Sains Malaysiana 55(3)(2026): 411-423
http://doi.org/10.17576/jsm-2026-5503-05

Impact of Sodium Chloride Substitutes on the Physicochemical and Sensory Properties of Sweet Thai Chili Sauce

(Kesan Pengganti Natrium Klorida terhadap Sifat Fizikokimia dan Sensori Sos Cili Thai Manis)

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Received: 28 September 2025/Accepted: 14 February 2026

ABSTRACT

Sodium reduction in food products is critical due to its link with cardiovascular diseases, necessitating healthier alternatives. This study investigated the impact of potassium chloride (KCl) and calcium chloride ($CaCl_2$) as sodium chloride (NaCl) substitutes on the physicochemical and sensory properties of sweet Thai chili sauce. Sweet Thai chili sauce was formulated with KCl and $CaCl_2$ replacing NaCl at 0%, 25%, 50%, and 75% substitution levels. The physicochemical properties measured included pH, total titratable acidity, syneresis, and total soluble solids. Rheological properties were analyzed to assess viscosity and flow behaviour. Sensory evaluation by untrained panelists determined taste, texture, and overall acceptability. The findings indicated significant differences ($p < 0.05$) in pH and syneresis at higher substitution levels. While the sauce's viscosity remained stable, sensory analysis showed that up to 50% KCl substitution was acceptable with minimal impact on taste and texture, whereas higher $CaCl_2$ levels introduced bitterness and reduced preference. Both physicochemical and sensory data supported KCl as a viable substitute for up to 50% NaCl replacement. It can be concluded that, KCl can substitute NaCl up to 50% without significantly affecting the sauce's quality. However, the application of $CaCl_2$ is limited due to its bitterness. These findings hold promise for industrial sodium reduction efforts in sweet Thai chili sauce. Further research is needed to explore the scalability and long-term stability of such substitutions in sweet Thai chili sauce.

Keywords: Rheology; salt substitutes; sensory evaluation; sodium reduction; sweet Thai chili sauce

ABSTRAK

Pengurangan natrium dalam produk makanan adalah penting kerana kaitannya dengan penyakit kardiovaskular, sekali gus memerlukan alternatif yang lebih sihat. Kajian ini meneliti kesan kalium klorida (KCl) dan kalsium klorida ($CaCl_2$) sebagai pengganti natrium klorida (NaCl) terhadap sifat fizikokimia dan sensori bagi sos cili Thai manis. Sos cili Thai manis telah diformulasikan dengan penggantian NaCl oleh KCl dan $CaCl_2$ pada tahap 0%, 25%, 50% dan 75%. Sifat fizikokimia yang diukur termasuk nilai pH, keasidan boleh dititratkan keseluruhan, sineresis dan jumlah pepejal larut. Sifat reologi dianalisis untuk menilai kelikatan dan tingkah laku aliran. Penilaian sensori oleh panel tidak terlatih menentukan skor atribut rasa, tekstur, dan kebolehterimaan keseluruhan. Hasil kaiian menunjukkan perbezaan yang signifikan ($p<0.05$) untuk nilai pH dan sineresis pada tahap penggantian yang lebih tinggi. Walaupun kelikatan sos kekal stabil, analisis sensori menunjukkan sehingga 50% penggantian KCl dapat diterima dengan kesan minimum terhadap rasa dan tekstur, manakala tahap $CaCl_2$ yang lebih tinggi memperkenalkan rasa pahit dan mengurangkan penerimaan. Data fizikokimia dan sensori menyokong KCl sebagai pengganti yang sesuai sehingga 50% penggantian NaCl. Kesimpulannya, KCl boleh menggantikan NaCl sehingga 50% tanpa menjejaskan kualiti sos secara signifikan. Walau bagaimanapun, penggunaan $CaCl_2$ adalah terhad kerana kepahitannya. Penemuan ini berpotensi menyumbang kepada usaha industri dalam pengurangan natrium dalam sos cili Thai manis. Kajian lanjut diperlukan untuk meneroka kebolehskalaan dan kestabilan jangka panjang penggantian ini dalam sos cili Thai manis.

Kata kunci: Pengganti garam; penilaian sensori; pengurangan natrium; reologi; sos cili Thai manis

INTRODUCTION

Sodium chloride (NaCl), commonly known as table salt, is a fundamental ingredient in food processing, prized for its ability to enhance flavour, improve texture, and act as a preservative. This mineral plays a crucial role in the sensory attributes of many food products, particularly in condiments and sauces, where it significantly contributes to the overall taste profile and shelf life (Muhoza 2022). However, high consumption of sodium has been associated with several health risks, including hypertension, cardiovascular diseases, and stroke (O'Donnell et al. 2019; Wen et al. 2019). These concerns have led public health authorities to advocate for a reduction in sodium intake as a preventive measure against these chronic conditions (Goland et al. 2022; Reynoso-Marreros et al. 2018).

In light of these health implications, the food industry has been increasingly focused on reformulating products to reduce their sodium content while maintaining quality, particularly in processed foods such as savory snacks, processed meats, and ready meals (Onyeaka et al. 2023). One promising approach involves the use of salt substitutes, such as potassium chloride (KCl) and calcium chloride ($CaCl_2$), which can replicate some of the functional properties of NaCl, such as flavour enhancement, preservation, and texture modification (Maia et al. 2020). These sodium chloride substitutes not only help in reducing sodium intake but also offer additional health benefits, such as increasing potassium and calcium levels, which is beneficial for cardiovascular health (Judge et al. 2020). However, the challenge lies in balancing the sensory and physicochemical properties of the food, particularly in flavour-rich products like sauces, to ensure consumer acceptance (Muhoza 2022; Reynoso-Marreros et al. 2018).

Sweet Thai chili sauce is a popular condiment, especially among Asian consumers. It is characterized by its sweet and sour taste, often with a spicy kick. The sauce is typically made from ingredients such as red chilies (specifically *Capsicum annuum* L. and *Capsicum frutescens* L.), sugar, vinegar, garlic, and salt. Modified corn starch is often used as a thickener to provide desirable rheological properties, and sodium benzoate may be added as a preservative (Ayed et al. 2021; Sinsawasdi, Rattanapanone & Toschka 2022). In Malaysia, chili sauce is widely used in daily cooking and as a condiment for various dishes, though it is often noted for its moderate to high salt content. Reducing sodium in food products, especially in sauces like sweet Thai chili sauce, presents significant challenges. These sauces rely heavily on NaCl not just for flavour enhancement but also for preservation and maintaining the desired consistency (Ayed et al. 2021). Sweet Thai chili sauce was chosen for this study due to its widespread popularity globally and its complex flavour profile. While it's difficult to pinpoint precise per capita consumption figures for sweet Thai chili sauce globally, it's a popular condiment, particularly in Southeast Asia and increasingly worldwide. The chili sauce market, including sweet chili varieties, is experiencing substantial growth, indicating a rising global demand (Global Growth Insights 2024), which makes it an excellent model for investigating the challenges and opportunities in sodium reduction for condiment products. Substituting NaCl with alternatives like KCl and $CaCl_2$ can potentially alter the sauce's taste, texture, and overall acceptability, leading to consumer rejection (Maia et al. 2020). The bitter aftertaste often associated with KCl and the potential of calcium salts to modify the texture and appearance of food products further complicate the reformulation process (Judge et al. 2020; Muhoza 2022; Rybicka et al. 2022). Hence, it is crucial to understand how these substitutes affect the overall quality of the sauce and to what extent they can replace NaCl without compromising the product quality especially its acceptance (Rybicka et al. 2022). This study aimed to address these challenges by systematically evaluating the impact of KCl, and $CaCl_2$ as NaCl substitutes, focusing on understanding how to leverage their benefits while mitigating potential drawbacks like bitterness and textural changes, thereby offering practical solutions for sodium reduction.

The primary objective was to determine the impact of these substitutions on the physicochemical properties, such as pH, total titratable acidity, syneresis, and total soluble solids. Additionally, the study aimed to understand how these substitutions influence the sauce's rheological properties, particularly viscosity and flow behaviour, which are critical to consumer acceptance (Judge et al. 2020). Finally, a sensory evaluation was conducted to assess the acceptability of the reformulated sauces, focusing on taste, texture, and overall preference. These objectives were intended to provide insights into the feasibility of using KCl and $CaCl_2$ as salt substitutes in sauces, contributing to the broader goal of reducing sodium intake in the diet without compromising food quality. By exploring the use of KCl and $CaCl_2$ as salt substitutes in sweet Thai chili sauce, this study could pave the way for the development of lower-sodium alternatives that retain the sensory and functional qualities consumers expect. Given the growing awareness of the health risks associated with high sodium intake, there is a pressing need for food manufacturers to reformulate products with a lower sodium content (Goland et al. 2022; Rybicka et al. 2022). By exploring the use of KCl and $CaCl_2$ as salt substitutes in sweet Thai chili sauce, this study could pave way for the development of lower-sodium alternatives that retain the sensory and functional qualities consumers expect. Moreover, the findings could have broader implications for other food products where sodium reduction is a priority, thereby supporting public health initiatives aimed at reducing the incidence of sodium-related health concerns (Goland et al. 2022; Reynoso-Marreros et al. 2018).

MATERIALS AND METHODS

MATERIALS

The materials used in this study included red chili (*Capsicum annuum* L.) and bird's eye chili (*Capsicum frutescens*), which were purchased from Tesco hypermarket in Penang, Malaysia. Other ingredients such as fresh garlic, table salt, sugar, vinegar, and flavour enhancers monosodium glutamate (MSG), also known as E621 were also sourced from Tesco. Food-grade sodium benzoate, calcium chloride ($CaCl_2$), and potassium chloride (KCl) were obtained from Liangtraco Sdn Bhd, Penang, Malaysia. Modified corn starch was purchased from Sim Company Sdn. Bhd., and reverse osmosis (RO) water was used in the preparation of the sweet Thai chili sauce. Chemicals used in the analytical tests, such as sodium hydroxide (NaOH), were procured from R & M Chemicals, Essex, UK.

SAMPLE PREPARATION

Table 1 shows the formula used to make the sweet Thai chili sauce. The preparation of the sauce involved the following unit operations. First, the chilies were destalked, washed thoroughly, and their seeds removed. Garlic was peeled, and both the chilies and garlic were blended with a small amount of water until smooth. The blended ingredients, along with half of the sugar, salt, and water were then placed into a steam-jacketed kettle. The mixture was boiled, and suspended modified corn starch was added, followed by the remaining sugar after gelatinization. The monosodium glutamate (flavour enhancer) was added once the sauce started to boil, and after 5 min, vinegar and sodium benzoate were introduced. The sauce was then cooked for an additional 5 to 10 min before being hot-filled into sterilized bottles at 80-90 °C. Sweet Thai chili sauce was formulated with KCl and $CaCl_2$ replacing NaCl at 0%, 20%, 30%, 40%, and 50% substitution levels. The 0% substitution level serves as the control, meaning the sauce contained 100% NaCl. The total amount of salt (70 g) was adjusted according to the substitution percentage to maintain consistent salt content across all samples.

ANALYSIS OF PHYSICOCHEMICAL PROPERTIES

The pH measurement

The pH values of the sauce samples were measured using a calibrated pH meter (S20 SevenEasy™ pH, Mettler Toledo, USA). Before measurement, the pH meter was calibrated using standard buffer solutions with pH values of 4.0, 7.0, and 9.0. The samples were brought to room temperature, and a mixture of 50 mL distilled water and 50 g of sauce was prepared for pH measurement. The analysis was conducted in triplicate.

Total Titratable Acidity (TTA)

Total titratable acidity was determined using the titration method (AOAC 942.15). A burette was filled with 0.5 M NaOH, and a mixture of 50 mL distilled water and 10 g of sauce sample was titrated until the endpoint (pH 8.2) was reached. The results were expressed as acetic acid percentage (w/w), calculated using the formula in Equation (1):

$$\text{TTA} = \left(\frac{Vt \; x \; Ct \; x \; 60 \; x \frac{1}{1000}}{Ms}\right) x \; 100 \qquad (1)$$

where Vt is the volume of titrant; C_t is the concentration of NaOH; and M_S is the sample weight. The analysis was performed in triplicate.

Total Soluble Solids (TSS)

The total soluble solid content of the sauce was measured using a digital refractometer (HI 96801, Hanna Instruments, USA). The refractometer was calibrated with distilled water, and the measurements were carried out in triplicate.

TABLE 1. Formulation to make sweet Thai chili sauce

Ingredients	Formulation	
	Weight (g)	%
Red chilies	126	6.33
Cili padi	63	3.16
Sugar	822	41.29
Commercial vinegar (Yakin)	325	16.33
Monosodium glutamate	2.1	0.11
Modified corn starch	54	2.71
Garlic	52.5	2.64
Sodium chloride	70	3.52
Sodium benzoate	1.05	0.05
Water	475	Make up to 100%
Total	1990.65	100

Syneresis

Syneresis, which indicates the separation of liquid from the solid phase in the sauce, was measured by centrifuging (Kubota 5500, Kubota Corporation, Japan) approximately 30 g of sauce at 6000 g for 15 min at 20 °C. The watery top layer was removed, and the remaining residue was weighed. Syneresis was expressed as the percentage of decanted liquid relative to the total weight before centrifugation, calculated as:

$$\%\ Syneresis = \frac{weight\ of\ decanted\ liquid}{total\ weight\ before\ centrifuge} \times 100 \quad (2)$$

Colour measurement

The colour of the sauce samples was measured using a Minolta spectrophotometer (Model CM-3500d, Osaka, Japan), which provided L*a*b* colour coordinates. The spectrophotometer was calibrated using a zero-calibration box and a white calibration plate. Each sample was measured in triplicate.

Rheology measurement

The rheological properties, specifically the apparent viscosity of the sauce samples, were assessed using a rheometer (TA Instruments AR1000-N) at a constant temperature of 25 °C. The shear rate ranged from 10 to 100 s^{-1}, and the data were fitted to the Herschel–Bulkley model to determine the yield stress, consistency coefficient, and flow index, from which apparent viscosity was derived.

SENSORY EVALUATION

The sensory properties of the sauces were evaluated by a panel of 30 untrained panelists but who had a good familiarity with the chili sauce. The panel size (n=30) was selected for this preliminary acceptability screening based on feasibility and alignment with similar consumer hedonic studies using untrained participants (Sirison et al. 2017). All participants were students from School of Industrial Technology, Universiti Sains Malaysia. All participants provided informed consent prior to their participation, and the study protocol was approved by the Research Ethics Committee of Universiti Sains Malaysia (JEPeM-USM). A seven-point hedonic scale, where a score of 1 corresponded with the most disliked and 7 with the most liked. The test was conducted in English. A 7-point hedonic scale was used to minimize respondent burden and fatigue in this untrained panel evaluating multiple attributes, while maintaining sufficient sensitivity to detect acceptability differences among formulations. Each panelist evaluated five coded sauce samples in a single session. Samples were presented simultaneously using three-digit random codes, and the tasting order was randomized across panelists. 5 g portions were served, and panelists rinsed with water between samples. Sauce samples were evaluated without a carrier to focus on intrinsic sauce attributes. The parameters assessed included flowability, spiciness, sweetness, sourness, bitterness, and overall acceptability. The evaluation was conducted in a sensory evaluation room at Universiti Sains Malaysia (USM). The results were analyzed to determine the acceptability of the salt-substituted sauces.

STATISTICAL ANALYSIS

Statistical analysis was performed using one-way ANOVA to determine the significance of differences among the samples. Duncan's New Multiple Range Test was employed for multiple comparisons, with a significance level set at $P<0.05$. The analyses were conducted using SPSS 20.0 for Windows. All measurements were done in triplicates.

RESULTS AND DISCUSSION

PHYSICOCHEMICAL PROPERTIES

The pH values and total titratable acidity

The pH levels of sweet Thai chili sauce were analyzed across different formulations, where NaCl was partially replaced with KCl $CaCl_2$. The results indicated that the pH values remained relatively stable across all formulations, with only slight variations observed (Tables 2 & 3). This stability is consistent with other studies on NaCl substitution in food products, which generally show minimal impact on pH due to the buffering capacity of other ingredients, such as vinegar and sugar, present in the formulations (Ojangba et al. 2022; Vidal et al. 2020).

Maintaining a stable pH is crucial for the sauce's overall stability, particularly in terms of microbial safety and shelf life. A consistent pH helps ensure that the sauce remains within a range that inhibits microbial growth, thereby reducing spoilage and enhancing product safety (Tan, Tan & Easa 2022). In sauces with acidic components, like vinegar, stable pH is also vital for preserving the sauce's tangy flavour, a key sensory attribute that consumers expect). Furthermore, pH stability suggests that the substitution of NaCl with KCl or $CaCl_2$ does not significantly alter the acid-base balance of the sauce, which is essential for maintaining its characteristic taste and quality. Titratable acidity, a measure of the total acidity in the sauce, also showed no significant differences between the control and the salt-substituted samples (Tables 2 & 3). This finding indicates that the substitution did not significantly impact the sauce's acid-base balance, which is important for maintaining the tangy flavor profile of sweet Thai chili sauce. Consistency in titratable acidity further supports the notion that KCl and $CaCl_2$ can be used as effective substitutes for NaCl without adversely affecting the product's acidity profile (Ojangba et al. 2022; Vidal et al. 2020).

TABLE 2. Physicochemical properties of sweet Thai chili sauce with varying potassium chloride (KCl) substitution levels

Sample	Test result			
	pH	Titratable acidity	Syneresis	°Brix
Control	3.67±0.06[a]	1.04±0.06[a]	14.91±0.10[ab]	55.00±1.23[a]
KCl-10 %	3.69±0.06[a]	1.02±0.03[a]	14.34±2.00[ab]	55.27±0.64[a]
KCl-20 %	3.66±0.09[a]	1.04±0.05[a]	18.79±1.26[b]	55.27±0.29[a]
KCl-30 %	3.65±0.11[a]	1.10±0.15[a]	17.00±1.41[ab]	54.40±1.65[a]
KCl-40 %	3.65±0.09[a]	1.16±0.01[a]	18.94±1.19[b]	54.10±1.83[a]
KCl-50 %	3.65±0.07[a]	1.15±0.08[a]	13.73±1.98[a]	53.80±1.39[a]

This table presents the impact of substituting sodium chloride with potassium chloride on the pH, titratable acidity, syneresis, and total soluble solids (°Brix) of sweet Thai chili sauce. The values are given as means ±standard deviations, and superscripts indicate statistically significant differences ($p < 0.05$) between the samples for each property

TABLE 3. Physicochemical properties of sweet Thai chili sauce with varying calcium chloride ($CaCl_2$) substitution levels

Sample	Test result			
	pH	Titratable acidity	Syneresis	°Brix
Control	3.67±0.06[a]	1.04±0.06[a]	14.91±0.10[ab]	55.00±1.23[a]
CCl-10 %	3.63±0.13[a]	1.14±0.08[a]	14.90±2.73[ab]	55.07±2.01[a]
CCl-20 %	3.63±0.10[a]	1.16±0.07[a]	15.38±3.25[ab]	55.90±2.08[a]
CCl-30 %	3.60±0.12[a]	1.13±0.03[a]	18.94±1.70[b]	55.50±1.57[a]
CCl-40 %	3.57±0.12[a]	1.09±0.06[a]	14.63±1.01[ab]	55.77±1.27[a]
CCl-50 %	3.59±0.15[a]	1.06±0.08[a]	13.54±0.05[a]	54.97±2.31[a]

The table outlines how the substitution of sodium chloride with calcium chloride affects the pH, titratable acidity, syneresis, and total soluble solids (°Brix) of sweet Thai chili sauce. Superscripts denote statistically significant differences ($p < 0.05$) among the samples for each parameter

Syneresis

Syneresis, or the extent of water separation from the sauce, was a key parameter measured in this study. The substitution of NaCl with KCl and $CaCl_2$ led to varying degrees of syneresis, particularly at higher substitution levels (Tables 2 & 3). Specifically, the highest levels of syneresis were observed in sauces with 30% $CaCl_2$ and 40% KCl substitution, indicating a reduction in water-holding capacity. This phenomenon can be attributed to the weaker ionic strength of $CaCl_2$ compared to NaCl, which reduces the sauce's ability to retain water within the starch matrix. The bivalent nature of calcium ions (Ca^{2+}) can disrupt the electrostatic interactions that hold water within the gel network, leading to increased syneresis (Beck, Jekle & Becker 2011; Fu et al. 2015). Previous studies have reported that salts with lower ionic strength, such as $CaCl_2$, can lead to increased syneresis in gel-like food systems due to their ability to weaken the electrostatic interactions within the matrix (Baek, Yoo & Lim 2004; Beck, Jekle & Becker 2011). This disruption results in a less cohesive texture, making the sauce appear more waterly, which can negatively impact consumer preference. Consumers generally favor sauces with a smooth, consistent texture, and increased syneresis could be perceived as a reduction in product quality. From a practical standpoint, this can affect the marketability of the sauce, as texture plays a crucial role in consumer acceptance of sauces. While $CaCl_2$ showed the lowest syneresis at 50% substitution (13.54±0.05%), this value was not statistically different from that observed with 50% KCl substitution (13.73±1.98%), indicating similar effects on syneresis at these levels. The reduced water-holding capacity observed with $CaCl_2$ substitution further supports previous findings that bivalent cations decrease starch re-crystallization rates more effectively than monovalent cations, such as Na^+ and K^+ (Baek, Yoo & Lim 2004; Beck, Jekle & Becker 2011). To counteract the increased syneresis caused by $CaCl_2$, manufacturers could consider incorporating hydrocolloids or other water-binding agents to improve the water retention capacity of the sauce. Such adjustments could help maintain the desired consistency and texture, even with significant NaCl reduction.

Total Soluble Solids (°Brix)

The °Brix, representing the total soluble solids in the sauce, remained consistent across all formulations, including those with salt substitutions (Table 2 & 3). This indicates that the replacement of NaCl with KCl and $CaCl_2$ did not significantly affect the concentration of dissolved solids, which primarily consists of sugars, acids, and other soluble components. Maintaining a stable °Brix level is essential for preserving the sauce's sweetness and overall flavour profile. The stability in °Brix across different formulations suggests that the solubility of other ingredients in the sauce was not adversely impacted by the salt substitutions. This finding aligns with other research that has demonstrated the feasibility of using KCl as a NaCl substitute without compromising the sweetness or soluble solid content of food products. The solubility of sodium chloride, potassium chloride, and calcium chloride is comparable under high temperature conditions, which supports the consistent °Brix measurements observed in this study. Additionally, sugar plays a more significant role in affecting the °Brix, as the quantity of sugar added is substantially higher compared to salt (Table 1) which further explains the stability of °Brix across all samples (Guerrero & Alzamora 1998; Nindo et al. 2007).

RHEOLOGICAL PROPERTIES

Viscosity

The viscosity of the sweet Thai chili sauce was measured to assess the impact of salt substitution on the sauce's flow behaviour. The results indicated that all sauces exhibited non-Newtonian, pseudo-plastic behaviour, where viscosity decreased with increasing shear rate (Figures 1-4). This shear-thinning property is typical of sauces and is desirable for ease of pouring and spreading, as it ensures that the sauce flows easily under applied stress, a characteristic important for consumer use (Gamonpilas et al. 2011; Herrmann et al. 2013). However, the viscosity of the sauce varied depending on the level and type of salt substitution. Sauces with higher levels of $CaCl_2$ substitution (50%) exhibited a noticeable reduction in viscosity compared to the control, while those with KCl substitution showed only minor changes. This reduction in viscosity with $CaCl_2$ substitution is likely due to calcium ions interacting with pectin and other gelling agents in the sauce, disrupting the gel network and leading to lower viscosity (Chen et al. 2014).

Calcium ions, being bivalent, can disrupt the starch matrix by hindering proper gelatinization, which further contributes to the reduced viscosity (Kaur et al. 2013). These findings align with previous research, which has shown that calcium salts can reduce viscosity in food systems by disrupting molecular interactions that are critical for gel formation (Beck, Jekle & Becker 2011). In contrast, KCl-substituted sauces exhibited minimal changes in viscosity, suggesting that KCl behaves more similarly to NaCl in maintaining the structural integrity of the sauce's gel network (Li, Li & Gao 2015). This minimal impact on viscosity further supports the suitability of KCl as a substitute for NaCl in maintaining desirable flow properties in the sauce.

From a practical perspective, reduced viscosity in sauces, such as those with higher $CaCl_2$ substitution, can lead to less favorable texture, making the sauce appear too thin or watery. This may not meet consumer expectations for thickness and consistency. In industrial sauce production, maintaining optimal viscosity is crucial for ensuring that the product has the desired consistency during bottling, storage, and consumer use (Herrmann et al. 2013). The reduction in viscosity with $CaCl_2$ substitution poses challenges for production and may require modifications to the formulation, such as the addition of stabilizers, to ensure the sauce retains its intended texture.

Yield stress

The yield stress, or the force required to initiate flow in the sauce, varied across the different formulations (Tables 4 & 5). Sauces with $CaCl_2$ substitution, particularly at higher levels, exhibited lower yield stress values, indicating that they flowed more easily under applied stress. This reduction in yield stress is likely due to the disruption of the gel network by calcium ions, which weakens the structural integrity of the sauce. The weakening of the gel network by calcium ions is consistent with findings that bivalent cations such as Ca^{2+} can reduce the re-crystallization rate of starch, thereby weakening the gel structure (Chen et al. 2014; Lang & Rha 1981).

Conversely, the KCl-substituted sauces showed yield stress values comparable to the control, suggesting that KCl does not significantly alter the gel structure of the sauce. These results align with the observed viscosity data and further underscore the suitability of KCl as a NaCl substitute in maintaining the desired rheological properties of the sauce (Yu, Kealy & Chen 2006).

SENSORY ACCEPTABILITY

The sensory evaluation, conducted with a panel of untrained participants, assessed the sauces based on attributes such as sourness, sweetness, spiciness, bitterness, and overall acceptability (Table 6). The results showed that up to 50% substitution of NaCl with KCl was well accepted by the panel, with minimal impact on taste and texture. This finding aligns with previous studies that demonstrate KCl's suitability as a salt substitute, offering a similar level of saltiness without significant adverse effects on sensory properties or consumer acceptance (Grummer et al. 2012). However, higher substitution levels with $CaCl_2$ (50%) led to increased bitterness, which negatively affected the sauce's overall acceptability. This aligns with findings from other studies where both KCl and $CaCl_2$ have been found to impart bitterness when used as salt substitutes, though the bitterness is more pronounced with $CaCl_2$ (Grummer et al. 2012). Calcium ions are known to activate specific taste

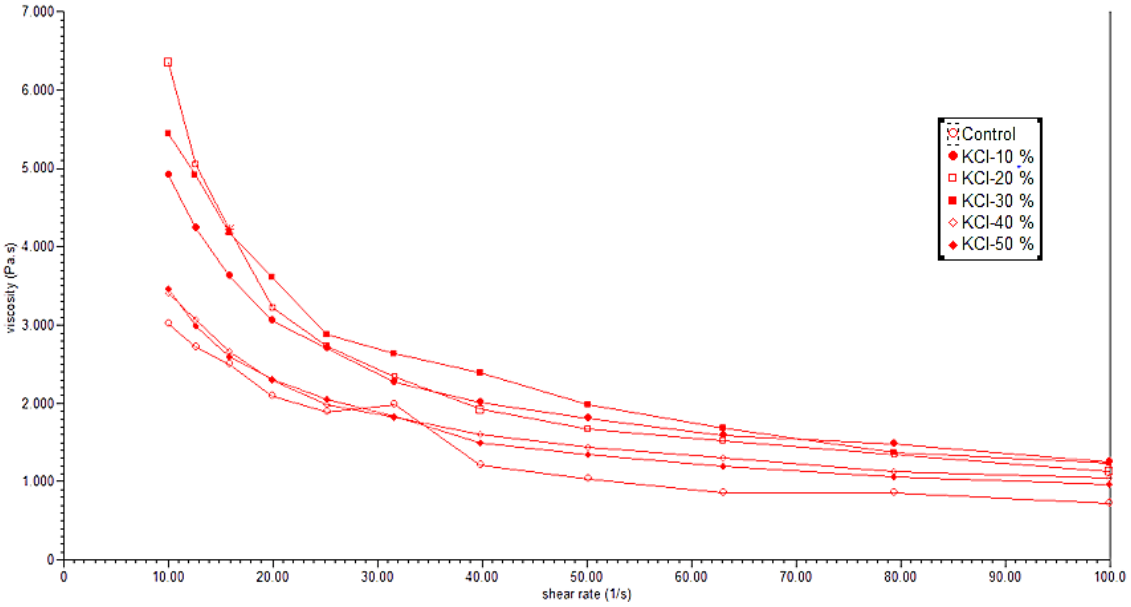

FIGURE 1. Viscosity as a function of shear rate for sweet Thai chili sauce with KCl Substitution (Batch 1). The figure illustrates the viscosity behaviour of sweet Thai chili sauce with different levels of potassium chloride substitution compared to the control. Viscosity decreases with increasing shear rate, indicating pseudo-plastic (shear-thinning) behaviour, which is typical for sauces

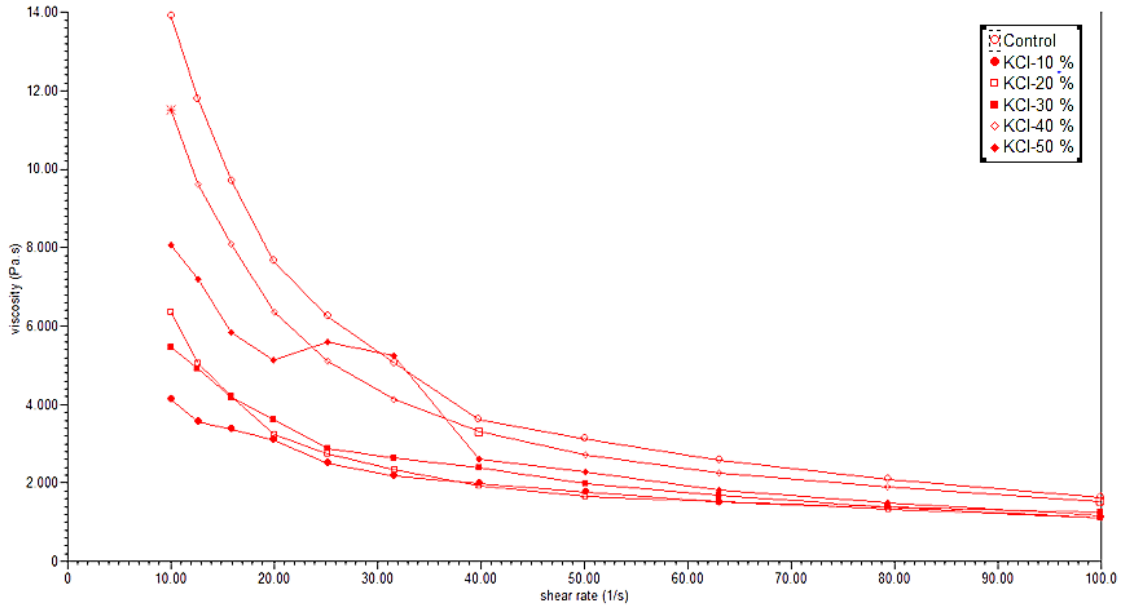

FIGURE 2. Viscosity as a function of shear rate for sweet Thai chili sauce with KCl Substitution (Batch 2). The figure shows the flow behaviour of batch 2 sweet Thai chili sauce samples with KCl substitution. Viscosity measurements help demonstrate how the substitution influences the sauce's ease of pouring and spreadability

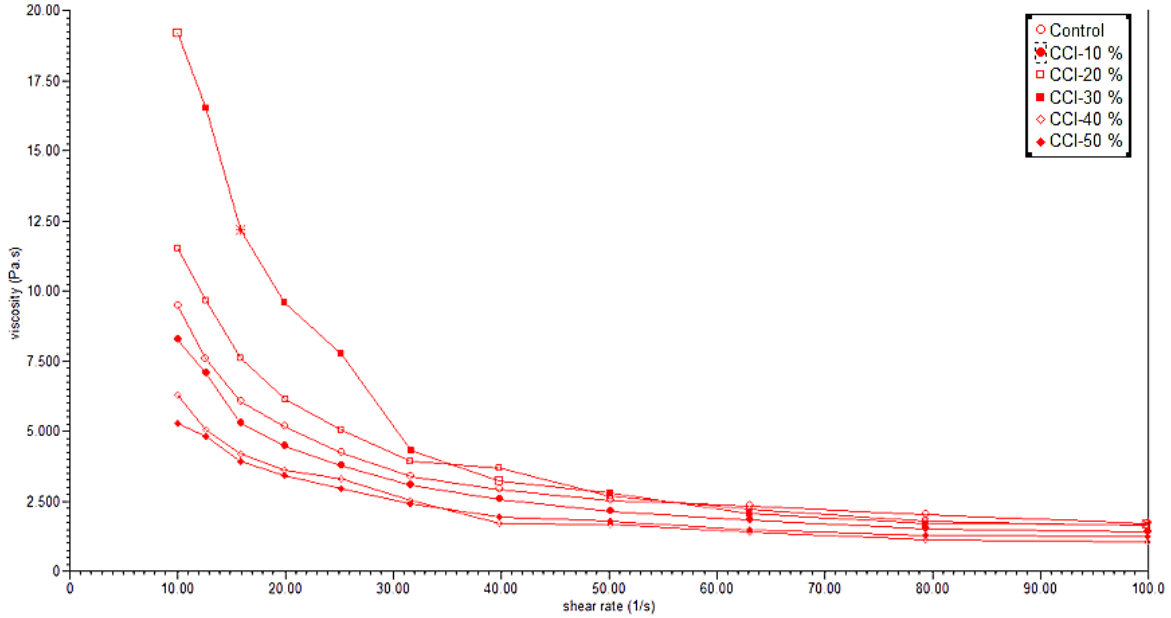

FIGURE 3. Viscosity as a function of shear rate for sweet Thai chili sauce with $CaCl_2$ Substitution " (Batch 1). This graph shows the change in viscosity as a function of shear rate for sweet Thai chili sauces with varying levels of calcium chloride substitution in batch 1. A notable reduction in viscosity is observed at higher $CaCl_2$ levels, indicating reduced gel strength

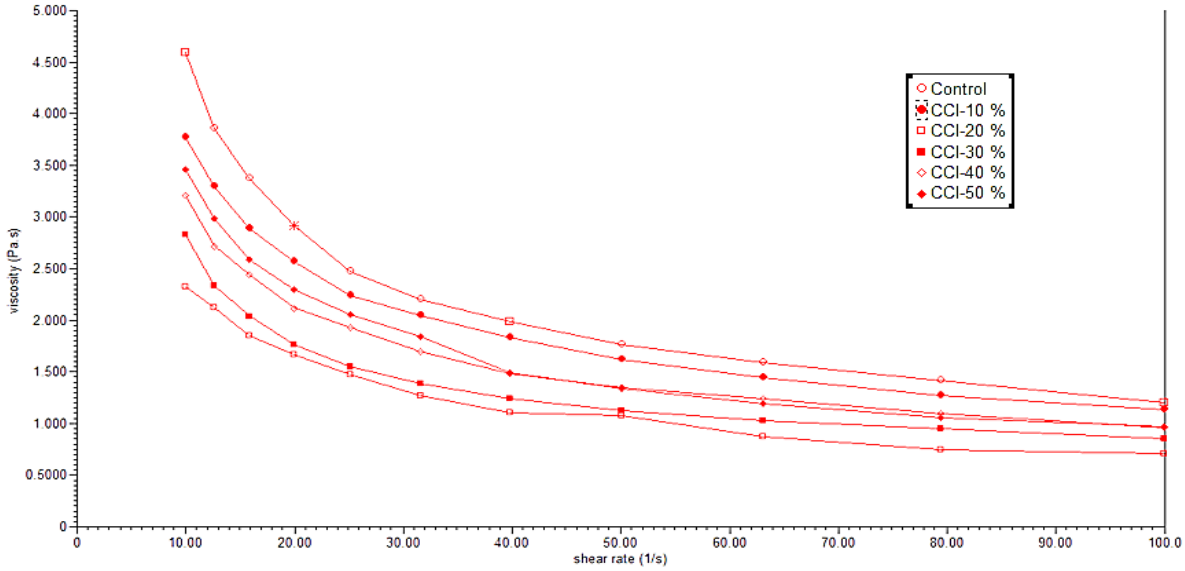

FIGURE 4. Viscosity as a function of shear rate for sweet Thai chili sauce with $CaCl_2$ substitution (Batch 2). The figure illustrates how calcium chloride substitution affects the viscosity of batch 2 sauces under different shear rates. A comparison with the control highlights the reduction in viscosity caused by $CaCl_2$ substitution

TABLE 4. Rheological parameters of sweet Thai chili sauce with KCl substitution using Herschel–Bulkley model

	Yield stress, τ_0 (Pa)		Viscosity, η (Pa. s)		Rate index, n	
Sample	Batch 1	Batch 2	Batch 1	Batch 2	Batch 1	Batch 2
Control	83.05	-1488	650.9	1615	0.02	0.004
KCl-10 %	79.23	-46.64	3.934	47.67	0.69	0.26
KCl-20 %	109.2	60.84	0.4469	0.78	1.06	1.14
KCl-30 %	116.5	24	50.41	3.57	0.24	0.56
KCl-40 %	55.40	106.2	4.575	3.6	0.65	0.56
KCl-50 %	46.49	-11450	4.975	11520	0.6	0.001

This table highlights rheological behaviour of sweet Thai chili sauce with various levels of potasium chloride substitution, showing yield stress, viscosity, and flow index for each sample

TABLE 5. Rheological parameters of sweet Thai chili sauce with $CaCl_2$ substitution using Herschel–Bulkley model

	Yield stress, τ_0 (Pa)		Viscosity, η (Pa. s)		Rate index, n	
Sample	Batch 1	Batch 2	Batch 1	Batch 2	Batch 1	Batch 2
Control	-654.6	15.93	0,88	7.665	1.00	0.57
CCl-10 %	29.62	1.654	0.41	11.22	1.07	0.50
CCl-20 %	56.58	-2.97	1.42	9.84	0.77	0.43
CCl-30 %	-33.37	16.81	432.41	1.67	-0.67	0.81
CCl-40 %	14.42	7.31	1.80	6.40	0.70	0.57
CCl-50 %	15.18	35.89	1.58	1.37	0.83	0.45

This table highlights rheological behaviour of sweet Thai chili sauce with various levels of calcium chloride substitution, showing yield stress, viscosity, and flow index for each sample

TABLE 6. Sensory acceptability of sweet Thai chili sauce with KCl and $CaCl_2$ substitution

Sample	Flow ability	Sourness	Sweetness	Spiciness	Bitterness	Overall acceptability
No salt	4.07 ± 1.27^{a}	4.13 ± 1.50^{a}	3.87 ± 1.68^{a}	4.50 ± 1.53^{a}	3.63 ± 0.79^{bc}	3.63 ± 1.38^{a}
Control	4.63 ± 1.64^{ab}	4.47 ± 1.38^{a}	4.37 ± 1.10^{a}	4.63 ± 1.50^{a}	4.30 ± 0.65^{e}	4.80 ± 0.96^{c}
KCl-10 %	4.67 ± 1.40^{ab}	4.37 ± 1.33^{a}	4.40 ± 1.16^{a}	4.90 ± 1.24^{a}	4.13 ± 0.90^{e}	4.57 ± 1.00^{bc}
KCl-20 %	4.93 ± 1.41^{b}	4.60 ± 1.28^{a}	4.37 ± 1.35^{a}	4.77 ± 1.31^{a}	4.17 ± 0.83^{de}	4.67 ± 1.30^{bc}
KCl-30 %	4.70 ± 1.44^{ab}	4.67 ± 1.42^{a}	4.60 ± 1.10^{a}	5.03 ± 1.22^{a}	3.87 ± 0.81^{e}	4.83 ± 1.18^{c}
KCl-40 %	4.77 ± 1.28^{ab}	4.40 ± 1.00^{a}	4.37 ± 0.72^{a}	4.57 ± 1.07^{a}	3.73 ± 0.82^{bc}	4.07 ± 0.74^{ab}
KCl-50 %	4.87 ± 1.25^{b}	4.20 ± 1.16^{a}	3.97 ± 1.00^{a}	4.30 ± 1.26^{a}	3.23 ± 1.14^{a}	3.60 ± 0.93^{a}
CCl-10 %	4.73 ± 1.39^{ab}	4.50 ± 1.25^{a}	4.53 ± 1.20^{a}	4.97 ± 1.10^{a}	4.33 ± 0.80^{de}	4.63 ± 1.16^{bc}
CCl-20 %	4.97 ± 1.16^{b}	4.37 ± 1.33^{a}	4.57 ± 1.55^{a}	4.83 ± 1.30^{a}	4.10 ± 0.80^{de}	4.80 ± 1.13^{c}
CCl-30 %	5.13 ± 1.17^{b}	4.30 ± 1.66^{a}	4.47 ± 1.38^{a}	4.90 ± 1.67^{a}	4.23 ± 0.57^{cde}	4.40 ± 1.16^{bc}
CCl-40 %	5.27 ± 1.23^{b}	4.37 ± 1.16^{a}	4.57 ± 1.19^{a}	4.80 ± 1.22^{a}	3.57 ± 0.68^{cd}	4.43 ± 0.94^{bc}
CCl-50 %	4.77 ± 1.41^{ab}	4.37 ± 1.22^{a}	4.40 ± 1.22^{a}	4.63 ± 1.33^{a}	3.07 ± 0.74^{ab}	3.70 ± 1.37^{a}

Sensory evaluation scores for flowability, sourness, sweetness, spiciness, bitterness, and overall acceptability of the sauces with varying levels of KCl and $CaCl_2$ substitution. Values are given as mean ± standard deviation (n=30). Values with different superscripts indicate significant differences ($p < 0.05$) between samples

receptors associated with bitterness, which explains the decreased acceptability at higher $CaCl_2$ substitution levels (Grummer et al. 2012). This suggests that while $CaCl_2$ can be used as a partial NaCl substitute, its levels should be carefully controlled to avoid adverse sensory impacts. The integration of sensory and physico-chemical data provides further insight into the challenges of using $CaCl_2$ as a salt substitute. The increased syneresis and reduced viscosity observed in the physico-chemical analysis contribute to a less favourable texture and mouthfeel, which, combined with the bitterness from $CaCl_2$, leads to lower consumer acceptability. To mitigate these negative effects, manufacturers seeking to reduce sodium content while maintaining consumer acceptance may consider using flavour masking agents or blending $CaCl_2$ with other less bitter substitutes (Grummer et al. 2012). Additionally, adjusting the levels of other ingredients, such as sugar or vinegar, might help counter balance the bitterness and improve the sauce's overall sensory profile.

COLOUR EVALUATION

The colour of sweet Thai chili sauce is a critical sensory attribute that affects consumer perception and acceptability, as consumers often associate the vibrant red-orange hue with product freshness and flavour intensity (Ketkaew, Wongthahan & Sae-Eaw 2021). In this study, the colour of the sauces was measured using a colorimeter, and the results were expressed in terms of L* (lightness), a* (red-green), and b* (yellow-blue) values (Figures 5 & 6).

The substitution of NaCl with KCl and $CaCl_2$ had noticeable effects on the colour parameters of the sauce. Specifically, increasing levels of KCl substitution led to a slight decrease in L* values, indicating a marginal darkening of the sauce. This could be due to interactions between KCl and other ingredients, which may slightly alter the colour pigments. Despite this darkening, the a* and b* values remained relatively stable, suggesting that the overall hue, characterized by its red and yellow tones, was largely preserved. These findings align with previous studies where KCl substitution did not significantly alter the colour profile of food products (Morales & Jiménez-Pérez 2001; Ranganna 1986). However, even slight darkening could potentially affect consumer perception, as studies have shown that minor alterations in product appearance can significantly influence purchasing decisions (Ketkaew, Wongthahan & Sae-Eaw 2021). On the other hand, the substitution with $CaCl_2$ had a more-pronounced impact on colour, particularly at higher substitution levels. A decrease in both L* and b* values was observed, indicating a darker and less yellow sauce. This reduction in b* values suggests that $CaCl_2$ might be affecting the carotenoid pigments responsible for the yellow-orange colour in chili sauce. The alteration in colour could negatively affect consumer perception, as the vibrant appearance of sweet Thai chili sauce is one of its key sensory attributes (Ladrón de Guevara et al. 2002; Morales & van Boekel 1998; Topuz, Feng & Kushad 2009). The changes in colour can be attributed to the interaction of calcium ions with the colour pigments in the sauce, potentially leading to precipitation or altered light absorption properties.

While KCl's impact on colour was minimal, likely due to its closer resemblance to NaCl in ionic behaviour, the more substantial impact of $CaCl_2$ suggests that it may not

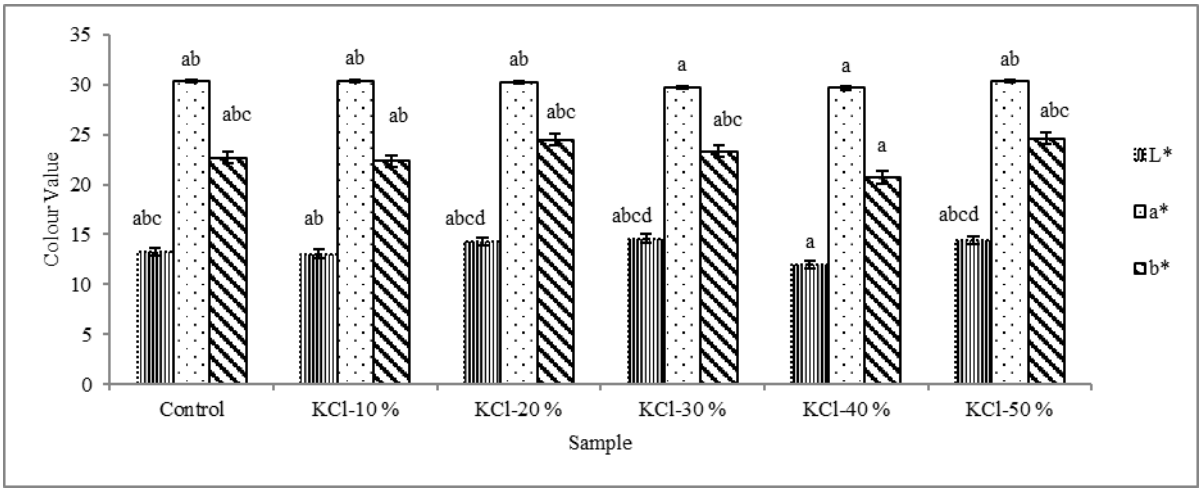

FIGURE 5. Colour measurements of sweet Thai chili sauce with potassium chloride (KCl) substitution. The figure shows the impact of KCl substitution on the colour parameters (L*, a*, and b* values) of sweet Thai chili sauce. L* represents lightness, a* indicates the red-green axis, and b* reflects the yellow-blue axis

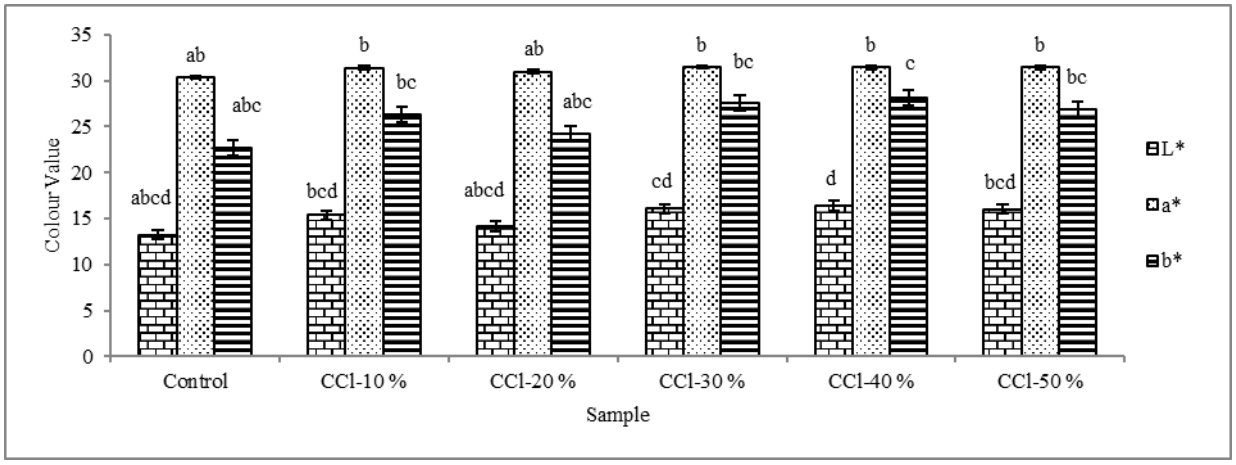

FIGURE 6. Colour measurements of sweet Thai chili sauce with calcium chloride ($CaCl_2$) substitution. The figure presents the colour measurements (L*, a*, and b* values) for sauces with different levels of $CaCl_2$ substitution

be suitable for products where colour retention is crucial. From a consumer acceptance perspective, the slight darkening caused by KCl substitution may not significantly impact the overall appeal of the sauce. However, the more pronounced colour changes with $CaCl_2$ could be a deterrent, especially if the sauce appears less vibrant. Sensory studies emphasize the importance of colour in the initial acceptance of food products, reinforcing the need for manufacturers to consider these effects when reformulating products (Gómez-García & Ochoa-Alejo 2013; Rattanathanalerk, Chiewchan & Srichumpoung 2005; Topuz, Feng & Kushad 2009). To mitigate the colour changes associated with salt substitution, manufacturers could explore the use of natural colour stabilizers or antioxidants to help preserve the sauce's vibrant appearance. Additionally, careful formulation adjustments may allow for reduced sodium content without sacrificing the product's visual and sensory appeal.

CONCLUSIONS

The study demonstrates that potassium chloride (KCl) can effectively replace up to 50% of sodium chloride (NaCl) in sweet Thai chili sauce without significantly compromising the sauce's physicochemical properties or sensory acceptability. Calcium chloride ($CaCl_2$), while a potential substitute, introduces challenges related to increased bitterness and reduced viscosity, suggesting that its use should be more limited. These findings provide a foundation for the development of reduced-sodium sauces that maintain consumer satisfaction while contributing to public health goals of reducing sodium intake.

ACKNOWLEDGMENTS

We wish to thank the Food Technology Division, School of Industrial Technology, Universiti Sains Malaysia, especially the laboratory assistants for their excellent assistance in making this research a success. We declare no conflict of interest to disclose.

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