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Bioactive Compounds and Nutrition of Thai Sauces in Retort Pouch and Physicochemical Properties Kinetics During Storage

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Abstract

The objectives of this study were to investigate the bioactive compounds, including carotenoids, flavonoids, total phenolics, antioxidant activity, and nutritional values of two ready-to-cook Thai sauces of stir-fry curry sauce (SCS) and spicy-sour sauce (SSS) in retort pouch and to investigate the kinetics of physicochemical properties, including lightness (L*), water activity, pH and total soluble solids, of the products during storage at 30°C and 55°C. The results showed that the temperature and time for sterilization of SCS (low acid foods) was 121°C for 43 minutes and SSS (acid foods) was 102°C for 31 minutes. The moisture content was between 57.9 and 63.2%. SCS had higher total fat, saturated fat, and calories because it contained soybean oil and chili paste, but SSS had higher sugar and sodium content than SCS. Trans fats and vitamin C were not detected in either product. SSS had a higher content of total phenols, carotenoids (especially capsanthin, zeaxanthin, and β-carotene) and antioxidants than SCS. The representation of the physicochemical properties of the products as a function of temperature and time resulted in a linear model (R^2 = 0.7222 – 0.9772). L*, water activity, pH decreased, and TSS increased during the 90-day storage at both 30°C and 55°C. The change was more remarkable when stored at 55°C than 30°C.

Keywords: *bioactive compounds; nutrition; kinetics; ready-to-cook; retort pouch; Thai sauce*

1. Introduction

Thai cuisine is internationally renowned and has gained popularity worldwide. It is appreciated for its bold flavors, fresh ingredients, and vibrant presentation. The popularity of Thai cuisine is due to its unique and diverse culinary offerings that cover a wide range of tastes and preferences. In addition, it is known for its vibrant flavors and aromatic herbs. Many herbs contain various bioactive compounds, including phytochemicals, antioxidants, and essential oils, which can positively affect human health (Guiné, & Gonçalves, 2016).

Stir-fry curry or “pad pong kari”, is a Thai dish that combines the flavor of fried seafood or meat with a creamy curry sauce. Garlic is one of the main ingredients in curry dishes because it adds an extra spicy flavor that complements the other ingredients. Garlic is associated with various health benefits due to its high nutritional content and potential bioactive compounds. One of garlic’s best-known and studied bioactive compounds is allicin, but several others that contribute to its potential health effects. Allicin is a sulfur-containing compound responsible for the characteristic odor of garlic when crushed or minced. It is known for its antimicrobial and potential cardiovascular benefits (Prati et al., 2014). Garlic contains several flavonoids, including quercetin and kaempferol, known for their antioxidant and anti-inflammatory properties. These compounds may contribute to garlic's potential cardiovascular and anti-cancer effects. Spicy and sour, or "Namtok", is a northeastern Thai dish. It is a spicy and flavorful Thai salad of grilled or pan-fried slices of meat, typically pork or beef, thinly sliced and served with a spicy and tangy dressing. Lemongrass and galangal are two flavorful ingredients in this menu, commonly used in Thai cuisine. Lemongrass is known for its distinct citrus aroma and flavor. In addition to its culinary uses, lemongrass is also believed to have potential health benefits, although scientific research is ongoing, and not all claims are fully substantiated. Lemongrass essential oil contains a considerable amount of numerous bioactive compounds, such as citral, isoneral, isogeranial, geraniol, geranyl acetate, citronellal, citronellol, germacrene-D, and elemol (Mukarram et al., 2021). These compounds are known for their antioxidant and possibly anti-inflammatory properties. Galangal contains several bioactive compounds contributing to its unique flavor, aroma, and potential health benefits. It contains a variety of polyphenolic compounds, including phenolic acids and flavonoids. The essential phytochemicals in the rhizome of galangal are phenolic compounds, polyphenols, flavonoids, saponins, phenylpropanoids, glycosides, diarylheptanoids, sesquiterpenes and diterpenes (Aljobair, 2022). These are known for their potential health benefits, including antioxidant and anti-inflammatory properties.

Ready-to-cook sauces have become even more diverse and widely available in recent years to accommodate a variety of tastes and dietary preferences. Ready-to-cook sauces are convenient, pre-made sauces that require minimal preparation before use. These sauces simplify cooking by providing a pre-seasoned base for various dishes. They usually come in packets and are available at supermarkets or grocery stores. A retort pouch is a package that can withstand high temperatures and is often used to store ready-to-cook sauces. The physical properties of ready-to-cook retort sauces can change during storage for various reasons, including time, temperature, and the composition of the sauce. Food quality during storage can be predicted using kinetic models of transient changes in quality parameters (Poonnakasem, 2021). Kinetic models help in optimizing processes by predicting the dynamic changes in quality parameters over time. This information can be used to identify the optimal conditions for a process, leading to improved efficiency and resource utilization. Interestingly, it is still questionable how the bioactive compounds and nutritional value of ready-to-cook Thai sauces in retort pouches and physicochemical properties change during storage.

2. Objectives

The work aimed to investigate bioactive compounds, including carotenoids, flavonoids, total phenolics, antioxidant activity, and nutrition of two ready-to-cook Thai sauces of stir-fried curry sauce (SCS) and spicy-sour sauce (SSS) in retort pouch and study the physicochemical properties kinetics, including pH, total soluble solid, water activity, color; of products during storage.

3. Materials and methods

3.1 Thai sauces recipe and production

The raw materials for stir-fried curry sauce were condensed milk (Nestle Carnation) (35%), soybean oil (Cook) (10%), oyster sauce (Tra Mae Krua) (10%), water (10%), chili paste (Chuahahseng) (8%), garlic (8%), sugar (Mitr Phol) (5%), curry powder (Waugh's) (5%), fish sauce (Tiparos) (4%), soy sauce (Deksomboon) (4%), and pepper powder (Raitip) (1%). To prepare the curry sauce, the oil was heated and add the garlic. The sauce was stir-fried until fragrant and added curry powder, condensed milk, water, chili paste, oyster sauce, fish sauce, soy sauce, sugar, and pepper. Spicy and sour sauce was made from tamarind juice (Taladthai) (35%), fish sauce (Tiparos) (35%), lemongrass (15%), galangal (5%), sugar (Mitr Phol) (5%), chili powder (Raitip) (5%). For preparing, all ingredients were mixed and heated until boiling.

The sauces were filled hot (temperature above 85°C), and the package weight was 160 grams/package in a retort pouch. The pouch used is 45 mm thick and has an outer layer of polyester, the second layer is nylon, the third layer is aluminum foil, and the fourth layer is polypropylene. The packages were heat sealed and contained in a retort (OFM-horizontal steam-water spray retort, owner foods machinery, Thailand). The temperature and duration of SCS and SSS sterilization process were 121°C for 43 minutes and 102°C for 31 minutes, respectively. The F_0 and F^{16}_{200} values of SCS and SSS are 6 and 10, respectively. After cooling, the products were analyzed for their nutritional value and bioactive substance.

3.2 Nutritional analysis

3.2.1 Proximate analysis

Moisture analysis was performed using the hot air oven at 105°C, with sand been soaked and rinsed with acid (AOAC method 990.19 and 925.23, 2016). Crude protein analysis was conducted using the Kjeldahl method (AOAC method 991.20 and 981.10, 2016). Crude fat analysis used the acid hydrolysis and solvent extraction method (AOAC method 922.32 and 945.16, 2016). Ash analysis used the dry ashing method (AOAC method 945.46 and 930.30, 2016). Total dietary fiber analysis was conducted using the enzymatic-gravimetric method (AOAC method 985.29, 2016). Finally, carbohydrate and energy content were calculated by subtracting moisture, protein, fat, and ash contents from 100%.

3.2.2 Mineral

Analysis of calcium and sodium used Atomic Absorption Spectrometry (AAS) (AOAC method 985.35, 2016), iron used Inductively Coupled Plasma (ICP) (AOAC method 984.27, 2016), and phosphorus used the gravimetric method (AOAC method, 2016).

3.2.3 Total sugar

Analysis of various types of sugars used high-performance liquid chromatography (HPLC) (AOAC method 980.13, 2016).

3.2.4 Saturated fatty acid

Analysis of fat content used gas chromatography (GC) (AOAC 969.33 and 963.22, 2016) and involved the extraction of fat from the sample.

3.3 Bioactive compounds analysis

3.3.1 Total phenolics

Total polyphenols were analyzed using the Folin-Ciocalteu method (Wiriya et al., 2009). The abbreviated method involved extracting the sample and using the extract to analyze the total polyphenols by the Folin-Ciocalteu assay. The absorbance at a wavelength of 760 nanometers was measured. The results were then compared to a gallic acid standard (expressed as gallic acid equivalents; GAE).

3.3.2 Phenolic acid

Phenolic acids were analyzed using the HPLC connected to a photodiode array detector (Merken, & Beecher, 2000). Four standard phenolic acids were commonly analyzed, including vanillic acid, syringic acid, p-coumaric acid, and ferulic acid. To quantify the flavonoids and each type of phenolic acid, they could be compared to standard curves constructed at wavelengths of 280, 325, and 338 nanometers.

3.3.3 Carotenoids

Carotenoids were analyzed using HPLC with a photodiode array detector (Ismail, & Fun, 2003). To determine the types of carotenoids, the retention time and spectrum were compared to standard reference compounds. The following were the six standard reference compounds commonly used for carotenoid analysis: Lutein, Zeaxanthin, β-Cryptoxanthin, Capsanthin, α-Carotene, and β-Carotene. Quantify the amount of each type of carotenoid by constructing a standard curve at a wavelength of 450 nanometers.

3.3.4 Antioxidant activity

Antioxidant activity was conducted in the laboratory (in vitro testing), performed through methods such as the DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging activity assay and the Oxygen Radical Absorbance Capacity (ORAC) assay, using spectrophotometry.

3.4 Storage experiment

The sauces in retort pouches were stored at ambient temperature (30 ± 1 ºC) and accelerated temperature, for the purpose of expediting the aging process of a product (55 ± 1 ºC) for 0, 30, 60, and 90 days before being measured for their physicochemical properties. Kinetics modeling of all responses was used to estimate the product.

3.5 Physicochemical properties analysis

3.5.1 Color

A Handy Colorimeter (Mini Scan EZ (MSEZ −4500 L model, USA) was used to measure the lightness (L*) of the sauces.

3.5.2 Water Activity

Thai sauces' water activity was measured at 25 ± 1 ºC, using a water activity meter (Decagon, AquaLab PRE, USA).

3.5.3 pH

The pH was recorded using a pH meter (Mettler Toledo, FE20 FiveEasy™ pH, USA) for the sauces at 25 ± 1 C.

3.5.4 Total soluble solid

A refractometer Brix 0.0–45.0% (YH equipment, RHB -32ATC, China) was used to measure the total soluble solids of the sauces at 25 ± 1°C.

3.6 Kinetics modeling

Kinetic assessment of reactions involves the study of the rate and mechanisms by which one chemical species transforms into another. Food quality changes were calculated using equation (1); (Kumar et al., 2006).

$$\frac{\pm dQ}{dt} = kQ^n \quad (1)$$

where Q is the quality characteristic, t is the reaction time, k is the rate constant, and n is the order of reaction.

For most foods, the time dependence relationships appear to be described by zero- or first-order models (Chen, & Ramaswamy, 2002). For zero-order reactions, the relationship between a quality characteristic and time is linear by substituting $n = 0$ into equation (2);

$$\frac{dQ}{dt} = k \quad (2)$$

Equation (2) can be integrated to obtain equation (3);

$$Q - Q_0 = kt \quad (3)$$

3.7 Statistical analysis

All physicochemical determinations and experiments were performed in triplicate. Analysis of variance (ANOVA) was performed and then the means of the results were compared by Duncan's multiple range tests (DMRT). A statistically significant difference was found at $P \leq 0.05$.

4. Results

Two Thai sauces were selected for this study, including stir-fry sauce (SCS) and spicy and sour sauce (SSS), which represent low-acid (pH > 4.6) and acid foods (pH ≤ 4.6), respectively. The temperature and time used to sterilize of SCS and SSS were 121°C for 43 minutes and 102°C for 31 minutes, respectively. Products with an acidic condition had a lower sterilization condition than those with low acidity. This is because the acidic condition specifically inhibits spore-forming bacteria, *Clostridium botulinum*, which can produce a neurotoxin called botulinum toxin, one of the most potent toxins known to humans (Nigam, & Nigam, 2010).

4.1 Bioactive compounds and nutrition of ready-to-cook Thai sauces in retort pouch

Table 1 showed that moisture was the majority of chemical composition in both Thai sauces, 57.9-63.2%. Total carbohydrate and proteins were 24.2 – 26.5% and 4.03 - 4.60%, respectively. SSS had a higher ash content (10.4%) than SCS, but SCS had a higher percentage of total fat (5.53%), resulting in a higher percentage of saturated fat (1.72%), calories (163 kcal) and calories from fat (49.8 kcal). No trans-fat was detected in either sauce. The sugar and sodium content of SSS was higher than that of SCS, about 2 and 4 times, respectively. The data on vitamins and minerals showed that the calcium content of SCS was 90.5 mg, the vitamin A content (β-carotene) in SSS was 67.2 ug RE, and no vitamin C was found in either product.

In the bioactive compounds data (Table 2), it was found that SSS had a higher total phenolic content (193 mg GAE) and a higher sum of carotenoids (2,139 mg) than SCS (62 mg GAE and 572 mg), which were about 3 and 4 times, respectively. SCS had 1.28 mg phenolic acid from 0.28 mg *p*-coumaric acid and 1 mg ferulic acid, while SSS had below the detection limit. For antioxidant data, SSS had both higher DPPH and ORAC than SCS.

4.2 Physicochemical properties kinetics during storage of ready-to-cook Thai sauces in retort pouch

The relationship between physicochemical properties, including L* (lightness), water activity, pH, and TSS (total soluble solids), and storage time was shown in Figure 1-4. It can be seen that L*, water activity, and pH decreased, and TSS increased during the 90-day storage at both 30 and 55°C. A zero-order response model best described the change in physicochemical properties of ready-to-cook Thai sauces in retort pouches over time, with the correlation coefficient (R^2) for all responses in the range of 0.7222 – 0.9772 (Table 3).

Table 1 Nutrition of Thai sauces in retort pouch

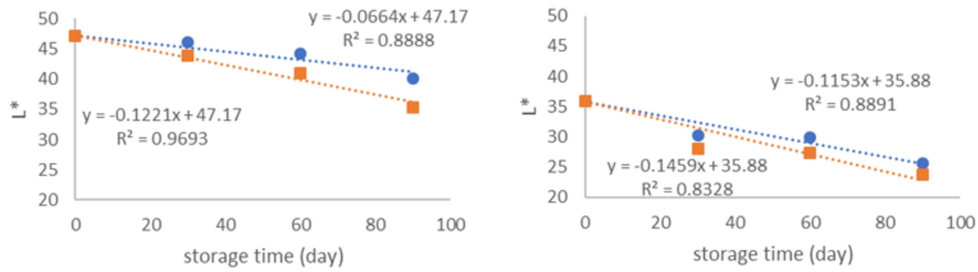
Nutrient (Amount per 100 g)	stir-fry curry sauce	spicy-sour sauce
Calories (kilocalories)	163	129
Calories from Fat (kilocalories)	49.8	5.04
Total Fat (g)	5.53	0.56
Saturated fat (g)	1.72	0.16
Trans Fat (g)	*ND*	*ND*
Cholesterol (mg)	1.93	*ND*
Protein (Nx6.25) (g)	4.03	4.6
Total Carbohydrate, Include DF (g)	24.2	26.5
Dietary Fiber (g)	1.85	2.63
Sugars (g)	12.6	23.7
Sodium (mg)	1091	4104
Vitamin A (β-carotene) (ug RE)	17.5	67.2
Vitamin B 1 (mg)	0.02	0.03
Vitamin B 2 (mg)	0.17	0.06
Calcium (mg)	90.5	26.8
Iron (mg)	2.09	1.78
Vitamin C (mg)	*ND*	*ND*
Ash (g)	3.08	10.4
Moisture (g)	63.2	57.9

Remark: * Not Detected at a lower detection limit

Table 2 Bioactive compounds of Thai sauces in retort pouch

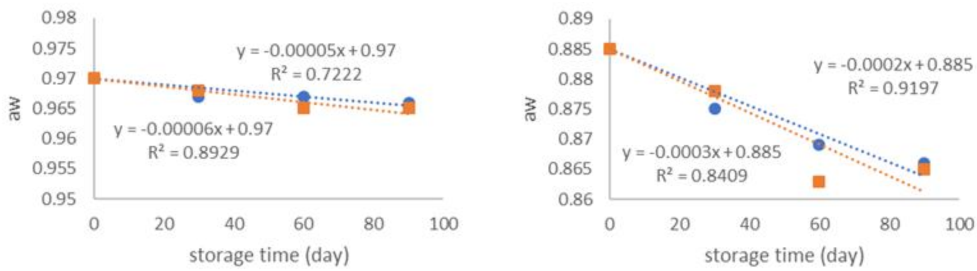
Bioactive compounds	stir-fry curry sauce	spicy-sour sauce
Total phenolics (mg GAE/100 g)	62	193
Phenolic acid (mg/100 g):		
- Vanillic acid	*ND*	*ND*
- Syringic acid	*ND*	*ND*
- *p*-Coumaric acid	0.28	*ND*
- Ferulic acid	1	*ND*
- Sum	1.28	*ND*
Carotenoids (mg/100 g):		
- Capsanthin	173	568
- Lutein	64	203
- Zeaxanthin	122	647
- β-cryptoxanthin	53	173
- α-carotene	5	11
- β-carotene	154	536
- Sum	572	2139
Antioxidant (mmol TE/100 g):		
- DPPH	275	767
- ORAC	1170	1613

Remark: * Not Detected at a lower detection limit



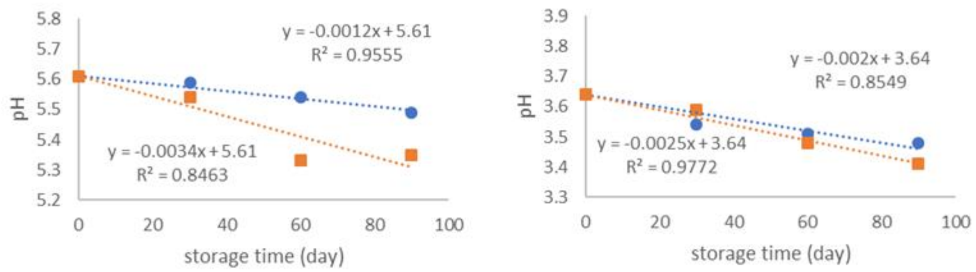
(a) (b)

Figure 1 Change of Lightness (L*) of SCS (a) and SSS (b) during storage at 30ºC (●) and 55ºC (■)



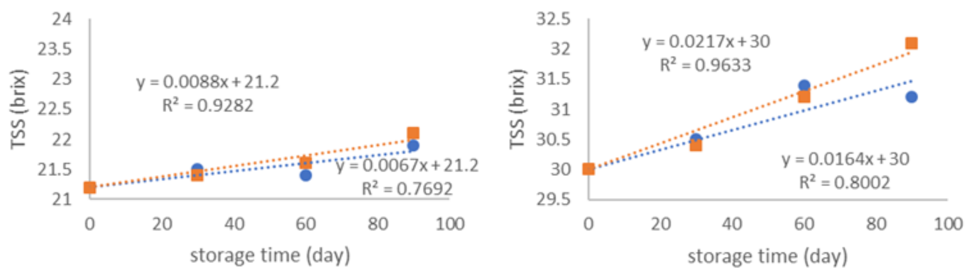
(a) (b)

Figure 2 Change of water activity of SCS (a) and SSS (b) during storage at 30ºC (●) and 55ºC (■)



(a) (b)

Figure 3 Change of pH of SCS (a) and SSS (b) during storage at 30ºC (●) and 55ºC (■)



(a) (b)

Figure 4 Change of total soluble solid (TSS) of SCS (a) and SSS (b) during storage at 30°C (●) and 55°C (■)

Table 3 Kinetics information of the physicochemical properties' kinetics during storage of ready-to-cook Thai sauces in retort pouch

Physicochemical properties	stir-fry curry sauce		spicy-sour sauce	
	30 °C	55°C	30°C	55°C
L*				
Correlation coefficient: R^2	0.8888	0.9693	0.8891	0.8328
0^{th}-order constant: k_0 (day^{-1})	-0.0664	-0.1221	-0.1153	-0.1459
water activity				
Correlation coefficient: R^2	0.7222	0.8929	0.9197	0.8409
0^{th}-order constant: k_0 (day^{-1})	-0.0001	-0.0001	-0.0002	-0.0003
pH				
Correlation coefficient: R^2	0.9555	0.8463	0.8549	0.9772
0^{th}-order constant: k_0 (day^{-1})	-0.0012	-0.0034	-0.0020	-0.0025
total soluble solid				
Correlation coefficient: R^2	0.7692	0.9282	0.8002	0.9633
0^{th}-order constant: k_0 (day^{-1})	0.0067	0.0088	0.0164	0.0217

5. Discussion

In this study, stir-fry curry sauce (SCS) (low-acid food) and spicy-sour sauce (SSS) (acid food) were selected as ready-to-cook Thai sauces in retort pouches using appropriate sterilization conditions, i.e., time and temperature, to destroy or eliminate all forms of microbial life, including all bacteria, especially spore-forming bacteria. It is intended to guarantee that no viable bacteria survive in products and represents the most significant level of microbial control. Because Thai sauces are meant to be used as ready-to-cook foods, the nutrition analysis in the retort pouch showed that moisture made up the most of the composition in both sauces—more than 50%. The primary components of SSS were fish sauce and tamarind juice (total 70%), and the main components of SCS were liquid condensed milk, soybean oil, and oyster sauce (total 55%). Because it contained soybean oil (10%) and chili paste (8%), SCS, used for stir-frying, had higher levels of total fat, saturated fat, and cholesterol. Calorie intake increased along with the fat content. Trans-fat, connected to a higher risk of heart disease and other health issues, was not found in either of the two products that could be said to have no trans-fat, and the sterilizing process did not affect the fat content of any ingredient. Furthermore, a higher quantity of calcium may result from the high percentage of condensed milk (35%) in the SCS formula. Tamarind juice, fish sauce, and sugar were the main seasonings in SSS. This resulted in higher sugar and sodium content and a distinct flavor profile for the menu. However, neither product contained any vitamin C. This could be due to the high heat utilized during sterilization in line with Koh et al. (2011) for tomato paste.

In terms of bioactive compounds, SSS had a higher total phenolic content (193 mg GAE), which was due to the main herbs: lemongrass (16%) and galangal (5%). Total phenolic content was previously studied for lemongrass (Adeyemo et al., 2018) and galangal (Aljobair, 2022). SCS containing 8% garlic had a total phenolic content of 62 mg GAE, 0.28 mg p-coumaric acid, and 1 mg ferulic acid, which was also previously reported for garlic (Alide et al., 2020, Kovarovič et al., 2019). The same trend was observed for carotenoids; SSS had a higher sum of carotenoids than SCS. This can be explained by the content of chili powder (5%) in SSS. These results followed the report of Giuffrida et al. (2014), which provided data on the sum of free carotenoids, capsanthin, zeaxanthin, and β-carotene in the powder of red chili peppers. Moreover, these bioactive compounds, total phenolics, and carotenoids, resulted in higher antioxidant effects of both DPPH and ORAC.

The kinetics of lightness (L*) during storage of ready-to-cook Thai sauces in retort pouches decreased during 90 days of storage (Figure 1). The change was greater when stored in pouches at 55°C than at 30°C, which was because the higher temperature resulted in a higher browning reaction. Specifically, the SCS containing 35% condensed milk exhibited a 2-fold change at 55°C compared to 30°C (Figure 1a), which is consistent with the reports of Sunds et al. (2018), who found that higher temperatures lead to an increased Maillard reaction rate in milk. However, in the present study, the water activity values of the two sauces remained close to those obtained after storage, indicating stability during storage at 30 and 55°C (Figure 2): 0.965-0.970 and 0.865–0.885 for SCS and SSS, respectively. A remarkable decrease in pH with increasing temperature was observed for both sauces during the 90-day storage period (Figure 3). The same pattern with L* was observed for SCS

(Figure 3a), which changed 3-fold at 55°C compared to 30°C. This could be due to the formation of formic acid in the intermediate stage and the degrading lactose can lead to the formation of organic acids (Sunds et al., 2018). In addition, casein micelles may undergo temperature-dependent dephosphorylation, and the association of dissolved calcium and phosphate with the casein micelle results in the release of protons, which lowers the pH (Gaucheron, 2005). In SSS, storage temperature affects L*, water activity, and pH to a lesser extent due to the lower complexity of ingredients. Over the 90 days of storage, the kinetics of TSS in Thai sauces increased (Figure 4). Because the higher temperature produced a higher response, there was a more considerable change when the sample was held at 55°C compared to 30°C. Mainly, the SSS contained 35% tamarind juice and 35% fish sauce (Figure 4b), which is in line with previous studies by Maia et al. (2021) on tamarind juice and Dagadkhair et al. (2016), who discovered that the hydrolysis and degradation of fat and carbohydrates may be the cause of the increase in TSS of fish sauce during storage.

6. Conclusion

The present study demonstrated the nutritional values and bioactive compounds of two ready-to-cook Thai sauces (SCS and SSS) in a retort pouch. The results showed that the temperature and time for sterilization of SCS (low acid food) was 121°C for 43 minutes, and SSS (acidic food) was 102°C for 31 minutes. This is because an acidic food is safe from *C. botulinum* if the heat process kills all organisms capable of growth at a pH of ≤ 4.6 and there is no contamination after the process. Sterilization of acidic foods requires less energy and time than low-acid food to produce safe ready-to-cook Thai sauces. The ingredients used in the sauces played an important role in nutrition and bioactive compounds. The moisture content accounted for the majority of the composition of both types of product, which was over 50% due to the use of ready-to-cook sauce. Other chemical compositions of the sauces varied depending on the ingredients, and the products were safe regarding trans fats. However, heat-sensitive vitamins such as vitamin C were not detected in either product. Thai herbs in the sauces of garlic, lemongrass, galangal, and chili related to the bioactive compounds. SSS showed a remarkably higher content of total phenolics, carotenoids, and antioxidants than SCS due to the presence of many herbs: lemongrass, galangal, and chili. During storage, the browning reaction was crucial for ready-to-cook Thai sauces. A linear model best described the relationship between the physicochemical properties of ready-to-cook Thai sauces in retort pouches for 90-day storage. L*, water activity, pH decreased, and TSS increased; the change was more significant when stored at 55°C than at 30°C. The work's findings suggest that there may be a good opportunity for commercial use in creating of ready-to-cook Thai sauces with prolonged shelf lives for distribution and home consumption using retort sterilization technology.

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