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Influence of *Capsicum chinense* concentration and salt varieties on the quality attributes of Kilishi, a sundried beef jerky

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ABSTRACT

The impact of *Capsicum chinense* concentration and salt varieties on cholesterol oxides, physicochemical properties, microbial profiles and organoleptic attributes of Kilishi, a sundried beef jerky, was assessed. **Kilishi (KL) was prepared from sundried strips of *Biceps femoris* and marinated with either 2 % Sodium chloride (NaCl) + 7 % fresh *Capsicum chinense* (CC) (KL−1), 1 % NaCl + 1 % Potassium chloride (KCl) + 7 % CC (KL−2), 1 % NaCl + 1 % Potassium citrate ($C_6H_5K_3O_7$) + 7 % CC (KL−3), 1 % NaCl + 14 % CC (KL-4), 1 % KCl + 14 % CC (KL-5) or 1 % $C_6H_5K_3O_7$ + 14 % CC (KL-6), and stored at 29 ± 1 °C for 90 d. The partial or total replacement of NaCl lowered ($P < 0.05$) the Na content in KL. The KL samples treated with 14 % CC had lower ($P < 0.05$) 25-hydroxy cholesterol, cholesta-3,5-dien-7-one, carbonyl, pH, malondialdehyde, and lightness and greater ($P < 0.05$) redness and *Lactobacillus* counts than those treated with 7 % CC. The chemical composition, sensory scores and water activity were unaffected by the additives. The taste, flavor, and overall acceptance scores of KL decreased ($P < 0.05$) after 30 days of storage. The substitution of KCl and $C_6H_5K_3O_7$ for NaCl and the increase in CC concentration from 7 to 14 % lowered the Na content and selected cholesterol oxides, respectively, without impairing the organoleptic traits of Kilishi.**

1. Introduction

Beef jerky is a dried meat snack typically made from lean cuts of beef marinated in a mixture of salt, spices, and seasonings before being dried (He et al., 2023; Shi, Kong, Wang, Liu, & Xia, 2020). The resulting chewy and flavorful snack is popular because of its long shelf life and high protein content, and it is often used as a convenient and portable snack (Aykın Dinçer, 2023; He et al., 2023; Shi et al., 2020). Beef jerky can be found in different flavors and styles (Aykın Dinçer, 2023; Hu et al., 2023; Ojha et al., 2018; Sulaimon & Adeyemi, 2024). Kilishi, a sundried jerky, is a popular traditional meat snack in the Sahelian region of West Africa, particularly in northern Nigeria and southern Niger (Adeyeye, Adesina, Olaleye, Olagboye, & Olatunya, 2020; Iheagwara, Okonkwo, Ofoedu, Shorstkii, & Okpala, 2021; Iyiola & Aladi, 2023). Kilishi is made from thinly sliced beef, mutton or chevon, which is sundried, marinated, seasoned, and grilled (Aworh, 2024; Iheagwara et al., 2021; Sulaimon & Adeyemi, 2024). However, because of the salt and spice mixtures employed in its production, kilishi can frequently be high in sodium content (Adeyeye et al., 2020; Sulaimon & Adeyemi, 2024). The sodium content in Kilishi should therefore be lowered to better satisfy consumers' need for healthier options.

Sodium chloride is an indispensable ingredient in meat processing because it enhances flavor and protein functionality and acts as a preservative (Desmond & Vasilopoulos, 2019; Elias, Laranjo, Agulheiro-Santos, & Potes, 2020). In most countries, salt intake has increased considerably beyond the recommended 5 g/day (Bhattacharya et al., 2022; World Health Organization, 2023). This scenario has increased harmful health impacts, and chronic health disorders have become a main concern (World Health Organization, 2023). Therefore, reducing salt intake has emerged as a major global health priority, highlighting

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the need for more low-sodium alternatives (Kurtz, Pravenec, & DiCarlo, 2022; World Health Organization, 2023). One strategy for reducing sodium content is to partially or completely replace NaCl with other chloride salts (Li et al., 2023; Ojangba et al., 2022; Sulaimon & Adeyemi, 2024; Yalınkılıç, Kaban, & Kaya, 2023) and non-chloride salts (Sulaimon & Adeyemi, 2024; Zhou, Wang, Chen, & Yuan, 2021). Nevertheless, a number of concerns are raised by this method, such as the potential loss of salty flavor, peculiar color and texture, and microbiological stability (Inguglia, Zhang, Tiwari, Kerry, & Burgess, 2017; Nurmilah, Cahyana, Utama, & Aït-Kaddour, 2022). The potential of KCl as a substitute for NaCl in beef jerky (Li et al., 2023; Sulaimon & Adeyemi, 2024) has been investigated. Potassium citrate is a versatile food additive that can be used to improve the taste, safety, and shelf life of a wide variety of food products (Sulaimon & Adeyemi, 2024; Zhou et al., 2021). However, not much research has been done on potassium citrate and potassium chloride as prospective NaCl substitutes in Kilishi.

Utilizing ingredients that enhance the perception of saltiness without simultaneously increasing the Na concentration is another method for lowering the amount of sodium in foods (Inguglia et al., 2017; Moss et al., 2023; Nurmilah et al., 2022). Piperine and capsaicin can enhance saltiness perception in foods by enhancing the sensitivity of taste buds to sodium ions or by stimulating specific salt-detecting taste receptors in the mouth (Moss, Fisher, et al., 2023; Narukawa, Sasaki, & Watanabe, 2011). Globally, *Capsicum chinense* (CC) is one of the most widely grown and consumed peppers (Castro-Concha, Tuyub-Che, Moo-Mukul, Vazquez-Flota, & Miranda-Ham, 2014; Chel-Guerrero et al., 2022). Its fruits are valued for their color, flavor, and aroma and are utilized as food ingredients in both conventional and industrial cooking (Campos, Gómez, Ordo, & Ancona, 2013; Chel-Guerrero et al., 2022). CC is rich in capsaicin and piperine (Buitimea-Cantúa et al., 2022; Olguín-Rojas et al., 2019; Palma-Orozco, Orozco-Álvarez, Chávez-Villeda, Mixtega-Martínez, & Castro-Muñoz, 2021). Thus, increasing the concentration of CC in marinade mixtures may enhance the perception of saltiness in low-salt beef jerky.

Meat products are rich in cholesterol, an unsaturated sterol that is easily oxidized to form cholesterol oxidation products (COPs) during processing and storage (Canzoneri et al., 2022; Liu et al., 2022). Concerns about the possible health implications of dietary COPs are becoming more prevalent owing to the increase in the use of food high in COPs (Liu et al., 2022). Dietary COPs have the potential to adversely impact human health by causing a number of inflammatory illnesses, such as atherosclerosis, inflammatory bowel disease, and neurological disorders (Deng et al., 2023; Liu et al., 2022). The food matrices, storage duration, and heating temperature all have significant impacts on the formation of COPs (Canzoneri et al., 2022; Khan et al., 2015; Liu et al., 2022). One of the most effective ways to prevent COP formation is to modify the conditions under which food is processed and stored (Liu et al., 2022). This can involve adding antioxidants, processing or storing food for a shorter period of time, and maintaining relatively low temperatures (Khan et al., 2015; Liu et al., 2022). CC is rich in bioactive components, including flavonoids, capsaicinoids, and carotenoids, that have antioxidant potential (Castro-Concha et al., 2014; Chel-Guerrero et al., 2022). Thus, the addition of CC may lower the formation of COP in Kilishi formulated with different salts. The objective of this study was to examine the influence of CC concentration and salt varieties on the cholesterol oxides, physicochemical properties, microbial profile and sensory attributes of Kilishi, a sundried beef jerky.

2. Materials and methods

2.1. Preparation of meat, marinade, and beef jerky

At 24 h postmortem, six batches of *Biceps femoris* (BF) muscle (7.5 ± 0.5 kg per batch) from six carcasses of White Fulani bulls were purchased from a local meat shop. Each batch was a replicate and was separately processed into Kilishi. The BF was sliced into 86–93 cm long and 0.10–0.20 cm-thick strips ($n = 18$ per batch). The BF strips were sundried for 8 h at a temperature of 37.3 ± 2.2 °C and a relative humidity of 23 ± 2.5 %. The sundried BF strips were randomly marinated in one of six infusion mixtures (treatments) for 2 h. The treatments are as follows: KL-1 (2 % NaCl +7 % CC), KL-2 (1 % NaCl +1 % KCl + 7 % CC), KL-3 (1 % NaCl +1 % $C_6H_5K_3O_7$ + 7 % CC), KL-4 (1 % NaCl +14 % CC), KL-5 (1 % KCl + 14 % CC), and KL-6 (1 % $C_6H_5K_3O_7$ + 14 % CC). (Table 1). The ratio of the marinade to raw BF strips was 1:1. After the first drying, the ratio of the marinade to sundried BF strips was 4:1. For every 1 g of sundried BF strip, about 3.5 g of marinade was absorbed. The marinated BF strips were sundried for 6 h as previously described. Thereafter, the dried marinated BF strips were roasted over fire for 3–4 min to heat-seal the product. Kilishi samples were cooled, packaged in Ziplock bags, and kept at 29 ± 1 °C for 90 d. Sodium and COPs were assessed on freshly prepared Kilishi samples. Monthly assessments were conducted for a total of 90 d for water activity, oxidative stability, chemical composition, microbial profiles, and sensory evaluations. For each treatment, six replicates (batches) were employed, each containing three samples for each storage period.

2.2. Determination of Na content

The Na content in Kilishi was quantified in accordance to the procedure of AOAC (1990) using flame atomic absorption spectrophotometry. The chemical composition of Kilishi was determined according to the AOAC (1990) procedures.

2.3. Measurement of pH, water activity, and color

The pH of Kilishi was measured with a pre-calibrated compact digital pH meter (MW102 pH meter, MILWAUKEE® instruments, Inc. NC, USA). Kilishi sample (2 g) was homogenized with 10 mL of distilled water, and the homogenate's pH was read three times.

Water activity was measured with a water activity meter (BT-RS1, Rotronic, Switzerland) that was calibrated at 25 °C using distilled water (aw = 0.999).

The color coordinates of Kilishi were measured with a pre-calibrated colorimeter (WR-10, Shenzhen, China) with an 8 mm port size, a 10° standard observer and a D_{65} illuminant according to the International Commission on Illumination's (CIE) L^* a^* b^* grouping method. The samples were bloomed for 25 min. Four spectral readings were taken on various sections of each sample, and the results were averaged.

Table 1
Proportion of ingredients in the marinade mixture of Kilishi.

	Treatment[1]					
Ingredients (%)	KL-1	KL-2	KL-3	KL-4	KL-5	KL-6
Peanut cake	46.00	46.00	46.00	46.00	46.00	46.00
Fresh *Capsicum chinense*	7.00	7.00	7.00	14.00	14.00	14.00
Fresh Onion	4.00	4.00	4.00	4.00	4.00	4.00
Garlic	3.00	3.00	3.00	3.00	3.00	3.00
Ginger	3.00	3.00	3.00	3.00	3.00	3.00
Fresh *Capsicum annuum*	2.70	2.70	2.70	2.70	2.70	2.70
NaCl	2.00	1.00	1.00	1.00	0.00	0.00
KCl	0.00	1.10	0.00	0.00	1.00	0.00
$C_6H_5K_3O_7$	0.00	0.00	1.00	0.00	0.00	1.00
Seasoning	1.00	1.00	1.00	1.00	1.00	1.00
Nutmeg	0.30	0.30	0.30	0.30	0.30	0.30
Clove	0.30	0.30	0.30	0.30	0.30	0.30
Black pepper (*Piper guineaense*)	0.30	0.30	0.30	0.30	0.30	0.30
Thyme	0.05	0.05	0.05	0.05	0.05	0.05
Water	30.35	30.35	30.35	24.35	24.35	24.35

KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC.

2.4. Determination of protein oxidation and lipid oxidation

The protein carbonyl content was determined as described by Wang, He, Gan, and Li (2018). Lipid oxidation was determined by measuring thiobarbituric acid reactive substances (TBARS) in accordance with the protocol described by Lan, Shang, Song, and Dong (2016).

2.5. Extraction and determination of cholesterol oxides

One gram of KL was added to 2 mL of 50 % KOH solution and 3 mL of ethanol, and the mixture was incubated in the dark at 27 °C for 22 h. Thereafter, 2.5 mL of distilled water and 5 mL of hexane were added to the sample and vortexed, followed by separation of the hexane fraction. Extraction with 5 mL of hexane was repeated three times. The solution was dried in a rotary evaporator. The residue was dissolved in 2.5 mL of hexane, transferred to a screw top flask under N_2, diluted with 0.5 mL of mobile phase and filtered through a 22 μm filter (Millipore, Maryland, MD, USA). Cholesterol oxides were determined by high-performance liquid chromatography (HPLC) (Shimadzu, Kyoto, Japan) with UV (SPD-10 AVVP) and refractive index (RID-10 A) detectors. Separation was achieved in a Nova Pack CN HP column (300 mm × 3.9 mm, × 4 mm, Waters, Milford, MA, USA) at 32 °C. Hexane:2-propanol (97:3, *v*/v) was used as the mobile phase at a flow rate of 1 mL/min. Cholesterol oxides were identified by comparing the retention time and mass spectra of verified standards (Sigma Adrich, St Louis, MO, USA) with those of the peak of the respective cholesterol oxide in the sample.

2.6. Enumeration of the microbial population

Microbes were cultured and counted according to standard protocols (AOAC, 2000). Briefly, 9 mL of phosphate-buffered saline was placed in a test tube along with 1 g of KL. After 1 min of vortexing, the mixture was serially diluted to 10^{-10}. Sterile molten agar was added to a Petri dish containing 1 mL of the mixture. To ensure that the sample and agar were evenly mixed, the plates were gently rotated. Total plate count (TPC) bacteria were cultured for 48 h at 32 °C on plate count agar. *Staphylococcus aureus* was cultured at 37 °C for 48 h on mannitol salt agar. Coliforms were cultured on MacConkey agar at 32 °C for 48 h. *Salmonella* spp. were cultured at 37 °C for 48 h on *Salmonella Shigella* agar. *Lactobacilli* spp. was cultured on DeMan Rogosa Sharpe agar at 37 °C for 48 h. Agars were obtained from Merck KGaA, Darmstadt, Germany.

2.7. Sensory analysis

The sensory qualities of KL were evaluated following the AMSA (1995) methods. Kilishi was assessed using a 9-point hedonic scale (1 = dislike extremely; 2 = dislike very much; 3 = dislike moderately; 4 = dislike slightly; 5 = neither like nor dislike; 6 = like slightly; 7 = like moderately; 8 = like very much; 9 = like extremely). Sensory evaluation was conducted at the sensory laboratory, Faculty of Agriculture, University of Ilorin. The sensory evaluation involved 80 panelists that were recruited verbally. The panelists included both staff and students of University of Ilorin and were familiar with KL. The assessors included 42 males and 38 females with age range of 19 to 53 years. One assessment session was conducted on each storage day. Each panelist evaluated six samples corresponding to the six treatments on each storage day. Over the course of the storage period, the same set of panelists assessed the KL samples. Before the sensory evaluation, the panelists received a briefing on the sensory protocols and characteristics. The panelists were given water and unsalted crackers to cleanse their palates after scoring each sample.

2.8. Statistical analysis

The experimental design was a completely randomized design with six replicates. The Na content and COP data were subjected to the generalized linear model procedure of Statistical Analysis System (SAS, 9.2) (SAS Institute Inc., Cary, NC, USA). The treatments were considered fixed effects, while the batches were considered random effects. Data for chemical composition, pH, water activity, malondialdehyde, color coordinates, carbonyl, microbial profile and sensory scores were analyzed by repeated measures analysis of variance using the PROC MIXED procedure of SAS, in which additive, storage time and interaction between additive and storage time were fitted as fixed effects, while batches and assessors (for sensory scores) were fitted as random effects. The level of significance was set at $P < 0.05$. If the F test proved significant, the least square means were distinguished with the PDIFF option of SAS.

3. Results and discussion

This study explores the combined effects of two strategies—partial replacement of sodium chloride with potassium chloride and potassium citrate, and varying the concentration of *Capsicum chinense*, which is rich in piperine and capsaicin that can enhance saltiness perception—on lowering sodium content and their implications for the oxidative stability, shelf life, and sensory attributes of Kilishi. Sodium chloride and *Capsicum chinense* are essential ingredients for making Kilishi (Alamuoye, Alamuoye, & Adebayo, 2024; Inusa & Muhammad, 2021; Sanusi et al., 2021; Sulaimon & Adeyemi, 2024). Thus, manipulating the concentration of these ingredients may be a viable strategy to reduce sodium content and optimize sensory qualities and storage stability in Kilishi. By studying these interactions, Kilishi processors can fine-tune recipes to enhance product quality, ensuring a balance between safety, sensory attributes, and shelf life.

3.1. Sodium content

The sodium content in Kilishi formulated with different salts and varying concentrations of ***Capsicum chinense*** is presented in Fig. 1. The sodium content ranged from 333 to 1360 mg/100 g. The Kilishi with the highest Na content ($P < 0.05$) was the KL-1, which received a 2 % NaCl treatment. Compared to the other treatments, the KL-5 and KL-6 had a reduced ($P < 0.05$) Na content. The Na content in KL-2, KL-3, and KL-4 that were treated with 1 % NaCl was lower than that of KL-1, and greater than that of KL-5 and KL-6. The varying NaCl levels may be responsible for the variations in the Na content of the KL samples. This finding infers that the strategies utilized in this study were successful in reducing the sodium content of KL. Even though NaCl was absent, the presence of Na in KL-5 and KL-6 indicated that the beef and other ingredients in the marinade mixture may have contributed to the Na content of the beef jerky. Overall, the reduction in Na in KL-2, KL-3, KL-4, KL-5, and KL-6 was 40.6, 40, 40.7, 75.7, and 75.6 %, respectively. Consistent with our findings, the amount of Na in beef jerky decreased when KCl, $MgCl_2$, and $CaCl_2$ were partially substituted for NaCl (Li et al., 2023; Sulaimon & Adeyemi, 2024; Yalınkılıç et al., 2023). Moreover, the partial substitution of NaCl with red pepper paste lowered the Na content in beef jerky (Lim et al., 2014).

3.2. Cholesterol oxides

This study identified seven COPs: cholesta-3,5-dien-7-one, 19-hydroxy cholesterol, 6β-epoxide, 25-hydroxy cholesterol, 20α-hydroxy cholesterol, 7α-hydroxy cholesterol, 7-keto cholesterol, and 20α-hydroxy cholesterol (Table 2). Of these, only 25-hydroxy cholesterol and cholesta-3,5-dien-7-one concentrations were affected by the treatments. Regardless of the salt variety, the KL samples treated with 14 % CC had lower ($P < 0.05$) concentrations of 25-hydroxy cholesterol and cholesta-3,5-dien-7-one than that of the KL samples treated with 7 % CC. This finding may be ascribed to the antioxidant properties of capsaicinoids, carotenoids, capsinoids, and other phytochemicals in *Capsicum chinense* (Haile, Ro, Ko, Oh, & Lee, 2023; Oney-Montalvo, Avilés-Betanzos, Ramírez-Rivera, Ramírez-Sucre, & Rodríguez-Buenfil, 2020). Similar to

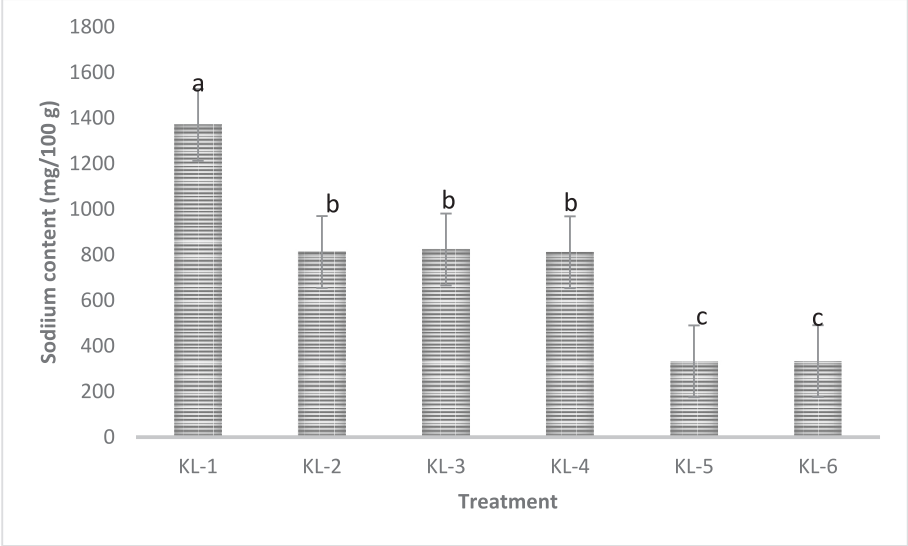


Fig. 1. Sodium content in Kilishi formulated with different salt varieties and *Capsicum chinense* concentration.
[a, b, c] error bars with different superscripts are significantly different ($P < 0.05$). KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC.

Table 2
Cholesterol oxides in Kilishi formulated with different *Capsicum chinense* concentration and salt varieties.

	Cholesterol oxidation products (μg/100 g)						
Treatment[1]	19-hydroxy cholesterol	6β-epoxide	25-hydroxy cholesterol	20α-hydroxy cholesterol	7α-hydroxy cholesterol	7-keto cholesterol	cholesta-3,5-dien-7-one
KL-1	0.01	23.00	392.80[a]	13.40	0.04	4.05	80.02[a]
KL-2	0.01	23.00	390.23[a]	14.24	0.05	3.14	75.24[a]
KL-3	0.01	23.40	389.10[a]	14.16	0.05	4.10	75.14[a]
KL-4	0.01	20.24	295.02[b]	13.45	0.04	4.10	54.21[b]
KL-5	0.01	21.52	301.68[b]	13.34	0.03	4.29	57.97[b]
KL-6	0.01	20.54	300.25[b]	14.23	0.04	4.12	56.25[b]
SEM	0.00	4.12	20.34	2.16	0.00	0.56	4.35
P value	0.34	0.13	0.02	0.23	0.09	0.001	0.001

[a, b, c, d]means with different superscripts in a column are significantly different ($P < 0.05$). [1]KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC. SEM, standard error of mean.

our findings, CC supplementation reduced COP formation in frozen fish balls (Mariano et al., 2022). The addition of pink pepper lowered cholesterol oxide levels in sardines (Barreira et al., 2023). Red and black pepper supplementation reduced COPs in roasted chickens (Hsu & Chen, 2020). Furthermore, the reduction in NaCl concentration in the KL-4, KL-5 and KL-6 samples may have contributed to the lower concentration of 25-hydroxy cholesterol and cholesta-3,5-dien-7-one. The potential mechanisms of the prooxidant action of salt include its ability to decrease cell membrane integrity, allowing oxidizing agents to easily access lipid substrates, release iron ions from molecules containing iron, such as heme proteins or suppress the activity of antioxidant enzymes (Mancini et al., 2020; Qu et al., 2020; Wu, Park, & Richards, 2022).

3.3. Chemical composition and water activity

Assessing the proximate composition of food is crucial for maintaining its quality, safety, and nutritional value. It also promotes transparent and accurate labeling practices. The chemical composition of KL in this study (Table 3) was comparable to those of previous works (Alamuoye et al., 2024; Iyiola & Aladi, 2023; Sulaimon & Adeyemi, 2024). The salt variety and CC concentration had no effect on the moisture, fat, protein or ash content of KL (Table 3). Throughout the 90-day storage period, the chemical components of the KL remained constant. Conversely, Kilishi that was stored for 70 days showed a decrease in moisture (Sulaimon & Adeyemi, 2024). In addition, over a 35-day storage period, the crude fat and ash contents decreased, while the moisture and protein levels of Kilishi increased (Alamuoye et al., 2024. These discrepancies can point to differences in the compositions of the ingredients and storage conditions of Kilishi.

Due to its potential impact on the quality, safety, and stability of end products, water activity is a crucial factor in food processing and storage (Fontana Jr & Carter, 2020). Neither the additives nor the storage period affected the water activity of KL (Table 3). This finding was anticipated since the moisture content of KL was not affected. In line with our results, Lim, Jung, Kim, Joo, and Yang (2013) observed that the moisture content and water activity of beef jerky remained unchanged when red pepper paste, soy sauce, or soybean paste was partially substituted for NaCl. The values of water activity (0.55–0.65) in Kilishi were within the usual range (<0.85) needed for jerky to be shelf stable (USDA-FSIS (U.S. Department of Agriculture–Food Safety and Inspection Service), 2014).

3.4. Color and pH

In terms of consumer decision-making, color significantly influences the quality assessment and perception of meat products. The salt varieties did not affect the color coordinates of KL (Table 4). This agrees with the homogenous color coordinates observed in beef jerky when NaCl was partly replaced with KCl (Li et al., 2023). The addition of 14 % CC improved the redness of KL. This finding could be explained by the carotenoid content of CC. High levels of carotenoids are found in CC

Table 3
Chemical composition and water activity of Kilishi formulated with different *Capsicum chinense* concentration and salt varieties.

		Item				
Factors		Moisture (%)	Crude protein (%)	Crude fat (%)	Ash (%)	Water activity
Additive[1] (A)	KL-1	12.91	62.50	6.93	6.76	0.67
	KL-2	12.84	63.00	6.98	6.72	0.67
	KL-3	12.99	63.16	6.90	6.68	0.67
	KL-4	12.97	62.75	6.99	6.63	0.67
	KL-5	13.00	63.17	6.99	6.89	0.68
	KL-6	12.83	62.58	6.98	6.63	0.67
	SEM	0.085	0.400	0.016	0.29	0.03
	P value	0.063	0.702	0.800	0.064	0.123
Storage day (S)	0	12.89	63.16	6.98	6.70	0.68
	30	12.77	62.89	6.98	6.71	0.67
	60	12.98	62.72	6.93	6.69	0.67
	90	13.03	62.67	6.95	6.68	0.67
	SEM	0.071	0.330	0.040	0.031	0.08
	P value	0.585	0.749	0.778	0.062	0.094
A × S	P value	0.997	0.297	0.890	0.134	0.118

[1] KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC. SEM, standard error of mean.

Table 4
Color coordinates and pH of Kilishi formulated with different *Capsicum chinense* concentration and salt varieties.

		Item			
Factors		L*	a*	b*	pH
Additive[1] (A)	KL-1	26.01^{a}	27.02^{b}	45.24	5.92^{a}
	KL-2	25.93^{a}	29.78^{b}	42.40	5.95^{a}
	KL-3	26.23^{a}	28.44^{b}	43.19	5.93^{a}
	KL-4	20.38^{b}	34.30^{a}	44.51	5.78^{b}
	KL-5	19.29^{b}	33.91^{a}	44.74	5.80^{b}
	KL-6	19.96^{b}	34.90^{a}	44.79	5.81^{b}
	SEM	3.45	2.007	5.04	0.06
	P value	<0.0001	<0.0001	0.056	0.016
Storage day (S)	0	16.808^{c}	27.89^{a}	43.466^{d}	5.76^{d}
	30	16.808^{c}	26.75^{b}	44.075^{c}	5.88^{c}
	60	18.658^{b}	24.48^{c}	46.275^{b}	5.96^{b}
	90	24.92^{a}	22.45^{d}	46.758^{a}	6.15^{a}
	SEM	0.019	0.022	0.094	0.07
	P value	<0.0001	<0.0001	<0.0001	0.034
A*S	P value	0.081	0.075	0.101	0.094

^{a,b,c,d}means bearing different superscripts along the same column for each factor are significantly different ($P < 0.05$). [1]KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC. SEM, standard error of mean.

(Haile et al., 2023; Oney-Montalvo et al., 2020). The major red compounds that are primarily responsible for the enhanced redness in CC-fortified foods are capsorubin (red xanthophylls) and the ketocarotenoid capsanthin (Ko et al., 2022). Our findings align with those of Zhou, Wang, et al. (2021), who noted that the addition of paprika enhanced the redness of spiced beef. The reduced lightness in the KL treated with 14 % CC may be explained by the decreased disruption of muscle proteins, as demonstrated by the decreased carbonyl content. Similarly, the substitution of pepper pastes for NaCl reduced the lightness of beef jerky (Lim et al., 2013; Lim et al., 2014).

After 30 d of storage, the lightness and yellowness increased, while the redness of KL decreased. Increased lightness during storage suggests greater light dispersion due to changes in meat structure, particularly protein denaturation (Rosario et al., 2020; Tao et al., 2021; Wang, Tu, Zhou, Lu, & Xu, 2021). This is consistent with the increase in carbonyl content, which indicates protein denaturation during storage. A decrease in redness could be associated with metmyoglobin buildup and myoglobin oxidation in the presence of light and oxygen (Adeyemi, Shittu, Sabow, Karim, & Sazili, 2017). An increase in yellowness may result from lipid oxidation-induced ferrous heme iron oxidation (Xu, Cheng, Liu, & Zhu, 2019). The changes in color coordinates during storage are consistent with findings in beef jerky stored for 21 d (Lim et al., 2013) and 70 d (Sulaimon & Adeyemi, 2024).

The pH of meat products is very important because it plays a vital role in the microbial profile and physicochemical properties. The salt variety did not significantly influence the pH of KL (Table 4). Similarly, the pH of beef jerky did not change when KCl was partially substituted for NaCl (Li et al., 2023). The addition of 14 % CC lowered ($P < 0.05$) the pH of KL. The natural acids found in CC could increase the overall acidity of KL, thereby reducing the pH. Similarly, adding red pepper instead of NaCl caused a pH reduction in beef jerky (Lim et al., 2013; Lim et al., 2014). The pH of KL increased ($P < 0.05$) during storage. This might be attributed to the oxidation of lipids and proteins, and microbial proliferation. The pH range (5.96–6.65) that we found in our study was comparable to the values reported in earlier works on beef jerky (Lim et al., 2013; Shi et al., 2020; Sulaimon & Adeyemi, 2024) and was within the normal pH range (4.72–6.73) for jerky (USDA-FSIS (U.S. Department of Agriculture–Food Safety and Inspection Service), 2014).

3.5. Lipid and protein oxidation

The oxidation of lipids and amino acids in meat can compromise its nutritional value and shelf life (Bhattacharya, Kandeepan, & Vishnuraj, 2016; Huang & Ahn, 2019). The salt variety had no significant effect on the TBARS value and carbonyl content in KL (Table 5). It is debatable how NaCl affects oxidative deterioration in meat products. Certain studies have reported prooxidant effects (Mancini et al., 2020; Qu et al., 2020; Wu et al., 2022), while others have reported antioxidant effects (Zhang et al., 2021) or no effect (Kong, Oliveira, Tang, Rasco, & Crapo, 2008). The addition of 14 % CC reduced the carbonyl content and TBARS value in KL by approximately 28 % and 36 %, respectively. This was possibly due to the antioxidant contents of CC. Similarly, capsaicin and dihydrocapsaicin in *Capsicum* reduced the carbonyl content in duck meat (Sun, He, Guo, & Xu, 2023). Moreover, the replacement of NaCl with red pepper lowered the TBARS value in beef jerky (Lim et al., 2013; Lim et al., 2014). Even though the highest TBARS value of 0.47 mg

Table 5
Lipid oxidation and protein oxidation of Kilishi formulated with different *Capsicum chinense* concentration and salt varieties.

		Item	
Factors		TBARS (mg MDA/kg)	Carbonyl (mmol/kg)
Additive[1] (A)	KL-1	0.36^{a}	0.64^{a}
	KL-2	0.34^{a}	0.66^{a}
	KL-3	0.35^{a}	0.63^{a}
	KL-4	0.23^{b}	0.46^{b}
	KL-5	0.23^{b}	0.47^{b}
	KL-6	0.25^{b}	0.43^{b}
	SEM	0.06	0.05
	P value	0.011	0.019
Storage day (S)	0	0.22^{d}	0.45^{d}
	30	0.26^{c}	0.57^{c}
	60	0.37^{b}	0.71^{b}
	90	0.47^{a}	1.19^{a}
	SEM	0.004	0.011
	P value	<0.0001	<0.0001
A × S	*P* value	0.072	0.219

^{a,b,c,d}means with different superscripts along a column for each factor are significantly different ($P < 0.05$). [1]KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC. SEM, standard error of mean.

MDA/kg was recorded on day 90, it was still below the threshold (3.0 mg MDA/kg), which was thought to be the upper limit for an unpleasant taste and odor (Wójciak, Stasiak, Ferysiuk, & Solska, 2019). The increase in the TBARS value and carbonyl content during storage may be attributed to autooxidation or photooxidation of lipids and proteins during storage (Narayanankutty, Anil, Illam, Kandiyil, & Raghavamenon, 2018). In a similar vein, Kilishi kept for 35 days showed higher TBARS levels than the freshly prepared ones (Alamuoye et al., 2024), while Kilishi kept for 70 days showed higher TBARS and carbonyl contents than those stored for fewer days (Sulaimon & Adeyemi, 2024).

3.6. Microbial profile

Ensuring the microbiological safety of meat products is essential for safeguarding public health and preventing economic losses. *Salmonella* spp., coliform bacteria, and *Staphylococcus aureus* were not detected in any of the KL samples (Table 6). This may be attributed to the low water activity of the KL samples and the proper hygiene observed during the preparation and storage of the samples. The TPC (1.53–2.67 log CFU/g) and yeast-mold (0.73–1.82 log10 CFU/g) concentrations in this study were lower than the acceptable limits of 2.5×10^5 to 1.0×10^8 CFU/g for TPC and 1.0×10^4 CFU/g for yeast-mold (USDA-FSIS, 2014) for beef jerky. This implies that regardless of the salt variety and concentration of CC, Kilishi stored for 90 days are safe for human consumption microbiologically. Salt variety did not affect the microbial profile of KL. This finding was anticipated because the pH of KL was not influenced by the salt variety. The addition of 14 % CC increased the *Lactobacillus* counts and the reduced yeast counts. This finding may be attributed to the low pH induced by the presence of a myriad of acids in CC.

3.7. Sensory properties

The sensorial evaluation of meat products has a broad impact on product development, consumer acceptance, and marketing quality control and ultimately contributes to the overall success and competitiveness of meat products in the industry (Ruiz-Capillas, Herrero, Pintado, & Delgado-Pando, 2021). Additives had no effect on the sensory scores KL especially that of saltiness (Table 7). This result suggests that the saltiness perception remained unaffected despite the variations in salt types and CC concentrations. This implies that despite the reduction in NaCl concentration in the KL samples formulated with 14 % CC (KL-4, KL-5 and KL-6), the saltiness perception was not compromised. Piperine and capsaicin, which are abundant in CC can elicit salty taste perception in foods by activating certain taste receptors that are also responsible for detecting saltiness in the mouth (Moss, Fisher, et al., 2023; Narukawa et al., 2011). Likewise, the addition of white pepper, which contains piperin, enhanced the saltiness perception of salt-reduced soup (Moss et al., 2023). In contrast, the addition of 2 % pepper paste did not enhance the saltiness perception of beef jerky (Lim et al., 2013). It appears that the 14 % CC used in this study was sufficient for preserving the saltiness perception in KL.

The taste, flavor, and overall acceptance scores of KL decreased after 30 days of storage. This observation coincided with the increase in TBARS value and carbonyl content, which are indicators of quality deterioration. Moreover, the increase the yeast-mold count and color changes over storage may have contributed to the decrease in the sensorial quality of KL. This finding highlights a potential challenge for the long-term shelf life of Kilishi, and suggests the need to implement better storage practices and product improvements to maintain the sensory quality of Kilishi for longer periods. Consistently, it was noted that after 35 days of storage, the flavor, juiciness, and overall acceptability of Kilishi decreased (Alamuoye et al., 2024).

4. Conclusion

The partial replacement of NaCl with KCl and $C_6H_5K_3O_7$ reduced the Na content in Kilishi. Increasing the concentration of CC to 14 % in the marinade mixture decreased the concentration of 25-hydroxy cholesterol and cholesta-3,5-dien-7-one and improved the redness, oxidative stability and *Lactobacillus* counts of Kilishi. Neither salt variety nor CC concentration influenced the chemical composition and water activity of Kilishi. The yeast-mold count, pH, TBARS and carbonyl content increased over the 90-d storage of KL. The incorporation of 14 % CC in a marinade mixture enhanced the perception of saltiness in low-salt Kilishi. Storing Kilishi beyond 30 days reduced its flavor, taste and overall acceptance scores. The substitution of KCl and $C_6H_5K_3O_7$ for NaCl and the addition of 14 % CC lowered the Na content and selected cholesterol oxides without compromising the sensory attributes of Kilishi. The decline in the sensorial quality of Kilishi after 30 days of storage highlights the need for further research to maintain the sensory quality of Kilishi for longer periods.

Consent statement

The experimental protocol was carried out according to the guidelines of the Ethical Review Committee of the University of Ilorin. **Informed written consent** was obtained from all individuals who participated in the sensory assessment.

Table 6
Microbial profiles of Kilishi formulated with different *Capsicum chinense* concentration and salt varieties.

		Item (Log_{10} CFU/g)					
Factors		Total plate count	Yeast-mold	*Lactobacillus* spp	Coliform	*Salmonella* spp	*Staphylococcus aureus*
Additive[1] (A)	KL-1	2.60	1.34	0.89[b]	ND	ND	ND
	KL-2	2.64	1.35	0.90[b]	ND	ND	ND
	KL-3	2.63	1.34	0.87[b]	ND	ND	ND
	KL-4	2.65	0.78	1.54[a]	ND	ND	ND
	KL-5	2.57	0.75	1.52[a]	ND	ND	ND
	KL-6	2.65	0.79	1.50[b]	ND	ND	ND
	SEM	0.34	0.21	0.22			
	P value	0.184	0.042	0.035			
Storage day (S)	0	2.56	0.76[b]	1.45	ND	ND	ND
	30	2.60	0.94[b]	1.50	ND	ND	ND
	60	2.58	1.23[a]	1.48	ND	ND	ND
	90	2.62	1.67[a]	1.48	ND	ND	ND
	SEM	0.33	0.19	0.06			
	P Value	0.091	0.040	0.312			
A × S	P value	0.177	0.101	0.188			

[a, b]means with different superscripts along the same column are significantly different ($P < 0.05$). KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); [1]KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC. SEM, standard error of mean. CFU, Colony forming unit. ND, Not detected.

Table 7
Sensory attributes of Kilishi formulated with different *Capsicum chinense* concentration and salt varieties.

Factors		Taste	Texture	Appearance	Flavor	Saltiness	Overall acceptance
Additive (A)[1]	KL-1	7.32	6.85	7.43	6.82	7.08	7.33
	KL-2	7.91	7.02	7.58	6.83	7.00	7.87
	KL-3	7.85	6.70	7.08	6.95	7.05	7.05
	KL-4	7.53	7.28	7.33	6.73	7.10	7.52
	KL-5	7,35	7.25	7.42	7.00	7.00	7.43
	KL-6	7.43	6.92	6.93	6.93	7.10	7.53
	SEM	0.83	0.67	0.58	0.17	0.23	0.86
	P value	0.110	0.091	0.066	0.120	0.104	0.092
Storage day (S)	1	7.68[a]	7.22	7.50	7.31[a]	7.10	7.75[a]
	30	7.58[a]	7.05	7.36	7.29[a]	7.10	7.68[a]
	60	7.16[b]	6.82	7.07	6.77[b]	7.00	6.68[b]
	90	7.07[b]	6.88	7.38	6.80[b]	7.00	6.64[b]
	SEM	0.15	0.15	0.13	0.14	0.13	0.13
	P value	0.011	0.006	0.123	0.042	0.111	0.021
A × S	P value	0.128	0.093	0.145	0.220	0.120	0.116

[a, b, c]means with different superscripts along the same column for each factor are significantly different ($P < 0.05$). [1]KL-1, 2 % NaCl + 7 % ***Capsicum chinense*** (CC); KL-2, 1 % NaCl + 1 % KCl + 7 % CC; KL-3, 1 % NaCl + 1 % $C_6H_5K_3O_7$ + 7 % CC; KL-4, 1 % NaCl + 14 % CC; KL-5, 1 % KCl + 14 % CC; KL-6, 1 % $C_6H_5K_3O_7$ + 14 % CC. SEM, standard error of mean.

CRediT authorship contribution statement

Kazeem D. Adeyemi: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Hakeem Ishola:** Investigation, Methodology, Resources. **Rafiat M. Shittu:** Investigation, Methodology, Resources. **Feranmi J. Olaniran:** Resources, Methodology, Investigation. **Jamiu O. Jimoh:** Resources, Methodology, Investigation. **Halimat O. Akinola:** Resources, Methodology, Investigation. **Ahmed O. Rasheed:** Resources, Methodology, Investigation. **Yusuf Ibn. Yusuf:** Resources, Methodology, Investigation. **Abdulfatai Oluwasola:** Resources, Methodology, Investigation. **Bukunmi M. Olabisi:** Resources, Methodology, Investigation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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