**Effect of glazing and frying on shelf life and quality attributes of *Litopenaeus vannamei* shrimp during frozen storage: A Comparative Study**

**Abstract**

During the present study, the effect of glazing and frying on the shelf life of shrimps, *Litopenaeus vannamei* was recorded after 2, 4, 8, 12, and 16 weeks of storage. Glazing and frying significantly influenced the biochemical and organoleptic properties in frozen shrimps, *Litopenaeus vannamei.* Among the treatments, pan fry was significantly better in reducing trimethyl amine content (4.65 mg/ 100g), total volatile basic nitrogen content (11.96 mg/ 100g), moisture (10.17%), pH (6.65) followed by air fry (5.81, 12.90 mg/ 100g, 10.51%, 6.73) and turmeric glazing (6.05, 13.53 mg/ 100g, 10.65%, 6.78). The appearance (7.44, 7.38, 7.44), smell (7.39, 7.34, 7.31), and taste (7.30, 7.28, 7.23) scores of frozen shrimps were significantly better in turmeric glazed, air fry and pan fry treatments showing no significant difference with each other after 16 weeks. The texture (7.41) and overall quality (7.81) score of turmeric-glazed frozen shrimps was significantly higher than the scores at other treatments

**Keywords:** Glazing, *Litopenaeus vannamei*, Frying, Quality changes, Frozen storage

**Introduction**

Increased consumer consciousness regarding healthy eating and nutrition motivates them to modify their dietary choices and educate themselves about a product's attributes before buying. This awareness drives a preference for minimally processed convenience foods and items containing natural additives that offer safety and stability. (Simat V. et al., 2023). Pacific white shrimp (*Litopenaeus vannamei*) have gained global popularity, especially in Southern Asia and China, for their rich nutritional profile comprising amino acids, peptides, polyunsaturated fatty acids, and other beneficial compounds. Despite their nutritional value, these shrimps are prone to rapid spoilage due to their high levels of non-protein nitrogen compounds, autolytic enzymes, and susceptibility to microbial contamination. This perishability leads to a noticeable decline in taste and texture post-mortem. (Mastromatteo et al., 2010). Seafood is a valuable source of nutrition due to its high protein content and other essential nutrients, such as peptides, essential amino acids, long-chain omega-3 polyunsaturated fatty acids, carotenoids, vitamins, and minerals. These minerals include calcium, copper, zinc, sodium, potassium, selenium, iodine, and other trace elements, making seafood a well-rounded and nutritious food choice. (Daneshi et al., 2023). Prolonged frozen storage of shrimp can lead to protein denaturation, lipid oxidation, and the formation and melting of ice crystals, which can negatively impact the quality of the product. These changes can result in discoloration, off-flavors, rancidity, dehydration, and drip loss, as reported in studies by Baron et al. (2007) and Haghshenas et al. (2015). These issues can affect the sensory and nutritional qualities of the shrimp, potentially leading to a decline in consumer acceptance and a shorter shelf life. A prior investigation indicated that lipid breakdown and oxidation, along with protein structural changes, observed in seafood during freezing storage significantly impacted the acceptability of the product. (Tironi et al., 2010). The shrimp is prone to spoiling and deteriorating throughout transportation, sales, and storage due to factors such as bacterial contamination, the breakdown of internal enzymes, and melanosis. (Qian et al., 2013). Conventionally, methods like freezing, water glazing, preservative application (like phosphates), and varied packaging materials have been employed to manage spoilage in shrimp (Okpala et al., 2014). Recent research indicates that natural extracts like turmeric can also enhance shrimp products' quality. Aside from turmeric extract, the application of antioxidants in preserving frozen shrimp has been investigated. Research findings indicate that incorporating antioxidants like α-tocopherol into the muscle of frozen blue shrimp (*Litopenaeus stylirostris*) contributed to preserving the product's quality during storage (Fernandes et al., 2017). Turmeric has been examined for its possible antioxidant impact on shrimp during frozen storage. In one study, scientists explored how glaze absorption affects the storage quality of frozen shrimp. They discovered that incorporating turmeric extract into the glaze aided in preserving pH and total volatile basic nitrogen (TVB-N) levels throughout storage (Gonçalves et al., 2009). In addition to turmeric extract, the cooking method used for shrimp has been noted to affect its quality during frozen storage. This study also examined the effects of pan-frying and air-frying on frozen shrimp. These results indicate that the inclusion of turmeric extract may assist in mitigating quality alterations and spoilage during frozen storage, potentially prolonging the product's shelf life.

**Materials and methods**

**Preparation of extract**

Turmeric extraction preparation followed the method outlined by (Soni et al., 2021) with minor adjustments. Initially, the leaves were cleaned and dried at 50°C. After drying, they were ground and sifted through an 80-mesh stainless-steel sieve. For the ethanolic extract, 40 grams of turmeric powder were macerated in 1000 mL of 70% ethanol and placed in a shaker incubator at 120 rpm for 24 hours at room temperature. The extract was then concentrated by filtration using Whatman filter paper no. 1 and subjected to rotary evaporation (IKA HB10) at 50°C for 20 minutes. The concentrated sample was dried in a hot air oven at 60°C for 12 hours. The resulting residue was stored in the dark at 4°C.

**Shrimp preparation and treatment**

Pacific white shrimp weighing 40-50 shrimps per kilogram were harvested from a shrimp farm located in Kemari, Hisar, Haryana, India. These shrimps were exceptionally fresh and devoid of any additives. They were packed in a ratio of 2 parts ice to 1 part shrimp and promptly transported to the Department of Fish Processing Technology at Chaudhary Charan Singh Haryana Agricultural University in Hisar within an hour. After being rinsed with cold water and placed into frozen storage. In the laboratory, the shrimps were washed, headed, and deveined by hand and finally divided into five groups and treated as follows: Group 1: Nonglazed shrimps (NG) 2: water glazed shrimps (DWG) Groups 3 Turmeric glazed shrimps 4% (TG), Group 4 Air fry, Group 5 Pan fry. To initiate the glazing procedure, the samples were first submerged in distilled water and turmeric extract for a minute, followed by a ten-second dripping phase. Another set of samples underwent a cooking process, where shrimp were marinated, and cooked using both a pan fryer and an air fryer. Subsequently, after glazing, the samples were stored at -18°C for 16 weeks, with biochemical and sensory evaluations performed at intervals of 0, 2, 4, 8, 12, and 16 weeks. The cooking process involved using peeled and deveined shrimp.

**Determination of Trimethylamine**

TVB-N determination was conducted using the Conway micro-diffusion method (Conway, 1933), Initially, 10 grams of meat sample underwent extraction with 10% trichloroacetic acid (TCA) and filtration using Whatman No. 1 to gather the supernatant. Subsequently, 1 mL of the supernatant was transferred to the outer chamber of the Conway micro-diffusion unit. In the inner chamber, 1 mL of 0.01 N sulphuric acid was placed along with 1 mL of saturated potassium carbonate and 0.5 mL of formaldehyde solution. The unit was sealed and gently swirled to ensure mixing of the solutions in the outer chamber, and then left overnight at room temperature. Titration was conducted in the inner chamber using 0.01 N sodium hydroxide. A blank, following the same procedure without the sample, was also prepared. To minimize errors, the sample was analyzed in triplicate. The resulting value was expressed as milligrams of TVB-N per 100 grams of muscle.

The following formula was used to calculate TMA.

TMA as mg/100 g shrimp sample = ((R×0.14×D×100)/(V1×W)

Where,

R – Titer value (sample – blank)

D – Dilution factor

V1 – Volume of shrimp sample taken for the experiment,

W – Weight of shrimp sample taken for experiment.

**Determination of Total volatile base nitrogen (TVB-N)**

TVB-N of shrimp samples were analyzed by Pandian et al. (2022). Initially, a 10-gram meat sample was treated with 10% trichloroacetic acid (TCA) and filtered using Whatman No. 1 paper to obtain the supernatant. Subsequently, 1 mL of this supernatant was transferred into the outer chamber of the Conway micro-diffusion unit. Within the unit's inner chamber, 1 mL of 0.01 N sulphuric acid was added, while the outer chamber received 1 mL of saturated potassium carbonate solution. The unit was sealed, and the solutions in the outer chamber were gently mixed by swirling. It was then left at room temperature overnight. Titration with 0.01 N sodium hydroxide was carried out in the inner chamber, with a blank sample processed in the same manner but without the meat sample. To minimize potential errors, the sample was taken in triplicate. The following formula was used to calculate TVB-N:

TVB-N as mg per 100 g shrimp sample = (R\*0.14\*D\*100) / (V1\*W)

Where,

R – Titer value (sample – blank),

D – Dilution factor

V1 – Volume of shrimp sample taken for the experiment,

W – Weight of shrimp sample taken for experiment.

**Determination of pH**

The pH measurement followed the method outlined by Trout (1989). The pH measurement was conducted once the meat samples had reached room temperature through water thawing. Subsequently, 2 grams of sample were agitated with 20 mL of distilled water for 1 minute using a vortex machine. The pH of the resulting suspension was determined using a pH meter, with the electrode positioned directly in the center of the container. Before use, the pH meter underwent a three-point calibration process.

**Determination of moisture content**

An empty dry and clean petri dish was weighed (W1) and minced shrimp (10 g) was added. The petri dish with minced shrimp was weighed and the reading was noted as W2. It was kept in the oven for overnight drying. The weight was taken again and noted as W3. The moisture content was calculated as

$$Moisture content \left(\%\right)=\frac{W2-W3}{W2-W1}\*100$$

 Where,

W1= Weight of Petridis.

W2= weight of the minced shrimp meat.

W3= Weight of Petridis along with minced meat after drying in the oven

**Result**

**Determination of Trimethylamine**

Trimethylamine (TMAN) serves as a valuable indicator of freshness, with an acceptable range of 10 to 15 mg/100g in shrimp (Sedyaaw et al., 2024). Figure 1 shows the TMA value of Group 1: Nonglazed shrimps (NG) Group 2: water glazed shrimps (DWG) Group 3 turmeric-glazed shrimps 4% (TG), Group 4 Air fry, and Group 5 Pan fry. The changes of TMA-N in different treatments at 0 weeks was 2.27- 2.8 mg per 100 g meat, then increased up to 7.9 -11.4 mg per 100 g during 16 weeks of storage.

**Determination of Total volatile base nitrogen (TVB-N)**

TVB-N is used as an important indicator of seafood quality, correlating with bacterial spoilage and enzymatic activity (Daneshi et al., 2023). The changes in TVB-N value of different Group 1: Nonglazed shrimps (NG) Group 2: water glazed shrimps (DWG) Groups 3 Turmeric glazed shrimps 4% (TG), Group 4 Air fry, and Group 5 Pan fry. Treatments are shown in Figure 2. At the 0 weeks, TVBN of different treatments was found between the range of 5.6- 7.47 mg per 100 g of shrimp then increased up to 21.47 -27.07 mg per 100 g shrimp during 16 weeks of frozen storage.

**Determination of moisture content**

Higher moisture levels in shrimp contribute to heightened ice crystal formation during freezing, leading to texture deterioration and reduced quality upon thawing. It underscores the significance of managing shrimp moisture content to uphold its quality during frozen storage (Azam et al., 2013). The changes in moisture in all the treatments are shown in Figure 3. Initially, the range of moisture content in all treatments was 9.14%-9.58 % then increased up to 11.32%-12.62 %.

**Determination of pH**

pH plays an important role in maintaining the quality of shrimp,in frozen storage, shrimp quality is affected by pH levels. Lower pH, indicating greater acidity, tends to preserve shrimp by preventing the growth of bacteria and enzymes that spoil its quality. Conversely, higher pH, signaling a more basic environment, can hasten the deterioration of shrimp quality because it fosters heightened enzymatic activity and microbial growth (Huan et al., 2003). The changes in pH among all treatments are shown in Figure 4. The range of pH was 6.5-6.8, then increased up to 6.8-7.1 during the 16 weeks of storage.

**Sensory analysis**

Sensory properties ofNon-glazed shrimps (NG), Distilled water-glazed shrimps (DWG), Turmeric glazed shrimps 4% (TG), Air fry, and Pan fry are given in Table 1. The sensory score was 7 to 7.8 which includes appearance, texture, smell, and taste observed at the 16 weeks of storage.

**Discussion**

The present study was done to evaluate the effect of turmeric glazing and frying on quality changes of peeled deveined shrimp during frozen storage. Among the treatments, pan fry was significantly better in reducing trimethyl amine content (4.65 mg/ 100g), followed by air fry (5.81 mg/ 100g) and turmeric glazed (6.05 mg/ 100g) as compared to water glazed and non-glazed shrimps (CD= 0.60; p= 0.05) (Figure 1). The difference between trimethyl amine content in non-glazed and distilled water-glazed shrimps was non-significant. Storage weeks significantly influenced the trimethyl amine content in frozen shrimps. At 0 week, trimethyl amine content in frozen shrimps was 2.71 mg/100 g which significantly increased to 4.29, 5.76, 6.97, 7.63, and 9.38 mg/ 100g at 2nd,4th,8th, 12th, and 16th week of storage (CD= 0.98; p= 0.05). The interaction between treatments and storage weeks was also significant which indicated that changes in trimethyl amine content in frozen shrimps in pan fry, air fry 4, and turmeric glazed was significantly lower than distilled water glazed and non-glazed shrimps during different weeks of storage. Tsironi et al. (2009) observed that the trimethylamine (TMA) content in frozen shrimp rose from 2.85 mg N/100 g to 14 mg N/100 g over the storage period. Amanatidou et al. (2000) reported the TMA increased from 5.6 to 9.89 mg N/100g during 5 months of frozen storage of shrimp. The permissible range for TMA is between 5 and 15 mg N/100 g according to Bindu et al. (2013).

A similar trend was recorded on the changes in total volatile basic nitrogen content (Figure 2) in frozen shrimps, *L. vannamei,* there was a significant increase (16.33mg/100 g) in non-glazed shrimps which was at par with total volatile basic nitrogen content (15.56mg/100 g) in distilled water glazed shrimps (CD=1.52; p= 0.05). Statistically comparable trimethyl amine content in pan fry (5.81 mg/ 100g), air fry (5.81 mg/ 100g), and turmeric glazed (6.05 mg/ 100g) shrimps were observed which were significantly lower than other treatments (CD= 0.98; p= 0.05). The total volatile basic nitrogen content of frozen shrimps was low (6.53, 7.84mg/100 g) at 0 and 2nd week which significantly increased with the progression of storage weeks (CD= 1.67; p= 0.05). Statistical analysis done through ANOVA recorded a non-significant interaction between glazed treatments and storage weeks. Shi et al. (2019) found that applying rosemary extract as a coating on mud shrimp (*Solenocera melantho*) could reduce the rise in TVB-N levels throughout frozen storage. Tsironi et al. (2009) reported that the TVB-N level in frozen shrimp increased from 6.49 mg N/100 g to 25 mg N/100 g, similar to our current investigation's outcomes. The effect of glazed treatment on the moisture content of frozen shrimps, *Litopenaeus vannamei,* is presented in Figure 3. The frying and glazed treatment influenced the moisture content of frozen shrimps, *Litopenaeus vannamei* which was higher (10.83%) in non-glazed shrimps followed by water glazed (10.71%), turmeric glazed (10.65%), air fry (10.51%)and pan fry (10.17%)shrimps. A significant effect of storage weeks was observed on the moisture content of frozen shrimps. It was 9.34 percent at 0 weeks which was statistically at par with 2 weeks (9.33%) of storage which significantly increased to 11.91 percent at 16 weeks of storage (CD= 0.29; p= 0.05). The frozen shrimp's pH changed over time and in response to various treatments as recorded under Figure 4. Pan fry, air fry, and turmeric glazed shrimps had significantly lower pH (6.65, 6.73, 6.78) than distilled water glazed (6.89) and without glazed (6.91) shrimps (CD= 0.03; p= 0.05); the latter two values were at par with each other. The pH of glazed and non-glazed shrimps increased gradually showing no significant difference at 4 and 8 weeks of storage (CD= 0.03; p= 0.05). The interaction between treatments and storage weeks was found to be statistically significant indicating higher pH in non-glazed shrimps than other treatments at different weeks of storage (CD= 0.03; p= 0.05). Sensory analysis of frozen shrimps, *Litopenaeus vannamei* were compared in terms of appearance during monthly data analysis (Table 1). Effect of glazing on the appearance of frozen shrimps, *Litopenaeus vannamei* did not show any significant difference among treatments although all were significantly better than non-glazed shrimps (Table 1). The smell and taste of frozen shrimps, *Litopenaeus vannamei* were statistically comparable in pan fry, air fry, and turmeric glazed shrimps (CD= 0.0.05, 0.06; p= 0.05). However, significantly better scores for treated shrimps were recorded by respondents. Daneshi et al. (2023) examined how glazing and the addition of *Arthrospira platensis* (Spirulina) affect the quality of *Litopenaeus vannamei* shrimp fillets during frozen storage. The study found that glazing significantly reduced quality deterioration over 150 days compared to unglazed samples. Furthermore, shrimp glazed with Spirulina exhibited lower levels of certain indicators of spoilage such as TVB-N, PV, and TBA, while also showing improved texture and sensory properties compared to other treatments. This study focused on preserving the chemical and sensory qualities of peeled *Litopenaeus vannamei* shrimp using turmeric glazing and frying. After 16 weeks of frozen storage, untreated shrimp showed greater chemical deterioration and poorer texture and sensory attributes compared to treated shrimp. The findings suggest that turmeric glazing and pan frying are effective methods for preserving shrimp quality during frozen storage.

**Conclusion**

Turmeric glazing and frying significantly influenced the quality of peeled and deveined shrimp during frozen storage. Among the treatments, pan-fried shrimp exhibited the lowest trimethyl amine and total volatile basic nitrogen content, followed by air-fried and turmeric-glazed shrimp, indicating reduced spoilage compared to non-glazed and water-glazed shrimp. Moisture content, pH, and sensory attributes also showed significant improvements in treated samples, with turmeric glazing and frying effectively delaying quality deterioration over 16 weeks of storage. These findings highlight the potential of turmeric-based treatments in enhancing seafood preservation, providing a natural and effective approach to maintaining shrimp quality during frozen storage.

**Figure 1. Changes in TMA-N OF Nonglazed shrimps (NG), water glazed shrimps (DWG), Turmeric glazed shrimps 4% (TG), Air fry, and Pan fry *L. vannamei* during frozen storage**

**CD (p=0.05) for Treatments =0.60; S E (m) = 0.31**

**CD (p=0.05) for Weeks = 0.98; S E (m) = 0.34**

**CD (p=0.05) for Treatments × Weeks =2.19; S E (m) =0.77**

**Figure 2. Changes in TVB-N of Nonglazed shrimps (NG), water glazed shrimps (DWG), Turmeric glazed shrimps 4% (TG), Air fry, and Pan fry *L. vannamei* during frozen storage**

**CD (p=0.05) for Treatments =1.52; S E (m) = 0.53**

**CD (p=0.05) for Weeks = 1.67; S E (m) = 0.59**

**CD (p=0.05) for Treatments × Weeks =N/A; S E (m) =1.31**

**Figure 3. Moisture of Nonglazed shrimps (NG), water glazed shrimps (DWG), Turmeric glazed shrimps 4% (TG), Air fry, and Pan fry *L. vannamei* during frozen storage**

**CD (p=0.05) for Treatments =N/A; S E (m) = 0.09**

**CD (p=0.05) for Weeks = 0.29; S E (m) = 0.10**

**CD (p=0.05) for Treatments × Weeks =0.66; S E (m) =0.23**

**Figure 4**. **Changes in pH Nonglazed shrimps (NG), water glazed shrimps (DWG), Turmeric glazed shrimps 4% (TG), Air fry, and Pan fry of peeled *L. vannamei* during frozen storage**

**CD (p=0.05) for Treatments =0.03; S E (m) = 0.01**

**CD (p=0.05) for Weeks = 0.03; S E (m) = 0.01**

**CD (p=0.05) for Treatments × Weeks =0.08; S E (m) =0.02**

**Table 1: Effect of glazing and frying on organoleptic properties of frozen shrimps,*****Litopenaeus vannamei***

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Treatments | Appearance | Texture | Smell | Taste | Overall Quality |
| Non-glazed shrimps (Control) | 6.43 | 6.25 | 6.12 | 5.60 | 7.00 |
| Water glazed shrimps | 7.33a | 6.46 | 6.41 | 6.80 | 7.25 a |
| Turmeric glazed shrimp (4%) | 7.44 a | 7.41 | 7.39 a | 7.30 a | 7.81 |
| Air Fry | 7.38 a | 7.25 | 7.34 a | 7.28 a | 7.46 |
| Pan Fry | 7.44 a | 6.84 | 7.31 a | 7.23 a | 7.25 a |
| CD (p=0.05) | 0.12 | 0.14 | 0.14 | 0.18 | 0.11 |
| SE (m) | 0.04 | 0.05 | 0.05 | 0.06 | 0.04 |

**Values with same superscript do not differ significantly**

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1. There is no AI technology used in this draft

2.Not used Any AI tool

3.

**References**

Amanatidou, A., Schlüter, O., Lemkau, K., Gorris, L.G.M., Smid, E.J. and Knorr, D., 2000. Effect of combined application of high-pressure treatment and modified atmospheres on the shelf life of fresh Atlantic salmon. Innovative Food Science & Emerging Technologies, 1(2), pp.87-98. [https://doi.org/10.1016/S1466-8564(00)00007-2](https://doi.org/10.1016/S1466-8564%2800%2900007-2)

Azam, A.K.M.S., Mansur, M.A., Asadujjaman, M., Rahman, M. and Sarwer, M.G., 2013. Quality and safety aspects of fresh and frozen prawn (*Macrobrachium rosenbergii*), Bangladesh. *American Journal of Food Science and Technology*, *1*(4), pp.77-81. DOI:10.12691/ajfst-1-4-3

Baron, C. P., KjÆrsgård, I. V. H., Jessen, F., & Jacobsen, C. (2007). Protein and lipid oxidation during frozen storage of rainbow trout (Oncorhynchus mykiss). Journal of Agricultural and Food Chemistry, 55(20), 8118–8125. <https://doi.org/10.1021/jf070686f>

Bindu, J., Ginson, J., Kamalakanth, C.K., Asha, K.K. and Gopal, T.K.S. (2013) Physico-chemical changes in high pressure treated Indian white prawn (*Fenneropenaeus indicus*) during chill storage. Innov. Food. Sci. Emerg. Technol. 17: 37-42. <https://doi.org/10.1016/j.ifset.2012.10.003>

Conway, E. J., & Byrne, A. (1933). An absorption apparatus for the micro-determination of certain volatile substances: The micro-determination of ammonia. Biochemical Journal, 27(2), 419. <https://doi.org/10.1042/bj0292221>

Daneshi, M. H., Motallebi Moghanjoughi, A. A., & Golestan, L. (2023). Effects of glazing and Arthrospira platensis on physical and chemical characterization of *Litopenaeus vannamei* fillets during frozen storage. *Iranian Journal of Fisheries Sciences*, *22*(1), 36-43. refrigerated storage. *Food bioscience*, *53*, 102673. [20.1001.1.15622916.2023.22.1.3.6](http://dorl.net/dor/20.1001.1.15622916.2023.22.1.3.6)

Fernandes, M.G., Cervi, C.B., Aparecida de Carvalho, R. and Lapa-Guimarães, J., 2017. Evaluation of turmeric extract as an antioxidant for frozen streaked prochilod *(Prochilodus lineatus*) fillets. *Journal of aquatic food product technology*, *26*(9), pp.1057-1069.<https://doi.org/10.1080/10498850.2017.1376025>

Gonçalves, A.A. and Junior, C.S.G.G., 2009. The effect of glaze uptake on storage quality of frozen shrimp. Journal of food engineering, 90(2), pp.285-290. <https://doi.org/10.1016/j.jfoodeng.2008.06.038>

Haghshenas, M., Hosseini, H., Nayebzadeh, K., Kakesh, B. S., Mahmoudzadeh, M., & Fonood, R. K. (2015). Effect of beta glucan and carboxymethyl cellulose on lipid oxidation and fatty acid composition of pre-cooked shrimp nugget during storage. *LWT-Food Science and Technology*, *62*(2), 1192-1197.

Huan, Z., He, S. and Ma, Y., 2003. Numerical simulation and analysis for quick-frozen food processing. Journal of Food Engineering, 60(3), pp.267-273. [https://doi.org/10.1016/S0260-8774(03)00047-5](https://doi.org/10.1016/S0260-8774%2803%2900047-5)

Mastromatteo, M., Danza, A., Conte, A., Muratore, G., & Del Nobile, M. A. (2010). Shelf life of ready to use peeled shrimps as affected by thymol essential oil and modified atmosphere packaging. International Journal of Food Microbiology, 144(2), 250e256 <https://doi.org/10.1016/j.ijfoodmicro.2010.10.002>

Okpala, C. O. R., Choo, W. S., & Dykes, G. A. (2014). Quality and shelf life assessment of Pacific white shrimp (*Litopenaeus vannamei*) freshly harvested and stored on ice. *LWT-Food Science and Technology*, *55*(1), 110-116.

Pandiyan, P., Soni, A., & Elumalai, P. (2022). Inhibition of melanosis and quality changes on Indian white prawn treated with lemon and pomelo peel extracts conjugated with copper sulfide nanoparticles during chilled storage. *Journal of Aquatic Food Product Technology*, *31*(6), 497-507.

Qian, Y. F., Xie, J., Yang, S. P., & Wu, W. H. (2013). Study of the quality changes and myofibrillar proteins of white shrimp (*Litopenaeus vannamei*) under modified atmosphere packaging with varying CO 2 levels. *European Food Research and Technology*, *236*, 629-635.

Sedyaaw, P., Pathan, D.I., Mohite, A.S., Mohite, S.A., Desai, A.S., Sharangdher, S.T., Koli, J.M., Sawant, S.S. and Gedam, S.P., 2024. DEVELOPMENT AND STANDARDIZATION OF CHUTNEY FROM SHRIMP HEAD WASTE. Journal of Experimental Zoology India. <https://connectjournals.com/03895.2024.27.899>

Shi, J., Lei, Y., Shen, H., Hong, H., Yu, X., Zhu, B. and Luo, Y., 2019. Effect of glazing and rosemary (*Rosmarinus officinalis*) extract on preservation of mud shrimp (*Solenocera melantho*) during frozen storage. *Food chemistry*, *272*, pp.604-612. <https://doi.org/10.1016/j.foodchem.2018.08.056>

Simat, V., Skroza, D., Čagalj, M., Soldo, B. and Mekinić, I.G., 2023. Effect of plant extracts on quality characteristics and shelf-life of cold-marinated shrimp (*Parapenaeus longirostris*, Lucas, 1846) under refrigerated storage. *Food bioscience*, *53*, p.102673. <https://doi.org/10.1016/j.fbio.2023.102673>

Trout, G. R. (1989). Variation in myoglobin denaturation and color of cooked beef, pork, and turkey meat as influenced by pH, sodium chloride, sodium tripolyphosphate, and cooking temperature. *Journal of Food Science*, *54*(3), 536-540.  [**https://doi.org/10.1111/j.1365-2621.1989.tb04644.x**](https://doi.org/10.1111/j.1365-2621.1989.tb04644.x)

Tironi, V. A., Tomás, M. C., & Añón, M. C. (2010). Quality loss during the frozen storage of sea salmon (*Pseudopercis semifasciata*). Effect of rosemary (Rosmarinus officinalis L.) extract. *LWT-Food Science and Technology*, *43*(2), 263-272.

Tsironi, T., Dermesonlouoglou, E., Giannakourou, M. and Taoukis, P., 2009. Shelf life modelling of frozen shrimp at variable temperature conditions. *LWT-Food Science and Technology*, *42*(2), pp.664-671. <https://doi.org/10.1016/j.lwt.2008.07.010>