab* color system, the b* parameter represents yellowness. As shown in Table 5, storage for up to 4 weeks did not affect the b* value of beef jerky. These findings are consistent with the study of Salim et al. (2019), who reported that the b* values were not influenced by storage time or muscle type.

Sensory attribute

Organoleptic test results are presented in Table 6. Based on the analysis of variance, the type of curing agent, either synthetic nitrite (saltpeter) or natural (celery leaf), had no significant effect on any of the sensory parameters during the storage period (p > 0.05). These findings indicated that the use of celery leaves as a natural source of nitrite did not negatively impact the sensory quality of ground beef jerky. Furthermore, its performance in terms of consumer perception, specifically color, meat aroma, chewiness, texture, and overall acceptability, was comparable to that of synthetic nitrite. These results aligned with the findings of Pennisi et al. (2020), who reported that vegetable-derived nitrates, whether in powder or juice form, exhibit high potential as natural alternatives to synthetic nitrates and nitrites in processed meat products, providing a high nitrite source without leaving residues. In particular, celery powder provides a pleasant, mild aroma without negatively affecting the product's appearance.

Table 5. Color values (L, a, b*) of beef jerky

Color	Curing Agent (%)	Storage Period (week)			Mean ± SD
		0	2	4	
L	C0	31,07±1,54	31,55±1,11	31,49±0,07	31,37±0,98^{a}
	C2	30,22±0,93	32,91±1,55	32,68±0,50	31,94±1,60^{a}
	C3	33,90±3,50	33,89±3,50	34,40±2,19	34,06±2,49^{b}
	Average	31,73±2,58	32,78±1,96	32,86±1,69	
a	C0	12,44±0,40	12,90±0,23	11,81±0,57	12,38±0,60^{c}
	C2	8,84±0,38	10,86±1,13	9,46±0,64	9,72±1,12^{a}
	C3	10,49±1,06	11,39±1,04	11,75±0,93	11,21±1,04^{b}
	Average	10,59±1,67^{a}	11,71±1,20^{b}	11,01±1,32^{ab}	
b	C0	9,72±4,38	9,96±2,57	10,83±1,16	10,17±2,66
	C2	8,00±0,79	10,80±1,42	10,76±0,25	9,85±1,61
	C3	12,46±3,83	11,57±2,75	12,65±2,13	12,23±2,63
	Average	10,06±3,52	10,78±2,13	11,41±1,53	

Note: Color parameters (L*, a*, b*) of beef jerky treated with different curing agents (C0: 0.03% saltpeter; C2: 4% celery leaves; C3: 6% celery leaves) during storage. $^{a,\,b}$ Different superscript letters in the same column indicate significant differences (p < 0.05), while different superscripts in the same row indicate highly significant differences (p < 0.01), where applicable.

Table 6. Sensory evaluation results of ground beef jerky

Parameter	Curing Agent (%)	Storage Period (week)			Mean ± SD
		0	2	4	
Color	C0	3.44±0.67	2.67±0.22	3.06±0.69	3.06±0.60
	C2	2.31±0.13	2.810.82	2.72±0.17	2.61±0.48
	C3	3.17±0.29	3.11±0.69	2.53±0.13	2.94±0.49
	Average	2.97±0.63	2.86±0.58	2.77±0.43	
Aroma	C0	3.06±0.10	3.08±0.22	3.14±0.55	3.09±0.30
	C2	3.42±0.14	2.92±0.17	3.11±0.34	3.15±0.30
	C3	2.94±0.19	2.83±0.50	2.94±0.39	2.91±0.34
	Average	3.14±0.25	2.94±0.31	3.06±0.39	
Tenderness	C0	3.00±0.29	3.08±0.44	3.06±0.29	3.05±0.30
	C2	3.50±0.17	3.11±0.27	3.17±0.44	3.26±0.33
	C3	2.64±0.17	3.14±0.29	3.08±0.22	2.95±0.31
	Average	3.05±0.42	3.11±0.30	3.10±0.29	
Texture	C0	3.03±0.49	3.39±0.13	3.36±0.17	3.26±0.32
	C2	3.69±0.27	3.22±0.13	3.25±0.08	3.39±0.28
	C3	3.25±0.30	3.00±0.44	3.28±0.32	3.18±0.34
	Average	3.22±0.43	3.20±0.29	3.30±0.19	
Overall acceptability	C0	3.11±0.19	3.14±0.55	3.11±0.55	3.12±0.40
	C2	2.81±0.13	3.11±0.34	3.14±0.32	3.02±0.29
	C3	3.19±0.38	2.94±0.39	3.17±0.30	3.10±0.33
	Average	3.04±0.28	3.06±0.39	3.14±0.35	

CONCLUSION

Treatment with 4% and 6% celery combined with 2 hours of incubation successfully produced safe nitrite levels, maintained the color of the preserved meat, and maintained oxidative stability during 4 weeks of storage. Among such treatments, 6% celery showed comparable performance to saltpeter, especially in retaining redness, minimizing lipid oxidation, and not negatively impacting the sensory qualities of ground beef jerky. These findings confirmed the potential of fresh celery leaves as a natural preservative agent in processed meat products and reduce reliance on synthetic additives. This study has not evaluated the taste aspects of beef jerky, so further study is needed to optimize the potential of fresh celery as a natural curing ingredient. In addition, further study is also needed to validate its effectiveness in terms of food safety to ensure its feasibility for application in commercial meat processing

DECLARATIONS

Acknowledgments

The authors would like to thank the panelists who were willing to spend time on this research, as well as the Meat and Egg Laboratory, the Faculty of Animal Husbandry, Hasanuddin University, Indonesia.

Funding

The present study did not receive any financial support.

Ethical considerations

This article was originally written by the author and is not being considered or published elsewhere. The authors have checked the text of the article and confirmed that this article was written based on the results of their original research. The authors declare that no AI was used for conducting current study.

Authors' contributions

Nurafni Mallu performed formal analysis, investigation, writing, and data curation. Wahniyathi Hatta contributed to conceptualization, methodology, resources, supervision, validation, and review. Fatma Maruddin contributed to methodology, resources, supervision, validation, and review. All authors approved the edition of the article before submission to the journal.

Competing interests

The authors have stated that they have no conflicts of interest

Availability of data and materials

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

Apriyantono A, Fardiaz D, Puspitasari NL, Sudarnawati, and Budjijanto S (1989). Petunjuk laboratorium analisis pangan [Laboratory manual for food analysis]. IPB Press., Bogor. Available at: https://books.google.co.id/books/about/Analisis_pangan.html?id=TY4unQAACAAJ

Bolognesi JV, Roberto do Rego Monteiro de Carvalho P, Maria Ferreira de Castro Ville G, Lúcia Masson M, Mara Woranovicz Barreira S, and Eduardo Rocha Garcia C (2015). Nitrite, oxidation, and color during shelf life of jerked beef. African Journal of Pharmacy and Pharmacology, 9(34): 856-860. DOI: https://www.doi.org/10.5897/AJPP2015

Domínguez R, Pateiro M, Gagaoua M, Barba FJ, Zhang W, and Lorenzo JM (2019). A comprehensive review on lipid oxidation in meat and meat products. Antioxidants, 8(10): 429. DOI: https://www.doi.org/10.3390/antiox8100429

do Santos TC, Gates RS, de Fatima Souza C, Tinôco ID, Cândido MGL, da Silva Ramos Freitas LC (2019). Meat quality parameters and the effects of stress: A review. Journal of Agricultural Science and Technology, 9(5): 305-315. DOI: https://www.doi.org/10.17265/2161-6264/2019.05.001

Eisinaitė V, Tamkutė L, Vinauskienė R, and Leskauskaitė D (2020). Freeze-dried celery as an indirect nitrate source in cold-smoked sausages: Effect on safety and color formation. LWT-Food Science and Technology, 129: 1-9. DOI: https://www.doi.org/10.1016/j.lwt.2020.109586

Fadlilah A, Rosyidi D, and Susilo A (2022). Karakteristik warna L* a* b* dan tekstur dendeng daging kelinci yang difermentasi dengan Lactobacillus plantarum [Characteristics of L* a* b* color and texture of rabbit meat jerky fermented with *Lactobacillus plantarum*]. Wahana Peternakan, 6(1): 30-37. DOI: https://www.doi.org/10.37090/jwputb.v6i1.533

Ferysiuk K and Wójciak KM (2020). Reduction of nitrite in meat products through the application of various plant-based ingredients. Antioxidants, 9(8): 711. DOI: https://www.doi.org/10.3390/antiox9080711

Govari M and Pexara A (2015). Nitrates and nitrites in meat products. Journal of the Hellenic Veterinary Medical Society, 66(3): 127-140. DOI: https://www.doi.10.12681/jhvms.15856

Han J, Wang Y, Wang Y, Hao S, Zhang K, Tian J, and Jin Y (2024). Effect of changes in the structure of myoglobin on the color of meat products. Food Materials Research, 4: 1-9. DOI: https://www.doi.org/10.48130/fmr-0024-0003

Hassanen NH, Eissa FAM, Hafez MEBA, and Mosa MEA (2015). Antioxidant and antimicrobial activity of celery (*Apium graveolens*) and coriander (*Coriandrum sativum*) herb and seed essential oils. International Journal of Current Microbiology and Applied Sciences, 4(3): 284-296. Available at: https://www.ijcmas.com

Horsch A, Sebranek JG, Dickson JS, Niebuhr SE, Larson EM, Lavieri NA, Ruther BL, and Wilson LA (2014). The effect of pH and nitrite concentration on the antimicrobial impact of celery juice concentrate compared with conventional sodium nitrite on *Listeria monocytogenes*. Meat Science, 96: 400-407. DOI: https://www.doi.org/10.1016/j.meatsci.2013.07.036

Hosry EL, Elias V, Chamoun V, Halawi M, Cayot P, Nehme A, and Bou-Maroun E (2025). Maillard reaction: Mechanism, influencing parameters, advantages, disadvantages, and food industrial applications: A review. Foods, 14(11): 1-43. DOI: https://www.doi.org/10.3390/foods14111881

Indonesian food and drug authority (BPOM) (2019). Peraturan kepala badan pengwas obat dan makanan Indonesia nomor 36 tentang batas maksimum penggunaan bahan tambahan pangan pengawet [Regulation of the head of the Indonesian food and drug supervisory agency number 36 concerning the maximum limit for the use of preservative food additives]. Available at: https://jdih.pom.go.id

Jo K, Lee S, Yong HI, Choi YS, and Jung S (2020). Nitrite sources for cured meat products. Food Science and Technology, 129: 109583. DOI: https://www.doi.org/10.1016/j.lwt.2020.109583

Karwowska M and Dolatowski ZJ (2017). Effect of acid whey and freeze-dried cranberries on lipid oxidation and fatty acid composition of nitrite-/nitrate-free fermented sausage made from deer meat. Asian-Australian Journal of Animal Science, 30(1): 85-93. DOI: https://www.doi.org/10.5713/ajas.16.0023

Keszler A, Piknova B, Schechter AN, and Hogg N (2008). The reaction between nitrite and oxyhemoglobin: A mechanistic study. Journal of Biological Chemistry, 283(15): 9615-9622. DOI: https://www.doi.org/10.1074/jbc.M705630200

Kisworo D, Yasin M, Wulandani B, Chotimah CM, and Fudholi A. (2020). Beef sousage traits enhanced with celery leaf powder (*Apium graveolens* L.). Journal of Critical Reviews, 7(19): 4488-4497. DOI: https://www.doi:10.31838/jcr.07.19.526

Li N, Mandrean L, and Tita O (2011). Celery as a natural alternative to chemical nitrite added to meat products. Bulletin UASVM Agriculture, 68(2): 317-320. Available at: https://www.cabidigitallibrary.org/doi/full/10.5555/20123003869

Meawad Ahmed A, Alkazzaz ASRM, Abdelrahman HA, Ahmed AM, Helal IM, and Ahmed NI (2022). Effect of replacing sodium nitrite with celery on sensory and chemical quality of popular dry sausage. Journal of Advanced Veterinary Research, 12(4): 404-408. Available at: https://www.advetresearch.com/index.php/AVR/article/view/1026/567

Oral ZFY, Kaya M, and Kaban G (2024). Using celery powder in a semi-dry fermented sausage 'heat-treated sucuk': Nitrosamine formation, lipid oxidation, and volatile compounds. Foods, 13(20): 3306. DOI: https://www.doi.org/10.3390/foods13203306

Pennisi L, Verrocchi E, Paludi D, and Vergara A (2020). Effects of vegetable powders as nitrite alternative in Italian dry fermented sausage. Italian Journal of Food Safety, 9(2): 132-136. DOI: https://www.doi.org/10.4081/ijfs.2020.8422

Policarpio JKJ (2024). Evaluation of celery juice powder as a natural curing agent for tocino. American Journal of Food Science and Technology, 3(2): 30-35. DOI: https://www.doi.org/10.54536/ajfst.v3i2.3087

Ramachandraiah K and Chin KB (2021). Antioxidant, antimicrobial, and curing potentials of micronized celery powders added to pork sausages. Food Science of Animal Resources, 41(1): 110-121. DOI: https://www.doi.org/10.5851/KOSFA.2020.E86

Riel G, Boulaaba A, Popp J, and Klein G (2017). Effects of parsley extract powder as an alternative for the direct addition of sodium Nitrite in the production of mortadella-type sausages–impact on microbiological, physicochemical and sensory aspects. Meat Science, 131: 166-175. DOI: https://www.doi.org/10.1016/j.meatsci.2017.05.007

Salim APAA, Suman SP, Canto ACVCS, Costa-Lima BRC, Viana FM, Monteiro MLG, Silva TJP, and Conte-Junior CA (2019). Muscle-specific color stability in fresh beef from grain-finished Bos indicus cattle. Asian-Australian Journal of Animal Sciences, 32(7): 1036-1043. DOI: https://www.doi.org/10.5713/ajas.18.0531

Saputro VP, Bintoro, and Pramono YB (2016a). Agen kyuring alami pengganti natrium nitrit sintesis pada kyuring daging sapi [Natural curing agent to replace synthetic sodium nitrite in meat curing]. Jurnal Ilmu Pertanian, 12(1): 65-75. Available at: https://download.garuda.kemdikbud.go.id/article.php?article=2936913&val=25919&title=AGEN%20KYURING%20ALAMI%20PENGGANTI%20NATRIUM%20NITRIT%20SINTETIS%20PADA%20KYURING%20DAGING%20SAPI

Saputro VP, Bintoro, and Pramono YB (2016b). Color, pigment, and residual nitrite of dendeng sapi naturally cured at various levels of celery leaves and incubation temperatures. Journal of the Indonesian Tropical Animal Agriculture, 41(2): 99-105. DOI: https://www.doi.org/10.14710/jitaa.41.2.99-105

Saputro E (2017). Pemanfaatan kyuring alami pada produk daging sapi [The use of natural curing on beef products]. Wartazoa, 26(4): 183-190. DOI: https://www.doi.org/10.14334/wartazoa.v26i4.1399

Sebranek JG and Bacus JN (2007). Cured meat products without direct addition of nitrate or nitrite: What are the issues?. Meat Science, 77(1): 136-147. DOI: https://www.doi.org/10.1016/j.meatsci.2007.03.025

Shakil M H, Trisha AT, Rahman M, Talukdar S, Kobun R, Huda N, and Zzaman W (2022). Nitrites in cured meats, health risk issues, alternatives to nitrites: A review. Foods, 11(21): 3355. DOI: https://www.doi.org/10.3390/foods11213355

Sindelar JJ and Milkowski AL (2012). Human safety controversies surrounding nitrate and nitrite in the diet. Nitric Oxide - Biology and Chemistry, 26(4): 259-266. DOI: https://www.doi.org/10.1016/j.niox.2012.03.011

Standar nasional Indonesia (SNI) (1992). Standar nasional Indonesia dengan nomor series 01-2894-1992 tentang cara uji bahan pengawet makanan dan bahan tambahan yang dilarang untuk makanan [Indonesian national standard with series number 01-2894-1992 regarding testing methods for food preservatives and prohibited food additives]. Dewan Standarisasi Nasional. Available at: https://pesta.bsn.go.id

Sorour MA, Mehanni AHE, Mahmoud ESA, and El-Hawashy RM (2023). Nitrate, nitrite, and N-nitrosamine in meat products. Journal of Sohag Agriscience, 8(1): 121-135. Available at: https://jsasj.journals.ekb.eg

Sucu C and Turp GY (2018). The investigation of the use of beetroot powder in Turkish fermented beef sausage (sucuk) as nitrite alternative. Meat Science, 140: 158-166. DOI: https://www.doi.org/10.1016/j.meatsci.2018.03.012

Sugiarto and Marfuah N (2023). Kualitas kimia dan organoleptik dendeng sapi dengan kemasan ukuran rongga udara yang berbeda [Chemical and organoleptic quality of beef jerky with different air cavity size packaging]. Prosiding Seminar Nasional Pembangunan dan Pendidikan Vokasi Pertanian, 4(1): 350-362. DOI: https://www.doi.org/10.47687/snppvp.v4i1.658

Suryati T, Astawan M, Lioe HN, Wresdiyati T, and Usmiati S (2014). Nitrite residue and malonaldehyde reduction in dendeng Indonesian dried meat influenced by spices, curing methods, and precooking preparation. Meat Science, 96(3): 1403-1408. DOI: https://www.doi.org/10.1016/j.meatsci.2013.11.023

Wulandari P, Herdini, and Yumita A (2015). Uji aktivitas antioksidan DPPH dan aktivitas terhadap Artemia salina Leach ekstrak etanol 96% daun seledri (*Apium graveolens L*) [DPPH antioxidant activity and activity against Artemia salina Leach using 96% ethanol extract of celery leaves (*Apium graveolens L*). Sainstech Farma, 8(2): 6-13. Available at: https://journal.istn.ac.id/index.php/saintechfarma/article/view/381