



Extension of the Shelf Life of Rice Field Crab Chili Paste using Hurdle Technology

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Abstract

Rice field crab chili paste is a traditional Thai condiment known for its rich flavor and cultural significance. However, its high moisture content and susceptibility to microbial contamination limits its shelf life and market potential. This study aimed to extend the shelf life of rice field crab chili paste using hurdle technology, focusing on reducing water activity (a_w), adjusting pH, and incorporating food-grade preservatives. Various formulations were tested, including addition of humectants (glycerol) and preservatives (sodium benzoate). Physicochemical properties (pH, a_w) and microbiological safety (Total Plate Count, pathogen detection), were analyzed. The original-recipe rice field crab chili paste had a high pH (4.75 ± 0.10) and high free water (a_w) level (0.93 ± 0.03). It had a shelf life of 5 days at room temperature and 141 days under refrigerated conditions (5°C). From the 6th day of storage at room temperature, the Total Plate Count (TPC) was found to have exceeded the standard ($>1 \times 10^4$ CFU/g). The addition of 3% and 6% glycerol to the chili paste extended its room-temperature shelf life to 7 days and its refrigerated shelf life to 169 days with the average pH 4.11 ± 0.02 and 4.10 ± 0.00 respectively and the average a_w at 0.77 ± 0.03 and 0.77 ± 0.01 respectively. Adding sodium benzoate under pH 4.10 revealed that the average a_w of the chili pastes with sodium benzoate 250 and 500 ppm were 0.75 ± 0.25 and 0.76 ± 0.26 respectively. This method extended the shelf life of chili paste under room temperature conditions to 31 days. ANOVA testing confirmed significant differences in microbial stability, and the effectiveness of glycerol and preservative use. The results of this study found that hurdle technology effectively extended the shelf life of rice field crab chili paste while maintaining product safety and quality. Sodium benzoate proved most effective for long-term storage, whereas glycerol-based formulations benefited from refrigeration. These findings provide practical insights for small-scale producers aiming to improve product stability and marketability.

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Introduction

Currently, the production of ready-to-eat processed foods in Thailand is extensive and diverse. However, there are no official reports confirming the exact production volume of chili paste (*Nam Prik*) in the market, nor is there available macro-level data regarding its market value. Nevertheless, when considering a similar product category—specifically curry paste produced for export—it was found that the export value in 2025 reached approximately 1,925 million Baht (Information and Communication Technology Center with Cooperation of the Customs Department, 2026). This demonstrates a high demand for products in this category and indicates significant market value. Consequently, the production of rice field crab chili paste (*Nam Prik Pu Na*) presents a viable alternative for generating income and developing alternative processed food products, while effectively utilizing domestic raw materials. Rice field crab chili paste (*Nam Prik Poo Na*) is a traditional Thai condiment celebrated for its bold flavor and deep cultural roots. As a staple in many Thai households, it holds culinary significance; however, its high moisture content and susceptibility to microbial contamination pose challenges for shelf stability. Like many fresh and minimally processed foods, the short shelf life of rice field crab chili pastes limits its commercial potential and raises concerns regarding food safety. Typically, such products spoil within a week of production due to microbial proliferation, leading to economic losses and food waste, particularly for small-scale producers (Wongchaiya et al., 2024).

In addition, the spoiled chili paste can cause illness, such as diarrhea and food poisoning. Foodborne illnesses are a major cause for significant public health concern, particularly food poisoning. This condition results from the consumption of food or water contaminated with residual microbial toxins and pathogenic microorganisms. The trend of food poisoning has been increasing. Between 2021 and 2024, the morbidity rate was recorded at 203.51/100,000 population (Sunan et al, 2025). Due to Thailand being located in a hot climate, food poisoning remains a critical public health issue that can occur throughout the year (Joob & Wiwanitkit, 2015). The spoilage of rice field crab chili paste can be a risk factor to the consumer. Therefore, the high risk of food borne disease requires ongoing surveillance and the implementation of strategies to mitigate illness.

In response to these challenges, hurdle technology has emerged as an effective method for extending the shelf life of perishable foods. This preservation approach strategically applies multiple inhibitory factors—such as reducing water activity (a_w), adjusting pH, and incorporating food-grade preservatives—to create an unfavorable environment for microbial growth while maintaining product quality (Abdullahi & Dandago, 2021; Tapia et al., 2020). By layering these “hurdles” the method prevents spoilage and enhances food safety without relying on a single preservation factor. Hurdle technology has been successfully applied to various food products, including fermented vegetables and seafood-based condiments, where it has been shown to inhibit microbial proliferation and prolong shelf life (Giannakourou & Tsironi, 2021; Woldemariam et al., 2022). In particular, studies on chili-based condiments such as Sambal, which is a chili-based condiment—ranging from a sauce to a paste—that often incorporates aromatics like garlic, shallots, ginger, and shrimp paste, have demonstrated that adjusting a_w and pH can significantly impact microbial stability and shelf life (Surya & Tedjakusuma, 2022). However, its application in traditional Thai condiments, particularly rice field crab chili paste, remains underexplored. This gap presents an opportunity to merge traditional culinary practices with modern food preservation techniques. Moreover, the cultural and economic significance of traditional foods like rice field crab chili paste cannot be overlooked. Local food identity plays a crucial role in community sustainability and tourism, particularly in regions where culinary heritage is a vital part of the local economy (Tagong & Sirisawat Apichayakul, 2023). Preserving and enhancing the quality of such traditional products not only benefits local producers but also supports cultural tourism initiatives.

The primary objective of this study was to extend the shelf life of rice field crab chili paste using hurdle technology. Specifically, the approach focused on lowering free water activity (a_w) using humectants such as glycerol, alongside food-grade preservatives (sodium benzoate, INS211) to inhibit microbial growth. The research further evaluated the product’s physicochemical properties (pH and a_w) and microbial safety (Total Plate Count and pathogen detection). This study hypothesizes that applying hurdle technology can reduce a_w below 0.85—creating conditions that significantly inhibit microbial growth—while maintaining the sensory quality that consumers expect (Tapia et al., 2020).

Extending the shelf life of rice field crab chili paste not only addresses food safety concerns but also promotes sustainability by reducing food waste. Importantly, this advancement could expand market opportunities for small-scale producers, allowing them to distribute traditional Thai condiments more broadly while preserving cultural heritage (Tagong & Sirisawat Apichayakul, 2023).

Materials and methods

1. Experimental design

This study investigated the effects of hurdle technology—specifically, the reduction of free water using glycerol and the addition of sodium benzoate (INS211)—on field crab paste. A randomized complete block design (RCBD) was used to evaluate the effects of hurdle technology on the physicochemical and microbiological properties of the chili paste. The experiment consisted of a control group (original formula), formulations with glycerol at 3% and 6% (w/w), and formulations with INS211 preservative at 250 ppm and 500 ppm, as shown in Table 1. In each experimental batch, the rice field crab chili pastes for each treatment were freshly produced at least three times. To evaluate shelf-life extension, Total Plate Count (TPC) was used as an indicator of spoilage. Specifically, to study the effect of free water reduction using glycerol, changes in TPC, a_w and pH were measured under room temperature and refrigerated (5°C) conditions. For the study on the effect of INS211 preservative, TPC and pH were monitored under room temperature conditions.

Table 1 Experimental design of this study

Rice field crab chili pastes recipe	Treatments conditions and investigated parameters					
	Room temperature			Under 5°C storage		
	pH	a_w (%)	TPC (CFU/g)	pH	a_w (%)	TPC (CFU/g)
Control (original recipe)	✓	✓	✓	✓	✓	✓
Adding glycerol	✓	✓	✓	✓	✓	✓
Adding food preservative	✓		✓			

Remark: ✓ indicates that the parameter was evaluated in that treatment.

2. Original crab chili paste preparation

The compositions of the original recipe of rice field crab chili paste were kindly provided by an entrepreneur that produces rice field chili paste. The compositions are the hepatopancreatic part of rice field crab or “crab fat”, roasted chili, Thai garlic, shallot and tamarind paste as shown in Table 2. The chili paste was prepared by weighing

all ingredients according to the proportions shown in Table 2, preparing a total weight of 750–800 g/production cycle. The crab fat and crab meat (Crab house, Crab house group limited, Bangkok, Thailand) were stir-fried over medium heat at 120–150°C in an iron pan until fragrant. The roasted dried chilies, garlic, and shallots were finely ground by a grinder (3000 W, 5 L, Sharp Corporation, Japan) and were mixed thoroughly. After seasoning powder (RosDee, Ajinomoto, Thailand), sea salt (Roongthara, Kleur Samut RoongThara, Samut Songkhram) and tamarind paste (Chua Hah Seang, Chua Hah Seng Food Product Co., Ltd, Nakhon Pathom, Thailand) were incorporated, the mixture was simmered at 120–150°C until the liquid reduced. The chili paste was allowed to cool completely before being refrigerated overnight. The following day, 25 g samples of the crab chili paste were packaged into polypropylene bottles. In all, 15 bottles of 25 g of rice field crab chili paste were produced.

Table 2 The components of rice field crab chili paste

Components	Percent (%)
Thai local chili “Huea Ruea chili” <i>Capsicum annuum</i> L.	2.82
Thai local chili “Yod Son chili” <i>Capsicum annuum</i> L.	2.82
Thai garlic	8.06
Shallot	8.06
Crab fat	8.06
Tamarind paste	26.19
Boiled crab meat	40.29
Seasoning	2.01
Salt	1.69
Total	100

3. Physical and microbial properties examination

The physical and microbial properties of the rice field crab chili paste examinations were performed as follow;

3.1 Microbial analysis

The rice field crab chili paste was sent to be analyzed for microbial contamination at the Asia medical and agricultural laboratory and research center, Bangkok, Thailand. Total plate count (TPC), yeast and mold, and some pathogenic microorganisms including, *Salmonella* spp., *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens* and *Escherichia coli* were determined based on the standard methods, as shown in Table 3.

3.2 Physical properties analysis

The free water activity (a_w) of rice field crab chili paste was detected by a portable water activity meter (Model TH2/RTD33, Navasina AG, Switzerland). The pH of the chili paste was determined by a pH meter (Model 713, Metrohm Ltd., Switzerland).

Table 3 Analytical methods for microbial in rice crab chili pastes

Parameters	Analytical methods	Units
Total plate count (TPC)	FDA-BAM online, 2001 (Chapter3) (Maturin & Peeler, 2001)	CFU/g
Yeast and mold	AOAC (2001) 997.02 (Tournas et al., 2001)	CFU/g
<i>Salmonella</i> spp.	ISO 6579-1: 2020 (International Organization for Standardization, 2020)	per 25 g
<i>Staphylococcus aureus</i>	ISO 6888-1: 2021 (International Organization for Standardization, 2021)	CFU/g
<i>Bacillus cereus</i>	ISO 7932: 2004 (International Organization for Standardization, 2004)	CFU/g
<i>Clostridium perfringens</i>	FDA-BAM online, 2001 (Chapter 16) (Rhodehamel & Harm, 2001)	CFU/g
<i>Escherichia coli</i>	FDA-BAM online, 2020 (Chapter 4) (Feng et al., 2020)	MPN/g

4. Processes for the extension of the shelf life of rice field crab chili paste

There were 3 methods for extension of chili paste shelf life, including;

4.1 Adjustment of the pH of the chili pastes

The pH level in chili paste affects its shelf life. In this study, the pH of the chili paste was adjusted to 4.10 by adding tamarind juice after all of ingredients were added and well mixed. The pH of chili paste was measured by using a pH meter (Model 713, Metrohm Ltd., Switzerland).

4.2 Lowering the free water or a_w

The reduction of a_w was performed by using food grade vegetable glycerol (F001 VG, Krungthepchemi Co., Ltd., Thailand) at 2 different concentrations, which were 3% and 6% w/w of chili paste.

4.3 Incorporation of a preservative

The food additive sodium benzoate (INS211) as a powder (INS211, Wuhan Youji Industries Co., Ltd., China) was used at 2 concentrations, including 250 ppm and 500 ppm to determine the best storage conditions for extending shelf life.

5. Methods for parameters investigation and food additives incorporation

5.1 Physical and microbial properties of original rice field crab chili paste

The minimum of 3 productions batches of chili pastes were sampled. Five bottles were randomly selected from each batch, and the collected samples were determined for pH, a_w and microbial analysis

5.2 Reduction of a_w in the chili pastes

The rice field crab chili pastes were made as previously mentioned. The pH of the chili pastes was

adjusted to 4.10 by using tamarind paste. The pH of the tamarind paste ranged from 2.41–2.45. Glycerol at the concentration 3% and 6 % were added to the rice field crab chili paste after the seasoning process was finished and the well mixed chili pastes were brought to cool rapidly in an ice container. Then, the chili pastes were added to polypropylene (PP) bottles.

5.3 Preservative addition

The rice field crab chili pastes were made as previously mentioned. The pH of the chili pastes was adjusted to 4.10 by using tamarind paste. Sodium benzoate at the concentration 250 and 500 ppm were added to the rice field crab chili paste after the seasoning process was finished and the well mixed chili pastes were stirred fried at 70°C for 15 min. Then, the chili pastes were brought to cool at 5°C rapidly in an ice container for 15 min and they were added to polypropylene bottles.

The preparation of the rice field crab chili paste (*Nam Prik Poo Na*) samples was structured into 3 distinct experimental groups to evaluate the effects of glycerol as a humectant or stabilizer. These groups consisted of a control formula (no adding INS211), a 250-ppm formula, and a 500-ppm formula. To ensure statistical validity and provide sufficient volume for longitudinal testing, each formulation was replicated across 50 individual units, resulting in a total of 150 samples. The production of a large master batch of chili paste was carried out to ensure base consistency across all treatments. This master batch was then divided into three equal portions. For the treated samples, INS211 was incorporated by weight; specifically, the 250 and 500 ppm were calculated based on the total mass of the respective chili paste portions. Following the preparation of the mixtures, the aliquoting process was performed using a high-precision digital scale. From each formulation, 25 g of the paste were carefully weighed into 50 food-grade plastic containers. All 150 containers were stored under room temperature conditions. The chili pastes of each treatment were randomly selected to evaluate the TPC.

5.4 Shelf-life evaluation

The original rice field crab chili pastes product and the chili pastes added with glycerol, packaged in 50 g polypropylene (PP) plastic jars, were stored at a room temperature and 5°C. Samples from these storage conditions were randomly selected for determination of TPC until the TPC value exceeded 1×10^4 CFU/g, indicating that the chili paste started to be spoiled. The shelf-life evaluation of chili paste added with sodium

benzoate was determined by stored the chili paste at room temperature until its TPC value exceeded 1×10^4 CFU/g.

6. Samples preparation for evaluation of the effect of the addition of glycerol

The preparation of the rice field crab chili samples was structured into three distinct experimental groups to evaluate the effects of glycerol as a humectant or stabilizer. These groups consisted of a control formula (containing no glycerol), a 3% glycerol formula, and a 6% glycerol formula. To ensure statistical validity and provide sufficient volume for longitudinal testing, each formulation was replicated across 50 individual units, resulting in a total of 150 samples.

The process was started with the production of a large master batch of chili paste to ensure base consistency across all treatments. This master batch was then divided into three equal portions. For the treated samples, glycerol was incorporated by weight; specifically, the 3% and 6% concentrations that were calculated based on the total mass of the respective chili paste portions. According to Kong and Singh (2016), the precise incorporation of polyols like glycerol is essential for controlling water activity (a_w) and maintaining the textural integrity of intermediate-moisture foods. Each mixture was stirred thoroughly using a standardized mixing time and speed to achieve a completely homogenous distribution of the additive, which was critical for accurate downstream analysis.

Following the preparation of the mixtures, the aliquoting process was performed using a high-precision digital scale. From each formulation, 25 g of the paste were carefully weighed into 50 food-grade plastic containers. As noted by Marsh and Bugusu (2007), plastic packaging—specifically polypropylene—is widely utilized for its effective moisture barrier properties and durability during cold chain distribution. It was imperative that the filling process was conducted efficiently to minimize exposure to air and potential environmental contaminants. Once the 25-g threshold was met, each plastic container was immediately and securely sealed with a lid.

To maintain the quality and safety of the product throughout the study, all 150 containers were stored under controlled refrigerated conditions (approx. 5°C). Refrigeration is a critical factor in inhibiting microbial growth and slowing down lipid oxidation in seafood-based pastes (Gram & Huss, 1996). This chilled storage environment is essential for preserving the

sensory characteristics of the field crab and ensuring the stability of the chili paste during the observation period. Each container was marked with its specific treatment code and a unique sample number to ensure traceability during subsequent testing phases, such as texture profile analysis or shelf-life stability monitoring.

7. Statistical analysis

Data of pH, a_w , and TPC as log CFU/g of all chili pastes recipes were analyzed using ANOVA to assess significant differences among treatment groups. Mean values were compared using Tukey's HSD at a significance level of $\alpha=0.05$.

Results and discussion

1. Physicochemical and microbial properties

After testing the physical, chemical, and microbiological properties of original rice field crab chili paste, it was found that the a_w was above the standard and the pH level was high (4.75), while none of the microbiological indicators exceeded the standard as shown in Table 4.

Table 4 Physical, chemical, and microbiological properties of original rice field crab chili paste

Parameters	Results	Standard values (Thai Industrial Standards Institute, 2023)
a_w	0.93±0.03	<0.85
pH	4.75±0.10	—
Total plate count	1×10^2 CFU/g (2.00 log CFU/g)	< 1×10^4 CFU/g sample (4.00 log CFU/g)
<i>Salmonella</i> spp.	ND	ND
<i>Staphylococcus aureus</i>	<10	< 1×10^4 CFU/g sample
<i>Bacillus cereus</i>	<10	< 1×10^4 CFU/g sample
<i>Clostridium perfringens</i>	<10	<100 colony/g sample
<i>Escherichia coli</i>	<3	<3 MPN/g sample
Yeast and mold	<10	<100 colony/g sample

Remark: ND means not detected.

Based on the inspection results, the chili paste with rice paddy crab has a water activity (a_w) value of 0.93. This is a relatively high amount of free water compared to the standard for the Thai Community Product Standard for chili paste (0.85) (Thai Industrial Standards Institute, 2023). The recipe should be improved to reduce the a_w value in order to decrease the chance of microbial growth. The results showed that the initial microbial count of the chili paste was 1×10^2 CFU/g of the sample, which is still within the standard for community-produced roasted chili paste (Thai Industrial Standards Institute, 2023).

When chili paste was stored at room temperature and its physical and microbial properties were examined, it was found that after 7 days, the pH and a_w had increased,

and the total plate count (TPC) exceeded the standard, which was 1×10^4 CFU/g, as shown in Table 5. The shelf life of the original-recipe rice field crab chili paste was 5 days when stored at room temperature. The rice field crab chili paste's shelf life stored at room temperature was only 5 days resulting from the product's pH value being higher than 4.6 and its high-water activity. The results demonstrate that the pH level varies across different production lots. This is attributed to the lack of quality control during the production process and the use of agricultural raw materials, such as tamarind paste. These chilies paste products that are adjusted for flavor by tasting may result in an inconsistent pH level. When chili paste was restored at room temperature, it was found that the pH value was between 6.35 and 6.60. Since pH is a critical factor for extending shelf life, the ability to maintain a consistent pH level across each production lot would result in a product with a more uniform quality and a reduced risk of spoilage.

Research by Kaewthong et al. (2025) indicates that the rapid spoilage of Southern Thai curry pastes was correlated with high pH and high-water activity (greater than 0.85), which is consistent with the characteristics of the chili paste examined in this study. It was found that after the 5th day of storage, the original chili paste's pH and water activity of this study both showed a continuous increase. A low pH (meaning high acidity) is what typically inhibits the growth of most spoilage bacteria and pathogens. A low level of acidity would correspond to a higher pH, which generally promotes microbial growth and spoilage. A high level of acidity in chili paste helps to reduce the absorption of nutrients through the microbial cell membrane, effectively limiting microbial growth in the paste and extending its shelf life (Kaewthong et al, 2025).

The pH value showed a significant increasing trend ($p < 0.05$) from 6.35 on day 1 to 6.60 on day 9 (Table 5). This increase in pH might be attributed to the degradation of proteins in the crab meat by either endogenous enzymes or microbial activity, leading to the formation of basic nitrogenous compounds such as ammonia and trimethylamine (Huss, 1995). Regarding water activity (a_w), there were no significant differences (ns) observed throughout the 9-day storage period, with values remaining high between 0.916 and 0.932. These high a_w levels (above 0.85) create a favorable environment for the growth of most spoilage bacteria and pathogens (Fontana & Carter, 2007).

The TPC remained relatively stable during the first 5

days (1.30–1.47 log CFU/g). However, a sharp and significant increase was observed starting from day 7 (4.14 log CFU/g) and reaching 5.20 log CFU/g by day 9. This rapid growth correlates with the high-water activity and the near-neutral pH of the product, which are optimal for microbial proliferation. According to the Thai Community Product Standard (TCPS), the microbial limit for such products often requires TPC to be controlled to ensure safety; the surge after day 5 suggests that the shelf-life of the product at room temperature without preservatives is limited to less than 7 days. The microbial quality of the rice field crab chili paste during storage was evaluated in comparison with the Thai Community Product Standard for Fried Chili Paste (TCPS 144/2018). According to this standard, the Total Plate Count (TPC) must not exceed 1×10^4 CFU/g (or 4.00 log CFU/g). The experimental results shown in Table 5 are consistent with the TCPS requirements during the initial period of storage. From Day 1 to Day 5, the TPC remained low, ranging from 1.30 ± 0.03 to 1.47 ± 0.01 log CFU/g, which is well within the safety limits defined by the standard. However, a significant transition occurred after Day 5. By Day 7, the TPC increased to 4.14 ± 0.01 log CFU/g, which exceeds the maximum limit permitted by TCPS 144/2018. The count further escalated to 5.20 ± 0.04 log CFU/g on Day 9. This correlation suggests that while the product maintains its microbial safety under the community standard for up to 5 days at room temperature, it becomes non-compliant by Day 7 due to rapid microbial proliferation favored by high a_w and near-neutral pH.

2. The effect of hurdle technology on chili pastes shelf life

2.1 The effect of adding glycerol under room temperature condition

Reducing a_w using glycerol was essential in limiting microbial activity. The study demonstrated that formulations with 3% and 6% glycerol effectively lowered a_w to levels that inhibit microbial growth. This aligns with Tapia et al. (2020), who reported that a_w levels below 0.85 significantly hinder the growth of spoilage microorganisms. The ability to lower a_w without negatively affecting product texture highlights the suitability of glycerol as a humectant in chili paste preservation.

Adding 3% and 6% glycerol to a traditional chili paste recipe, and storing it at room temperature under pH 4.10 showed that by adding glycerol it was possible to extend the shelf life of the chili paste by 7 days when

compared to the original recipe of chili paste as shown in Table 5.

In this experiment, glycerol was used at concentrations of 3% and 6% by weight of the rice field crab chili paste. The results showed that this extended the product's shelf life by 7 days. This is because the original chili paste had a relatively high-water content, as indicated by a water activity (a_w) of up to 0.9. In the improved formula for extending shelf life, the a_w decreased to a range of 0.7–0.8.

The experimental results presented in Table 5 illustrate the chemical and microbiological stability of rice field crab chili paste. In the control sample (Table 5), the pH value increased significantly ($p<0.05$) from 6.35 ± 0.00 on Day 1 to 6.60 ± 0.00 on Day 9. This increase in pH is generally attributed to the degradation of proteins in crab meat by either microbial activity or endogenous enzymes, leading to the formation of volatile basic nitrogenous compounds such as ammonia and amines (Huss, 1995). A critical observation from Table 5 is the high-water activity (a_w), which remained between 0.916 and 0.932. Such high a_w levels (above 0.85) are highly conducive to the rapid growth of spoilage and pathogenic bacteria (Fontana & Carter, 2007). This is reflected in the total plate count (TPC) of the control sample, which surged from 1.39 log CFU/g on Day 1 to 5.20 log CFU/g on Day 9. Notably, by Day 7, the TPC (4.14 log CFU/g) had already exceeded the limit of 1×10^4 CFU/g specified by the Thai Community Product Standard for fried chili paste (TCPS 144/2018). In contrast, Table 5 shows the effect of incorporating glycerol as a humectant. The addition of 3% and 6% glycerol significantly lowered the a_w values to ranges of 0.73–0.81 and 0.75–0.79, respectively. Glycerol reduces a_w by forming hydrogen bonds with water molecules, making them unavailable for microbial use (Abdullahi & Dandago, 2021). This reduction in a_w directly influenced microbial stability; on Day 7, the formulation with 6% glycerol maintained

a much lower TPC (2.32 log CFU/g) compared to the control (4.14 log CFU/g in Table 5). This demonstrates that the application of hurdle technology, specifically lowering a_w , is effective in inhibiting microbial proliferation and extending the shelf-life of the chili paste (Abdullahi & Dandago, 2021; Fontana & Carter, 2007).

2.2 The effect of adding glycerol under refrigerated conditions

A study on the shelf life of rice field crab chili pastes stored under refrigerated conditions found that it can be stored for 134 days, or approximately 4 months, at 5°C as shown in Table 6. During storage, it was found that the pH of the chili paste varied slightly with the range of 6.42–6.66, while the a_w remained in the range of 0.91–0.93. The original rice field crab chili pastes stored under refrigerated conditions showed signs of spoilage on the 141st day of storage. This was because the TPC exceeded the community product standard for roasted chili paste (which requires a total microbial count of no more than 4.00 log CFU/g). Therefore, the original-recipe rice field crab chili paste has a refrigerated shelf life of 134 days, or approximately 4 months, as shown in Table 6. When the original-recipe chili paste with the addition of 3% and 6% glycerol were stored under refrigerated conditions, its shelf life was found to be more than 169 days. When evaluating the difference of a_w in chili paste with added glycerol 250 and 500 ppm, a statistically significant difference ($p<0.05$) was found between the 4th month and the 1st month of storage. There was a trend of increasing free water content in relation to the extended storage period, as shown in Table 6. When evaluating the difference of in chili paste of the control group and the chili pastes with added glycerol 250 and 500 ppm, a statistically significant difference ($p<0.05$) was found between the 113rd day and the 1st day to the day 106th day of storage as shown in Table 6. There was no statistically significant difference in the chili paste with added glycerol between storage Day 1 and Day 169.

Table 5 The results of the analysis of pH, water activity (a_w), and the quantity of TPC of original rice field crab chili paste and the with the addition of glycerol 3% and 6 % under room temperature storage conditions

Days	a_w			pH			TPC log (CFU/g)		
	Original ^{ns}	Glycerol 3%	Glycerol ^{ns} 6%	Original	Glycerol ^{ns} 3%	Glycerol ^{ns} 6%	Original	Glycerol 3%	Glycerol 6%
1	0.916±0.04	0.73±0.03 ^c	0.75±0.20	6.35±0.00 ^{bc}	4.10±0.01	4.10±0.01	1.39±0.02 ^{bc}	1.31±0.04 ^d	1.39±0.10 ^d
3	0.919±0.01	0.76±0.10 ^{bc}	0.79±0.41	6.51±0.01 ^b	4.09±0.02	4.10±0.01	1.47±0.01 ^{ab}	1.60±0.05 ^c	1.54±0.12 ^{cd}
5	0.916±0.00	0.77±0.20 ^{bc}	0.77±0.20	6.46±0.06 ^c	4.10±0.03	4.11±0.01	1.30±0.03 ^c	1.67±0.20 ^c	1.62±0.07 ^c
7	0.932±0.01	0.79±0.11 ^{ab}	0.78±0.03	6.52±0.04 ^b	4.13±0.01	4.12±0.02	4.14±0.01 ^b	3.17±0.05 ^b	2.32±0.13 ^b
9	0.927±0.06	0.81±0.25 ^a	0.79±0.04	6.60±0.03 ^a	4.14±0.01	4.13±0.03	5.20±0.04 ^a	5.56±0.05 ^a	4.68±0.01 ^a

Remark: Values are expressed as mean±SD on log10 scale. Data were analyzed by One-way ANOVA followed by Tukey's HSD ($\alpha=0.05$). Means followed by different superscript letters indicate significant differences. ns indicates no statistically significant difference at $p<0.05$.

Application of hurdle technology by decreasing a_w and increasing acidic conditions in processing food can help to maintain the quality and extend shelf life (Sriphochanart et al., 2024). This study demonstrates that using glycerol to lower a_w is an effective method for extending the shelf life of chili paste when stored under refrigerated conditions. Using hurdle technology including, lowering a_w , and lowering pH can decrease TPC in green papaya salad dressing (Sriphochanart et al., 2024). Moreover, it should be noted that maintaining a low pH value of 4.10 is important for preserving chili paste. Storage temperature had a notable impact on shelf life. While formulations stored at room temperature showed limited longevity, refrigeration significantly extended shelf life, especially in glycerol-enhanced formulations. This is consistent with the work of Giannakourou and Tsironi (2021), who found that low temperatures slow microbial growth and maintain food quality over time. Due to the inherent high a_w of rice field crab chili paste, attempts to reduce it can only be successful to a certain extent. If the water activity is lowered further, the product would lose its unique characteristics and identity. Therefore, using food preservative is the alternative method that was further addressed.

The impact of storage temperature is further highlighted in Table 6, where samples stored at 5°C exhibited much higher stability. Under refrigerated conditions, even without glycerol, the TPC remained relatively low for a longer duration. However, the combination of refrigeration and glycerol (hurdle technology) showed the most superior results, with TPC levels remaining stable at 1.00 log CFU/g for over 169 days. Low temperatures reduce the kinetic energy of molecules and decrease the rate of enzymatic reactions and microbial respiration (Huss, 1995; Abdullahi & Dandago, 2021). These findings confirm that combining reduced a_w and low-temperature storage effectively inhibits microbial proliferation and extends the shelf-life of rice field crab chili paste far beyond room temperature storage.

2.3 The effect of adding food preservatives under room temperature storage conditions

According to the Food and Drug Administration (FDA)'s announcement titled "Clarification of the Ministry of Public Health Announcement No. 389 B.E. 2561 (2018) on Food Additives (No. 5)," the use of food additives in food is permitted as long as they are not

harmful to consumers (Food and Drug administration, 2018).

This experiment used sodium benzoate (INS211), which is permitted for use in food at a concentration not exceeding 500 ppm, according to the relevant announcement. To extend the shelf life of the rice field crab chili paste, the pH level was adjusted to 4.10 in conjunction with the use of sodium benzoate at concentrations of 250 and 500 ppm. The study found that the original-recipe rice field crab chili pastes (without added sodium benzoate) had a room temperature shelf life of only 5 days. However, when sodium benzoate was added at concentrations of 250 and 500 ppm, the shelf life of the chili paste at room temperature was extended to at least 31 days. The average a_w of the chili pastes with sodium benzoate 250 and 500 ppm were 0.75 ± 0.25 and 0.76 ± 0.26 , respectively. An evaluation of the original formula chili paste revealed statistically significant differences ($p < 0.05$) in both TPC and pH values between Day 3 and Days 5 and 7 of the storage periods. There was no statistically significant difference in the chili paste with added INS211 between storage Day 1 and Day 31, as shown in Table 7.

The use of sodium benzoate further illustrates the effect of chemical hurdles. As indicated in Table 7, while the original recipe's TPC rose significantly by Day 7 (4.97 log CFU/g), samples with 250 ppm and 500 ppm of sodium benzoate remained stable at 1.00 log CFU/g throughout the 31-day study period. Sodium benzoate inhibits microbial growth by disrupting cell membrane permeability and interfering with enzymatic mechanisms (Huss, 1995).

The result of using sodium benzoate in this study are consistent with Pongsetkul and Benjakul (2021) report, which used sodium benzoate to extend the shelf life of Northern Thai green chili paste (*Nam Prik Num*). Adding sodium benzoate helps to inhibit the growth of microbial, which can effectively extend chili pastes shelf life (Pongsetkul & Benjakul, 2021). The addition of sodium benzoate further reinforced microbial inhibition. Sodium benzoate, in particular, proved highly effective in extending shelf life to 31 days at room temperature. This finding supports the observations of Abdullahi and Dandago (2021), who identified benzoic acid as a reliable preservative in acidic food matrices. The synergistic effect between pH adjustment, a_w reduction, and preservative incorporation was critical to achieving prolonged shelf life.

Table 6 The results of the analysis of pH, water activity (a_w), and the quantity of TPC of rice field crab chili paste under 5°C storage conditions

Days	pH			a_w			TPC log (CFU/g)		
	Original ^{ns}	Glycerol ^{ns} 3%	Glycerol ^{ns} 6%	Original ^{ns}	Glycerol 3%	Glycerol 6%	Original	Glycerol ^{ns} 3%	Glycerol ^{ns} 6%
1	6.52±0.00	4.10±0.00	4.10±0.01	0.91±0.01	0.75±0.01 ^{cd}	0.73±0.01 ^d	1.00±0.00 ^c	1.00±0.00	1.00±0.00
22	6.44±0.07	4.10±0.00	4.10±0.00	0.92±0.02	0.76±0.02 ^{cd}	0.76±0.00 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
36	6.52±0.04	4.02±0.01	4.09±0.01	0.92±0.06	0.79±0.00 ^c	0.76±0.01 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
50	6.50±0.03	4.10±0.04	4.08±0.02	0.91±0.07	0.81±0.01 ^b	0.75±0.02 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
57	6.44±0.01	4.12±0.00	4.09±0.01	0.93±0.01	0.81±0.02 ^b	0.74±0.03 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
64	6.53±0.01	4.11±0.01	4.12±0.00	0.92±0.03	0.74±0.03 ^c	0.79±0.01 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
71	6.48±0.00	4.09±0.01	4.10±0.01	0.93±0.00	0.77±0.01 ^{cd}	0.79±0.01 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
78	6.42±0.05	4.10±0.00	4.10±0.03	0.92±0.01	0.82±0.01 ^{ab}	0.80±0.00 ^{ab}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
85	6.44±0.00	4.08±0.05	4.10±0.00	0.93±0.02	0.84 ±0.01 ^a	0.82±0.04 ^a	1.00±0.00 ^c	1.00±0.00	1.00±0.00
92	6.45±0.01	4.10±0.00	4.12±0.01	0.93±0.03	0.76±0.04 ^{cd}	0.79±0.03 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
99	6.55±0.01	4.09±0.00	4.10±0.05	0.93±0.07	0.79±0.06 ^c	0.79±0.01 ^{bc}	1.00±0.00 ^c	1.00±0.00	1.00±0.00
106	6.53±0.02	4.10±0.01	4.09±0.01	0.92±0.01	0.81±0.02 ^b	0.80±0.02 ^b	1.00±0.00 ^c	1.00±0.00	1.00±0.00
106	6.59±0.00	4.10±0.03	4.11±0.01	0.93±0.00	0.74±0.01 ^d	0.82±0.03 ^a	1.00±0.00 ^c	1.00±0.00	1.00±0.00
113	6.57±0.07	4.10±0.00	4.07±0.02	0.93±0.07	0.77±0.00 ^{cd}	0.79±0.01 ^{bc}	1.70±0.03 ^d	1.00±0.00	1.00±0.00
120	6.55±0.01	4.10±0.02	4.08±0.01	0.93±0.00	0.82±0.04 ^{ab}	0.79±0.01 ^{bc}	2.39±0.01 ^c	1.00±0.00	1.00±0.00
127	6.59±0.00	4.07±0.01	4.10±0.02	0.93±0.02	0.81±0.03 ^{ab}	0.80±0.02 ^b	3.50±0.01 ^b	1.00±0.00	1.00±0.00
134	6.60±0.06	4.10±0.06	4.10±0.03	0.93±0.03	0.74±0.07 ^c	0.82±0.04 ^a	4.65±0.09 ^a	1.00±0.00	1.00±0.00
141	–	4.11±0.03	4.10±0.01	–	0.77±0.06 ^{cd}	0.79±0.03 ^{bc}	–	1.00±0.00	1.00±0.00
148	–	4.11±0.01	4.09±0.00	–	0.79±0.01 ^c	0.79±0.04 ^{bc}	–	1.00±0.00	1.00±0.00
155	–	4.10±0.00	4.08±0.03	–	0.79±0.00 ^c	0.80±0.06 ^b	–	1.00±0.00	1.00±0.00
162	–	4.12±0.01	4.11±0.01	–	0.80±0.02 ^b	0.82±0.06 ^a	–	1.00±0.00	1.00±0.00
169	–	4.10±0.03	4.11±0.02	–	0.83±0.03 ^{ab}	0.80±0.03 ^b	–	1.00±0.00	1.00±0.00

Remark: Values are expressed as mean±SD on log10 scale. Data were analyzed by One-way ANOVA followed by Tukey's HSD ($\alpha=0.05$). Means followed by different superscript letters indicate significant differences. ns indicates no statistically significant difference at $p<0.05$.

Table 7 TPC in the original-recipe rice field crab chili paste and the chili pastes with added sodium benzoate (INS211) at 250 and 500 ppm

Days	Original recipe		Adding INS211 250 ppm ^{ns}		Adding INS211 500 ppm	
	TPC log (CFU/g)	pH	TPC ^{ns} log (CFU/g)	pH ^{ns}	TPC ^{ns} log (CFU/g)	pH ^{ns}
0	1.00±0.00 ^c	6.35±0.01 ^d	1.00±0.00	4.10±0.00	1.00±0.00	4.10±0.00
1	1.00±0.00 ^c	6.51±0.01 ^b	1.00±0.00	4.10±0.01	1.00±0.00	4.10±0.01
2	1.00±0.00 ^c	6.46±0.01 ^c	1.00±0.00	4.10±0.00	1.00±0.00	4.10±0.00
3	1.00±0.00 ^c	6.52±0.02 ^b	1.00±0.00	4.10±0.02	1.00±0.00	4.10±0.01
5	1.70±0.02 ^b	6.60±0.01 ^b	1.00±0.00	4.10±0.01	1.00±0.00	4.10±0.01
7	4.97±0.01 ^a	6.75±0.04 ^a	1.00±0.00	4.10±0.00	1.00±0.00	4.10±0.01
9	–	–	1.00±0.00	4.10±0.00	1.00±0.00	4.10±0.00
11	–	–	1.00±0.00	4.10±0.03	1.00±0.00	4.10±0.03
13	–	–	1.00±0.00	4.11±0.01	1.00±0.00	4.10±0.02
15	–	–	1.00±0.00	4.10±0.02	1.00±0.00	4.10±0.01
17	–	–	1.00±0.00	4.14±0.01	1.00±0.00	4.10±0.00
19	–	–	1.00±0.00	4.10±0.00	1.00±0.00	4.10±0.01
21	–	–	1.00±0.00	4.11±0.01	1.00±0.00	4.10±0.01
23	–	–	1.00±0.00	4.10±0.03	1.00±0.00	4.11±0.01
25	–	–	1.00±0.00	4.10±0.01	1.00±0.00	4.12±0.02
27	–	–	1.00±0.00	4.13±0.02	1.00±0.00	4.11±0.01
29	–	–	1.00±0.00	4.12±0.01	1.00±0.00	4.11±0.01
31	–	–	1.00±0.00	4.11±0.02	1.00±0.00	4.11±0.02

Remark: Values are expressed as mean±SD on log10 scale. Data were analyzed by One-way ANOVA followed by Tukey's HSD ($\alpha=0.05$). Means followed by different superscript letters indicate significant differences. ns indicates no statistically significant difference at $p<0.05$.

3. Statistical analysis

When evaluating the differences in the Total Plate Count (TPC) between each treatment condition by using one way ANOVA, it was found that the original rice field

crab chili paste formulation exhibited significantly higher microbial loads compared to all hurdle-treated formulations ($p<0.05$), as shown in Table 8. Treatments with pH adjustment, glycerol, or sodium benzoate

maintained microbial counts near detection limits, demonstrating the strong inhibitory effect of hurdle technology.

Table 8 provides a comprehensive comparison of microbial stability among the various rice field crab chili paste formulations. The statistical analysis reveals a significant difference ($p<0.05$) between the original recipe and all other treated formulations. The Original recipe exhibited the highest means total plate count (TPC) at 4.54 ± 0.63 log CFU/g. This value exceeds the safety threshold of 4.0 log CFU/g established by the Thai Community Product Standard (TCPS 144/2018), indicating that the traditional formulation without additional hurdles is highly susceptible to microbial spoilage at room temperature.

In contrast, all treatments utilizing Hurdle Technology—specifically the addition of Glycerol (3 % and 6%) and Sodium Benzoate (250 and 500 ppm)—maintained a baseline microbial level of 1.00 ± 0.00 log CFU/g. The effectiveness of these treatments can be explained as follows: Glycerol Hurdle: The significant reduction in TPC compared to the original recipe is due to glycerol's ability to lower water activity (a_w), thereby depriving microorganisms of the moisture required for metabolic processes. Chemical Hurdle: Sodium benzoate acted as an effective antimicrobial agent, maintaining the TPC at the lowest detectable limit throughout the observation period by disrupting microbial cell membranes. Overall, the results in Table 8 confirm that the application of either humectants or preservatives significantly enhances the microbial safety and stability of the product, bringing it into compliance with community standards compared to the original formulation.

Table 8 Comparison of microbial stability during storage by using Total Plate Count (TPC, log CFU/g) of rice field crab chili paste formulations in each treatment

Treatments	TPC log (CFU/g)
Original	4.54 ± 0.63^a
Glycerol 3 %	1.00 ± 0.00^b
Glycerol 6%	1.00 ± 0.00^b
Sodium Benzoate 250 ppm	1.00 ± 0.00^b
Sodium Benzoate 500 ppm	1.00 ± 0.00^b

Remark: Values are expressed as mean $\pm$ SD on log₁₀ scale. Data were analyzed by One-way ANOVA followed by Tukey's HSD ($\alpha=0.05$). Means followed by different superscript letters indicate significant differences.

Conclusion

The results of this study indicated that the short shelf life of field crab chili paste was primarily caused by excessive water activity (a_w) and inappropriate pH

levels. This issue stems from the use of tamarind paste, which results in uncontrollable pH variations. Although the general production process met standards, the management of ingredients and cooking methods remained substandard, leading to water activity levels exceeding the standard limit and rendering the product susceptible to spoilage. Furthermore, producers lack the necessary knowledge to apply hurdle technology to extend the product's shelf life. The integration of hurdle technology—through pH adjustment, water activity (a_w) reduction, and preservative incorporation—has proven highly effective in extending the shelf life of rice field crab chili paste while ensuring its microbiological safety and maintaining physicochemical stability. This study highlights the practical potential of hurdle technology for small-scale producers, enabling them to improve product quality, reduce food waste, and expand market opportunities. The findings suggest that the incorporation of sodium benzoate alongside the use of glycerol as humectants, offers an optimal balance between safety, quality, and shelf-life extension. While the current research successfully demonstrates the effectiveness of these preservation methods, future studies should focus on evaluating the sensory attributes of the product to ensure consumer acceptance.

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Conflicts of interest

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

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used Google Gemini for enhancing language clarity and improving grammar. The final content was reviewed and edited by the authors, who take full responsibility for the accuracy and integrity of the publication.

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