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Optimization of thermal processing and quality evaluation of retort-pouch processed black tiger shrimp (*Penaeus monodon*) in masala

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Abstract
The present study evaluated the impact of thermal process time on the physicochemical, microbial, textural, and sensory quality of retort-processed black tiger shrimp (*Penaeus monodon*) in masala packed in flexible pouches. Products were processed at two different lethality levels (F_0 8 and F_0 9 minutes) using a pilot-scale overpressure retort and stored under ambient conditions for 180 days. Heat penetration studies confirmed the stable thermal profiles with process times of 30.59 and 32.67 minutes, achieving the recommended lethality for low-acid seafoods. Thermal processing reduced moisture content while increasing protein, fat, and ash levels compared with fresh shrimp. Biochemical parameters (TVB-N, TMA-N, TBARS, FFA, and PV) showed gradual increases during storage but remained within acceptable limits, whereas pH values exhibited minimal variation. Commercial sterility tests confirmed the absence of microbial growth and ensured product safety. Color analysis revealed a decline in lightness with corresponding increases in redness and yellowness during storage. Texture profile analysis indicated an initial increase in hardness and chewiness after processing, followed by significant reductions over time, with greater softening observed in F_0 9 samples compared with F_0 8. Sensory scores decreased slightly during storage but remained within acceptable levels, with F_0 8 samples retaining superior sensory and textural attributes. Overall, retort pouch processing produced a safe, shelf-stable shrimp masala with a 180-day ambient shelf life, with F_0 8 demonstrating better quality retention, underscoring its suitability for ready-to-eat shrimp products.

Keywords: *Penaeus monodon*, retort pouch, color analysis, commercial sterility, sensory quality

Introduction
Shrimps are one of the most popular seafood globally due to its desirable flavor, high protein content (FAO, 2019) [1]. These are highly nutritious due to their significant amount of essential omega-3 and omega-6 fatty acids contents (Oksuz *et al*., 2009) [2]. These fatty acids are essential for maintaining normal brain structure and function, preventing coronary heart disease, diabetes, and some types of cancer, and must be received through diet because the human body is unable to produce them. Presently, in both domestic and international markets demand for ready to eat shrimp (RTE) products has been steadily increasing due to the recognized health benefits of shrimp and shrimp-based food products. Thermal processing is one of the most widely used and significant techniques in the seafood industry for extending the shelf life of ready-to-eat shrimp in masala. The process involves subjecting the product to a predetermined temperature for a specified duration to inactivate pathogenic microorganisms that may pose public health risks, as well as spoilage and enzymes that can compromise product stability during storage (Karel *et al*., 1975) [3]. In India, processing of retort pouch is increasingly preferred over convectional metal containers because of its multiple advantages, including lower cost, thinner profile, minimized processing time, reduced loss of nutrients, ease of opening, direct consumption from the pouch, compact storage requirements and convenient disposal (Mermelstein, 1978) [4]. Retort pouch technology helps to prevent overcooking and excessive softening of food, thereby preserving desirable taste and texture. Most of the retort pouches are manufactured using a four-ply laminate structure, comprising an outer layer of polyester for mechanical strength, a nylon layer for puncture resistance, an aluminum foil layer for barrier properties, and an inner layer

of polypropylene, which is in direct contact with the food. Polypropylene has a melting point of approximately 138 °C (280 °F), which is well above the standard thermal sterilization temperature of 121 °C (250 °F), ensuring structural integrity during processing (Majumdar *et al*., 2017) [5]. Color is a critical quality attribute in thermally processed seafood products, as it directly influences consumer acceptability. Thermal processing alters the sensory and textural properties of shrimp primarily through protein denaturation. Texture is one of the most crucial aspects in consumption of shellfish (Cheret *et al*., 2005) [6]. Hardness, cohesiveness, gumminess, chewiness, greasiness, and juiciness are only some of the characteristics that are included in the term texture (Brandt *et al*., 1963) [7]. Texture is particularly important because it undergoes significant changes during extended heating, whereas shrimp flavor develops relatively early in the process and remains largely stable during prolonged cooking (Ma *et al*., 1983) [8].

The unique flavor of black tiger shrimp (*Penaeus monodon*) makes it highly desirable, texture, and nutritional benefits. In India, a variety of culinary practices are employed to develop thermally processed shrimp-based products. The incorporation of spices and aromatic compounds enhances the flavour profile; Nevertheless, these additives might also influence the product's viscosity, color, and heat transfer characteristics during thermal sterilization (Manju *et al*., 2007; Sreenivasan *et al*., 2010) [9, 10]. Ready to eat shrimp in masala is a product prepared using shrimp, Indian spices and other ingredients and it holds a significant market potential across India. The present investigation aimed to optimize the processing conditions for shrimp in masala packed in flexible retortable pouches and to evaluate the resulting changes in textural, biochemical and sensory attribute of the product post-processing.

Materials and Methods

Materials

Fresh black tiger shrimp (*Penaeus monodon*) samples weighing 71.20±24.53 gm (16-20 count/kg) were procured from the landing centre in Mangaluru, Karnataka, India, and brought to the Department of Fish Processing Technology, College of Fisheries Mangaluru in insulated ice box (ice to shrimp ratio 1:1). They were washed with chilled potable water, peeled, beheaded, deveined. The product was packed in a laminated flexible pouch (four-ply) made of 70 µm polypropylene (inner cast), 14 µm nylon (middle layer), 9 µm aluminum foil, and 12 µm polyester (outer layer). In this study, 300 g pouches (150 × 200 mm) made by Floeter India Retort Pouches Pvt Ltd in Haryana, India, were used. The pilot-scale horizontal over pressure retorting unit (Lakshmi Engineering Works, Chennai, India) was used for the heat processing. Analytical reagent (AR) grade chemicals and glassware were used throughout the study.

Preparation of Shrimp Masala

The masala was prepared using a standardized method involving dry masala paste and wet pastes. The wet paste was made up of tomato, onion, ginger, garlic, green chilli, turmeric powder and curry leaves were fried in small quantity of oil, whereas, dry masala paste consisted of Byadagi chilli, black pepper, poppy seeds, cinnamon, turmeric, coriander, cumin and salt, which were lightly roasted in a minimal amount of oil over medium flame. The ingredients used for masala preparation are listed in Table 1. The prepared ingredients were blended into a fine paste. Refined sunflower oil was heated on a pan, followed by addition of chopped onion, green chilli, curry leaves, garlic, ginger, turmeric powder and shallots, which were fried over low flame for 2-3 minutes until light brown color developed. The wet paste (Onio-tomato mixture) was then incorporated and cooked until the mixture changed color. Subsequently, the dry masala, tamarind paste, and coconut milk were added and gently simmered over law flame until a characteristics aroma was released. Finally, salt and an appropriate quantity of water were added to adjust taste and consistency, and cooking was continued until the masala reached a gentle boil. The dressed shrimps were hot blanched in 6% brine (100±2 ℃) for 10 min and added into the prepared masala followed by boiling.

Table 1: Preparation of shrimp in masala medium

Sr. No	Ingredients	Quantity (weight)
1	Dressed Shrimp	1000g
2	Onion (Big)	250g
3	Tomato	250g
4	Green chilli	100g
5	Crushed ginger and garlic	50g
6	Byadagi red chilli	100g
7	Coriander seed	100g
8	Turmeric powder	4g
9	Black pepper powder	10g
10	Poppy seeds	20g
11	Cinnamon	10g
12	Cumin	10g
13	Curry and coriander leaves	15g
14	Shallots-small onion	150g
15	Tamarind	50g
16	Round chilli	25g
17	Coconut	1 piece
18	Oil	150 ml
19	Water	As required
20	Salt	As per taste
21	Cashew	20g

Filling and sealing of the pouches

Retort pouches were filled with approximately 250 ± 5 g of hot shrimp masala. Thermocouple tips were placed into shrimp pieces at the slowest rate of heating point, and certain pouches have packaging glands made of stainless-steel (Model GKJ 13009C052). Sterile tissue was used to clean the sealing surfaces. To achieve the required F_0 values, pouches were steam-exhausted, hermetically sealed, and placed into the retort chamber for thermal processing.

Thermal processing of Black tiger shrimp in masala

To reach the desired lethality (F_0 8 and 9 minutes), the shrimp masala pouches were thermally processed. After that, they were cooled and allowed to air dry before being stored and analyzed. The Ellab E-Val Flex Four Channel System (Cat. 21401004; Ellab A/S, Trollesmindealle 25, DK-3400 Hilleroed, Denmark) was used for thermal validation. It recorded cook values (CV), F_0 values, and core and retort temperatures in real time at 60-second intervals. Ellab SSATS copper/cupronickel thermocouples with stainless-steel electrodes (4 cm length, 1.2 mm diameter, precision < 0.2 °C) were used to record the measurements. The Cook value constants (for thiamine degradation) were applied at T = 100 °C and Z = 33 °C, while F_0 calculations were carried out with system settings of T = 121.1 °C and Z

= 10 °C. According to Stumbo (1973) [11] technique, processing time was calculated using Ball's mathematical model.

Quality evaluation

The proximate, biochemical, and microbiological analysis

The moisture, ash, fat, and crude protein contents of fresh shrimp and thermally processed shrimp in masala at different F_0 values were determined by following the AOAC (2010) [12] standard procedures. The values were expressed as% (wet weight basis). Biochemical parameters, including TVB-N, TMA-N, PV, FFA, TBARS, indole, and pH, were analyzed for both fresh and thermally processed shrimp in masala. TVB-N and TMA-N were estimated using Conway's micro-diffusion method (Conway, 1962) [13], while TBARS values were determined following the procedure of Raghavan and Hultin (2005) [14]. Free fatty acids (FFA) were analyzed according to Dyer and Morten (1956) [15], and peroxide values (PV) were assessed using the method of Kirk and Sawyer (1991) [16]. Indole content was determined following Cheuk *et al*. (1981) [17], and pH was measured using a digital pH meter. In addition, the total plate count (TPC) of fresh shrimp meat was determined by the spread plate technique (ICMSF, 1986) [18].

Commercial sterility test

Commercial sterility was evaluated by IS:2168 (1971) [19]. Processed samples were incubated at 37 °C for 15 days and at 55 °C for 5 days to detect any surviving mesophilic or thermophilic bacteria. After incubation, the pouches were aseptically cut open, and 1-2 g of sample was collected using sterilized forceps and inoculated into sterilized fluid thioglycolate broth contained in test tubes. To establish anaerobic conditions, a layer of sterilized liquid paraffin was added over the broth, which was then incubated at 37 °C for 48 hours and 55 °C for 5 days, respectively. to assess the commercial sterility of the product.

Texture profile analysis

A textural property of fresh and thermally processed black tiger shrimp products were evaluated using a texture analyzer (TA-XT Plus, Stable Micro Systems, UK). A two-fold compression test was conducted using a cylindrical probe (75 mm in diameter) fitted with a 50 N load cell. The conventional procedure outlined by Bourne (1978) [20] and further modified by Mohan *et al*. (2006) [21] was followed, compressing the samples twice to 40% of their initial height at a crosshead speed of 12 mm/min.

Color Analysis

A spectrocolorimeter (ColorFlex EZ, HunterLab, Reston, VA, USA) with an 8° diffuse geometry and a D65/10° standard illuminant was used to quantify the color of every sample. Prior to analysis, the equipment was calibrated using the manufacturer's standard white and black reference tiles. The CIELAB color system was used to record the color, yielding values for L* (lightness), a* (red-green), and b* (yellow-blue).

Sensory evaluation

The sensory analysis of the processed product in masala medium was evaluated by a trained panel of 25 members, scientists, researchers and postgraduate students, using 9-point hedonic scale (Meilgaard *et al*., 1999) [22]. For 180 days of storage study, the processed retort pouches were kept in ambient conditions after conditioning. Samples were chosen at randomly for sensory analysis after post-storage. The pouches were reheated in boiling water for 10 minutes before being evaluated. For objective evaluation, the samples were served warm on coded white enamel plates, and the attributes assessed included appearance, color, flavor, succulence, toughness, firmness, and overall acceptance.

Statistical analysis

All analyses were performed in triplicate for statistical evaluation. The findings were presented as mean ± standard deviation. To determine the mean difference ($p < 0.05$), the Duncan multiple range test was used. The statistical program SPSS 27.00 was utilized to analyze the experimental findings.

Results and Discussion

Heat penetration characteristics

Black tiger shrimp masala packed in flexible retortable pouches were thermally processed at two lethality levels, F_0 8 and F_0 9 minutes. Heat penetration characteristics were determined by using data recorded with the Ellab system (Table 2). The retort chamber reached sterilizing temperature rapidly in both cases, as shown by the come-up times of 5.5 minutes (F_0 *8*) and 6.5 minutes (F_0 *9*) (Figure 1). Stable heat transfer dynamics throughout processing were indicated by the little fluctuation in heating lag (*Jh*) and cooling lag (*Jc*) variables between treatments. For F_0 8 and F_0 9 min, the heating curve slope (f_h) was 26 and 25 minutes, respectively. The total process time taken to reach lethality F_0 8 and F_0 9min shrimp in masala were 30.59 and 32.67 min, respectively. Cook value indicates the extent of cooking of the products were 94.07 for F_0 8 and 90.16 min for F_0 9. A slight reduction in cook value was observed in shrimp processed at F_0 9 min compared to F_0 8 min, which may be attributed to the shorter come-up time, as both parameters are interrelated. It was observed from the results that as F_0 value increased, the total process time also increased proportionally. The recommended F_0 value for fish and fishery products ranges from 5-20 min (Frott and Lewis, 1994) [23]. Sreenath *et al*. (2007) [24] reported a processing time of 48 minutes and a cook value of 95.4 minutes for shrimp curry processed in TFS cans. Comparable finding was reported by Dasan *et al*. (2021) [25] documented process times of 37.11 and 39.88 minutes and CV of 84.07 and 92.41 minutes for masala-packed shrimp processed at F_0 8 and F_0 9 min. However, the processing times obtained in the present study were slightly lower than those reported for shrimp kuruma and shrimp in masala, which may be attributed to differences in shrimp species, container size and composition, and product consistency

Table 2: Heat penetration characteristics of shrimp masala in reportable pouches at two different F_0 values

Parameters	F_0 8.76	F_0 9.82
Come-up-time	5.5	6.5
Heating lag factor (J_h)	0.941	1.00
Cooling lag factor (J_c)	1.091	1.011
fh slope of heating curve (min)	26	25
U	8.96	10.04
fh/*U*	2.90	2.49
g (°C)	7.05	6.23
Cook value (min)	94.07	90.16
Balls process time (min)	27.406	28.90
Total process time (min)	30.596	32.67

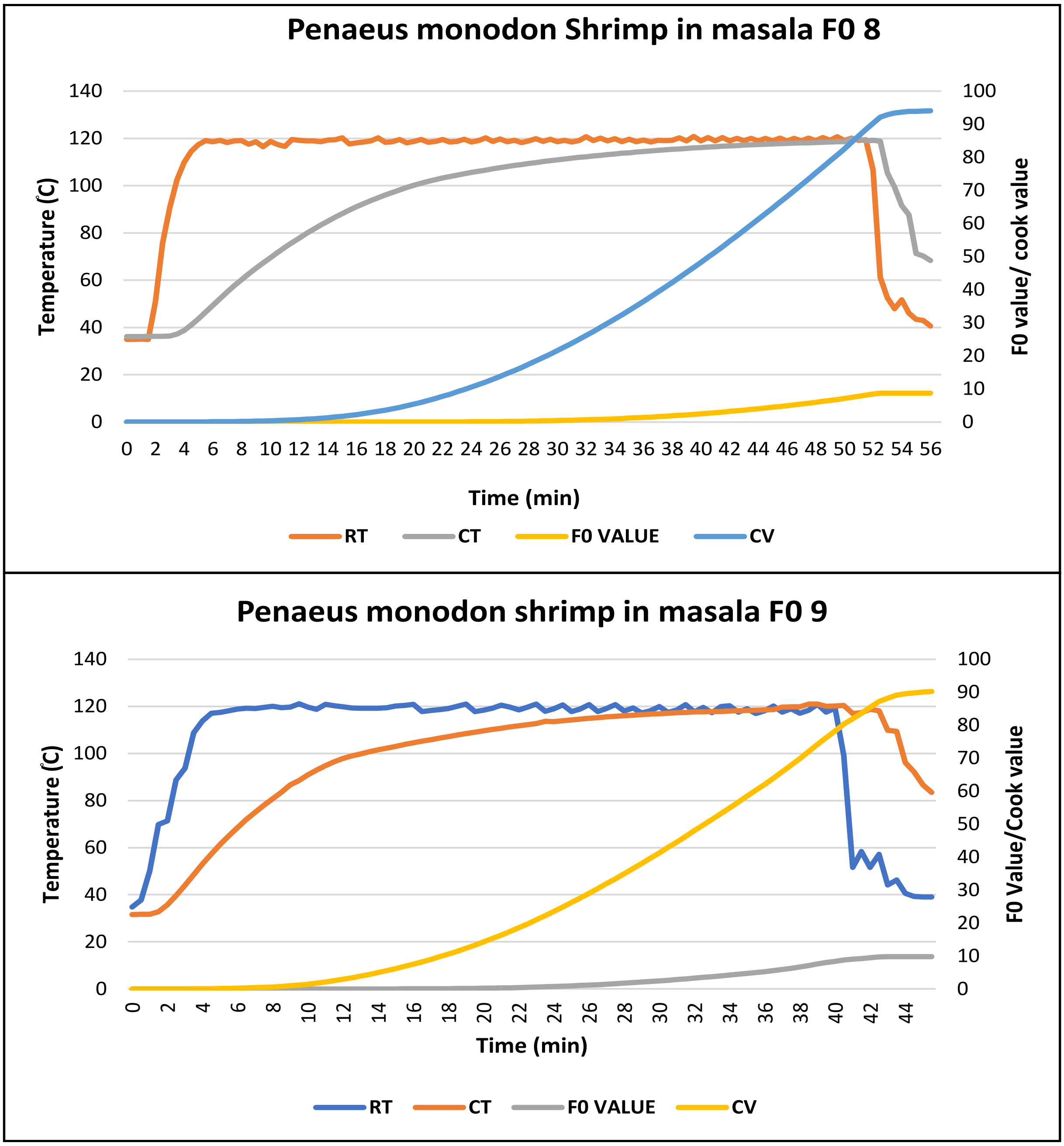

Fig 1: Heat penetration rate of black tiger shrimp in masala thermally processed at F_0 8 and F_0 9 min (121.1°C)

Proximate composition

Proximate composition results of fresh and thermally processed shrimp (*P. monodon*) in masala are shown in Table 3. In the present study, the moisture content of *P. monodon* 79.36%, ash content of 1.05%, fat content of 1.23%, and protein content of 17.15% was reported. This suggests that the *P. monodon* used in the present study represents a lean variety with high-quality protein content. After thermal processing of shrimp in masala at F_0 8.76 and F_0 9.82 min were showed moisture content of 73.69% and 74.53%, ash content 1.44% and 1.68%, crude fat content of 3.19% and 3.48% and crude protein content of 19.90% and 20.13%, respectively. Compared to fresh shrimp, processed shrimp in masala at different F_0 values had higher protein content. According to previous studies on black tiger shrimp, the proximate composition found in this study is very similar. Sriket *et al*. (2007) [26] reported 80.47% moisture, 17.1% protein, 1.23% fat, and 0.95% ash in *P. monodon*. Similarly, Akintola *et al*. (2013) [27] and Marichamy *et al*. (2011) [28] documented moisture and protein contents of 75.18% and 20.34%, respectively. More recently, Yang *et al*. (2025) [29] reported values of 81.67% moisture, 17.1% protein, 0.6% fat, and 1.0% ash in black tiger shrimp. The variation in proximate composition among different studies may be attributed to factors such as species, size, diet, and environmental conditions.

Table 3: Proximate composition of fresh shrimp (*P. monodon*) and thermally processed shrimp masala at F_0 8 and F_0 9

S. No.	Proximate composition	Fresh Shrimp	Fish curry	
			F_0 8	F_0 9
1	Moisture (%)	79.36±0.69	76.35±0.56	74.88±0.83
2	Crude protein (%)	17.15±0.46	18.77±0.29	18.83±0.39
3	Total lipid (%)	1.23±0.35	2.98±0.49	2.92±0.51
4	Ash content (%)	1.05±0.04	1.80±0.12	1.79±0.10

* Values are presented as mean ± standard deviation of triplicates sample (n=3).

Biochemical analysis

For 180 days, the biochemical of shrimp masala was assessed at room temperature. Changes in biochemical parameters like TVB-N, TMAN, TBA, FFA and pH which were analyzed for fresh and processed shrimp in masala for 180 days of storage (Figure 2). Fresh black tiger shrimp showed lower content of all biochemical parameters as compared to processed shrimp. During entire 180 storage days biochemical parameters were increased for thermally processed shrimp masala at F_0 8 and F_0 9. TVB-N and TMA-N values for the fresh shrimp were 5.64 and 2.84 mg N/100g, respectively. Following thermal processing, the TVB-N content increased to 8.31 mg N/100 g for F_0 8 and 8.87 mg N/100 g for F_0 9. After 180 days of storage, these values further increased to 17.27 mg N/100 g and 18.16 mg N/100 g, respectively. Protein and TMAO degradation during heating and storage was the cause of the increase in this study. According to previous reports on retorted salmon and shrimp (Mohan *et al*., 2006; Rodriguez *et al*., 2009; Biji *et al*., 2015) [21, 30, 31], these results were consistent. The spoiling threshold of 20 mg N/100 g was maintained by all samples. TMA-N content of fresh black tiger shrimp was 2.84 mg N/100g. After thermal processing the samples had slightly increased values of 3.03 mg N/100g (F_0 8) and 3.12 mg N/100g (F_0 9). By 180 days, TMA-N rose to 7.10 mg N/100g (F_0 8) and 7.78 mg N/100g (F_0 9), which is due to the thermal degradation of TMAO into TMA. In the current investigation, the TMA-N content was slightly closer to the value reported by Kaur *et al*. (2016) [32], which was 3.92 mg N/100g in fresh Black tiger shrimp. Therefore, the breakdown of proteins, amino acids, and other nitrogenous substances, including TMAO, may be the cause of the rise in TMA-N and TVB-N (Chia *et al*., 1983; Mohan *et al*., 2006) [33, 21]. The current analysis is in line with earlier research that found comparable TVBN and TMAN trends in thermally processed shrimp in masala (Dasan *et al*., 2021, Tekade *et al*., 2024, Tameshwar *et al*., 2024) [25, 34, 35].

The initial peroxide value (PV) of fresh shrimp was 1.86 mEq O_2/kg. Thermally processed samples recorded PV of 2.03 mEq O_2/kg F_0 8) and 2.40 mEq O_2/kg (F_0 9). During storage, PV increased progressively, reaching 7.15 mEq O_2/kg and 7.84 mEq O_2/kg, respectively. This increase was attributed to oxidative changes in lipids induced by heat and oxygen exposure. Previous studies have indicated that PV levels in the range of 10-20 mEq O_2/kg correspond to the onset of rancidity in fish products (Connell, 1995; Ahn & Min, 2005) [36, 37]. Recently, Chavan *et al*., (2025) [38] observed similar trend in Pacu fish masala thermally processed at F_0 6 and F_0 7. TBARS content was 0.30 mg malondialdehyde/kg in fresh sample which indicates that the raw material was used of prime quality. Kaur *et al*. (2016) [32] reported that the TBA value in fresh Black tiger shrimp was 0.54 malonaldehyde/kg. Thermally processed shrimp products had values of 0.39 malondialdehyde/kg (F_0 8) and 0.42 malondialdehyde/kg (F_0 9). By day 180, the values reached 0.87 malondialdehyde/kg and 0.92 malondialdehyde/kg. The increase was attributed to secondary lipid oxidation during prolonged storage. Comparable TBARS trends in heat treated shrimp masala and pacu fish masala have been reported in previous studies (Dasan *et al*., 2021; Chavan *et al*., 2025) [25, 38].

The free fatty acid (FFA) content of fresh shrimp was 0.18% oleic acid. Thermally processed shrimp samples showed initial values of 0.78% oleic acid and 0.80% oleic acid, which increased to 1.27% oleic acid and 1.42% oleic acid, respectively, by day 180 of storage. This was seen to be increased by thermal hydrolysis of the triglycerides. It has been reported that thermal processing has accelerated lipid degradation in fish (Aubourg *et al*., 1990; Medina *et al*., 1995) [39, 40]. The values of FFA that were seen in the current study were acceptable. Likewise, progressive rise of free fatty acid content in pacu fish in masala with storage period of 150 days indicated by Chavan *et al*. (2025) [38]. The pH of fresh shrimp was 6.31, thermal processing decreased the pH to 5.71 (F_0 8) and 5.80 (F_0 9). As time went on during storage, pH gradually went to 6.40 and 6.46, respectively. This is attributed to the destruction of proteins and release of amines. The indole content in raw black tiger shrimp was found to be 0.98 μg/100 g, indicating a high degree of freshness of the shrimp used in the present study. Since indole formation primarily results from microbial activity, it was not detected in the thermally processed samples. Similar result was reported by Mohan *et al*. (2006) [21] in shrimp kuruma.

The initial total plate count (TPC) of fresh black tiger shrimp was recorded 4.40 × 10^3 CFU/g, indicating a moderate level of microbial load. Notably, potential bacterial pathogens such as Salmonella, *E coli*, Vibrio spp, Listeria spp and *Staphylococcus aureus* were not detected in fresh and thermally processed shrimp samples. This absence of pathogenic microorganisms suggests effective hygienic practices during handling and processing.

Fig 2: Changes in biochemical parameters of fresh and thermally processed Black tiger shrimp (*Penaeus monodon*) in masala during storage at ambient temperature

Commercial sterility test

The commercial sterility of thermally processed shrimp masala packed in flexible retortable pouches was evaluated. No turbidity or microbial growth was observed in thioglycolate broth after incubation at 37°C for 48 hours and at 55°C for 4 days. Both the products, processed at F_0 8 and 9 minutes, remained sterile throughout the 180 days ambient storage period. This research showed that the main safety concern in low-acid seafood products, *Clostridium botulinum*, as well as vegetative cells and heat-resistant spores, could be completely inactive by the total lethality achieved during retort processing. These findings are consistent with earlier studies on pacific whiteleg shrimp in masala (Dasan *et al.*, 2021) [25], tilapia fish masala (Taral *et al.*, 2024) [41] and pacu fish in masala (Chavan *et al.*, 2025) [38]. The use of validated retort conditions and effective heat penetration ensured microbial safety and contributed to an extended shelf life.

Color analysis

The color parameters of shrimp masala exhibited significant changes over 180 days of ambient storage (Table 4). The fresh shrimps had lightness (L*) value 52.40, redness (a*) value 3.04, yellowness (b*) value 25.50, and whiteness (ΔE*) value 45.92. Recently, Yang *et al.* (2025) [29] reported that L* value (43.04), b* value (7.18) and a* value (28.49) in black tiger shrimp. The main pigments in shrimp muscle are carotenoids, including astaxanthin and canthaxanthin (Okada *et al.*,1994) [42]. The results of color analysis indicate significant changes in L*, a*, b*, and ΔE* values of black tiger shrimp masala during storage, influenced by thermal processing and storage duration. The lightness (L)* of thermally processed shrimp at F_0 8 and 9 min decreased progressively from 54.68 to 43.15 and 53.26 to 42.08 over 180 days. This reduction in lightness was likely due to the formation of red pigment as a result of prolonged heat treatment (Mallick *et al.*, 2010) [43]. Similarly, both redness (a*) value and yellowness (b*) value of processed shrimps were increased significantly, due to enhanced pigment intensity and browning reactions. The muscle tissue produced reddish-orange colors due to the exposure and intensification of carotenoid pigments, particularly astaxanthin (Okada *et al*., 1994) [42]. The oxidation of myoglobin, which increases redness and can decrease lightness, is the primary cause of color changes in meat when exposed to high temperatures (Boles, 2010) [44]. Recently, thermally processed tilapia in masala and pacu fish in masala showed a growing tendency in color parameters with higher F_0 values (Taral *et al*., 2023 and Chavan *et al*., 2025) [41, 38]. Higher F_0 values showed increased darkening and pigment concentration, although F_0 8 and 9 did not significantly differ visually, suggesting that both treatments produced similar color transitions.

Table 4: Changes in color parameters of fresh and thermally processed black tiger shrimp masala processed at F_0 8 and 9 min.

Parameters	DOS	Fresh shrimp	F_0 8	F_0 9	*p* Value
L*	0	52.40±0.62	54.68±0.52ᵃ	53.26±0.33ᵃ	0.119
	30		51.35±0.57ᵇ	50.16±0.38ᵃ	0.469
	60		50.03±0.33ᵇ	49.16±0.75ᵇ	0.054
	90		48.96±0.52ᶜ	46.59±2.76ᵇ	0.168
	120		45.17±0.44ᵈ	46.59±0.39ᶜ	0.625
	150		44.17±1.00ᵉ	44.19±0.48ᵈ	0.100
	180		43.15±0.57ᶠ	42.08±0.42ᵉ	1.000
	p Value		<0.001	<0.001	
*a**	0	3.04±0.17	4.26±0.24ᵃ	4.93±0.19ᵃ	0.001
	30		4.89±0.42ᵃ	5.35±0.48ᵇ	0.001
	60		5.81±0.23ᵇ	5.98±0.35ᶜ	0.026
	90		6.72±0.51ᶜ	6.66±0.54ᶜ	0.221
	120		7.30±0.67ᵈ	7.15±0.41ᵈ	0.144
	150		8.14±0.14ᵉ	8.55±0.44ᵉ	0.035
	180		8.59±0.52ᶠ	9.28±0.51ᵉ	0.016
	p Value		<0.001	<0.001	
*b**	0	25.50±0.65	32.17±0.73ᵃ	33.14±0.25ᵃ	0.486
	30		33.87±0.58ᵇ	33.87±0.58ᵇ	0.228
	60		35.15±0.32ᶜ	36.69±0.74ᶜ	1.000
	90		36.42±0.52ᵈ	37.67±0.42ᵈ	0.971
	120		36.68±0.30ᵉ	38.19±0.45ᵉ	0.867
	150		37.44±0.54ᶠ	39.99±0.48ᶠ	0.895
	180		38.17±0.45ᶠ	40.13±0.27ᵍ	0.442
	p Value		<0.001	<0.001	
*dE**	0	45.92±0.84	41.86±0.30ᵃ	41.02±0.33ᵃ	0.031
	30		39.45±0.55ᵇ	38.68±0.39ᵇ	0.115
	60		36.92±0.25ᶜ	36.13±0.34ᶜ	0.031
	90		34.65±0.62ᵈ	33.90±0.34ᵈ	0.140
	120		32.43±0.77ᵉ	32.57±0.49ᵉ	0.817
	150		31.09±0.29ᶠ	29.94±0.77ᶠ	0.073
	180		29.45±0.64ᵍ	28.84±0.67ᵍ	0.314
	p Value		<0.001	<0.001	

Values are expressed as mean ± standard deviation Different superscripts in same rows indicate significant differences (*p*<0.05) (n=3)

Texture profile analysis

Textural changes in shrimp masala resulting from thermal processing and subsequent storage were assessed using texture profile analysis (TPA). The texture profile analysis (TPA) of black tiger shrimp masala processed at F_0 8 and 9 minutes revealed significant variations in hardness, springiness, gumminess, cohesiveness and chewiness during 180 days of ambient storage study (Table 5). The fresh black tiger shrimp exhibited gumminess (1.73 Kgf), cohesiveness (0.55), chewiness (1.20 Kgf·mm), hardness (3.14 Kgf), and springiness (0.69 mm). After thermal processing, these values increased due to protein denaturation and structural tightening (Mohan *et al*., 2006). Hardness gradually decreased throughout the entire period of storage, decreasing from 3.65 and 3.57 kg force in thermally shrimp samples (F_0 8 and 9 min, respectively) to 2.02 and 1.98 kg force after 180 days. This decrease was attributed to moisture loss and muscle weakness caused on by heat. At 180 days, springiness decreased gradually but not significantly from 0.67 (F_0 8) to 0.65 (F_0 9) mm at the beginning to 0.52 (F_0 8) to 0.51(F_0 9) mm, suggesting a decrease in the elastic recovery of muscle tissue with increasing F_0 values. The gumminess and chewiness reduced dramatically in storage (p < 0.05) and followed the same trends as hardness. After 180 days of storage, chewiness decreased from 1.45 to 0.49 kgf mm at F_0 8 and from 1.36 to 0.48 Kgf. mm at F_0 9, while gumminess showed a slight reduction from 0.95 to 0.94 Kgf over the same period. The causes of these reductions include a decline in structural stability due to degradation of myofibrillar and connective tissue, and loss of moisture. The decrease in cohesiveness between 0.60 and 0.58mm in processed samples to 0.50 and 0.48mm (F_0 8 and F_0 9) at the end of storage may indicate a weakening of the internal bonding in the shrimp muscle. Nevertheless, the decrease was less significant when compared with hardness and gumminess. The better texture was observed in samples processed at F_0 8 than at F_0 9, which suggests that further increase in F_0 value led to increased myofibrillar structural weakening and breakdown (Sreenath *et al*., 2007; Mallick *et al*., 2010) [24, 43]. In comparison to the higher F_0 value, the milder F_0 8 min treatment-maintained firmness, flavor, and color better.

There were no notable differences in toughness recorded during the storage period indicating that both treatments maintained an appropriate level of texture integrity. These findings proved that shrimp in masala processed at F_0 8 minutes had better sensory retention. Similar patterns were observed by Dasan *et al.* (2021) [25], Taral *et al.* (2023) [41], Ganachari *et al.* (2025) [45] and Chavan *et al.* (2025) [38], who observed that slightly responding shrimp masala, tilapia masala and pacu fish masala products were more accepted by consumers.

Table 5: Changes in texture Profile analysis for fresh and thermally processed black tiger shrimp masala processed at F_0 8 and 9 min.

Parameters	DOS	Fresh shrimp	F_0 8	F_0 9	*p* Value
Hardness (Kg. Force)	0	3.14±0.05	3.65±0.06^{a}	3.57±0.03^{a}	0.112
	30		3.35±0.05^{b}	3.32±0.05^{b}	0.469
	60		3.14±0.05^{c}	3.02±0.03^{c}	0.020
	90		2.88±0.05^{d}	2.72±0.05^{d}	0.017
	120		2.57±0.07^{e}	2.45±0.06^{e}	0.109
	150		2.26±0.06^{f}	2.16±0.0^{5f}	0.102
	180		2.02±0.01^{g}	1.98±0.11^{g}	0.549
	p Value		<0.001	<0.001	
Springiness (*mm*)	0	0.69±0.03	0.67±0.05^{a}	0.65±0.05^{a}	0.828
	30		0.63±0.06^{a}	0.62±0.05^{ab}	0.812
	60		0.62±0.05^{ab}	0.60±0.01^{abc}	0.699
	90		0.58±0.04^{ab}	0.57±0.04^{abc}	0.708
	120		0.56±0.05^{ab}	0.55±0.05^{bcd}	0.795
	150		0.54±0.06^{ab}	0.53±0.04^{cd}	0.773
	180		0.52±0.09^{b}	0.51±0.04^{d}	0.862
	p Value		<0.001	<0.001	
Gumminess (*kg*/*force*)	0	1.73±0.06	2.19±0.02^{a}	2.07±0.05^{a}	0.016
	30		1.98±0.07^{b}	1.91±0.02^{b}	0.159
	60		1.78±0.06^{c}	1.67±0.06^{c}	0.089
	90		1.55±0.07^{d}	1.42±0.03^{d}	0.041
	120		1.34±0.06^{e}	1.24±0.05^{e}	0.098
	150		1.16±0.05^{f}	1.06±0.08^{f}	0.150
	180		0.95±0.01^{g}	0.94±0.05^{g}	0.839
	p Value		<0.001	<0.001	
Cohesiveness	0	0.55±0.08	0.60±0.06^{a}	0.58±0.06^{a}	0.760
	30		0.58±0.04^{b}	0.57±0.07^{b}	0.809
	60		0.57±0.06^{c}	0.55±0.05^{c}	0.768
	90		0.54±0.05^{d}	0.53±0.06^{d}	0.803
	120		0.52±0.07^{e}	0.51±0.03^{e}	0.713
	150		0.51±0.03^{f}	0.49±0.03^{f}	0.515
	180		0.50±0.04^{g}	0.48±0.03^{g}	0.624
	p Value		<0.001	<0.001	
Chewiness kg force/*mm*)	0	1.21±0.08	1.45±0.05^{a}	1.36±0.04^{a}	0.058
	30		1.25±0.06^{b}	1.19±0.05^{b}	0.234
	60		1.09±0.10^{c}	1.01±0.02^{c}	0.220
	90		0.90±0.09^{d}	0.83±0.04^{d}	0.269
	120		0.75±0.05^{e}	0.69±0.02^{e}	0.097
	150		0.63±0.08^{f}	0.57±0.04^{f}	0.292
	180		0.49±0.01^{g}	^{0}.48±0.04^{g}	0.637
	p Value		<0.001	<0.001	

Values are expressed as mean ± standard deviation Different superscripts in same rows indicate significant differences (p<0.05) (n=3)

Sensory evaluation

During 180 days of storage, a trained panel evaluated the sensory qualities of shrimp masala. Appearance, color, flavor, firmness, succulence, toughness, and overall acceptability were assessed for samples processed at F_0 8 and 9 minutes (Figure 3). At day 0, both treatments received high scores across all attributes. Initially, appearance and succulence scored similar sensory score for both F_0 values, but later decreasing trend was observed by 180 days of storage period. At first, both treatments had the same overall acceptance score (8.80). Over the storage period, the scores gradually decreased. Samples treated at F_0 8 min maintained higher ratings than those handled at F_0 9 min by day 180. Overall acceptability scores were 8.10 (F_0 8) and 8.0 (F_0 9), respectively. In the F_0 9 sample, the decline in sensory quality was more noticeable. The accumulation of lipid oxidation products, texture weakening, and color oxidation were blamed for the gradual decline in scores. Compared to the higher F_0 value, the milder F_0 8 treatment better maintained firmness, flavor, and color. Throughout the storage period, no noticeable differences in toughness were found, suggesting that both treatments achieved a suitable level of texture integrity. According to these results, shrimp masala that was cooked for eight minutes at F_0 had better sensory retention over time. Dasan *et al.* (2021) [25], Chavan *et al.* (2025) [38], and Mohan *et al.* (2006) [21] showed similar findings, pointing to improved customer acceptance of moderately retorted, shrimp masala, pacu fish in masala and shrimp kuruma products. The findings highlighted how crucial it is to maximize thermal load in order to balance safety and sensory quality in seafood that is ready to eat.

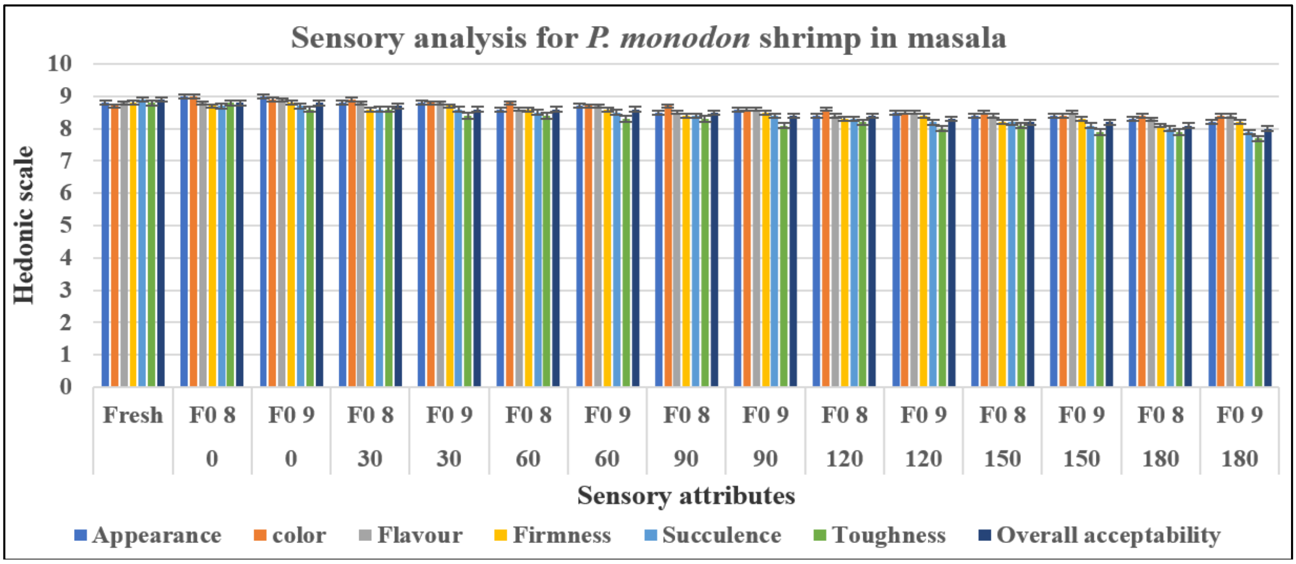

Fig 3: Sensory analysis for fresh and thermally processed black tiger shrimp in masala processed at F_0 8 and 9 min.

Conclusion

This study successfully developed ready to eat thermally processed Shrimp masala packed in flexible retort pouches. Product was heat treated using a commercial pilot scale over pressure retort at two distinct lethality (F_0 8 and 9 min). The study demonstrated that the moisture content of both the products was significantly decreased, while the values of crude protein, crude fat, and ash contents were increased. Additionally, all biochemical constituents, including TVB-N, TMA-N, TBARS, FFA, and PV values, increased, but remained within an acceptable limit. Very little change in pH was seen throughout the storage period, suggesting that the product's microbiological quality was preserved. The products with good sensory acceptability and commercial sterility were processed at F_0 8 and 9 minutes. These results demonstrated that shrimp masala processed for F_0 8 minutes provided better sensory retention over time.

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