

Research article**Development of Seasoned Tilapia Fillet with Spicy Stir-fried Curry Paste Product****Arunothai Juemanee*, Supaporn Apirattananusorn
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Abstract

The aim of this work was to develop ready-to-eat seasoned Tilapia fish with stir-fried red curry paste. A focus group discussion was conducted to generate product concepts. These concepts were then applied to study preliminary fish processing using 4 treatments: blanching and baking (BB) at 180°C (BB180) and at 200°C (BB200), marination (M), and sous-vide (SV) at 65°C. The relationship between physical, chemical, and sensory qualities of processed fish (with/without curry paste) packed in microwaveable packaging was analyzed. A biplot result explained 71.33% of the total variance. Among these, treatment BB200-FC (fish with curry paste) was found to be strongly linked to the positive end of PC1 with high sensory acceptance. In contrast, treatment BB180-F (fish without curry paste) was at a negative end. Then, the ingredients of seasoned curry paste were modified into 4 formulars (A-D) based on BB200-FC and compared with 2 commercial formulars (E and F). The results showed that all paste formulas received significantly different liking scores ($p < 0.05$). Seasoned curry paste formular B received the highest overall liking score of 7.53 with slightly strong spiciness and saltiness. Therefore, the amount of curry and shrimp paste was reduced and tasted by 3 consumer groups (low, medium and high preferred spiciness levels). The results revealed no significant differences in preference scores among the various consumer groups ($p > 0.05$) except for appearance. From PCA, there was a higher concentration of consumers close to formula B1 (with curry paste reduced by 75%) and formular B. These findings highlight the potential for developing a convenient and well-accepted Thai-inspired healthy seasoned fish with a nutritious curry paste.

Keywords: stir-fried red curry paste; seasoned fish; baking; sous-vide; focus group discussion

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1. Introduction

Fish and fish products have long been recognized for their substantial health benefits, making them essential to a balanced diet. Fish provides numerous advantages for overall health and well-being (Sarojnalini & Hei, 2019; Fitzsimmons, 2000). Especially, Nile tilapia (*Oreochromis niloticus*), one of the most widely consumed freshwater fish globally, is prized for its mild flavor, firm texture, and high nutritional content such as protein and essential nutrients, including omega-3 and omega-6 fatty acids, vitamins, and minerals, making it a healthy choice for a balanced diet (Chavan et al., 2015; Abelti, 2017; Ioannis, 2017; El-Sayed & Fitzsimmons, 2023).

Thai cuisine is celebrated not only within Thailand but also enjoys widespread admiration across the globe. In Thai cuisine, Nile tilapia is often paired with bold flavors, particularly in dishes like spicy red curry, which showcase the rich and aromatic ingredients traditional to Thai cooking. Key ingredients in Thai red curry include dried red chilies, garlic, shallots, lemongrass, galangal, and kaffir lime leaves (Inchuen et al., 2011). All ingredients are ground together into a paste, stir-fried or cooked in various styles. Red curry paste provides a balance of spicy, salty, and slightly sweet flavors. Moreover, Thai red curry also includes essential spices and seasonings such as fish sauce, shrimp paste, and palm sugar, which add layers of umami and sweetness to balance the heat of the chilies. The mild flavor of tilapia complements the intense, spicy notes of the red curry, making it an ideal pairing for this quintessential Thai meal. Moreover, Thai food is also recognized as a healthy and functional diet because it contains phytochemical compounds possess diverse and targeted medicinal properties, enabling them to play a preventative role in combating various diseases (Khanthapok & Sukrong, 2019; Buathong & Duangsrirai, 2023).

In curry with fish processing, preliminary processing methods such as blanching, marinating or sous-vide of fish can be employed before the final cooking stage. Blanching fish before processing helps inactivate enzymes, reduce microbial load, reduce fishy odor and preserve the fish's natural color, texture, and flavor (Chew et al., 2024). Marinating and immersing fish in a mixture containing acids, enzymes, or spices tenderizes the flesh, reduces microbial load, and infuses desirable tastes and aromas (Serdaroğlu et al., 2024). While sous-vide cooking, in particular, has gained popularity for its precision and ability to maintain the quality of the meat, reflecting an evolution in processing approaches compared to traditional methods (Singh et al., 2023; Chew et al., 2024).

After preliminary processing, fish used in food product manufacturing is typically cooked using various methods, with frying and baking being the most commonly employed techniques. Frying is tailored to meet consumer preferences as this process produces desirable organoleptic properties such as a golden-brown crust, a rich flavor and a crispy texture that enhances the sensory appeal of food (Zarulakmam et al., 2021; NurSyahirah & Rozzamri, 2022;). However, the growing health awareness has shifted consumer perception away from fried foods, leading them to prefer healthier food as part of their lifestyle. Meanwhile, baking offers a healthier alternative to frying, requiring less oil and resulting in lower fat content. It ensures even cooking, preserves nutritional quality, avoids harmful oil degradation, and is safer, cleaner, and more scalable for large-scale processing (Oppong et al., 2021). This study employed multiple processing techniques including baking, marination and sous-vide combined with a qualitative comparison of physical and sensory properties. The product concept emphasizes on health, in that the product contains fish and herbal curry paste, and convenience, as it comes in microwaveable packaging. These are unique selling points that align well with current food market trends.

This study focused on product development by generating ideas through focus group discussions (FGD) which ensured alignment with actual consumer needs. Subsequently, the processing methods for filleted Nile tilapia including baking at different temperatures (180°C and 200°C), marination and sous-vide at 65°C were optimized to provide a comprehensive understanding of their effects on product quality. Additionally, the study investigates the formulation of a seasoned curry paste using stir-fried red curry paste. Advanced statistical analyses were employed to explore relationships among physical and sensory attributes. The seasoned curry paste formulation was further refined based on consumer segmentation by spiciness preference, resulting in the development of a ready-to-eat seasoned tilapia fish product with stir-fried red curry paste. These offer a new application of health-forward functional ingredients, such as herbs and spices with known phytochemical properties, contributing to the "food as medicine" trend.

2. Materials and Methods

2.1 Materials

Fresh tilapias (*Oreochromis niloticus*) (weight of 1,000 + 100 g), spicy stir-fried red curry paste (Brand: Kuan Thong Community Enterprise), salt (Brand: Prung Thip), sugar (Brand: Mitr Phol), palm oil (Brand: Morakot), lemongrass, garlic, galangal were obtained from a local market in Surat Thani province, Thailand.

2.2 Fish preparation

Fish were quickly transported to the laboratory in boxes containing ice. They were cleaned, gutted, skinned, and headed, then rinsed with tap water several times to remove excessive mucus and adhering blood. Individual fish were rubbed using 100 g of salt and cleaned with 1 L. of water to dispose of fishy odor. Subsequently the fish samples were filleted in sizes 4 x 5 x 2 mm.

2.3 Product concept generation of seasoned fish product

FGD is one of the techniques frequently used in sensory descriptive analysis for investigating the perceptions of a specific group of consumers and new product/idea development (Lawless & Heymann, 2010; Boquin et al., 2014; Barlagne et al., 2017).

In this study, FGD was conducted to trigger insights into the concept of ready-to-eat seasoned fish products. While focus group approaches are widely employed across various fields, their implementation may differ. Casey and Krueger (2015) proposed a group of six to nine people, with a minimum of three groups assembled to mitigate eccentricities among them. Therefore, twenty-one consumers (age 18-52) consisting of people who could consume fish seasoned with spicy curry paste or food products using various spicy curry pastes were recruited for discussion in a total of 3 focus groups.

The discussions were held in the conference room of the sensory evaluation laboratory for 2-3 h per group. Four seasoned fish products were presented to participants together with cooked rice. Fish were prepared using the process shown in Table 1 and kept at 4°C. Before serving, the fish were poured with seasoned spicy stir-fried red curry paste (prototype formula) consisting of 40% water, 22% spicy stir-fried red curry paste, 11% shrimp paste, 11% palm oil, 11% sugar, 4% salt and 0.6% citric acid (a_w 0.78, pH 4.53) and heated in a microwave oven (Electrolux Model EMS3288X) at 800 watts for 1 min.

Table 1. Fish processing used in FDG

Treatment		Process
B	Baking	Baking* at 180°C for 60 min
BB	Blanching and baking	Blanching in boiling water for 15 min and baking* at 180°C for 60 min
M	Marinating	Marinating fish fillet in marinade** at room temperature for 30 min and deep frying*** at 150°C for 20 min
SV	Sous-vide	Sous-vide fish fillet in marinade** with water-bath (Unity Lab Services Model TSSWB27 (Precision SWB27)) at 65°C for 30 min and deep frying*** at 150°C for 20 min

Note: *Baking in a hot air oven (*Unity* equipment and Service Model Si-CO12E)

**Marinade: prepared by mixing 100 g of stir-fried red curry paste with 150 g of water and used for marinating 30 pieces of fish

***Frying in palm oil with a deep fryer (Homemate® Model ZG28A)

Before proceeding with the test, the purpose and evaluating procedure of the focused approach to sensory assessment were briefed to the participants. They were asked to taste and discuss each sample's positive and negative characteristics. Moreover, the determination of the most important sensory parameters, the ingredients of curry pastes and the packaging that need to be considered were discussed. The product concept obtained was utilized in the subsequent stage of product development.

2.4 Development of fish processing

Based on the product concept, which was the result from the previous experiment, it was necessary to develop the fish processing method to achieve characteristics that closely align with the product concept and initial product attributes. These involved adjusting the processing methods chosen from the previously used techniques (Table 1) to compare the temperature and duration used in fish drying. Fish processing used in development of fish processing is shown in Table 2 and processed fish is shown in Figure 1.

The experiment involved increasing the temperature and reducing the drying time compared to the previous fish preparation methods. Additionally, it included studying the ingredients used in the marinade preparation for sous-vide and marination. The marinade ingredients excluded salt to reduce the fish's saltiness and omitted turmeric, as its presence caused dark spots after frying and an overly strong aroma and flavor. Cooked fish and pasteurized seasoned curry paste were packaged separately, and both were contained in microwaveable packaging.

2.4.1 Physical analysis of processed fish

For physical qualities, color was determined using CIE L*a*b* color space (Konica Minolta Model CR-400). L* (lightness), a* (redness-greenness) and b* (yellowness-blueness) were read using a D₆₅ light source and an observer angle of 2° with port size of 8 mm. Texture profile analysis was measured using a texture analyzer (Brookfield Model CT3) with a load cell of 5-kg and a cross-head speed 1 mm/s, which was equipped with a TA25/1000 (50.8

Table 2. Fish processing used in development of fish processing

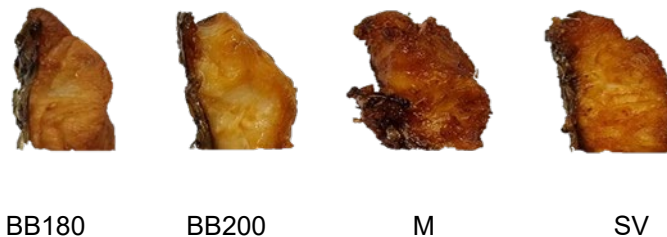
Treatment	Process
BB180	Blanching in boiling water for 15 min and baking* at 180°C for 60 min
BB200	Blanching in boiling water for 15 min and baking* at 200°C for 30 min
M	Marinating fish fillet in marinade** at room temperature for 30 min and deep frying*** at 150°C for 20 min
SV	Sous-vide fish fillet in marinade** with water bath (Unity Lab Services Model TSSWB27 (Precision SWB27)) at 65°C for 5 min and deep frying*** at 150°C for 20 min

Note: BB180: Blanch and bake at 180°C, BB200: Blanch and bake at 200°C, M: Marinate, SV: Sous-vide

*Baking with hot air oven (Unity equipment and Service Model Si-CO12E)

**Marinade: prepared by mixing 100 g of stir-fried red curry paste with 150 g of water and used for marinating 30 pieces of fish

***Frying in palm oil with a deep fryer (Homemate® Model ZG28A)

**Figure 1.** Processed fish without curry paste under different processing conditions

Note: BB180: Blanch and bake at 180°C, BB200: Blanch and bake at 200°C, M: Marinate, SV: Sous-vide

mm) diameter cylinder probe. a_w was analyzed using an AquaLab Lite water activity meter (Decagon Model Aqualab Lite). Moisture content was measured using the method according to AOAC (2000).

2.4.2 Sensory evaluation of processed fish

Sensory evaluation involved 30 general consumers. The evaluation was done in a sensory laboratory with individual booths under artificial daylight-type illumination at a temperature of $25 \pm 2^\circ\text{C}$. The acceptability (appearance, odor, texture, taste, and overall liking) was assessed using a 9-point hedonic scale (1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely) and hardness, saltiness, and spiciness were assessed using a 5-point JAR (just-about-right) scale (1 = too weak, 3 = just right and 5 = too strong). Processed fish with and without curry, a total of 8 samples, were served in a monadic sequential with balanced form presentation and coded with 3-digit random numbers accompanied by cooked rice and milk to reduce any carryover effect on the perceived spiciness.

2.5 Development of pasteurized seasoned curry paste

From the previous steps, an appropriate fish processing method was identified; therefore, this stage focused on developing the seasoning curry paste formulation. This part involves two stages. The first stage was to develop pasteurized seasoned red curry paste by modifying the process and ingredients of the prototype formula. Another stage was to optimize the recipe to achieve the optimal formula that closely aligns with the product concept based on consumer segmentation by spiciness preference.

2.5.1 Adjustment of prototype formula seasoned curry paste

According to the FDG results of prototype seasoned curry paste which indicated that the appearance of the ingredients was slightly coarse, and the spiciness and saltiness were slightly intense. Accordingly, variations in ingredients of formulars A-D are presented in Table 3. The mixture was blended for 40 s (PHILIPS Model HR2115) to reduce the roughness, and heated (stir-fried) until boiled for 15 min. The hot mixture was packed into vacuum bags (polypropylene), sealed, and steamed over boiling water for 30 min. It was then stored at 4°C. Subsequently, the color, a_w , and pH were analyzed using the same methods as described in Section 2.4.1.

Table 3. Ingredients of pasteurized seasoned curry pastes (formulars A-D)

Ingredients	Formular A	Formular B	Formular C	Formular D
	g (%)	g (%)	g (%)	g (%)
Water	200 (64.9)	200 (68.7)	200 (68.7)	200 (78.8)
Stir-fried red curry paste	40 (13.0)	40 (13.8)	-	20 (7.4)
Coconut-based red curry paste	-	-	40 (13.5)	-
Shrimp paste	20 (6.5)	20 (6.9)	20 (6.9)	20 (7.4)
Palm oil	20 (6.5)	20 (6.9)	20 (6.9)	20 (7.4)
Sugar	20 (6.5)	10 (3.4)	10 (3.4)	10 (3.7)
Monosodium glutamate	-	1 (0.3)	1 (0.3)	1 (0.4)
Salt	7 (2.3)	-	-	-
Citric acid	1 (0.3)	-	-	-

The quality of formulars B-D was compared with formular A (prototype formula) and two commercially available seasoned curry paste products (formulars E and F). The commercial curry pastes (E, F) were mixed with water at a ratio of 1:5 and heated similarly to formulars A-D. All samples (Figure 2) were poured over processed fish for both preference and JAR testing (the same methods as described in Section 2.4.2).

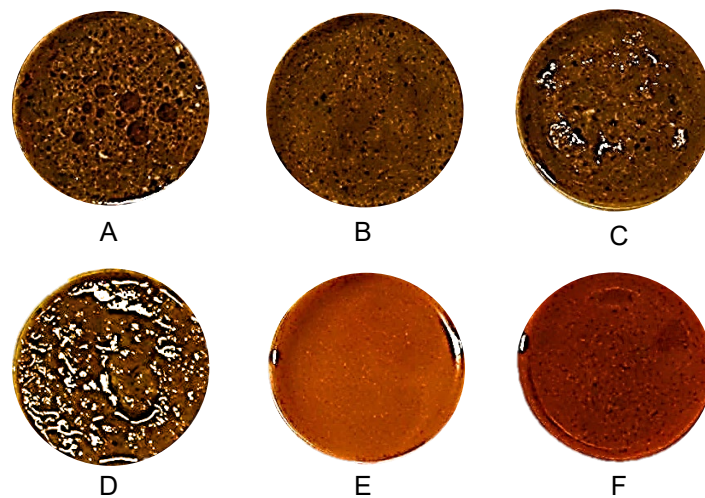


Figure 2. Pasteurized seasoned curry pastes (B-D) used in the adjustment of the formula based on the prototype formula (A) compared to commercial formulars (E, F)

2.5.2 Optimizing the pasteurized seasoned curry paste recipe

The best seasoned curry paste recipe from Section 2.5.1 (formular B), which still had a slightly intense spiciness and saltiness, was taken as control sample. The amount of curry paste (40 g) was reduced to 30 g (formulars B1 and B2) and 20 g (formulars B3 and B4) as presented in Table 4. The amount of shrimp pastes in formulars B2 and B4 was reduced by 50% compared to formulars B1 and B3, respectively. All formulas used a fixed ratio of 50% oil, 25% sugar, and 0.025% monosodium glutamate based on the amount of curry paste. All samples were shown in Figure 3. This adjustment was aimed at balancing the flavors to address issues related to intensity and excess saltiness, while maintaining consistency in the fat and sugar content to ensure the desired texture and taste profile.

Table 4. Ingredients of pasteurized seasoned curry paste used in optimization of curry paste recipe

Ingredients	Formular B (Control)	Formular B1	Formular B2	Formular B3	Formular B4
	g (%)	g (%)	g (%)	g (%)	g (%)
Water	200 (68.7)	200 (76.0)	200 (77.4)	200 (82.6)	200 (83.8)
Stir-fried red curry paste	40 (13.8)	30 (11.4)	30 (11.6)	20 (8.3)	20 (8.4)
Shrimp paste	20 (6.9)	10 (3.8)	5 (1.9)	6.7 (2.8)	3.3 (1.4)
Palm oil	20 (6.9)	15 (5.7)	15 (5.8)	10 (4.1)	10 (4.2)
Sugar	10 (3.4)	7.5 (2.8)	7.5 (2.9)	5 (2.1)	5 (2.1)
Monosodium glutamate	1 (0.3)	0.75 (0.3)	0.75 (0.3)	0.5 (0.2)	0.5 (0.2)

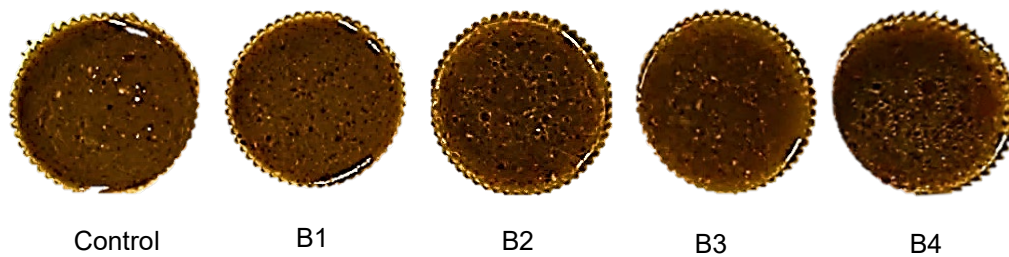


Figure 3. Pasteurized seasoned curry paste formulars (B1-B4) used in optimization of curry paste recipe (formular B, control)

The physical properties of pasteurized seasoned curry paste were analyzed using the same method as described in Section 2.5.1. In terms of preference and JAR-testing, 90 consumers, with 30 people in each group, were involved. The consumers were divided into three groups based on their preferred level of spiciness in consumption (Group 1: low, Group 2: medium and Group 3: high level of spiciness preference).

2.6 Ethical statement

This study was approved by the ethics committee of Suratthani Rajabhat University (SRU-EC2022/114).

2.7 Statistical analysis

Data from the FGDs were recorded, coded, and interpreted. Physical quality data were analyzed using analysis of variance (ANOVA). A randomized complete block design (RCBD) was performed for sensory analysis. The differences of mean comparisons were carried out by Duncan's multiple range tests to identify significant differences ($p < 0.05$) among treatments using Statistical Package for Social Science (SPSS for Windows, SPSS Inc., Chicago, IL, USA.). The relation of physical and sensory data was analyzed using principal component analysis (PCA) computed by XLSTAT© (Addinsoft-XLSTAT2016, New York, USA).

3. Results and Discussion

3.1 Product concept of seasoned fish product from FGD

FGDs with 3 consumer groups (21 people) consisting of 19 females and 2 males, aged between 18 and 52 years, including lecturers, students, and research assistants showed the sensory characteristics of the 4 treatments in Table 5. The participants shared their opinions on the taste-tested samples as follows:

3.1.1 Fish fillet

The majority of participants were concerned about the fish fillet. The inside of the fish should have a light yellow-white color, and the outside should be light-brown in color to

Table 5. Sensory characteristic perception of processed fish from FGD

Treatment	Good Sensory Characteristic	Bad Sensory Characteristic
B	Dry fish meat, no fishy smell, salty, natural sweet	White areas of some outer part of the fish (appearing undercooked and unappetizing)
BB	Light-brown color of fish meat (indicating appetizing color), dry outer part and juicy inside of fish meat, no fishy smell, natural sweet	Slightly too salty
M	Herbal aroma	Dark color fish meat (appearing burnt or over-fried), very soft texture, very salty
SV	Herbal aroma	Dark color and broken fish meat (appearing unappetizing), slightly fishy smell, very salty, intense turmeric aroma/flavor

Note: B: Baking, BB: Blanching and baking, M: Marinating, SV: Sous-vide

make it more appetizing. The size of the fillet could be bite-sized pieces or long pieces. The fish could be presented with or without the skin. The texture should remain moist inside (not dry, not hard) and not greasy. These showed the desirable texture, neither hard nor dry, which is a key factor in consumer acceptance.

Some participants preferred the fish to be boneless, as they expected the product to be premium and offer the convenience of being deboned for the consumer. The taste of fish should not be salty on its own, as consuming it with the seasoned curry paste could make it too salty. Sensorial appreciation is an important motivation for consumers, and it also contributes to the acceptance of different fish products (Saidi et al., 2023; Collier et al., 2024).

3.1.2 Pasteurized seasoned curry paste

The seasoned curry paste had a dark brown color, which most participants found appropriate as it indicated richness and was reminiscent of similar product types, such as spicy stir-fried catfish and various spicy stir-fried meats. However, some participants, especially those who did not usually eat very spicy food, thought the color was slightly too dark, leading them to expect a very spicy flavor, which was not as intense as anticipated. They suggested that lightening the color or adding more yellow could make the curry paste more appetizing.

The panel expressed that the spiciness was appropriate. However, some participants, especially those who did not usually eat spicy food, felt that the product was slightly too spicy. It was noted that the spiciness level might be too much for general consumers, although it was satisfied by consumers who usually ate spicy food. The spiciness was thought to come from fingerroot and black pepper. Participants considered that the spicy curry paste could either include or exclude fingerroot. Those who did not

prefer fingerroot mentioned that they could detect its presence in the curry paste, but the amount was still acceptable. However, if the concentration were higher, it might be too strong for those who do not consume fingerroot.

The appearance of the ingredients was perceived as slightly coarse and contained too much residue. The texture of spicy stir-fried red curry paste should be ground more finely but not completely smooth. The amount of curry paste used per piece of fish was also considered suitable.

3.1.3 Packing and packaging

The fish and seasoned curry paste should be packaged separately. This would allow for various reheating methods such as microwaving, baking, stir-frying, or searing the fish to give it a brown surface. In addition, families with children could use only fish for their kids. Moreover, separating the fish and curry paste into different packages might extend shelf life and prevent the fish from becoming swollen or mushy when reheated.

The recommended amount of fish fillet for 1-2 consumers was 12-16 bite-sized pieces (or 3-4 long-size pieces) packed in microwaveable packaging like those commonly available on the market. Most consumers are familiar with rectangular boxes, but round containers could also be used.

Therefore, the product concept of a ready-to-eat seasoned fish product is fish fillet. The inside of the fish is a light yellow-white color, and the outside is a light-brown color. The taste of fish should not be too salty. The stir-fried red curry paste has a light-brown color and is spicy. The red curry paste should have semi-rough ingredients. The fish and seasoned curry paste should be packaged separately. The amount of fish fillet is 12-16 bite-sized pieces and packed in microwaveable packaging.

The product concept for ready-to-eat seasoned fish centers on convenience, visual appeal, and sensory balance, aligning with modern consumer demands for high-quality, health-conscious meals that are easy to prepare. The core component, the fish fillet, is designed to offer a light yellow-white interior, which is a visual indicator of proper cooking and freshness and in contrast with a lightly browned exterior that signals flavor development through the Maillard reaction during baking. This contrast enhances the perceived quality and appetizing appearance.

The seasoning aspect is equally crucial. The stir-fried red curry paste is intentionally formulated to have a light-brown color and moderate spiciness, appealing to a broad spectrum of consumers while staying true to Thai culinary identity. The inclusion of semi-rough ingredients (such as visible herbs or spices) enhances authenticity and texture, giving a homemade appeal that many consumers seek in ready meals.

Importantly, the product is modular in design, with the fish and curry paste packaged separately. This separation prevents sogginess and allows consumers to control mixing, catering to personal preferences. The portioning of 12-16 bite-sized pieces makes it suitable for single or shared consumption, and the use of microwaveable packaging supports convenience without compromising food safety or flavor.

This concept effectively integrates consumer insights, culinary authenticity, and industrial feasibility, setting a foundation for a differentiated and competitive product in the growing ready-to-eat market. Consequently, in the next step of this work, it was necessary to develop the fish processing method and curry paste ingredients to achieve characteristics that closely align with the product concept and initial product attributes.

3.2 Development of fish processing

Figure 4 presented the relation of physical and sensory quality of 8 samples (4 processed fish with and without curry). The PCA biplot explained 71.33% of the total variance of this data set. The eigenvalue of PC1 and PC2 was 7.61 and 3.79, respectively. PC1 exhibited high loading values for “overall acceptance” (loading = 0.967), “odor” (loading = 0.945) and “b” (loading = 0.934), suggesting that these attributes were primary contributors to sample discrimination along this dimension. PC2 was predominantly associated with “hardness” (loading = 0.989), “chewiness” (loading = 0.978) and “gumminess” (loading = 0.963), implying that textural characteristics played a significant role in the secondary differentiation of the products.

As expected, all FC treatments (processed fish with curry) were completely different from F (processed fish without curry) when discriminated against sensory acceptance (S), color, and a_w of samples (PC1). It was shown that consumers preferred processed fish with curry paste over fish. SV and M, two different methods of fish with and without curry paste, were perceived quite similarly. In comparison, BB180 and BB200 were perceived quite differently.

3.2.1 Physical properties of processed fish

According to Figure 4, among the fish processing methods, baking was positively correlated with the L^* value. Meanwhile SV and marinated methods were positively correlated with the a^* value. This result indicated that the cooking processes influenced the color value of the fish. Heat processes enhance texture and flavor/aroma through browning and the formation of colored compounds on the food surface (Fellows, 2000).

During the baking and frying process, several chemical reactions take place in the food system including oxidation reaction, browning, and hydrolysis of oil. These can be attributed to polymer compounds responsible for brown food coloring (Shukla et al., 2022). During baking, heat transfer occurs through convection of heated air circulating in the sample (Bainy et al., 2015). Maillard browning and caramelization reactions result in golden to brown hue of baked foods, and these processes are influenced by the heating conditions of food baking (Shukla et al., 2022). The marinated SV fish fillets and frying exhibited more redness than those baked. Frying leads to heat and mass transfer by both convection and conduction. Water in food is rapidly removed and replaced by the penetration of oil used as the heating medium. These mechanisms promote the browning of the outer crust (Zhang et al., 2020; Dangal et al., 2024), which is one of the key factors in consumer perception and acceptance (Shukla et al., 2022). This aligns with research findings showing that the redness value of fried fish nuggets was higher than that of baked fish nuggets (Oppong et al., 2021).

When considering the texture of processed fish, baking was positively correlated with hardness. Whereas SV and marination methods were negatively correlated with hardness but positively correlated with cohesiveness. Additionally, hardness was negatively correlated with moisture content and a_w . The observation that baking was positively correlated with hardness aligns with established thermal processing mechanisms. Baking involves exposure to dry heat, which drives off surface moisture and induces protein denaturation and aggregation, leading to a firmer texture (Tornberg, 2005). The increased hardness can also be attributed to moisture loss, as evidenced by the negative correlation between hardness and both moisture content and a_w . This finding is

consistent with Cárcel et al. (2007), who noted that lower moisture levels, resulting from drying or baking, produced a denser, less tender texture in fish products.

Conversely, SV and marination techniques, which employed gentler processing under moist conditions, reduced hardness but enhanced cohesiveness. SV cooking, typically conducted at lower temperatures in vacuum-sealed packaging, helps retain moisture and preserves structural integrity, yielding a more cohesive and tender texture (Baldwin, 2012). Similarly, marination, depending on its acid and salt content, can partially denature muscle proteins and improve water retention, thereby increasing cohesiveness while reducing rigidity (Roldán et al., 2013).

3.2.2 Sensory acceptance of processed fish

In terms of sensory evaluation (Figure 4), sensory acceptance using the 9-point hedonic score, with processed fish poured with curry paste (BB200-FC) was highly represented at the positive end of PC1 and was associated with all acceptance attributes, except appearance. Meanwhile, BB180-F (processed fish without curry paste) was positioned on the opposing end of PC1. Texture acceptance on BB200-FC was dominant and positively correlated with the adhesiveness value analyzed by TPA.

Therefore, according to sensory acceptance of samples, BB200-FC was selected for penalty analysis for decision-making processes (Table 6). This analysis combines JAR and overall liking score results to investigate a decrease in consumer acceptance to attributes not at the JAR level (Lawless & Heymann, 2010). The step of penalty analysis in this work was evaluated using the method of ASTM (Schraidt, 2009). Pareto principle that uses a minimum of 20% of non-JAR consumers is also considered, in other words, responses lower than 20% are too small to be considered and they might not be reliable enough (Rothman, 2007; Narayanan et al., 2014; Iserliyska et al., 2017; Škrobot et al., 2022). Therefore, a percentage of consumers above the cut-off point (20%) was used for the penalty analysis.

According to the penalty analysis, the proportion of non-JAR consumers for saltiness and spiciness in BB200-FC was below the 20% threshold. This indicates that these flavor attributes were generally well-received and did not require formulation adjustments. Although more than 70% of consumers rated the hardness as JAR, the proportion of those who perceived it as 'too hard' exceeded 20%, which would typically signal an area of concern. However, the corresponding mean drops in "too hard" dimension was only -0.688 , well below the ASTM (Schraidt, 2009) defined threshold of -1.0 for attributes warranting improvement. This suggests that, despite the frequency of 'too hard' responses, the actual influence on consumer acceptance was negligible.

The overall findings confirmed that BB200-FC possessed sensory characteristics that aligned well with consumer expectations. No individual attribute showed both a high percentage of dissatisfaction and a significant negative impact on preference. Thus, from a product development standpoint, no immediate sensory reformulations were required, and BB200-FC sample could therefore be considered stable and well-optimized in terms of flavor and texture.

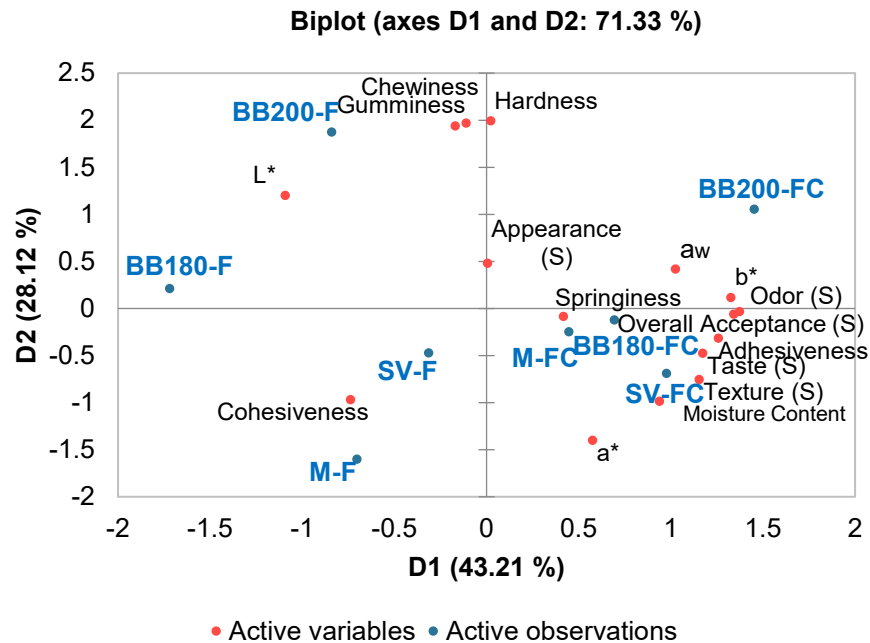


Figure 4. Principal component analysis (PCA) biplot for physical and sensory qualities (S) of processed fish poured with curry paste (FC) and without curry paste (F).
Note: B: Baking, BB: Blanching and baking, M: Marinating, SV: Sous-vide

Table 6. Penalty analysis of processed fish poured with curry paste (BB200-FC)

Variable	Level	Frequencies	%	Mean (OV)	Mean Drops	Standardized Difference	Penalties	p-Value
Hardness	Not hard enough	1	3.33	8.000	-0.545			
	JAR	22	73.33	7.455			-0.670	0.176
	Too hard	7	23.33	8.143	-0.688	-1.332		
Saltiness	Not salty enough	5	16.67	8.000	-0.600			
	JAR	20	66.67	7.400			-0.700	0.131
	Too salty	5	16.67	8.200	-0.800			
Spiciness	Not spicy enough	4	13.33	7.750	-0.141			
	JAR	23	76.67	7.609			-0.106	0.841
	Too spicy	3	10.00	7.667	-0.058			

Note: JAR: Just-about-right

3.3 Development of pasteurized seasoned curry paste

3.3.1 Screening of seasoned curry paste formular

The results obtained from physical analysis of 6 pasteurized seasoned curry pastes are illustrated in Table 7. It was found that treatment A and F had the lowest a_w values. This may be due to ingredients A and F containing salt and oil, respectively. Adding salt, sugar, or other ingredients can reduce a_w of food by binding it with free water molecules (Pittia & Antonello, 2016). While there were no significant differences in a_w between B - E ($p>0.05$).

The pH value of treatment A was the lowest, below 4.6, due to the inclusion of citric acid as the pH-control agent. A pH below 4.6 inhibits most pathogenic bacteria (e.g., *Clostridium botulinum*) and spoilage microorganisms, enabling shelf stability at room temperature (FDA, 2014). Citric acid acts as a chelating agent and pH buffer, disrupting microbial enzyme systems (Jay et al., 2005). In contrast, the other treatments had pH values more than 4.6 and must be kept refrigerated to preserve the product. According to color examination, treatment E had the highest a^* which indicated a red-orange tone. This was followed by treatment F, which had a deep red color or maroon tone. Treatment C, which used curry paste for coconut milk curry which generally contained fewer herbs than curry paste for stir-fried curry, had a higher L^* than B. Whereas, treatment E had the highest L^* ($p<0.05$).

According to sensory evaluation using a 9-point hedonic scale from 30 participants (Figure 5), the six formulas received significantly different liking scores ($p<0.05$). B received the highest overall liking score of 7.53 with all sensory characteristics averaging above 7 points. While 2 commercial formulas received the lowest liking scores across all attributes ($p<0.05$) with averages below 7 points.

The sensory evaluation results demonstrate the effectiveness of formulation B in aligning with consumer preferences. With a mean overall liking score of 7.53 and scores exceeding 7 across all sensory attributes, this formulation achieved high consumer acceptance. Notably, formulation B outperformed the two commercial formulations, which received significantly lower scores ($p<0.05$), indicating a clear consumer preference for the newly developed formulation.

Table 7. Physical properties of six pasteurized seasoned curry pastes

Formular	a_w	pH	Color		
			L^*	a^*	b^*
A	0.93±0.01 ^b	4.19±0.02 ^f	29.26±1.22 ^c	3.73±1.06 ^{de}	10.78±1.68 ^c
B	0.96±0.01 ^a	6.89±0.02 ^a	29.47±0.24 ^c	4.44±0.15 ^d	12.64±0.28 ^{ab}
C	0.96±0.00 ^a	6.67±0.01 ^c	31.49±0.33 ^{ab}	6.23±0.31 ^c	13.81±0.92 ^a
D	0.95±0.00 ^a	6.84±0.02 ^b	30.06±0.45 ^{bc}	2.99±0.33 ^e	7.64±1.33 ^d
E(Brand 1)	0.96±0.00 ^a	5.10±0.01 ^d	32.32±0.55 ^a	12.61±0.65 ^a	12.28±0.87 ^b
F(Brand 2)	0.94±0.01 ^b	4.82±0.03 ^e	27.28±2.36 ^d	7.99±1.19 ^b	7.59±0.83 ^d

Note: Values are presented as mean±SD of a_w , pH ($n=3$), color ($n=5$). Different lowercase superscripts (a-f) in the same column indicate significant differences ($p<0.05$).

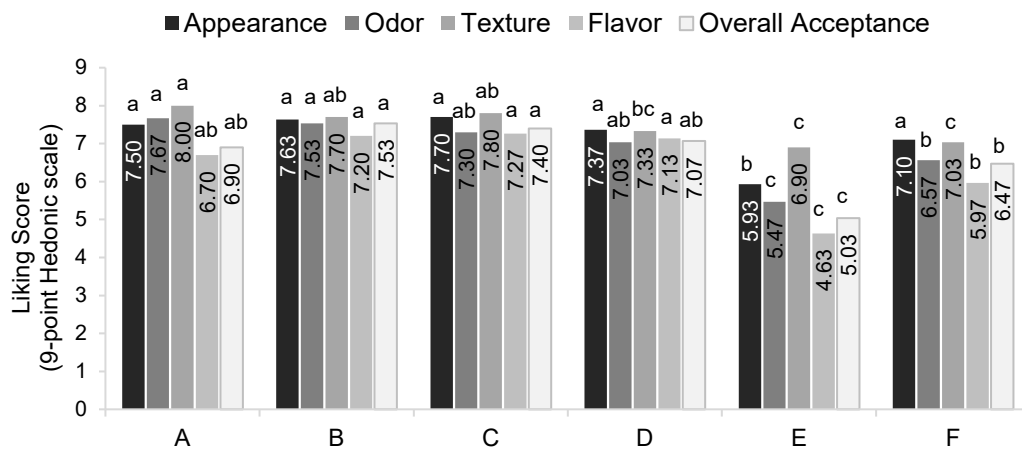


Figure 5. Liking scores for fish with six seasoned curry pastes (formulars A-F) from 30 panelists.

Note: Different lowercase letters (a-c) within the same sample indicate significant differences ($p < 0.05$).

Considering the JAR analysis of the B seasoned curry paste (Table 8), more than 20% of consumers identified the color, saltiness, and spiciness attributes as deviating from the JAR range. However, the actual impact on overall liking, as indicated by the mean drops, varied notably among these attributes. Specifically, spiciness, although frequently rated as “too spicy”, resulted in a relatively small mean drop (-0.514), suggesting that the intensity of spiciness was not a critical deterrent for most consumers. Similarly, the color attribute was penalized by a significant portion of respondents for being “too dark”. However, the mean drop was minimal (-0.075), suggesting that this visual characteristic had limited influence on overall product acceptance.

Table 8. Penalty analysis of formular B seasoned curry paste sample

Variable	Level	Frequencies	%	Mean (OV)	Mean drops	Standardized Difference	Penalties	p-Value
Color	Not dark enough	1	3.33	7.000	-0.800			
	JAR	15	50.00	7.800			0.533	0.090
	Too dark	14	46.67	7.286	-0.514	1.639		
Saltiness	Not salty enough	8	26.67	7.000	-0.833			
	JAR	12	40.00	7.833			0.500	0.121
	Too salty	10	33.33	7.600	-0.233			
Spiciness	Not spicy enough	2	6.67	8.000	0.455			
	JAR	11	36.67	7.545			0.019	0.954
	Too spicy	17	56.67	7.471	-0.075			

Note: Jar: just-about-right

On the other hand, the saltiness dimension displayed a different trend: the mean drop for “too salty” ratings exceeded that of “not salty enough”, indicating that consumers were more sensitive to excessive salt than to mild under-seasoning. This insight is particularly valuable for guiding formulation adjustments, as it highlights the need to prioritize salt balance to avoid rejection.

Although the penalties associated with color and spiciness were low, the relatively high proportion of non-JAR responses suggest that these attributes still warranted attention during product development. Continuous refinement, informed by both penalty magnitude and consumer proportions, is essential for optimizing sensory attributes and enhancing overall product quality and acceptance.

In terms of food acceptability, sensory attributes such as aroma, flavor, and texture are critical for consumer acceptance of food products. The performance of the B formulation could be attributed to its optimized balance of flavor compounds, texture, and seasoning intensity, aligning with the JAR expectations of target consumers. Furthermore, the statistically significant differences in scores confirm the importance of tailoring formulations to consumer preferences, as supported by Lawless and Heymann (2010), who emphasized the role of sensory testing in guiding product development.

3.3.2 Development of pasteurized seasoned curry paste

The consumer sensory evaluation (Figure 6) revealed no statistically significant differences in preference scores among the various consumer groups ($p > 0.05$), except in the aspect of appearance. Group 2 consumers rated formular B2 higher than the other samples regarding appearance liking score (Figure 6A). In terms of the overall acceptance score (Figure 6C), Group 2 consumers rated all samples above 7 points.

From the trend shown in the bar graph, it is evident that as the amounts of curry paste and shrimp paste were reduced, the liking scores declined consistently. This decline was especially noticeable for flavor and overall acceptance across all three consumer groups. This suggests that these two ingredients play a key role in driving consumer preference. This is likely due to their contribution to the product's characteristic taste and aroma. Reducing these components may result in a perceived loss of authenticity or flavor intensity, which can negatively affect consumer evaluations. These findings underscore the importance of maintaining adequate levels of curry and shrimp paste to ensure favorable sensory appeal.

According to Figure 7, PCA were analyzed based on physical and consumer liking scores (ID1–ID90). PC1 (D1) and PC2 (D2) explain 73.96% of the variance among the samples with eigenvalues of 48.98 and 21.29, respectively. PC1 showed high loading values for 45 consumers (loading > 0.5), representing 50% of the total consumers. On PC2, 37 consumers exhibited high loading scores (loading > 0.5). Consumers were clustered near the samples (shown in blue color) that received higher acceptance scores. A greater concentration of consumers was observed near formular B1 and the control, indicating higher preference. In contrast, formulars B3 and B4, located opposite formular B1 on the plot, had fewer consumers nearby, suggesting that the low-spiciness formular B1 was more acceptable to these consumers.

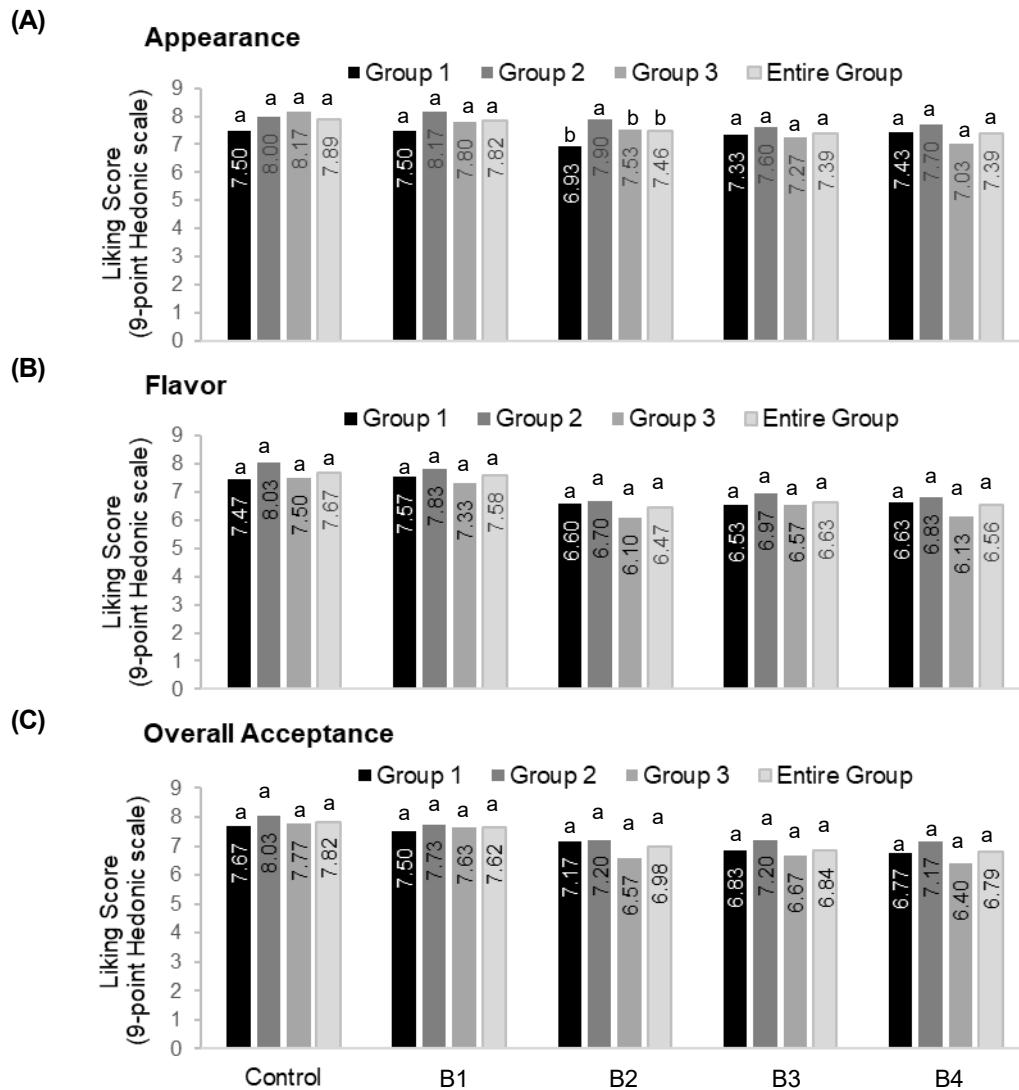


Figure 6. Liking scores of fish poured with seasoned curry paste evaluated by three consumer groups and the entire group for (A) appearance, (B) flavor, and (C) overall acceptance.

Note: Different lowercase letters (a-b) within the same sample indicate significant differences ($p < 0.05$).

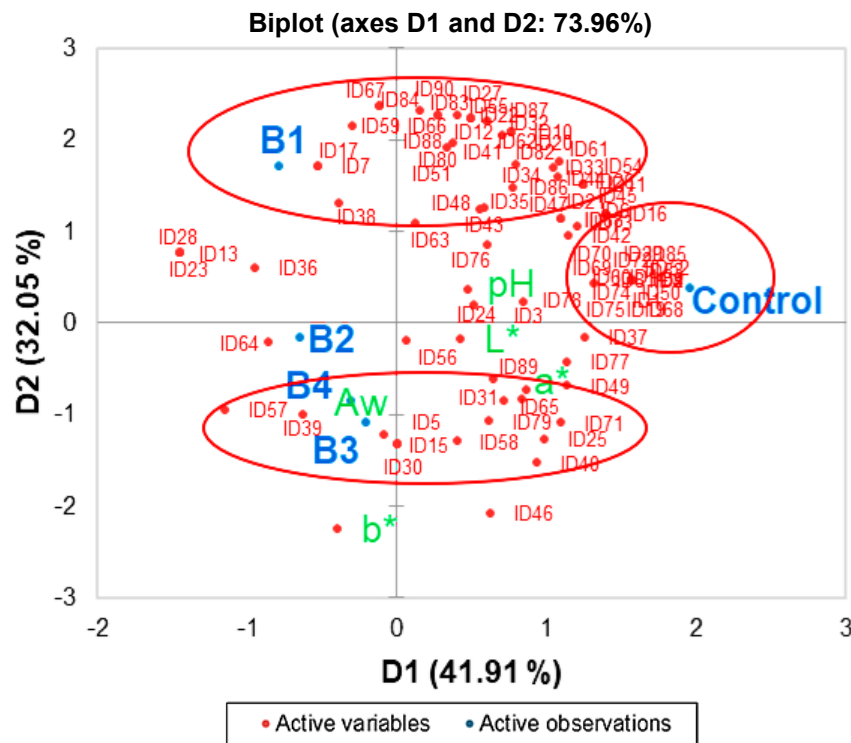


Figure 7. Principal component analysis generated with consumer liking score (red color) and physical properties (green color) of 5 seasoned fish (blue color) evaluated by entire consumer (ID1-ID90)

Despite this trend, formular B1 and the control sample received preference scores exceeding 7 in all attributes from all three consumer groups. Both samples appeared near the majority of consumer responses, indicating that these formulations were generally well-received compared to the others. This suggests that reducing key ingredients like curry paste and shrimp paste might affect the sensory appeal, particularly in flavor and overall taste, for most consumers.

According to the penalty analysis of formular B1 among Group 1 consumers (Table 9), the color attribute was rated as JAR by a substantial proportion of respondents (70%), suggesting that the appearance of the sample was generally acceptable. While more than 20% of respondents identified saltiness (as 'not salty enough') and spiciness (as 'too spicy') as deviating from JAR, the associated mean drops in overall liking scores were relatively small (1.303 and 0.140, respectively). This indicates that, although these two attributes were noted as potential issues, they had only a minor impact on overall product acceptance in this group.

For Group 2 consumers, all evaluated sensory attributes were within the JAR range, as the proportion of non-JAR responses for each attribute did not exceed 20%. This implies a good overall balance in sensory characteristics for this group. In contrast, for Group 3 consumers, while color and saltiness were perceived as JAR, spiciness emerged as a significant concern. Specifically, 63.33% of respondents rated the product as 'not spicy

Table 9. Penalty analysis of formular B1 seasoned curry paste sample from 3 consumer groups

Consumer Group	Penalty Analysis	Color			Saltiness			Spiciness		
		NE	JAR	TM	NE	JAR	TM	NE	JAR	TM
1	Frequency (%)	13.33	70.00	16.67	26.67	63.33	10.00	16.67	56.67	26.67
	Mean drops	1.952		1.152	1.303		2.053	1.365		0.140
	Penalties		1.508			1.507			0.611	
2	Frequency (%)	3.33	83.33	13.33	20.00	66.67	13.33	26.67	70.00	3.33
	Mean drops	-1.360		-0.360	0.733		0.150	0.232		1.857
	Penalties		-0.560			-0.500			0.413	
3	Frequency (%)	10.00	80.00	10.00	26.67	73.33	0.00	63.33	30.00	6.67
	Mean drops	-0.917		-1.250	1.375			1.614		0.167
	Penalties		-1.083						1.476	

Note: NE: Not enough, JAR: Just-about-right, TM: Too much

enough' and this perception was associated with a substantial negative penalty, indicating that insufficient spiciness considerably lowered overall liking among this group.

Overall, the penalty analysis highlighted the importance of tailoring sensory attributes to specific consumer group preferences. While formular B1 was generally well accepted in terms of color and saltiness across Groups 1 and 2, spiciness appeared to be a divisive factor, particularly among Group 3 consumers.

4. Conclusions

The development of ready-to-eat seasoned fish products exhibited favorable attributes and sensory properties. The product concept for a ready-to-eat seasoned fish item consisted of fish fillets with a light yellow-white interior and a light-brown exterior. The flavor profile should be non-salty, complemented by light brown, spicy stir-fried red curry pastes with semi-rough ingredients. The fish and seasoned curry paste must be packaged separately, with the fish fillets comprising 12-16 bite-sized pieces, all contained in microwaveable packaging. Among the processing methods tested, blanching before baking produced superior results to baking alone, marination, and sous-vide techniques. The optimal method involved blanching and baking in a hot oven at 200°C for 30 min. The best seasoning formular (B1) consisted of 200 g of water, 30 g of spicy stir-fried red curry paste, 10 g of shrimp paste, 15 g of palm oil, 7.5 g of sugar, and 0.75 g of monosodium glutamate. This formulation received the highest consumer acceptance and achieved the most Just-About-Right scores. The cooked fish and pasteurized seasoned curry paste were packaged individually, with both components enclosed in microwave-safe containers. Thus, the developed processing method effectively preserved the authentic flavor of the curry paste while enhancing consumer acceptance of the ready-to-eat seasoned fish prototype. These outcomes supported the development of a high-quality, consumer-driven Thai-style seasoned fish product. Furthermore, the incorporation of stir-fried red curry

paste served as a signature element of Southern Thai cuisine. This inclusion helped reinforce the region's unique culinary identity. It also created potential for international market expansion under the banner of authentic Thai food. Additionally, the use of locally sourced ingredients such as tilapia and traditional herbs fostered the sustainability of regional agri-food systems.

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6. Authors' Contributions

Arunothai Juemanee designed research; Arunothai Juemanee and Ruangnalin Thepnuan performed research; Arunothai Juemanee and Supaporn Apirattananusorn contributed new reagents/analytic tools; Arunothai Juemanee analyzed data; Arunothai Juemanee coordinated research; and Arunothai Juemanee and Ruangnalin Thepnuan wrote the paper.

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7. Conflicts of Interest

The authors declare that they have no conflict of interest.

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