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Quality Assessment and Sensory Evaluation of Dried Pickle Green Mussels (*Perna viridis* L.) after Prepared by Different Drying Processes

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ABSTRACT

Background: Pickle-green mussels have been reported as a functional food with health promoting effects provided by lactic acid bacteria (LAB) and its metabolites. Therefore, the inappropriate chemical preservative use may reduce its shelf-life.

Methods: Pickle-green mussel without chemical preservative was determined the condition of fermentation and was dried with hot air-and freeze-drying techniques. The dried products were evaluated for appearance and color, moisture content, water activity (aw), texture profile and rehydration property. The original and seasoning flavors of freeze-dried products were determined for nutritive values, microbial contamination and sensory evaluation.

Result: The fermentation conditions of pickle mussels were proper acidity and amount of LAB, while the salinity was lower than previous study. The color of freeze-dried pickles mussels was brighter than hot air-dried pickle mussels. The seasoning within freeze-dried products slightly affects the appearance of these dried products. The moisture and aw of dried pickle mussels from both drying methods were able to preserve this products. The texture profiles of freeze-dried pickle mussels were crispier and easy to consume as snacks, while hot air-dried pickle mussels were harder and stickier, which were suitable for jerky food. The rehydration ratio (RR) of freeze-dried pickle mussels was preferable at 1:5 and 1:10. The nutritive values of different product flavors were not different and total plate counts were < 10^3 CFU/g that was lower enough for prolonging shelf life as ready-to-eat food. As a sensory evaluation, the panels tasted like almost all parameters of the seasoning flavor, except their appearance.

Key words: Aquatic product, Asian green mussels, Drying process, *Perna viridis* L., Pickle mussels.

INTRODUCTION

Asian green mussels (*Perna viridis* L.) originate from the tropical Indo-Pacific region, including the Gulf of Thailand. They are a rich source of protein, omega-3 fatty acids and essential vitamins. In Thai cuisine, green mussels are widely consumed in soups, curries and grilled dishes (Chakraborty and Joy, 2020; Wood *et al.*, 2007; Keawtawee *et al.*, 2018; 2023; Gobin *et al.*, 2013). Pickled green mussels, locally known as Hoi-dong, are a traditional Thai fermented product prepared by salt fermentation. Their characteristic sour taste is produced by lactic acid bacteria (LAB). The product is commonly consumed raw or uncooked and is popular among Thai consumers. Pickled green mussels are considered a functional food due to their health-promoting effects, including cholesterol reduction and immune modulation. These benefits are mainly attributed to LAB and their metabolites formed during fermentation (Phithakpol *et al.*, 1995; Tanasupawat and Komagata, 1995; Tanasupawat *et al.*, 1998).

Despite their popularity, the consumption of raw fermented products raises concerns related to food safety. Recent studies have reported that pickled green mussels are safe, with undetectable levels of foodborne pathogens and heavy metals. However, potential risks remain, particularly due to the use of food additives such as chemical preservatives and coloring agents. In addition, the sodium content of pickled green mussels is relatively high when evaluated against Thai recommended dietary intakes. Improper use of chemical preservatives may further reduce shelf life from one week to only three days, creating challenges for storage and transportation (Sudjaroen *et al.*, 2023; Sudjaroen and Petcharaporn, 2023). Therefore, extending the shelf life of pickled green mussels without relying on chemical preservatives is a critical issue for product safety, distribution and consumer acceptance

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(Ghuriani *et al.*, 2023; Al-Sharqi *et al.*, 2025; Alshahrani, 2024; Kim and AlZubi, 2024; AlZubi, 2023).

Drying techniques are commonly applied in developing countries to control moisture content and extend the shelf life of aquatic products. Hot air drying is a traditional method that uses heated air circulation to remove moisture. It is suitable for small- and medium-sized enterprises, especially in rural areas of Thailand, due to its simple operation, low investment cost and high productivity. However, drying efficiency depends strongly on temperature. High drying temperatures often cause uneven moisture removal, increased hardness and higher chewiness in dried aquatic products. Elevated temperatures can also degrade heat-sensitive compounds, including essential fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) (Wu *et al.*, 2024; Li *et al.*, 2020; Bong-Hyun *et al.*, 2024).

Freeze drying is considered a high-quality drying method. It operates under low temperature and low pressure, allowing water to sublimate directly from ice to vapor. This process helps preserve nutritional value and sensory quality. Freeze-dried products typically show minimal shrinkage, good rehydration capacity and improved structural integrity. Drying is usually performed at temperatures between -35°C and -45°C, which supports flavor retention and overall product quality (Wu *et al.*, 2024; Liu *et al.*, 2021; Lee *et al.*, 2024; Hu *et al.*, 2013; Zeng *et al.*, 2023). However, industrial application is limited due to high equipment costs, longer processing time and greater energy consumption (Wu *et al.*, 2024; Lee *et al.*, 2024).

Although drying is widely used for aquatic products, comparative studies evaluating different drying methods specifically applied to fermented pickled green mussels are lacking. In particular, limited information is available on how drying methods influence shelf life, quality attributes, sodium-rich fermented matrices and consumer acceptance without the use of chemical preservatives. This represents a clear research gap.

Therefore, this study aimed to compare hot air drying and freeze drying applied to fermented pickled green mussels. The effects of these drying methods on physicochemical properties, nutritional content, microbial safety and sensory characteristics were evaluated. Quality attributes such as texture, rehydration capacity and sensory acceptance are critical factors influencing consumer preference and marketability of dried fermented products. The findings of this study are expected to support the development of value-added dried pickled green mussel products with improved shelf life, reduced reliance on chemical preservatives and enhanced potential for storage, distribution and export as traditional Thai food products.

MATERIALS AND METHODS

Sample collection and storage

Pickled mussels were purchased from local manufacturers at Bang Kaeo subdistrict, Muang district, Samut Songkhram, who processed pickled mussels without the use of chemical food preservatives. Samples (3 kg) were pooled from three independent sample bags and each sample bag (1 kg) was collected from one separate fermentation batch. All analyses were performed in triplicate unless otherwise stated.

The pooled pickled mussels (100 g per replicate) were separated for pH, salinity and lactic acid bacteria analyses. The remaining samples were transferred to sterile plastic bags and stored at 4°C for further drying experiments.

Fermentation condition

Acidity and salinity

A food pH meter (HI981036, Hanna, Romania) and a salinity checker (SO-303, Tanita, Japan) were used to monitor acidity and salinity during fermentation. Fermentation conditions were represented as pH and NaCl (%), respectively. Measurements were conducted in triplicate.

Lactic acid bacteria (LAB) count and lactic acid production

Lactic acid bacteria (LAB) within pickled mussels were screened and represented as LAB count. Each pickled mussel sample (25 g) was stored at 4°C or 25°C for 2 h, homogenized and serially diluted with 0.1% (w/v) peptone water (ten-fold serial dilution: 10^{-1} to 10^{-10}. Each dilution was spread on MRS agar supplemented with 0.8-1.0% (w/v) $CaCO_3$, then incubated at 30°C under anaerobic conditions for 72 h.

Colonies were counted and expressed as CFU/g. LAB colonies were randomly isolated and identified based on colony morphology, Gram staining and biochemical tests. All microbiological analyses were conducted in triplicate.

Lactic acid production was measured on day 1 and day 14 of refrigerated storage (4°C). The liquid layer (10 mL) was centrifuged and the supernatant was titrated with 0.02 N NaOH using phenolphthalein as an indicator. Lactic acid content was calculated and expressed as percentage (%).

Interpretation of green mussel ferment conditions

Results were compared with optimal pickle green mussel fermentation conditions reported previously, including acidity (pH 3.98-4.74), salinity (NaCl 3.5-4.4%) and LAB count (1.92×10^7 -3.60×10^{10} CFU/g) (Tanasupawat *et al.*, 1998).

Drying processes

Hot air drying

Pickled green mussels were separated from the fermented liquid. The mussels were pressed using food-grade plastic bags to form a uniform flat layer. The layer was placed on a stainless-steel sieve, flipped and the plastic bag was removed.

Hot air drying was performed at a controlled temperature of 60°C with continuous airflow for 12 h until constant weight was achieved. After drying, mussels were separated by gentle shaking and passed through a 60-mesh sieve to obtain uniformly dried samples. Each drying experiment was conducted in triplicate.

Freeze-drying

Separated pickled green mussels were frozen at -80°C for 24 h. Frozen samples (~100 g per batch) were transferred to drying plates and dried at -45°C using a freeze dryer (FDTE-SERIES, Operon, Korea) under vacuum pressure ($P < 133 \times 10^{-3}$ Pa) for 72 h. The maximum load was four plates per run. Freeze-dried mussels were stored at -20 °C prior to quality analysis.

This procedure was repeated independently for pickled green mussels with 1-2% Thai seasoning added.

Qualities of dried pickled mussels from different methods

Appearance and color

Appearance and color were evaluated by trained panelists (n = 15) specializing in Thai cooking. Color measurements were obtained using a colorimeter and expressed as L*, a* and b* values. Each sample was measured ten times and analyses were performed in triplicate (AOAC, 2015).

Moisture content

Moisture content was determined by oven drying at 100-105°C until constant weight. This parameter was used to evaluate shelf life, texture, microbial stability and product weight.

Water activity

Water activity (a_v) was measured using a water activity analyzer based on vapor pressure. Dried foods with $a_v < 0.6$ are considered microbiologically stable (AOAC, 2015).

Texture profile analysis (TPA)

TPA was conducted using a texture analyzer to simulate chewing through double compression. Parameters measured included hardness, cohesiveness, springiness, gumminess, chewiness and adhesiveness (AOAC, 2015). Each measurement was performed in triplicate.

Rehydration test

Dried samples (5 g) were rehydrated in water at 30°C at ratios of 1:2, 1:5, 1:10 and 1:20 (w/v). Rehydrated samples were weighed and rehydration ratio (RR) was calculated (Giri and Prasad, 2005).

Qualities of freeze-dried pickled mussels between original and seasoning tastes

Freeze-dried pickled mussels were further processed with spices and condiments, producing original and seasoning-flavored products. Quality parameters including appearance, color, moisture content, water activity, texture and rehydration were evaluated. Nutritional composition and microbial safety were also assessed.

Nutritional analysis

Proximate composition including calories, carbohydrate, protein, lipid, ash and moisture was determined according to AOAC methods (AOAC, 2015). All analyses were conducted in triplicate.

Microbial contamination test

Total plate count (TPC) analysis was performed. Dried samples (25 g) were homogenized with 225 mL peptone buffer, followed by ten-fold serial dilutions (10^{-2}-10^{-6}). Aliquots (1 mL) were plated with plate count agar (PCA, 20 mL). Plates were incubated at 35 ± 1°C for 48 h. Colonies (30-300 CFU) were counted and expressed as CFU/g.

Each analysis was performed in duplicate, with PCA plates without samples as negative controls. Acceptable TPC values for dried products ranged between 10^3-10^4 CFU/g (Jay *et al.*, 2002).

Sensory evaluation

Dried pickled mussel samples were coded and evaluated by panellists (n = 30) using a 9-point hedonic scale for color, odor, flavor, texture and overall liking (Lawless and Heymann, 1999; Meilgaard *et al.*, 1999). Statistical analysis was performed using one-way ANOVA and mean differences were compared using Duncan's multiple range test ($p<0.05$). Statistical analysis was conducted using SPSS software.

Ethical approval

This study was exempted from review by the Suan Sunandha University Ethics Committee (COE.1-050/2024).

RESULTS AND DISCUSSION

Fermentation characteristics of pickle green mussels

The fermented pickle green mussels showed suitable acidity and high lactic acid bacteria (LAB) counts (Table 1). The pH was 4.35 and LAB population reached 2.35×10^8 CFU/g, both within reported reference ranges. The NaCl content was 2.2%, which was lower than values reported previously. Lactic acid content was 5.80% on the first day of storage at 4°C.

Effects of drying methods on appearance, moisture and water activity

Distinct visual differences were observed between drying methods (Fig 1). Freeze-dried mussels showed brighter

Table 1: Chemical properties of pickle green mussels, number of lactic acid bacteria (LAB) and amount of lactic acid.

Fermented product	pH	NaCl (%)	LAB count (CFU/g)	Lactic acid (%)
Pickle green mussels	4.35	2.2	2.35×10^8	5.80**
Reference range*	3.98-4.74	3.5-4.4	1.92×10^7-3.60×10^{10}	-

* Tanasupawat *et al.* (1998) ** The result was determined from the first day of storage at 4°C and lactic acid was slightly reduced to 5.76% at 14 days in the same conditions.

color values (L*, a*, b*) than hot air–dried samples (Table 2). Moisture content and water activity (aw) decreased significantly after drying. Freeze-dried samples had lower aw values (0.3388-0.3488) compared with hot air–dried samples (0.5772).

Texture properties

Texture profile analysis showed significant differences among drying methods (Table 3). Freeze-dried mussels exhibited lower hardness values and higher cohesiveness and springiness than hot air-dried samples.

Rehydration behavior of freeze-dried pickle mussels

Only freeze-dried pickle mussels showed measurable rehydration (Table 4; Fig. 2). Rehydration ratios of 1:5 and 1:10 resulted in proper rehydration. At 1:20, samples became overhydrated and mushy. Hot air–dried samples showed negligible rehydration.

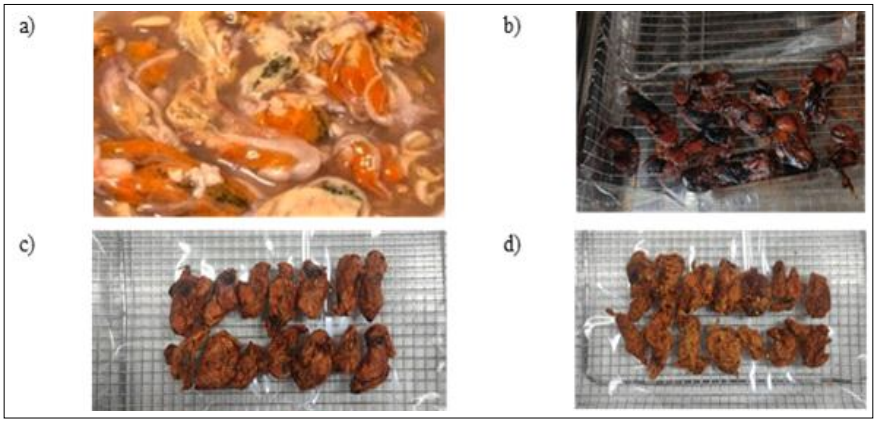


Fig 1: The appearances of a) pickle green mussels, b) drying with hot air, c) drying with freeze drying and d) freeze drying with seasoning.

Table 2: Color, moisture, water activity (aw) of dried pickle green mussel from different processes.

Process	Color (L*a*b*)			Moisture (%)	a_w
	L*	a*	b*		
Hot air-drying[a]	37.60±11.46	2.054±1.21	1.32±0.60	2.70	0.5772
Freeze drying[b]	47.88±3.40	20.20±13.73	40.46±2.76	8.63	0.3488
Freeze drying with seasoning[b]	52.76±2.88	24.90±12.94	49.51±7.39	4.21	0.3388
Pickle mussels (control)	44.25±12.20	21.76±7.96	38.04±23.84	100	0.9345

[a]All parameters of dried pickle green mussels from hot air drying were significantly different when compared with freeze drying and freeze drying with seasoning (p <0.05). While [b]Freez drying and freeze drying with seasoning parameters were not significantly different.

Table 3: The texture profiles of dried pickle green mussel from different processes.

Process	H1 (N)	H2 (N)	Co	Sp (mm)	Gu (N)	Ch (Nmm)	Ad (Nmm)
Hot air-drying	34.38±10.34	5.93±7.74	0.006±0.0	0.55±0.25	0.20±0.01	0.11±0.07	2.05±0.59
Freeze drying	14.31±6.27	9.55±3.41	0.227±0.09	1.52±0.66	2.96±0.05	4.48±0.89	-0.02±0.01
Freeze drying with seasoning	27.29±7.68	15.46±2.83	0.127±0.07	0.96±0.03	3.43±0.77	3.27±0.64	-0.05±0.01

H1 = Hardness1; H2 = Hardness2; Co = Cohesiveness; Sp = Springiness, Gu = Gumminess, Ch = Chewiness, Ad = Adhesiveness.

Table 4: The rehydration data of freeze-dried pickle mussel in different ratios of product and water.

Rehydration	Rehydration ratio	Appearance and characteristics
1:2	2.05	Still hardness and unsaturated watery
1:5	3.15	Propper rehydrated and soft texture
1:10	3.54	Propper rehydrated, soft texture and clear color
1:20	3.61	Over rehydrated and mushy mussels

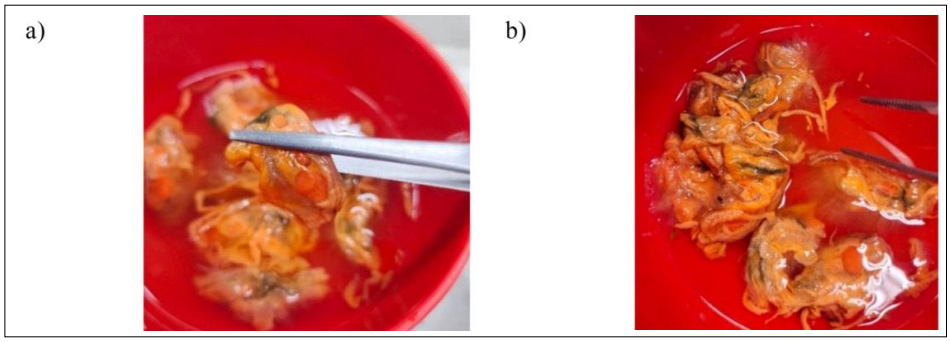


Fig 2: The appearances of dried mussel rehydration A) at 1:5 to 1:10; and B) at 1:20.

CONCLUSION

The use of low salinity without chemical preservatives during fermentation effectively maintained suitable acidity and viable lactic acid bacteria (LAB) in pickle green mussels. Both hot air drying and freeze drying successfully reduced moisture content and contributed to shelf-life extension. However, freeze-dried pickle mussels exhibited superior quality attributes, including improved color, texture and water activity, compared with hot air–dried products. Sensory evaluation further indicated that seasoned freeze-dried pickle mussels achieved higher taste and flavor acceptance than the original formulation. Overall, freeze drying is recommended for producing high-quality ready-to-eat pickle mussel products, while hot air drying remains a practical alternative for value-added products requiring lower processing costs.

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Authors' contributions

All authors contributed toward data analysis, drafting and revising the paper and agreed to be responsible for all the aspects of this work.

Use of artificial intelligence

Not applicable.

Declarations

Authors declare that all works are original and this manuscript has not been published in any other journal.

Disclaimers

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Declaration of conflict of interest

Authors declare that they have no conflict of interest.

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