

Nutritional value and total quality of sour curry powder, the most popular southern Thailand dish

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Abstract

As cross-cultural interactions continuously transform global dietary habits, the traditional Japanese rice seasoning (furikake) offers an innovative blueprint for Thai food product development. Inspired by this concept, a novel instant Thai sour curry rice topping was formulated. This product successfully integrates a high-protein nutritional profile with superior consumer palatability and extended storage stability. Key ingredients for Southern Thai sour curry paste including hot chili (*Capsicum frutescens* L.), shallot (*Allium ascalonicum* L), garlic bulb (*Allium sativum* L), lemongrass (*Cymbopogon citratus* (DC.) Stapf), and salt were blended, mixed with pre-cooked fish meat and souring agents tamarind pulp (*Tamarindus indica* L.) and dried cowa leaves (*Garcinia cowa* Roxb. ex Choisy leaves), stir-fried, and subsequently dried to yield the instant product. Results revealed that the combination of tamarind pulp and dried *Garcinia cowa* Roxb. ex Choisy leaves as souring agents achieved the highest sensory acceptability (92%) and demonstrated high antioxidant activity. Nutritional analysis reveals that the final dehydrated product is rich in protein ($39.45 \pm 0.24\%$), while unsaturated fatty acids constitute a substantial portion ($5.59 \pm 0.05\%$) of the total lipid content ($9.62 \pm 0.08\%$). Furthermore, the sequential thermal treatment of stir-frying followed by hot air oven drying effectively minimized the microbial count, successfully complying with the safety standards established by the Thai FDA.

Keywords: traditional Japanese rice seasoning; Thai sour curry; *Garcinia cowa* Roxb. ex Choisy leaves; Hot air oven; Southern Thai sour curry paste

1 Introduction

The traditional Japanese rice seasoning condiment, Furikake, is a dry savory mixture of dried fish, seaweed, and sesame seeds, seasoned with salt, sugar, and MSG (Monosodium Glutamate). Used primarily as a topping for rice, vegetables, and seafood, it blends agricultural and livestock products to enhance both flavor and texture of a meal. Furthermore, ingredients like kat-

suobushi (Dried Bonito Flakes), dried salmon, shiso leaves (*Perilla frutescens*), egg, miso (fermented soybean paste), and vegetable powders are often added to diversify its flavor profile (Mahae et al., 2021). As a dry condiment, traditional Japanese rice seasoning offers excellent shelf stability. Drying techniques are highly favored in food processing because the reduction of moisture and water activity effectively controls microbial growth to prolong shelf life (Siripongvut-

tikorn, Usawakesmanee, et al., 2023). Furthermore, the heat applied during drying generates distinct and desirable flavors (Thamkaew et al., 2021; Wang, Liu, et al., 2024; Wang, Li, et al., 2023). This technological benefit aligns with modern consumer trends, like busy lifestyles, limited cooking skills, smaller families, while compact living spaces continue to accelerate the market demand for convenient, ready-to-eat products (Pisuchpen et al., 2024; Siripongvutikorn, Usawakesmanee, et al., 2023; Usawakesmanee et al., 2024). Modern social connections and advanced travel facilities heavily drive international food exchange and shift global consumption patterns. As a result, global dishes either spread widely in their original forms or are adapted and blended to satisfy local customer demands. A prominent example of this cultural integration is Japanese cuisine; it consistently ranks as one of the top ten most consumed international foods globally and holds a dominant position in the Thai food market. Subsequently, some food concepts and templates, as indicated by an insight marketing survey, were adopted and widely applied to many Thai products. Similarly, the Japanese have incorporated Thai ingredients or dishes, such as stirred-fried holy basil (Pad-Ka-pow), mixed spices soup with shrimp (Tom-Yum Kung), green curry in coconut milk (Green Curry), Thai-style grilled chicken (Kai-Yaang), and chicken topping on oily-rice (Kaw mun-kai), resulting from the crossover of food culture.

Backed by local wisdom and rigorous scientific research, cuisine serves as a powerful national asset. Globally, numerous countries leverage policies such as gastronomy tourism and gastronomy democracy to drive sustainability and elevate regional revenue (Siripongvutikorn, Pumethakul, Thantrirat, et al., 2025). Thailand stands out as a premier global destination celebrated for its exceptional hospitality, economic affordability, and rich diversity of regional cuisines. Southern Thai cuisine, for instance, exemplifies this through its distinct historical blend of Indian, Chinese, and Indonesian peninsular influences. Building on this momentum, Songkhla Province is currently undergoing preparations to secure its own designation within the UNESCO Creative Cities Network (UCCN) soon (Creative Songkhla City of

Gastronomy, 2025).

Empirical data from a regional survey in Southern Thailand indicates that Southern Thai sour curry (Kaeng Som) represents the primary dietary staple, with daily consumption exceeding 60% of the population. Driven by individual sensory preferences, health consciousness, and cultural familiarity, this dish is frequently consumed across consecutive daily meals. As illustrated in Figure 1, Southern Thai sour curry is distinguished from other regional Thai variants by its highly intense, multifaceted organoleptic profile characterized by a harmonious integration of sour, spicy, salty, and sweet notes and its distinctive yellow-orange aesthetic. Nevertheless, profound formulation disparities exist across different geographical localities and individual households (Siripongvutikorn, Pumethakul, Yupanqui, et al., 2024), as detailed in the supplementary material. From a biomedical and nutritional standpoint, clinicians and dietitians frequently endorse Southern Thai sour curry as a therapeutic dietary intervention for individuals requiring low-carbohydrate, hypolipidemic, or weight-management regimens. Crucially, the Southern variant exhibits the highest pungency index among all regional styles, primarily attributed to an elevated concentration of chili and pepper constituents (Caswell, 2025). Consequently, foreign consumers unaccustomed to high capsaicin thresholds should exercise caution when ingesting Southern Thai sour curries. Furthermore, while mixed spices soup and Southern Thai sour curries exhibit overlapping acidic and pungent volatile attributes, the latter is differentiated by a more robust and complex amalgamation of spicy notes. Conversely, mixed spices soup typically presents a more pronounced flavor matrix derived from galangal rhizomes (*Alpinia galanga* (L.) Willd.) and kaffir lime leaves (*Cymbopogon citratus* (DC.) Stapf leaves). This culinary versatility of Southern Thai sour curry is further exemplified by regional adaptations that incorporate diverse fermented matrices, including bamboo shoots, coconut hearts, and Palmyra sap vinegar. Such cross-cultural dietary adaptability is also evident among Thai expatriates residing globally (e.g., in North America, Europe, or South Korea), who effectively substitute traditional components with localized ingredients like

kimchi (Korean fermented vegetables) to serve simultaneously as a souring agent and a vegetable base (Figure 2). These observations, corroborated by qualitative interviews and preliminary culinary assessments, validate the highly dynamic nature of traditional food preparation frameworks. Ultimately, culinary cultures possess the capacity for seamless modification and adaptation, facilitated by the strategic deployment of localized raw materials, indigenous adaptive wisdom, creative innovation, and the technical resourcefulness of the practitioner.

Medical professionals and dietitians advocate Southern Thai sour curry as a therapeutic dietary intervention for managing metabolic disorders, including obesity, constipation, diabetes, and hypertension. This clinical endorsement is underpinned by the abundance of bioactive phytochemicals within the curry paste matrices, alongside a favorable nutritional profile characterized by high dietary fiber, low lipid density, easily digestible carbohydrates, and substantial protein levels (Figure 1). Concurrently, global food markets are experiencing an escalation in cross-cultural culinary hybridization and tactical gastronomic utilization. Modern consumer demographics increasingly demand innovative, ready-to-prepare, and health-optimized food products, with a behavioral shift accelerated by ubiquitous digital connectivity, demanding lifestyles, and a contraction in traditional culinary skills (Siripongvutikorn, Usawakesmanee, et al., 2023). Catalyzed by these transnational cultural exchanges, health trends, and shelf-life optimization requirements, novel functional iterations derived from traditional heritage foods are increasingly penetrating premium market segments as multi-purpose seasonings and rice toppings. Within this domain, Japanese rice seasoning represents a benchmark household staple with universal appeal that successfully transcends generational boundaries.

Building upon this paradigm, the present study aims to innovate by transforming Southern Thai sour curry, the region's apex traditional dish, into a shelf-stable, convenient Japanese rice seasoning-style condiment. To execute this, pre-cooked fish and authentic Southern Thai sour curry paste were homogenized, thermally processed, and subsequently dehydrated. The com-

prehensive quality attributes of the developed formulation encompassing its physical, chemical, microbiological, and organoleptic profiles were systematically evaluated, as delineated in the experimental framework (Figure 3).



(a) Southern Thai style



(b) Central Thai style



(c) Northern Thai style



(d) Northeast Thai style

Figure 1: Characteristic and appearance of a sour curry dish from 4 parts of Thailand.



Figure 2: Cooking sour curry dish from Korean fermented vegetables, Kimchi.

Besides serving as a low calorie dish, ingredients used in the Southern Thai sour curry are sources of phytochemicals providing several health benefits including antioxidant, antimicrobial, and gut health benefits as shown in Table 1.

Therefore, this experiment aimed to create and market test a popular sour southern Thai dish.

The whole framework of this experiment is shown in Figure 3.

Table 1: Major phytochemical compounds and biological activity in each used ingredient of southern Thai sour curry paste

Spices/ used part	Phytochemicals	Biological activity	Mode of action	Reference(s)
Garlic/bulbs (<i>Allium sativum</i> L)	Allicin, alliin, ajoene, flavonoids, phenolic acids, and essential oils	Exhibits antioxidant and antimicrobial properties as well as taste enhancement in meat and meat product. Contains prebiotic as oligosaccharides (fructan), helping gut microbiota function.	Scavenge free radicals and inhibits lipid peroxidation, lower high blood sugar levels, lower the risk of cardiovascular illnesses, antidiabetic, antitumor, antiviral, anti-inflammatory, and antimicrobial properties.	(Arreola et al., 2015; Bayan et al., 2014; Beato et al., 2011; Bhatwalkar et al., 2021; Borlinghaus et al., 2014; Dianat et al., 2013; Dini et al., 2011; Farhat et al., 2021; Hazzaa et al., 2020; Kallel & Chaabouni, 2017; Khanum et al., 2004; Lolok et al., 2019; Lu et al., 2021; Mishra & Patel, 2020; Rouf et al., 2020; Sabikun et al., 2021; Santhosha et al., 2013; Shang et al., 2019; Tresina et al., 2022; Yin, Ren, et al., 2018)
Shallot (<i>Allium ascalonicum</i> L)	Quercetin, catechin, apigenin, ajoene, gallic acid, sapogenin, thiosulfinates, and kaempferol	Possesses strong antioxidant, anti-inflammatory effect and antidiabetic potential as well as liver cancer protection.	Neutralizes free radicals and modulates inflammatory pathways.	(Bhattacharjee, 2013; Hosseini et al., 2017; Mohammadi-Motlagh et al., 2011; Moradi et al., 2013; Omoba et al., 2022; Raeisi et al., 2016; Sittisart et al., 2017; Yin, Hsu, et al., 2003)
Chili (<i>Capsicum frutescens</i> L.)	Capsaicin, ascorbic acid, beta-carotene, vitamin E and fatty acids particularly linoleic acid containing mainly in chili seed and omega-3 containing in the pulp	Demonstrates antioxidant, analgesic, and anti-inflammatory activities, enhances food flavor and stimulates appetite, also triggering bodily reactions to pungency, food colorant and pest control	Inhibits oxidative stress and modulates pain receptors, once integrated into cells. Omega-3 regulates various metabolic signals and protects against inflammation and tumor development.	(Azlan et al., 2022; Gladine et al., 2012; Hwang et al., 2014; Jang, Choi, et al., 2024; Simon & Tesfaye, 2014; Sora et al., 2015; Wahyuni et al., 2013)
Turmeric (<i>Curcuma longa</i> L.)	Curcumin, demethoxycurcumin, and bisdemethoxycurcumin, curcumin-O-glucuronide and Isorhamnetin along with other compounds like volatile oils, flavonoids, and terpenoids, contributing to its medicinal properties. Zingiberene and other terpenes (Ar-turmerone, Alpha-atlantone) found in turmeric oil	Known for its potent antioxidant, anti-inflammatory, antimicrobial properties and anticancer as well as antidiabetic, neuroprotective and wound healing. Known as a worldwide food colorant and flavorant, and as an essential ingredient in several cosmetics.	Scavenges and helps neutralize reactive oxygen species and inhibits oxidative enzymes. Its anticancer properties stem from regulating immune factors like cytokines, COX-2, and ROS. Additionally, it suppresses various oncogenic molecules and signalling pathways, including NF- κ B, JNK, and STAT3, to inhibit tumor growth.	(Fu et al., 2021; Fuloria et al., 2022; Maiti & Dunbar, 2018; Sabir et al., 2021; Shehzad et al., 2013; Sulaymanov et al., 2024; Zoi et al., 2021)

Table 1 (continued): Major phytochemical compounds and biological activity in each used ingredient of southern Thai sour curry paste

Spices/ used part	Phytochemicals	Biological activity	Mode of action	Reference(s)
Tamarind (<i>Tamarindus indica</i> L.)	Tartaric acid, acetic acid, citric acid, ascorbic acid, pectin, gums, parenchymatous fiber, phenolic acids and flavonoids excellent source of potassium	Organic acids are recognized for their antioxidant and anticarcinogenic activities. They serve as vital agents in managing malarial fever, neuroinflammation, and blood sugar levels, while also demonstrating clinical relevance in addressing viral infections such as COVID-19. Helps wound healing while potassium is essential for controlling the effect of sodium in the body; thereby regulating the heart rate and blood. Tamarind pulp is used as a food additive for improving the viscosity and texture of processed foods	Donates electrons to neutralize free radicals.	(De Caluwé et al., 2010; Merecz-Sadowska et al., 2023; Nyadoi & Abdullah, 2004; Perico et al., 2023; Rana & Sharma, 2018; Tavanappanavar et al., 2024)
cowa leave (<i>Garcinia cowa</i> Roxb. ex Choisy leaves)	Hydroxycitric acid, citric acid, ascorbic acid, tannins, xanthonones, phloroglucinols, polyprenylated benzophenone and cowa leave as well as kaempferol, vitexin, and isovitexin	Exhibits antioxidant, antimicrobial, antimalarial, anti-inflammatory, antidiabetic, and anticancer properties. Alleviates cough, fever, inflammation, infections, indigestion, and constipation, while improving blood circulation.	Chelation of metal ions and inhibition of lipid peroxidation.	(Kaennakam et al., 2015; Negi et al., 2008; Pathak et al., 2023; Phukhatmuen et al., 2020; Rahman & Panichayupakaranant, 2024; Rukachaisirikul et al., 2003; Yorsin et al., 2023)

2 Materials and Methods

2.1 Fish preparation

Barracuda or Sea pike (Sphyraenidae) was selected due to its higher meat yield (45%), fewer small bones, whiter flesh, and less fishy odor (Fig. 4, A) compared to other options like scombroid fish (e.g., tuna). After cutting off the head, guts, scales, and pectoral fin, as well as the fork tail, the trimmed fish was rubbed with salt to remove fish slime and washed with running tap water until there was no sign of slime (Fig. 4, B). Later, the clean fish was boiled in hot water at a ratio of 1:1 (fish: water) until the fish core temperature reached 85 °C (Fig. 4, C), as monitored by inserting a digital probe thermometer into the geometric center of the thickest part of

the fish meat. To minimize the fishy odor, 17% of lemongrass and 17% of garlic bulbs were added to 1 liter of hot water. Only fish meat was removed and used in the next step.

2.2 Curry paste preparation

The curry paste recipe is shown in Table 2. The used ingredients were trimmed, peeled off, or cut into a smaller size before weighing, and blended in a blender with speeds 1 (10,000–12,000 RPM), 2 (15,000–20,000) and 3 (25,000–40,000) until it became a paste as shown in Fig. 5. The paste and fish meat were weighed as shown in Table 3. The cooking oil (approximately 5% of total weight) was heated over medium heat at 40–45 °C. The mixture of curry pastes and fish meat was then



Figure 3: Framework and output experiment.

added and stirred until the core temperature reached approximately 60 °C for 15 minutes.

2.3 Drying process

The resulting mixture was distributed on a silicone mat and dried in a tray dryer at 65–70 °C until achieving a final moisture content of less than 10% (wet basis). A preliminary test found that ripened tamarind pulp and dried cowa leaves were to be selected for creating the popular Southern dish as a rice topping product due to consumer acceptability (with > 6.5/9) using a focus group of 7 people who are familiar with and regularly consume sour curry dishes at least 2 times a week. Thereafter, all formulas were set up, and the ingredients used in each group are shown in Table 2. Formula 3 was created based on the hypothesis that using mixed souring agents would lead to improved consumer acceptance or other benefits, for instance, antioxidant activity. The paste of each formula was stir-fried with vegetable oil before fish meat was added, and then vegetable oil was added during stir-frying until the temperature reached 85 °C for 5 min. The stir-fried samples were taken to dry in a hot air oven at 60–65 °C until moisture was less than 10% (wet basis).

Table 2: Ingredients used in each formula

Ingredient	Quantity (%)		
	Formula 1	Formula 2	Formula 3
Fresh chili (Jinda variety)	5.56	5.56	5.56
Dried chili (Jinda variety)	2.78	2.78	2.78
Garlic bulb (Chinese variety)	22.22	22.22	22.22
Shallot bulb (Thai variety)	22.22	22.22	22.22
Turmeric rhizome	9.26	9.26	9.26
Lemon grass	11.11	11.11	11.11
Palm sugar	7.41	7.41	7.41
Shrimp paste	7.41	7.41	7.41
Solar salt	0.93	0.93	0.93
Tamarind pulp	11.11	–	5.56
Dried <i>Garcinia cowa</i> Roxb. ex Choisy leaves	–	11.11	5.56
Total	100	100	100

2.4 Chemicals and reagents

The following HPLC-grade solvents were used: acetonitrile, acetic acid, and chloroform (RCI Labscan Co., Ltd., Bangkok, Thailand); formic acid and hydrochloric acid (Sigma-Aldrich, Inc., St. Louis, MO, USA); and methanol (Loba Chemie Pvt. Ltd., Mumbai, India). Analyti-

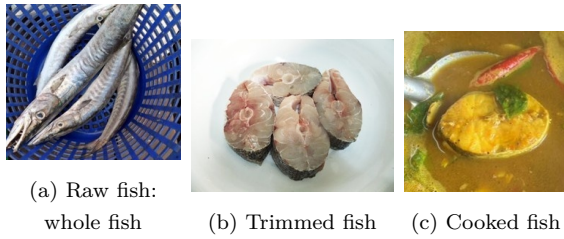


Figure 4: The used fish (Sphyraenidae) characteristic as whole (a), trimmed (b) and cooked

Table 3: Quantity of precooked fish meat and vegetable oil.

Ingredient	Quantity (%)		
	Formula 1	Formula 2	Formula 3
Fish meat	88.89	88.89	88.89
Vegetable oil	4.63	4.63	4.63

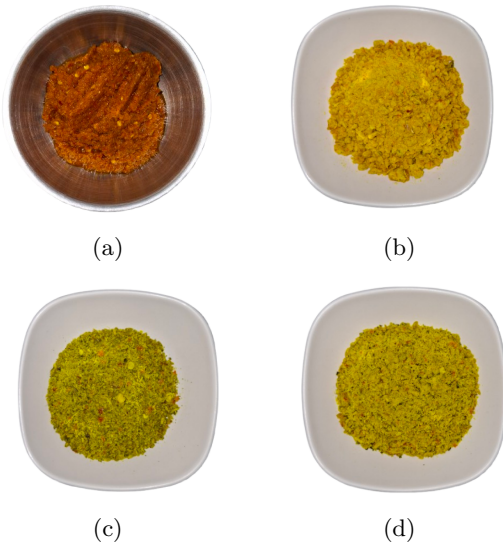


Figure 5: Characteristics of basic sour curry paste before souring agents were added and dried product (mixture of sour curry paste and cooked fish meat) (a), using dried tamarind pulp (b), using dried garcinia leaves (c) and using a mixture of (b) and (c) as souring agents (d).

cal reagent (A.R.) grade chemicals, including sulfuric acid (65%), nitric acid (65%), and silver nitrate, were obtained from RCI Labscan Co., Ltd. Ammonium iron(III) sulfate, copper(II) sulfate, and bromocresol green were supplied by Ajax Finechem Pty. Ltd. (NSW, Australia).

Other A.R. grade reagents, such as phenyl isothiocyanate, potassium sulfate, monosodium phosphate, and sodium acetate trihydrate, along with hydrogen peroxide, were purchased from Sigma-Aldrich, Inc. Hydrochloric acid and petroleum ether were sourced from J.T. Baker (Phillipsburg, NJ, USA). Additionally, trichloroacetic acid and triethanolamine were procured from Loba Chemie Pvt. Ltd., while methyl red and potassium thiocyanate were from QREC (Auckland, New Zealand). Methylene blue and boric acid were provided by Asia Pacific Specialty Chemicals and KemAus (Australia), respectively. Sodium hydroxide was of food-grade quality.

2.5 Physiochemical properties

The physicochemical properties water activity (a_w) and pH were determined in triplicate, following the methods of Vicent (2024). The a_w values were measured using a water activity meter (Aqualab Pre, Decagon Devices Inc., USA), and the pH values were recorded using a pH meter (Docu-pH+ Meter, Sartorius AG, Göttingen, Germany).

2.6 Color

Color profiles of the samples were assessed using a Color Flex EZ spectrophotometer (HunterLab Co., Ltd., USA). The device operated with a D65 illuminant at a 10° observer angle, following calibration against standard black and white tiles. Results were recorded in the CIELAB system as L^* (lightness), a^* (redness), and b^* (yellowness). To further analyze color variations, total color difference (ΔE^*) and chroma difference (ΔC^*) were determined using the following equations:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$$C^* = \sqrt{(a^*)^2 + (b^*)^2}$$

To determine ΔL^* , Δa^* and Δb^* the color parameters of each sample were compared against a white standard tile, which served as a baseline ($L^* = 93.55$, $a^* = -0.84$, $b^* = 0.37$).

2.7 Chemical composition analysis

The moisture, crude protein, crude fat, saturated fat, crude ash, cholesterol, and sugar contents of the sour curry powder were determined according to the standard methods of the Association of Official Analytical Chemists (AOAC) (Latimer, 2023). The contents of carbohydrate were measured according to standard methods of the Association of Official Analytical Chemists (1984).

2.8 Minerals

The determination of available minerals (K and Na) was measured according to standard methods of the AOAC (Latimer, 2023).

2.9 Antioxidant Activity

Preparation of sample extract

Sample was extracted following the method described by Shindia et al. (2024). Extraction was performed using 5 g of sample in 100 ml acidified ethanol (5% HCL), with magnetic stirring in the dark at 30 °C for 24 h. The mixture was then separated by vacuum suction using a Buchner funnel and centrifuged (CR22GIII, Hitachi, Japan) at $17,700 \times g$ at 4 °C for 15 min. An evaporator (N-1000, EYELA, Rikakikai, Japan) was used to vaporize ethanol to obtain a concentrated sample.

Total Phenolic content (TPC)

TPC was quantified by modifying the procedure described by Yingngam et al. (2015). Briefly, 0.2 ml of extract was mixed with 2.5 ml of distilled water and 0.2 ml of 10% (v/v) Folin–Ciocalteu reagent. After adding 2.0 ml of 7.5% sodium carbonate, the mixture was kept in darkness at 30 °C for 90 minutes. Absorbance was then recorded at 765 nm via a Spectroquant® Vis Prove 100 spectrophotometer (Merck KGaA, Germany). TPC values were expressed as mg gallic acid equivalent per gram of dry basis, using a calibration range of 0–150 $\mu\text{g mL}^{-1}$.

Total Flavonoid content (TFC)

The content of TFC was determined using a method adapted from Yingngam et al. (2015). First, 1.5 ml of each extracted sample was mixed with 1.5 ml of 2% aluminum chloride solution in a test tube and incubated further in the dark at 30 °C for 1 hr. Absorbance readings were taken at 420 nm with a Spectroquant® Vis Prove 100 spectrophotometer (Merck KGaA, Darmstadt, Germany). Rutin equivalent mg per gram of dry basis at a concentration of 0, 10, 20, 30, 40, and 50 ppm was made as standard agent.

2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay

The DPPH scavenging activity was assessed following the procedure by Kanlayavattanakul et al. (2012) with minor adjustments. A 96-well plate was utilized, maintaining an optical density (OD) between 0.2–0.8. In brief, 0.10 ml of sample or Trolox standard was mixed with 2.90 ml of 60 μM DPPH solution. After a 1 hr. incubation in darkness, absorbance was measured at 517 nm. The percentage inhibition was determined using a standard curve of Trolox concentrations.

2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid (ABTS) cation radical scavenging assay

ABTS radical scavenging was measured based on the method by Re et al. (1999) with minor changes. The ABTS stock solution was prepared by dissolving 0.0496 g of ABTS in 50 ml of deionized water, while 0.0166 g of potassium persulfate ($\text{K}_2\text{S}_2\text{O}_8$) was dissolved in 25 ml. Both were kept in darkness for 14–16 hr before being mixed at a 1:0.5 ratio. This mixture was then diluted 20-fold with deionized water to reach an absorbance of 0.7–1.0 at 734 nm using a Spectroquant® Vis Prove 100 (Merck, Germany). Finally, 0.10 ml of sample or Trolox was combined with 2.90 ml of the ABTS reagent and incubated for 20 minutes in the dark before reading. Results were compared against a Trolox standard curve (0–200 mg/l).

2.10 Microbial load

Determination of total viable count

Total viable count (TVC) was determined using an adapted version of the method by Speck (1984). Initially, a 25 g sample was blended with 0.1% phosphate-buffered saline (PBS) for homogenization. A 1 ml aliquot of each dilution was then used for the pour plate method, using roughly 15 ml of plate count agar (PCA). After the medium had solidified following gentle mixing, plates were kept at 35 °C for 48 hr. The resulting microbial populations were expressed as log colony-forming units per gram (log CFU/g).

Yeast and Mold Determination

Yeast and mold populations were determined following the modified Speck (1984) procedure. A 25 g sample was first homogenized using PBS. For the assay, 0.1 ml of each dilution was spread onto the surface of pre-solidified potato dextrose agar (PDA) using a sterile glass rod. After an incubation period of 3–5 days at 25 °C, the resulting colonies were quantified and expressed as log colony-forming units per gram (log CFU/g).

2.11 Sensory evaluation

Sensory evaluation was conducted using a Central Location Test (CLT) involving at least 50 target participants. Sour curry powder samples were served alongside plain rice and water. Using a 9-point Hedonic scale, subjects rated their preferences for appearance, color, aroma, texture, and overall liking. This study adhered to ethical guidelines under approval PSU-HREC-2023-008-1-1. Furthermore, product acceptance and purchase intent were evaluated, and the collected data were analyzed.

2.12 Fatty acid and Amino acid profile

The fatty acid and amino acid profile were determined following the methods previously described by Siripongvutikorn, Pumethakul, Thantrirat, et al. (2025).

2.13 Statistical analysis

A completely randomized design (CRD) was employed for physicochemical and microbiological analyses, while sensory data were evaluated using a randomized complete block design (RCBD). All experiments were performed in triplicate. Statistical differences were determined via ANOVA, followed by Tukey's post-hoc test ($p < 0.05$), using IBM SPSS Statistics version 22 (IBM Corp., Armonk, NY, USA).

3 Results and discussion

3.1 Physiochemical properties

The physical quality, yield, and pH of the product from each formulation are exhibited in Table 4. Formula 2 gave a significantly higher pH (4.49 ± 0.01) compared with Formula 1 which had a lower pH of 4.38 ± 0.03 . This variation is intrinsically linked to the distinct organic acid profiles inherent in each souring agent. *Garcinia cowa* Roxb. ex Choisy leaves contain several weak organic acids, including citric acid, hydroxycitric acid, oxalic acid, and phenolics compounds (Jena et al., 2002). Conversely, tamarind pulp contains mainly tartaric acid (8–18%) (Obulesu & Bhattacharya, 2011), acetic acid, citric acid, malic acid, oxalic acid, and phenolics (Mamathashree et al., 2024). It was noticed that the weight of dried *Garcinia cowa* Roxb. ex Choisy leaves used in this Formula was greater than that of tamarind pulp due to the less intense sour taste sensation. It is known that tartaric acid expresses a sour level score or index of 0.7 compared with HCl (Marcus, 2019). Therefore, any ingredient or food item containing more tartaric acid tends to give a stronger sourness sensation (Da Conceicao Neta et al., 2007). Consistent a_w measurements across the treatments demonstrate successful control of the drying parameters during production. With low moisture content (3.5%–3.8%), low a_w (0.164–0.184) and low pH (due to the added souring agent), this instant topping product has a high possibility for shelf-life extension (Dey & Nagababu, 2022; Mafe et al., 2024; Marques et al., 2020; Sweis & Cressey,

2018). It is well known that the lower the water activity, the slower the growth of microorganisms (like bacteria, yeast, and mold), resulting in longer food storage (Alegbeleye et al., 2022). Using dried *Garcinia cowa* Roxb. ex Choisy leaves in Formula 2 and the combination in Formula 3 (mixed tamarind and *Garcinia cowa* Roxb. ex Choisy leaves) seemed to result in a slightly higher yield (34.46% and 34.94%, respectively) compared with using tamarind pulp in Formula 1 (34.10%). This may be due to the higher fiber content (7–10%) and lower moisture content (5–6%) in the dried *cowa* leaves (Mongkontanawat & Phuangborisut, 2016; Shahid et al., 2022), while tamarind pulp had 2.5–3.5% fiber content and 18–20% moisture content, respectively (Kumar et al., 2017; Muzaffar et al., 2018).

3.2 Color

Incorporating dried *Garcinia cowa* Roxb. ex Choisy leaves in Formula 2 significantly reduced the lightness (L^*), redness (a^*), and yellowness (b^*) of the dried product, an effect attributable to residual chlorophyll retained in the leaf material. This retention of green pigmentation is best understood in light of the thermal sensitivity of chlorophyll, its degradation to pheophytin and other colorless derivatives is accelerated by heat, low pH, and extended processing time (Heaton & Marangoni, 1996; Koca et al., 2007), so any spice or leaf ingredient carrying chlorophyll into a stir-fried, acidified product is expected to lose most of its green color while retaining a residual hue that skews the overall CIELAB coordinates toward lower lightness and redness (Manolopoulou & Varzakas, 2016). This is consistent with the lower L^* and a^* values recorded for Formula 2, in which the dried leaves were exposed to both the acidic curry matrix and the combined stir-frying and hot-air drying steps.

To determine whether these color differences were sensorially meaningful rather than merely statistical, the total color difference (ΔE^*) was also evaluated. Based on the thresholds proposed by Joyner and Yadav (2015), a ΔE^* below 2.0 is considered unnoticeable to the naked eye, values between 2.0 and 3.5 represent a slightly noticeable change, and values exceeding 3.5 indicate a distinct and clearly perceptible difference. The

ΔE^* values obtained in this study were considerably higher than any of these thresholds, ranging from 69–76 across formulations (Table 4), confirming that the color differences among the samples are highly perceptible to the human eye.

These exceptionally large ΔE^* values carry a practical implication beyond simple visual distinction: color alone would allow consumers to differentiate products made with different souring agents without any instrumental assistance. This has direct relevance for product standardisation, since even minor shifts in the tamarind to dried *Garcinia cowa* Roxb. ex Choisy leaves ratio during commercial scale production could shift the perceived color category of the final rice topping. Color should therefore be treated as a critical quality parameter to be controlled during scale-up, rather than as a purely aesthetic attribute. Therefore, the utilization of *Garcinia cowa* leaves offers a superior extraction yield, enhanced cost-efficiency, and a higher concentration of beneficial phytochemicals (including dietary fiber, chlorophyll, and carotene) compared to tamarind pulp.

Table 4: Physical parameters, yield and pH determined in each formula.

Sample	Formula 1	Formula 2	Formula 3
L^*	63 ± 2^a	53 ± 2^c	59 ± 1^b
a^*	9.8 ± 0.5^a	4 ± 1^c	5.8 ± 0.4^b
Color b^*	70 ± 3^a	57 ± 3^c	62.5 ± 0.6^b
ΔE^*	76 ± 1^a	69 ± 2^c	71.6 ± 0.3^b
ΔC^*	70 ± 2^a	57 ± 3^c	63 ± 1^b
moisture ^{ns} (%)	3.6 ± 0.4	3.5 ± 0.1	3.8 ± 0.5
a_w ^{ns}	0.172 ± 0.014	0.164 ± 0.004	0.184 ± 0.018
pH	4.38 ± 0.03^b	4.49 ± 0.01^a	4.39 ± 0.001^b
Yield (%) ^(ns)	34.10 ± 0.42	34.46 ± 0.48	34.94 ± 2.06

Remark: Data are presented as mean $\pm$ standard deviation ($n = 3$). Within each row, distinct superscript letters indicate significant differences ($p < 0.05$), ns is no significant difference ($p > 0.05$).

3.3 Antioxidant Activity

Total polyphenolic content was notably higher in Formula 1 (11.5 ± 0.4 mg GAE/g db.) than in Formula 2 (4.3 ± 0.2 mg GAE/g db.), as shown in Table 5. Flavonoid content followed the same pattern. This is not entirely surprising given the

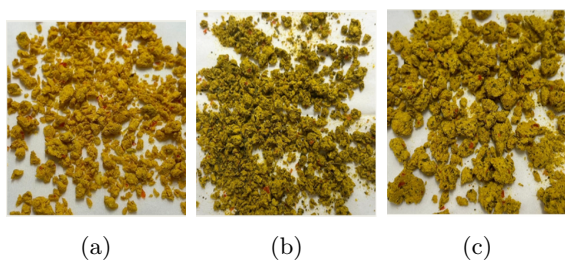


Figure 6: Characteristic of each dried product made from different formulae; (a) formula 1, (b) formula 2 and (c) formula 3.

inherently rich phenolic profile of tamarind pulp, which also contains several weak organic acids (tartaric, malic, and citric acid among them) that lower its pH to around 3–4 (De Caluwé et al., 2010; Nyadoi & Abdullah, 2004). Tamarind pulp also tends to darken during storage, and this non-enzymatic browning has previously been linked to increased antioxidant capacity in plant-based foods (Manzocco et al., 2000; Obulesu & Bhattacharya, 2011) which is a plausible additional contributor to its higher polyphenolic and flavonoid readings.

Dried *G. cowa* leaves by comparison, sit at a higher pH (4.5–5.2) and derive their acidity mainly from hydroxycitric acid rather than the tartaric acid dominant profile of tamarind. Despite their lower phenolic content overall, they outperformed Formula 1 on the ABTS assay (13.7 ± 0.8 mg TE/g db. versus a much lower DPPH value of 1.40 ± 0.01 mg TE/g db.) which is a result that runs counter to what the phenolic and flavonoid data alone would predict. One likely reason is that *G. cowa* leaves contain a mix of both hydrophilic and lipophilic bioactive compounds, whereas tamarind's antioxidant capacity derives mostly from hydrophilic sources (da Silva et al., 2024; Floegel et al., 2011).

The two assays are not measuring the same property, which helps explain this divergence. DPPH dissolves mainly in organic solvents and preferentially reacts with lipophilic antioxidants, whereas ABTS is soluble in both aqueous and organic media and captures a wider range of compounds (Kasote et al., 2019). Tamarind's hydrophilic acids and phenolics are therefore well captured by both methods, which accounts for the relatively balanced DPPH and ABTS val-

ues seen in Formula 1. *G. cowa* leaves by contrast, are rich in xanthenes and polyprenylated benzophenones moderately lipophilic compounds known for notable antioxidant activity (Wanna et al., 2023) which the broader-acting ABTS assay is better positioned to detect than DPPH, plausibly accounting for the disproportionately high ABTS relative to DPPH activity observed in Formula 2.

Taken together, these findings suggest that no single antioxidant assay can adequately characterise a multi-ingredient product like this curry paste. They also make a strong case for the Formula 3 approach: by blending both souring agents, the formulation can draw on tamarind's hydrophilic, DPPH-reactive fraction alongside the more lipophilic, ABTS-reactive fraction from the dried leaves. The result, as Table 7 shows, is not just a more balanced antioxidant profile across polarity ranges, but also better consumer acceptance than either single-agent formula achieved on its own.

3.4 Microbial load

As expected, the microbial quality of the formulated products passed all parameters following Thai FDA and Thai Industrial Standards Institute regulations, reflecting a sufficient thermal heating process together with adequate water activity reduction. Part of this antimicrobial effect is also likely contributed by the spices and herbs used in the formulation—*Cymbopogon citratus* (lemongrass), *Allium ascalonicum* (shallot), *Allium sativum* (garlic), *Citrus hystrix* (kaffir lime), *Curcuma longa* L. (cumin), and *Garcinia atroviridis* (Garcinia)—together with the high content of weak acids known to induce bacteriostatic and bactericidal effects (Kundukad et al., 2020). Volatile constituents from lemongrass, garlic, and shallot, along with the phenolic and terpenoid compounds present in turmeric and *Garcinia* species, are known to disrupt bacterial cell membranes, interfere with quorum-sensing and cell-division proteins, and deplete intracellular ATP; these actions work alongside, and reinforce, the acid-related hurdle already discussed for the souring agents (Li et al., 2022). Essential-oil components tend to partition into the lipid bilayer of microbial cells. Their effect would be ex-

Table 5: Phytochemicals, antioxidant activity of the formulated products.

Phytochemicals and antioxidant activity	Formula 1	Formula 2	Formula 3
Total polyphenolics (mg. Gallic equivalent /g db.)	11.5 ± 0.4 ^a	4.3 ± 0.2 ^c	10.2 ± 0.5 ^b
Total Flavonoid (mg. Rutin equivalent /g db.)	13.1 ± 3.8 ^a	7.0 ± 1.1 ^b	9.3 ± 2.2 ^{ab}
DPPH (mg. Trolox equivalent / g db.)	8.5 ± 0.2 ^a	1.40 ± 0.01 ^b	8.55 ± 0.04 ^a
ABTS (mg. Trolox equivalent /g db.)	8.0 ± 0.3 ^c	13.7 ± 0.8 ^a	12.20 ± 0.03 ^b

Remark: Data are presented as mean ± standard deviation ($n = 3$). Within each row, distinct superscript letters indicate significant differences ($p < 0.05$).

pected to be stronger once the surrounding matrix already has a reduced water activity and pH, since a membrane already under stress is less able to withstand further depolarising damage. Thermal lethality during stir-frying and hot-air drying, acid-driven cytoplasmic acidification, and spice-derived membrane disruption therefore appear to act together, which may explain why microbial counts remained consistently low and did not differ significantly across the three formulas or between production lots. This also points to the formulation itself, not only the drying step, contributing to protection against recontamination after processing, an advantage for a shelf-stable rice topping intended for storage and distribution at ambient temperature. Results from different work batches confirmed that the process was well controlled, with no significant differences found between lots; nonetheless, these laboratory-scale results would still need to be verified at pilot scale before further commercialization.

3.5 Sensory evaluation

Sensory evaluation of each sample is indicated in Table 7. In comparison to dried *Garcinia cowa* Roxb. ex Choisy leaves (Formula 2), using tamarind pulp (Formula 1) as a souring agent resulted in superior sensory ratings. Participants gave higher scores for Formula 1 across several parameters, including taste, color, appearance, and general acceptability. Interestingly, the combined agents (Formula 3) could improve the sensory score, making it comparable with the use of tamarind pulp. In addition, consumer acceptability increased from 84% (using tamarind pulp) or 60% (using the dried leaves)

to 92% when the combined Formula 3 was applied. This may be due to volatile aromas or some compounds remaining in the dried leaves that could reduce the fishy smell, which is a critical parameter for consumer preference, as shown in the acceptability data (Table 7). These observations are consistent with previous research by Wisootthipat et al. (2015), which demonstrated that specific souring agents, such as Salak, can effectively diminish unpleasant odors in shrimp paste. However, to better understand and form a solid conclusion, volatile and non-volatile compounds in fresh and dried forms of the souring agents used should be further investigated.

The sensory profiles can also be rationalised based on taste physiology. Sourness is transduced independently of the umami, sweet, and bitter pathways and the receptor mechanism itself responds differently depending on the acid and anion involved (Zhang, Jin, et al., 2019). So the intensity and quality of sourness perceived by a panellist depend heavily on which organic acid predominates in the sample. Tartaric acid delivers a sharper, more immediate sour sensation than the weaker acids such as citric acid even at equivalent concentrations, tamarind-based (D'Andrea et al., 2026). Formula 1 would be expected to register a more distinct sourness than the dried *Garcinia cowa* Roxb. ex Choisy leaves 2, despite the two formulas having a comparable measured pH (Table 4). This pattern is consistent with evidence that the sour-taste receptor responds differentially to the specific acid and anion present, rather than to proton concentration alone (Zhang, Jin, et al., 2019). This is in line with Formula 1's higher taste and overall-liking scores relative to Formula 2. At the same time, the umami-active free

Table 6: Microbiological quality of the formulated products.

Item		Formula 1	Formula 2	Formula 3
Total Variable Count ^{NS} (log CFU/g)	Lot no 1 ^{ns}	2.90 ± 0.26	2.73 ± 0.12	3.33 ± 0.15
	Lot no 2 ^{ns}	3.23 ± 0.21	3.40 ± 0.30	3.30 ± 0.09
Yeast & Mold ^{NS} (log CFU/g)	Lot no 1 ^{ns}	1.27 ± 0.07	1.30 ± 0.17	1.67 ± 0.18
	Lot no 2	1.13 ± 0.05	1.43 ± 0.15	1.23 ± 0.13

Remark: Data are presented as mean ± standard deviation ($n = 3$), ns is no significant difference ($p > 0.05$).

amino acids and peptides released from the pre-cooked fish protein during stir-frying and drying likely reinforced the savoury backbone common to all three formulas, providing a baseline of palatability onto which the souring agent then modulates the perceived balance of taste. This two-tier view, a shared umami-driven base flavour modulated by agent-specific sourness and odour-masking effects, helps explain why blending the two souring agents in Formula 3 could recover much of the sensory appeal lost with the dried leaves alone. The tamarind component appears to restore the sharper sour note while the residual volatile constituents from the leaves continue to suppress the fishy off-odour, together producing the highest overall acceptance among the three formulas.

3.6 Chemical composition analysis and Minerals

The nutritional profile of F3 (92% acceptability) showed that the powder is an excellent source of protein at $39.45 \pm 0.24\%$. Additionally, it is characterized by high mineral levels (ash) and contains healthy unsaturated fats. The protein content of dehydrated rice topping is among the higher-protein condiments reported for fish and spice based Thai products, and it substantially exceeds the protein density of the traditional Japanese furikake it was designed to emulate. Most versions of furikake report protein levels closer to 20–23% (Jang & Romulo, 2023), and thus rely on dried bonito flakes, seaweed, and sesame for protein rather than a full pre-cooked fish matrix. The elevated sodium content ($1,604.11 \pm 28.56$ mg/100 g) is an expected consequence of the shrimp paste, solar salt, and fish-protein base used in the curry

paste, and although the concurrent potassium level ($1,305.92 \pm 27.13$ mg/100 g) partially offsets the physiological load of sodium, a higher dietary sodium-to-potassium ratio has been consistently associated with elevated cardiovascular risk in recent meta-analytic evidence (Zwager et al., 2025). So this profile should be disclosed prominently on nutrition labelling given current public-health guidance on dietary sodium reduction. The moderate total lipid content ($9.62 \pm 0.08\%$), of which unsaturated fatty acids constitute more than half, together with a comparatively low proportion of saturated fat, supports the positioning of the product as a nutritionally favourable alternative to conventional fried or heavily oiled rice toppings (Pedersen et al., 2025), provided that portion size and sodium intake are considered jointly rather than the protein and mineral content being promoted in isolation.

3.7 Fatty acid and Amino acid profile

In formulation F3, fatty acid concentrations varied from 0.03–3.26 mg/100 g, giving a comprehensive profile that included lauric, myristic, palmitic, palmitoleic, heptadecanoic, stearic, oleic, γ -linolenic, α -linolenic, arachidic, and arachidonic acids, alongside DHA. The predominance of oleic acid was prominently influenced by the addition of soybean and palm oil during processing. This confirms that the type and quality of raw materials are fundamental in shaping the nutritional characteristics of the finished product. The predominance of oleic acid, a monounsaturated omega-9 fatty acid, is nutritionally advantageous, given that diets in which monounsaturated fat intake exceeds saturated fat

Table 7: Sensory score (9-Hedonic scale) and acceptability of the sample using different souring agents as individual and combined agents.

Item	Attributes	Formula 1	Formula 2	Formula 3
1	Appearance	6.98 ± 1.23 ^a	5.28 ± 1.27 ^b	6.60 ± 1.34 ^a
2	Color	6.78 ± 1.17 ^a	5.24 ± 1.25 ^b	6.44 ± 1.59 ^a
3	Taste (sour)	6.38 ± 1.51 ^a	5.56 ± 1.45 ^b	6.16 ± 1.33 ^a
4	Texture ^{ns}	6.38 ± 1.68	5.74 ± 1.40	6.38 ± 1.55
5	Overall	6.62 ± 1.16 ^a	5.68 ± 1.15 ^b	6.56 ± 1.18 ^a
6	Acceptance (%)	84	60	92

Remark: Data are presented as mean ± standard deviation ($n = 3$). Within each row, distinct superscript letters indicate significant differences ($p < 0.05$), ns is no significant difference ($p > 0.05$).

Table 8: Nutrient composition of sour curry powder, F3.

Composition	Quantity
Moisture (%)	3.78 ± 0.45
Ash (%)	7.75 ± 0.05
Protein (%)	39.45 ± 0.24
Fat (%)	9.62 ± 0.08
Sat fat (%)	3.87 ± 0.03
Carbohydrate (%)	40.60 ± 0.25
Total sugar (%)	27.18 ± 0.08
Cholesterol (mg/100g)	118.61 ± 2.19
Sodium (mg/100g)	1,604.11 ± 28.56
Potassium (mg/100g)	1,305.92 ± 27.13
Energy (Kcal)	406.8033 ± 0.59

Remark: Data are presented as mean ± standard deviation ($n = 3$).

intake have consistently been associated with improved lipid profiles and reduced cardiovascular risk markers in both cohort and mechanistic studies, primarily through their influence on the LDL:HDL-cholesterol balance and endothelial function (Pedersen et al., 2025). The essentially negligible levels of long-chain omega-3 fatty acids such as EPA and DHA in Formula 3 suggest that the fish component contributed only marginally to the overall lipid profile relative to the cooking oil. This is consistent with the fatty acid profile typical of soybean and related vegetable oils, in which oleic and linoleic acids predominate rather than long-chain omega-3 fatty acids (Clemente & Cahoon, 2009). This finding suggests that partially substituting the cooking oil with a source richer in omega-3 fatty acids or increasing the proportion of fish lipid retained through the pre-cooking and stir-frying

steps, could further enhance the functional lipid value of the product without altering the basic processing framework.

The major amino acids identified in Formula 3 are presented in Table 10, comprising all nine essential amino acids (phenylalanine, valine, lysine, isoleucine, threonine, leucine, tryptophan, histidine, and methionine) together with eleven nonessential components (glutamic acid, glutamine, aspartic acid, proline, glycine, alanine, tyrosine, arginine, asparagine, serine, and cystine). Glutamic acid was found in the highest concentration, whereas cystine was present at the lowest level. This predominance of glutamic acid is functionally significant on two fronts. Nutritionally, glutamic acid has been associated with anticancer bioactivity (Dutta et al., 2013). Sensorially, glutamate is the principal ligand of the umami taste receptor TAS1R1–TAS1R3 (Chandrasekar et al., 2006), and its presence alongside 5'-ribonucleotides derived from the fish protein can produce a synergistic enhancement of umami intensity through cooperative binding at the receptor's Venus flytrap domain (Zhang, Klebansky, et al., 2008), a phenomenon well documented in seafood and fermentation based Asian condiments (Diepeveen et al., 2022). This umami contribution likely worked in concert with the sourness and residual pungency of the curry paste to produce the high overall liking scores reported in sensory evaluation. Beyond its sensory role, the high protein content and complete essential amino acid profile of this product also support its marketing potential for health-oriented positioning. Furthermore, because umami compounds can partially substitute

Table 9: Fatty acid composition of the selected sour curry formula 3 (mg/100g).

Fatty acid	mg/100g
Butyric acid (C4:0)	0
Caproic (C6:0)	0
Caprylic acid (C8:0)	0
Capric acid (C10:0)	0
Undecanoic acid (C11:0)	0
Lauric acid (C12:0)	0.08
Tridecanoic acid (C13:0)	0
Myristic acid (C14:0)	0.12
Myristoleic acid (C14:1)	0
Pentadecanoic acid (C15:0)	0
Cis-10-Pentadecenoic acid (C15:1n10)	0
Palmitic acid (C16:0)	3.11
Palmitoleic acid (C16:1n7)	0.06
Heptadecanoic acid (C17:0)	0.03
Cis-10-Heptadecanoic acid (C17:1n10)	0
Stearic acid (C18:0)	0.5
Elaidic acid (C18:1n9t)	0
Oleic acid (C18:1n9c)	3.26
Linolelaidic acid (C18:2n6)	0
Linoleic acid (C18:2n6)	0
Gamma-Linolenic	1
Alpha Linolenic acid (C18:3n3)	0.14
Arachidic acid (C20:0)	0.04
cis-11-Eicosenoic acid (C20:1n9)	0
cis-11,14-Eicosadienoic acid (C20:2n9)	0
Heneicosanoic acid (C21:0)	0
Cis-8,11,14-Eicosatrienoic acid (C20:3n6)	0
Arachidonic acid (C20:4n6)	0.05
Cis-11,14,17-Eicosatrienoic acid (C20:3n3)	0
Behenic acid (C22:0)	0
Cis-5,8,11,14,17-Eicosapentaenoic acid; EPA (C20:5n3)	0
Eruic acid (C22:1n9)	0
Cis-13,16-Docosadienoic acid (C22:2)	0
Tricosanoic acid (C23:0)	0
Lignoceric acid (C24:0)	0
Nervonic acid (C24:1n9)	0
cis 4,7,10,13,16,19-Docosahehexa enoic acid; DHA (C22:6n3)	0.11

for sodium chloride in maintaining palatability, there may be scope in future formulations to reduce the relatively high sodium content of the final powder (Table 8) without a proportional loss of consumer acceptance—an approach worth exploring given current recommendations to limit dietary sodium intake.

4 Conclusions

The development of a dehydrated product modeled after Southern Thai sour curry necessitates stringent quality control of raw ingredients, specifically the freshness of the fish ma-

Table 10: Amino acid (mg/100g) composition of the Southern Thai sour curry powder, F3.

Amino acid	mg/100g
Alanine	989.48
Arginine	736.64
Aspartic acid	1828.58
Cystine	154.89
Glutamic acid	3326.49
Glycine	1216.35
Histidine	429.05
Isoleucine	963.5
Leucine	673.15
Lysine	1442.89
Methionine	371.53
Phenylalanine	2031.3
Proline	1334.61
Hydroxyproline	560.43
Serine	526.43
Threonine	805.05
Tryptophan	471.44
Tyrosine	940.14
Valine	1870.19
Asparagine	282.58
Glutamine	1877.58

trix and the optimization of the cooking technique. In this study, the integrated Southern-style paste paired with a synergistic souring blend of tamarind pulp and dried cowa leaves (*Garcinia cowa*) significantly enhanced sensory acceptability and antioxidant activities. Furthermore, sequential processing via stir-frying and hot-air cabinet drying successfully maintained microbial counts well within the safety thresholds regulated by the Thai FDA and Thai Industrial Standards Institute (TISI). Consequently, the developed Southern Thai rice seasoning (formula 3) achieved a sensory acceptability score exceeding 90%, showcasing high commercial feasibility. However, several critical issues must be further addressed to support commercial scaling. First, while thermal processing ensures microbial safety, the kinetic degradation of bioactive compounds—specifically curcumin from turmeric—during hot-air drying remains unquantified. Second, although formula 3 exhibits a promising, protein-rich macronutrient profile, its oxidative and hydrolytic stability during extended storage has not been system-

atically investigated; this data is vital for commercial shelf-life evaluation. Finally, the precise mechanism by which tamarind and cowa leaves interact to modulate the in vitro bioaccessibility of antioxidants during gastrointestinal digestion warrants deeper exploration. Addressing these research gaps will facilitate the transformation of this traditional culinary asset into a standardized, shelf-stable functional food product.

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References

- Alegbeleye, O., Odeyemi, O. A., Strateva, M., & Stratev, D. (2022). Microbial spoilage of vegetables, fruits and cereals. *Applied Food Research*, 2(1), Article 100122. <https://doi.org/10.1016/j.afres.2022.100122>
- Arreola, R., Quintero-Fabián, S., Lopez-Roa, R. I., Flores-Gutierrez, E. O., Reyes-Grajeda, J. P., Carrera-Quintanar, L., & Ortuno-Sahagun, D. (2015). Immunomodulation and anti-inflammatory effects of garlic compounds. *Journal of Immunology Research*, 2015, Article 401630. <https://doi.org/10.1155/2015/401630>
- Association of Official Analytical Chemists. (1984). *Official methods of analysis* (S. Williams, Ed.; 14th ed.).
- Azlan, A., Sultana, S., Huei, C. S., & Razman, M. R. (2022). Antioxidant, anti-obesity, nutritional and other beneficial effects of different chili pepper: A review. *Molecules*, 27(3), Article 898. <https://doi.org/10.3390/molecules27030898>
- Bayan, L., Koulivand, P. H., & Gorji, A. (2014). Garlic: A review of potential therapeutic effects. *Avicenna Journal of Phytomedicine*, 4(1), 1–14.
- Beato, V. M., Orgaz, F., Mansilla, F., & Montaña, A. (2011). Changes in phenolic compounds in garlic (*Allium sativum* L.) owing to the cultivar and location of growth. *Plant Foods for Human Nutrition*, 66(3), 218–223. <https://doi.org/10.1007/s11130-011-0236-2>
- Bhattacharjee, S. (2013). Analysis of the proximate composition and energy values of two varieties of onion (*Allium cepa* L.) bulbs of different origin: A comparative study. *International Journal of Nutrition and Food Sciences*, 2(5), 246. <https://doi.org/10.11648/j.ijnfs.20130205.16>
- Bhatwalkar, S. B., Mondal, R., Krishna, S. B. N., Adam, J. K., Govender, P., & Anupam, R. (2021). Antibacterial properties of organosulfur compounds of garlic (*Allium sativum*). *Frontiers in Microbiology*, 12, Article 613077. <https://doi.org/10.3389/fmicb.2021.613077>
- Borlinghaus, J., Albrecht, F., Gruhlke, M., Nwachukwu, I., & Slusarenko, A. (2014). Allicin: Chemistry and biological properties. *Molecules*, 19(8), 12591–12618. <https://doi.org/10.3390/molecules190812591>
- Caswell, C. (2025). *The dishes of Thailand's four culinary regions*. AMATravel. <https://www.amatravel.ca/articles/four-culinary-regions-thailand>
- Chandrashekar, J., Hoon, M. A., Ryba, N. J. P., & Zuker, C. S. (2006). The receptors and cells for mammalian taste. *Nature*, 444(7117), 288–294. <https://doi.org/10.1038/nature05401>
- Clemente, T. E., & Cahoon, E. B. (2009). Soybean oil: Genetic approaches for modification of functionality and total content. *Plant Physiology*, 151(3), 1030–1040. <https://doi.org/10.1104/pp.109.146282>
- Creative Songkhla City of Gastronomy. (2025). *Ban Muang*. <https://www.banmuang.co.th/news/education/418196>
- Da Conceicao Neta, E. R., Johanningsmeier, S. D., & McFeeters, R. F. (2007). The chemistry and physiology of sour taste—A review. *Journal of Food Science*, 72(2), R33–R38. <https://doi.org/10.1111/j.1750-3841.2007.00282.x>
- D'Andrea, A. E., Hayes, J. E., & Hopfer, H. (2026). Consumer segmentation for sourness: Exploring perception, liking, personality, and intake. *Food Quality and Preference*, 137, Article 105811. <https://doi.org/10.1016/j.foodqual.2025.105811>
- da Silva, M. A. S., Bridi, R., Arias-Santé, M. F.,

- Rincón-Cervera, M. A., Meisel, L. A., Rhein, S., Porras, O., Márquez Calvo, K., Carrasco, B., & de Camargo, A. C. (2024). Soluble and insoluble-bound phenolic bioactive compounds of Tortola bean leaf and their antioxidant properties in chemical-based assays and Caco-2 cells. *Food Bioscience*, 57, Article 103616. <https://doi.org/10.1016/j.fbio.2024.103616>
- De Caluwé, E., Haramová, K., & Van Damme, P. (2010). *Tamarindus indica* L. – A review of traditional uses, phytochemistry and pharmacology. *Afrika Focus*, 23(1), 53–83. <https://doi.org/10.1163/2031356X-02301006>
- Dey, S., & Nagababu, B. H. (2022). Applications of food color and bio-preservatives in the food and its effect on the human health. *Food Chemistry Advances*, 1, Article 100019. <https://doi.org/10.1016/j.focha.2022.100019>
- Dianat, O., Houshmand, B., & Mahjour, F. (2013). Antibacterial effect of different concentrations of garlic (*Allium sativum*) extract on dental plaque bacteria. *Indian Journal of Dental Research*, 24(1), 71. <https://doi.org/10.4103/0970-9290.114957>
- Diepeveen, J., Moerdijk-Poortvliet, T. C. W., & van der Leij, F. R. (2022). Molecular insights into human taste perception and umami tastants: A review. *Journal of Food Science*, 87(4), 1449–1465. <https://doi.org/10.1111/1750-3841.16101>
- Dini, C., Fabbri, A., & Geraci, A. (2011). The potential role of garlic (*Allium sativum*) against the multi-drug resistant tuberculosis pandemic: A review. *Annali dell'Istituto Superiore di Sanita*, 47(4), 465–473. https://doi.org/10.4415/ANN_11_04_18
- Dutta, S., Ray, S., & Nagarajan, K. (2013). Glutamic acid as anticancer agent: An overview. *Saudi Pharmaceutical Journal*, 21(4), 337–343. <https://doi.org/10.1016/j.jsps.2012.12.007>
- Farhat, Z., Hershberger, P. A., Freudenheim, J. L., Mammen, M. J., Hageman Blair, R., Aga, D. S., & Mu, L. (2021). Types of garlic and their anticancer and antioxidant activity: A review of the epidemiologic and experimental evidence. *European Journal of Nutrition*, 60(7), 3585–3609. <https://doi.org/10.1007/s00394-021-02482-7>
- Floegel, A., Kim, D.-O., Chung, S.-J., Koo, S. I., & Chun, O. K. (2011). Comparison of ABTS/DPPH assays to measure antioxidant capacity in popular antioxidant-rich US foods. *Journal of Food Composition and Analysis*, 24(7), 1043–1048. <https://doi.org/10.1016/j.jfca.2011.01.008>
- Fu, Y.-S., Chen, T.-H., Weng, L., Huang, L., Lai, D., & Weng, C.-F. (2021). Pharmacological properties and underlying mechanisms of curcumin and prospects in medicinal potential. *Biomedicine & Pharmacotherapy*, 141, Article 111888. <https://doi.org/10.1016/j.biopha.2021.111888>
- Fuloria, S., Mehta, J., Chandel, A., Sekar, M., Rani, N. N. I. M., Begum, M. Y., Subramanian, V., Chidambaram, K., Thangavelu, L., Nordin, R., Wu, Y. S., Sathasivam, K. V., Lum, P. T., Meenakshi, D. U., Kumarasamy, V., Azad, A. K., & Fuloria, N. K. (2022). A comprehensive review on the therapeutic potential of *Curcuma longa* Linn in relation to its major active constituent curcumin. *Frontiers in Pharmacology*, 13, Article 820806. <https://doi.org/10.3389/fphar.2022.820806>
- Gladine, C., Roy, N. C., Rigaudière, J.-P., Laillet, B., Da Silva, G., Joly, C., Pujos-Guillot, E., Morio, B., Feillet-Coudray, C., McNabb, W. C., Chardigny, J.-M., & Comte, B. (2012). Increasing intake of long-chain n-3 PUFA enhances lipoperoxidation and modulates hepatic gene expression in a dose-dependent manner. *British Journal of Nutrition*, 107(9), 1254–1273. <https://doi.org/10.1017/S0007114511004259>
- Hazzaa, S., Abdelaziz, S., Abd Eldaim, M., Abdel-Daim, M., & Elgarawany, G. (2020). Neuroprotective potential of *Allium sativum* against monosodium glutamate-induced excitotoxicity: Impact on short-term memory, gliosis, and oxidative stress. *Nutrients*, 12(4), Article 1028. <https://doi.org/10.3390/nu12041028>
- Heaton, J. W., & Marangoni, A. G. (1996). Chlorophyll degradation in processed foods and senescent plant tissues. *Trends in*

- Food Science & Technology*, 7(1), 8–15. [https://doi.org/10.1016/0924-2244\(96\)81352-5](https://doi.org/10.1016/0924-2244(96)81352-5)
- Hosseini, F. S., Falahati-pour, S. K., Hajizadeh, M. R., Khoshdel, A., Mirzaei, M. R., Ahmadi-rad, H., Behroozi, R., Jafari, N., & Mahmoodi, M. (2017). Persian shallot, *Allium hirtifolium* Boiss, induced apoptosis in human hepatocellular carcinoma cells. *Cytotechnology*, 69(4), 551–563. <https://doi.org/10.1007/s10616-017-0093-4>
- Hwang, I. G., Yoo, S. M., & Lee, J. (2014). Quality characteristics of red pepper cultivars according to cultivation years and regions. *The Korean Journal of Food And Nutrition*, 27(5), 817–825. <https://doi.org/10.9799/ksfan.2014.27.5.817>
- Jang, H. N., & Romulo, A. (2023). Nutritional and sensory evaluation of skipjack furikake-substituted catfish. *E3S Web of Conferences*, 442, Article 04001. <https://doi.org/10.1051/e3sconf/202344204001>
- Jang, H., Choi, M., & Jang, K.-S. (2024). Comprehensive phytochemical profiles and antioxidant activity of Korean local cultivars of red chili pepper (*Capsicum annuum* L.). *Frontiers in Plant Science*, 15, Article 1333035. <https://doi.org/10.3389/fpls.2024.1333035>
- Jena, B. S., Jayaprakasha, G. K., & Sakariah, K. K. (2002). Organic acids from leaves, fruits, and rinds of *Garcinia cowa*. *Journal of Agricultural and Food Chemistry*, 50(12), 3431–3434. <https://doi.org/10.1021/jf011627j>
- Joyner, J. J., & Yadav, B. K. (2015). Microwave assisted dehulling of black gram (*Vigna mungo* L.). *Journal of Food Science and Technology*, 52(4), 2003–2012. <https://doi.org/10.1007/s13197-013-1182-9>
- Kaennakam, S., Siripong, P., & Tip-pyang, S. (2015). Kaennacowanols A–C, three new xanthenes and their cytotoxicity from the roots of *Garcinia cowa*. *Fitoterapia*, 102, 171–176. <https://doi.org/10.1016/j.fitote.2015.03.008>
- Kallel, F., & Chaabouni, S. E. (2017). Perspective of garlic processing wastes as low-cost substrates for production of high-added value products: A review. *Environmental Progress & Sustainable Energy*, 36(6), 1765–1777. <https://doi.org/10.1002/ep.12649>
- Kanlayavattanakul, M., Ospondant, D., Ruktanonchai, U., & Lourith, N. (2012). Biological activity assessment and phenolic compounds characterization from the fruit pericarp of *Litchi chinensis* for cosmetic applications. *Pharmaceutical Biology*, 50(11), 1384–1390. <https://doi.org/10.3109/13880209.2012.675342>
- Kasote, D. M., Jayaprakasha, G. K., & Patil, B. S. (2019). Leaf disc assays for rapid measurement of antioxidant activity. *Scientific Reports*, 9, Article 1884. <https://doi.org/10.1038/s41598-018-38036-x>
- Khanum, F., Anilakumar, K. R., & Viswanathan, K. R. (2004). Anticarcinogenic properties of garlic: A review. *Critical Reviews in Food Science and Nutrition*, 44(6), 479–488. <https://doi.org/10.1080/10408690490886700>
- Koca, N., Karadeniz, F., & Burdurlu, H. S. (2007). Effect of pH on chlorophyll degradation and colour loss in blanched green peas. *Food Chemistry*, 100(2), 609–615. <https://doi.org/10.1016/j.foodchem.2005.09.079>
- Kumar, B., Patel, S. N. K., & Khokha, D. (2017). Evaluation of physical and chemical properties of tamarind (*Tamarindus indica* L.) fruits. *International Journal of Advanced Biochemistry Research*, 22, 39–42.
- Kundukad, B., Udayakumar, G., Grela, E., Kaur, D., Rice, S. A., Kjelleberg, S., & Doyle, P. S. (2020). Weak acids as an alternative anti-microbial therapy. *Biofilm*, 2, Article 100019. <https://doi.org/10.1016/j.bioflm.2020.100019>
- Latimer, G. W., Jr. (Ed.). (2023). *Official methods of analysis of AOAC International* (22nd ed.). Oxford University Press. <https://doi.org/10.1093/9780197610145.001.0001>
- Li, Y.-x., Erhunmwunsee, F., Liu, M., Yang, K., Zheng, W., & Tian, J. (2022). Antimicrobial mechanisms of spice essential oils and application in food industry. *Food Chemistry*, 382, Article 132312. <https://doi.org/10.1016/j.foodchem.2022.132312>
- Lolok, N., Mashar, H. M., Annah, I., Saleh, A., Yuliasri, W. O., & Isrul, M. (2019). Antidiabetic effect of the combination of garlic peel extract (*Allium sativum*) and

- onion peel (*Allium cepa*) in rats with oral-glucose tolerance method. *Research Journal of Pharmacy and Technology*, 12(5), 2153–2156. <https://doi.org/10.5958/0974-360X.2019.00357.3>
- Lu, X., Li, N., Zhao, R., Zhao, M., Cui, X., Xu, Y., & Qiao, X. (2021). In vitro prebiotic properties of garlic polysaccharides and its oligosaccharide mixtures obtained by acid hydrolysis. *Frontiers in Nutrition*, 8, Article 798450. <https://doi.org/10.3389/fnut.2021.798450>
- Mafe, A. N., Edo, G. I., Makia, R. S., Joshua, O. A., Akpogheli, P. O., Gaaz, T. S., Jikah, A. N., Yousif, E., Isoje, E. F., Igbuku, U. A., Ahmed, D. S., Essaghah, A. E. A., & Umar, H. (2024). A review on food spoilage mechanisms, food borne diseases and commercial aspects of food preservation and processing. *Food Chemistry Advances*, 5, Article 100852. <https://doi.org/10.1016/j.focha.2024.100852>
- Mahae, N., Pichairat, D., & Kachenpukdee, N. (2021). Product development of rice seasoning (Furikake) from fish and crispy fried seabass (*Lates calcarifer*) skin. *KKU Science Journal*, 49(1), 30–39. <https://ph01.tci-thaijo.org/index.php/KKUSciJ/article/view/250224>
- Maiti, P., & Dunbar, G. (2018). Use of curcumin, a natural polyphenol for targeting molecular pathways in treating age-related neurodegenerative diseases. *International Journal of Molecular Sciences*, 19(6), Article 1637. <https://doi.org/10.3390/ijms19061637>
- Mamathashree, M. N., Fakrudin, B., & Prakash, B. G. (2024). Organic acid profiling in tamarind (*Tamarindus indica* L.) genotypes by high-performance liquid chromatography. *International Journal of Advanced Biochemistry Research*, 8(8), 1452–1458. <https://doi.org/10.33545/26174693.2024.v8.i8r.2059>
- Manolopoulou, E., & Varzakas, T. (2016). Effect of temperature in color changes of green vegetables. *Current Research in Nutrition and Food Science Journal*, 4(Special Issue Conference October 2016). <https://doi.org/10.12944/CRNFSJ.4.Special-Issue-October.02>
- Manzocco, L., Calligaris, S., Mastrocola, D., Nicoli, M. C., & Lerici, C. R. (2000). Review of non-enzymatic browning and antioxidant capacity in processed foods. *Trends in Food Science & Technology*, 11(9–10), 340–346. [https://doi.org/10.1016/S0924-2244\(01\)00014-0](https://doi.org/10.1016/S0924-2244(01)00014-0)
- Marcus, J. B. (2019). *Aging, nutrition and taste: Nutrition, food science and culinary perspectives for aging tastefully*. Academic Press.
- Marques, C., Sotiles, A. R., Farias, F. O., Oliveira, G., Mitterer-Daltoé, M. L., & Masson, M. L. (2020). Full physicochemical characterization of malic acid: Emphasis in the potential as food ingredient and application in pectin gels. *Arabian Journal of Chemistry*, 13(12), 9118–9129. <https://doi.org/10.1016/j.arabjc.2020.10.036>
- Merecz-Sadowska, A., Sitarek, P., Kowalczyk, T., Zajdel, K., Jęcek, M., Nowak, P., & Zajdel, R. (2023). Food anthocyanins: Malvidin and its glycosides as promising antioxidant and anti-inflammatory agents with potential health benefits. *Nutrients*, 15(13), Article 3016. <https://doi.org/10.3390/nu15133016>
- Mishra, S., & Patel, M. (2020). Role of nutrition on immune system during COVID-19 pandemic. *Journal of Food Nutrition and Health*, 3(2).
- Mohammadi-Motlagh, H.-R., Mostafaie, A., & Mansouri, K. (2011). Anticancer and anti-inflammatory activities of shallot (*Allium ascalonicum*) extract. *Archives of Medical Science*, 1, 38–44. <https://doi.org/10.5114/aoms.2011.20602>
- Mongkontanawat, N., & Phuangsorisut, S. (2016). Product development of *Garcinia cowa* Roxb tea mixed with high β -glucan content from edible mushroom. *International Journal of Agricultural Technology*, 12, 1247–1258. <http://www.ijat-aatsea.com>
- Moradi, Y., Moradi-Sardareh, H., Ghasemi, H., Mohamadi, N., Moradi, M.-N., & Hosseini-Zijoud, S.-M. (2013). Medicinal properties of Persian shallot. *European Journal of Experimental Biology*, 3(1), 371–379. <https://www.imedpub.com/abstract/medicinal-properties-of-persian-shallot-11746.html>
- Muzaffar, K., Sofi, S. A., & Kumar, P. (2018). Comparative study of ripe tamarind pulp

- and spray dried tamarind pulp powder for compositional analysis. *International Journal of Advance Research in Science and Engineering*, 7(1), 754–761.
- Negi, P. S., Jayaprakasha, G. K., & Jena, B. S. (2008). Antibacterial activity of the extracts from the fruit rinds of *Garcinia cowa* and *Garcinia pedunculata* against food borne pathogens and spoilage bacteria. *LWT – Food Science and Technology*, 41(10), 1857–1861. <https://doi.org/10.1016/j.lwt.2008.02.009>
- Nyadoi, P., & Abdullah, K. (2004). Tamarind growth in Tharaka, Eastern Kenya. *Prunus Tribune*, 4–12.
- Obulesu, M., & Bhattacharya, S. (2011). Color changes of tamarind (*Tamarindus indica* L.) pulp during fruit development, ripening, and storage. *International Journal of Food Properties*, 14(3), 538–549. <https://doi.org/10.1080/10942910903262129>
- Omoba, O. S., Olagunju, A. I., Akinrinlola, F. O., & Oluwajuyitan, T. D. (2022). Shallot-enriched amaranth-based extruded snack influences blood glucose levels, hematological parameters, and carbohydrate degrading enzymes in streptozotocin-induced diabetic rats. *Journal of Food Biochemistry*, 46(11), Article e14098. <https://doi.org/10.1111/jfbc.14098>
- Pathak, K., Saikia, R., & Das, A. (2023). Unlocking the therapeutic potential of *Garcinia cowa* Rox in diabetes management. *Sciences of Phytochemistry*, 2(1), 31–33. <https://doi.org/10.58920/sciphy02010038>
- Pedersen, J., Hedegaard, B., Schmidt, E., Dahm, C., Holven, K., Retterstøl, K., Calder, P., & Bork, C. (2025). Monounsaturated fatty acids in cardiovascular disease: Intake, individual types, and content in adipose tissue as a biomarker of endogenous exposure. *Nutrients*, 17(15), Article 2509. <https://doi.org/10.3390/nu17152509>
- Perico, N., Cortinovis, M., Suter, F., & Remuzzi, G. (2023). Home as the new frontier for the treatment of COVID-19: The case for anti-inflammatory agents. *The Lancet Infectious Diseases*, 23(1), e22–e33. [https://doi.org/10.1016/S1473-3099\(22\)00433-9](https://doi.org/10.1016/S1473-3099(22)00433-9)
- Phukhatmuen, P., Raksat, A., Laphookhieo, S., Charoensup, R., Duangyod, T., & Maneerat, W. (2020). Bioassay-guided isolation and identification of antidiabetic compounds from *Garcinia cowa* leaf extract. *Heliyon*, 6(4), Article e03625. <https://doi.org/10.1016/j.heliyon.2020.e03625>
- Pisuchpen, S., Usawakesmanee, W., Siripongvutikorn, S., Khatcharin, N., & Rujirapong, C. (2024). Storage quality assessment of a sheet snack produced from liang leaves (*Gnetum gnemon* var. *tenerum*). *Italian Journal of Food Science*, 36(3), 203–223. <https://doi.org/10.15586/ijfs.v36i3.2607>
- Raeisi, S., Sharifi-Rad, M., Quek, S. Y., Shabanpour, B., & Sharifi-Rad, J. (2016). Evaluation of antioxidant and antimicrobial effects of shallot (*Allium ascalonicum* L.) fruit and ajwain (*Trachyspermum ammi* (L.) Sprague) seed extracts in semi-fried coated rainbow trout (*Oncorhynchus mykiss*) fillets for shelf-life extension. *LWT*, 65, 112–121. <https://doi.org/10.1016/j.lwt.2015.07.064>
- Rahman, A. U., & Panichayupakaranant, P. (2024). Exploring the diverse biological activities of *Garcinia cowa*: Implications for future cancer chemotherapy and beyond. *Food Bioscience*, 61, Article 104525. <https://doi.org/10.1016/j.fbio.2024.104525>
- Rana, M., & Sharma, P. (2018). Proximate and phytochemical screening of the seed and pulp of *Tamarind indica*. *Journal of Medicinal Plants Studies*, 6(2), 111–115.
- Re, R., Pellegrini, N., Proteggente, A., Pannala, A., Yang, M., & Rice-Evans, C. (1999). Antioxidant activity applying an improved ABTS radical cation decolorization assay. *Free Radical Biology and Medicine*, 26(9–10), 1231–1237. [https://doi.org/10.1016/S0891-5849\(98\)00315-3](https://doi.org/10.1016/S0891-5849(98)00315-3)
- Rouf, R., Uddin, S. J., Sarker, D. K., Islam, M. T., Ali, E. S., Shilpi, J. A., Nahar, L., Tiralongo, E., & Sarker, S. D. (2020). Antiviral potential of garlic (*Allium sativum*) and its organosulfur compounds: A systematic update of pre-clinical and clinical data. *Trends in Food Science & Technology*, 104, 219–234. <https://doi.org/10.1016/j.tifs.2020.08.006>
- Rukachaisirikul, V., Ritthiwigrom, T., Pinsa, A., Sawangchote, P., & Taylor, W. C. (2003).

- Xanthones from the stem bark of *Garcinia nigrolineata*. *Phytochemistry*, 64(6), 1149–1156. [https://doi.org/10.1016/S0031-9422\(03\)00502-8](https://doi.org/10.1016/S0031-9422(03)00502-8)
- Sabikun, N., Bakhsh, A., Rahman, M. S., Hwang, Y.-H., & Joo, S.-T. (2021). Volatile and nonvolatile taste compounds and their correlation with umami and flavor characteristics of chicken nuggets added with milkfat and potato mash. *Food Chemistry*, 343, Article 128499. <https://doi.org/10.1016/j.foodchem.2020.128499>
- Sabir, S. M., Zeb, A., Mahmood, M., Abbas, S. R., Ahmad, Z., & Iqbal, N. (2021). Phytochemical analysis and biological activities of ethanolic extract of *Curcuma longa* rhizome. *Brazilian Journal of Biology*, 81(3), 737–740. <https://doi.org/10.1590/1519-6984.230628>
- Santhosha, S. G., Jamuna, P., & Prabhavathi, S. N. (2013). Bioactive components of garlic and their physiological role in health maintenance: A review. *Food Bioscience*, 3, 59–74. <https://doi.org/10.1016/j.fbio.2013.07.001>
- Shahid, M., Law, D., Azfaralariff, A., Mackeen, M. M., Chong, T. F., & Fazry, S. (2022). Phytochemicals and biological activities of *Garcinia atroviridis*: A critical review. *Toxics*, 10(11), Article 656. <https://doi.org/10.3390/toxics10110656>
- Shang, A., Cao, S.-Y., Xu, X.-Y., Gan, R.-Y., Tang, G.-Y., Corke, H., Mavumengwana, V., & Li, H.-B. (2019). Bioactive compounds and biological functions of garlic (*Allium sativum* L.). *Foods*, 8(7), Article 246. <https://doi.org/10.3390/foods8070246>
- Shehzad, A., Rehman, G., & Lee, Y. S. (2013). Curcumin in inflammatory diseases. *BioFactors*, 39(1), 69–77. <https://doi.org/10.1002/biof.1066>
- Shindia, A., Abdel-Shafi, S., Atef, A., Osman, A., Sitohy, B., & Sitohy, M. (2024). Antibacterial activity of carrot peel HCl-ethanol extracts and its potential application in meat preservation. *LWT*, 207, Article 116638. <https://doi.org/10.1016/j.lwt.2024.116638>
- Simon, T., & Tesfaye, B. (2014). Growth and productivity of hot pepper (*Capsicum annuum* L.) as affected by variety, nitrogen and phosphorous at Jinka, Southern Ethiopia. *Journal of Biology, Agriculture and Healthcare*, 4(17), 56–62. www.iiste.org
- Siripongvutikorn, S., Pumethakul, K., Thantrirat, J., Sirinupong, N., Chansuwan, W., Usawakesmanee, W., & Rujirapong, C. (2025). Chemical and physical parameters supporting the top-rated product of Kapi-pla, a gastronomy of southern food, Thailand. *Journal of Agriculture and Food Research*, 21, Article 101856. <https://doi.org/10.1016/j.jafr.2025.101856>
- Siripongvutikorn, S., Pumethakul, K., Yupanqui, C. T., Seechamnaturakit, V., Detarun, P., Utaipan, T., Sirinupong, N., Chansuwan, W., Wittaya, T., & Samakradhamrongthai, R. S. (2024). Phytochemical profiling and antioxidant activities of the most favored ready-to-use Thai curries, Pad-Ka-Proa (spicy basil leaves) and Massaman. *Foods*, 13(4), Article 582. <https://doi.org/10.3390/foods13040582>
- Siripongvutikorn, S., Usawakesmanee, W., Pisuchpen, S., Khatcharin, N., & Rujirapong, C. (2023). Nutritional content and microbial load of fresh liang, *Gnetum gnemon* var. *tenerum* leaves. *Foods*, 12(20), Article 3848. <https://doi.org/10.3390/foods12203848>
- Sittisart, P., Yossan, S., & Prasertsan, P. (2017). Antifungal property of chili, shallot and garlic extracts against pathogenic fungi, *Phomopsis* spp., isolated from infected leaves of para rubber (*Hevea brasiliensis* Muell. Arg.). *Agriculture and Natural Resources*, 51(6), 485–491. <https://doi.org/10.1016/j.anres.2018.03.005>
- Sora, G. T. S., Souza, A. H. P., Zielinski, A. A. F., Haminiuk, C. W. I., Matsushita, M., & Peralta, R. M. (2015). Fatty acid composition of *Capsicum* genus peppers. *Ciência e Agrotecnologia*, 39(4), 372–380. <https://doi.org/10.1590/S1413-70542015000400008>
- Speck, M. L. (Ed.). (1984). *Compendium of methods for the microbiological examination of foods* (2nd ed.). American Public Health Association.
- Sulaymanov, K., Johri, P., Azimov, A., Narimanov, A., Kodiralieva, F., Singh, S., & Jabborova, D. (2024). Phytochemical analysis of turmeric (*Curcuma longa* L.) grown in Uzbekistan. *Turkish Journal of*

- Agriculture and Forestry*, 48(5), 647–657.
<https://doi.org/10.55730/1300-011X.3209>
- Sweis, I. E., & Cressey, B. C. (2018). Potential role of the common food additive manufactured citric acid in eliciting significant inflammatory reactions contributing to serious disease states: A series of four case reports. *Toxicology Reports*, 5, 808–812.
<https://doi.org/10.1016/j.toxrep.2018.08.002>
- Tavanappanavar, A. N., Mulla, S. I., Seth, C. S., Bagewadi, Z. K., Rahamathulla, M., Ahmed, M. M., & Farhana, S. A. (2024). Phytochemical analysis, GC–MS profile and determination of antibacterial, antifungal, anti-inflammatory, antioxidant activities of peel and seeds extracts (chloroform and ethyl acetate) of *Tamarindus indica* L. *Saudi Journal of Biological Sciences*, 31(1), Article 103878.
<https://doi.org/10.1016/j.sjbs.2023.103878>
- Thamkaew, G., Sjöholm, I., & Galindo, F. G. (2021). A review of drying methods for improving the quality of dried herbs. *Critical Reviews in Food Science and Nutrition*, 61(11), 1763–1786. <https://doi.org/10.1080/10408398.2020.1765309>
- Tresina, P. S., Selvam, M. S., Doss, A., & Mohan, V. R. (2022). Antidiabetic bioactive natural products from medicinal plants. In Atta-ur-Rahman (Ed.), *Studies in natural products chemistry* (Vol. 25, pp. 75–118). Elsevier. <https://doi.org/10.1016/B978-0-323-91250-1.00004-5>
- Usawakesmanee, W., Pisuchpen, S., Siripongvutikorn, S., Khatcharin, N., & Rujirapong, C. (2024). Packaging impact on quality changes of dried Liang leaf seasoning. *Heliyon*, 10(22), Article e40462.
<https://doi.org/10.1016/j.heliyon.2024.e40462>
- Vicent, V. (2024). Influence of banana powder on proximate composition, physicochemical and rheological properties of soy yoghurt. *Applied Food Research*, 4(2), Article 100450. <https://doi.org/10.1016/j.afres.2024.100450>
- Wahyuni, Y., Ballester, A.-R., Sudarmonowati, E., Bino, R. J., & Bovy, A. G. (2013). Secondary metabolites of *Capsicum* species and their importance in the human diet. *Journal of Natural Products*, 76(4), 783–793.
<https://doi.org/10.1021/np300898z>
- Wang, B., Liu, Y.-X., Dong, M., Zhang, Y.-Y., Huang, X.-H., & Qin, L. (2024). Flavor enhancement during the drying of scallop (*Patinopecten yessoensis*) as revealed by integrated metabolomic and lipidomic analysis. *Food Chemistry*, 432, Article 137218. <https://doi.org/10.1016/j.foodchem.2023.137218>
- Wang, Z., Li, H., Cao, W., Chen, Z., Gao, J., Zheng, H., Lin, H., & Qin, X. (2023). Effect of drying process on the formation of the characteristic flavor of oyster (*Crassostrea hongkongensis*). *Foods*, 12(11), Article 2136.
<https://doi.org/10.3390/foods12112136>
- Wanna, C., Boonman, N., & Phakpaknam, S. (2023). Antioxidant and antidiabetic properties of *Garcinia cowa* Roxb. extracts from leaves, fruit rind, and stem bark in different solvents. *Plant Science Today*, 10(3), 430–438.
<https://doi.org/10.14719/pst.2455>
- Wisootthipat, S., Rodhetbhai, C., & Siltragool, W. (2015). Local food wisdom: The management for tourism in the Eastern region of Thailand. *Silpakorn University Journal of Social Sciences, Humanities, and Arts*, 15(3), 177–195.
<https://so02.tci-thaijo.org/index.php/hasss/article/view/44677>
- Yin, J., Ren, W., Huang, X., Deng, J., Li, T., & Yin, Y. (2018). Potential mechanisms connecting purine metabolism and cancer therapy. *Frontiers in Immunology*, 9, Article 1697. <https://doi.org/10.3389/fimmu.2018.01697>
- Yin, M.-C., Hsu, P.-C., & Chang, H.-H. (2003). In vitro antioxidant and antibacterial activities of shallot and scallion. *Journal of Food Science*, 68(1), 281–284.
<https://doi.org/10.1111/j.1365-2621.2003.tb14153.x>
- Yingngam, B., Supaka, N., & Rungseewijitprapa, W. (2015). Optimization of process parameters for phenolics extraction of *Cratoxylum formosum* ssp. *formosum* leaves by response surface methodology. *Journal of Food Science and Technology*, 52(1), 129–140. <https://doi.org/10.1007/s13197-013-1030-y>

- Yorsin, S., Sriwiriyan, S., & Chongsa, W. (2023). Vasorelaxing effect of *Garcinia cowa* leaf extract in rat thoracic aorta and its underlying mechanisms. *Journal of Traditional and Complementary Medicine*, 13(3), 219–225. <https://doi.org/10.1016/j.jtcme.2022.12.001>
- Zhang, F., Klebansky, B., Fine, R. M., Xu, H., Pronin, A., Liu, H., Tachdjian, C., & Li, X. (2008). Molecular mechanism for the umami taste synergism. *Proceedings of the National Academy of Sciences*, 105(52), 20930–20934. <https://doi.org/10.1073/pnas.0810174106>
- Zhang, J., Jin, H., Zhang, W., Ding, C., O’Keeffe, S., Ye, M., & Zuker, C. S. (2019). Sour sensing from the tongue to the brain. *Cell*, 179(2), 392–402.e15. <https://doi.org/10.1016/j.cell.2019.08.031>
- Zoi, V., Galani, V., Lianos, G. D., Voulgaris, S., Kyritsis, A. P., & Alexiou, G. A. (2021). The role of curcumin in cancer treatment. *Biomedicines*, 9(9), Article 1086. <https://doi.org/10.3390/biomedicines9091086>
- Zwager, C. L., Esseghir, M. I., van Vliet, A. M. C., Daams, J. G., Vogt, L., & Olde Engberink, R. H. G. (2025). Estimated dietary Na^+/K^+ -ratio and cardiovascular disease: A systematic review and meta-analysis. *Kidney and Blood Pressure Research*, 50(1), 712–722. <https://doi.org/10.1159/000548424>