***Grouper: Jurnal Ilmiah Perikanan***
Vol. 17 No. 2 (2026) pp. 512 - 519
pISSN: 2086-8480 | eISSN: 2716-2702
Journal Homepage: https://grouper.unisla.ac.id/index.php/grouper

# Upcycling of Mud Crab Shell Waste as a Natural Source of Carotenoids: A Comparative Study of *Scylla olivacea* and *Scylla paramamosain*

**Aulia Audi Noorhaliza[1,2], Raihanasywa Satyarani [1,2], Apichai Bourchookarn[1], Annur Ahadi[2,3], Sukree Hajisamae[1], and Payap Masniyom[1]***

[1]Department of Agricultural and Fishery Science, Faculty of Science and Technology, Prince of Songkla University, Pattani 94000, Thailand
[2]Department of Marine, Faculty of Fisheries and Marine, Universitas Airlangga, Mulyorejo, Surabaya 60115, Indonesia
[3]Research Group of Post-harvest, Processing Technology, and Bioproducts, Faculty of Fisheries and Marine, Universitas Airlangga, Mulyorejo, Surabaya 60115, Indonesia

*Corresponding Author: payap.m@psu.ac.th

Submitted: 31 August 2026 Revised: 15 September 2026 Accepted: 29 September 2026

**Keywords:**
Astaxanthin; Carotenoids; Food Waste; *Scylla Olivacea*; *Scylla Paramamosain*

***ABSTRACT***

Mud crab shell waste is a food waste generated from crab processing and represents an underutilized by-product with the potential to serve as a natural source of carotenoids, particularly astaxanthin. This study aimed to compare the carotenoid extraction yield and astaxanthin content of shell extracts from *Scylla olivacea* and *Scylla paramamosain*. Carotenoids were extracted using 95% ethanol through three successive extraction cycles. The extraction yield was determined for each extraction cycle, while the presence and concentration of astaxanthin were analyzed using high-performance liquid chromatography coupled with a diode array detector (HPLC-DAD). The results showed that the highest extraction yield was obtained during the first extraction cycle for both species and decreased in the subsequent cycles. *Scylla olivacea* showed a higher extraction yield than *S. paramamosain*. HPLC-DAD analysis confirmed the presence of astaxanthin in both species, with *S. olivacea* showing a significantly higher astaxanthin concentration (20.12 ± 0.36 µg/mL) than *S. paramamosain* (11.31 ± 0.08 µg/mL) ($p < 0.05$). The astaxanthin peak was detected at a retention time of approximately 8.5 min, consistent with the astaxanthin standard. In conclusion, mud crab shell waste, particularly *S. olivacea*, has potential for valorization as a natural source of carotenoids and astaxanthin. Further studies are recommended to optimize the extraction process and evaluate the stability and potential applications of the recovered astaxanthin. This approach may contribute to reducing food waste while promoting the utilization of crab processing by-products as value-added resources.

## INTRODUCTION

Crustacean processing generates large amounts of shell waste, accounting for approximately 75% of the total biomass, which is difficult to degrade naturally and may pose environmental concerns (Kuddus & Ahmad, 2013). However, crustacean shells are valuable sources of bioactive compounds, particularly carotenoids (Cahu *et al.,* 2012; Hamdi *et al.,* 2020). Because crustaceans cannot synthesize carotenoids themselves, they acquire these pigments directly through the diet. The absorbed carotenoids are subsequently accumulated or metabolized into astaxanthin, which is predominantly deposited in the shell and contributes to its coloration (Babin *et al.,* 2019).

Natural carotenoids recovered from seafood by-products, including astaxanthin, canthaxanthin, zeaxanthin, and β-carotene, have attracted considerable attention because of

their health-promoting properties (Ashraf *et al.,* 2020). Among these compounds, astaxanthin (3,3′-dihydroxy-β,β′-carotene-4,4′-dione) is the predominant carotenoid in crustacean shells and exhibits remarkable biological activities, including antioxidant, anticancer, and neuroprotective effects (Roy *et al.,* 2023; Martins & Ferreira, 2017). Numerous studies have demonstrated the strong antioxidant activity of carotenoids, leading to their widespread application in the food, pharmaceutical, cosmetic, and aquaculture industries (Fawwaz *et al.,* 2024; Hegazy *et al.,* 2020; Linnewiel *et al.,* 2015; Ikeuchi *et al.,* 2006; Sowmya & Sachindra, 2012). Moreover, astaxanthin and its esters have been identified as the predominant carotenoids across several crab species, including the red kelp crab *Taliepus nuttallii* (Hooshmand *et al.,* 2017). The characteristic coloration of seafood, including crustaceans, fish, mollusks, and seaweeds, is attributed to carotenoid pigments (Ozogul *et al.,* 2021).

Mud crabs (*Scylla* spp.) are among the most economically important crustaceans in Thailand, with *Scylla olivacea* being the most abundant species, followed by *Scylla paramamosain* and *Scylla tranquebarica* (Sodsuk, 2006; Lovatelli *et al.,* 2025; Hajisamae *et al.,* 2025). Despite their commercial importance and the large amount of shell waste generated during processing, Comparative information on carotenoid recovery from closely related *Scylla* species remains limited. Therefore, this study compared *Scylla olivacea* and *Scylla paramamosain* to evaluate differences in carotenoid recovery and astaxanthin content from their shell waste. Ethanol was selected as an environmentally friendly and food- ompatible solvent (Nunes *et al.,* 2018), while three successive extraction cycles were performed to evaluate carotenoid recovery from the shell residue. This comparison may help identify mud crab shell waste as a potential source of natural carotenoids and support its valorization as a value-added by-product.

In this study, carotenoids were extracted from the shells of two mud crab species, *S. olivacea* and *S. paramamosain*, and their total carotenoid contents were compared. Total carotenoid content was determined by UV–Visible spectrophotometry, whereas astaxanthin content was confirmed using high-performance liquid chromatography coupled with a diode array detector (HPLC-DAD).

## METHOD

### Sample Collection and Preparation

Mud crab shells (*S. olivacea* and *S. paramamosain*) were obtained from local farms in Southern Thailand. The crabs originated from wild stocks and were subsequently reared under farm conditions. Samples were randomly collected from several farms and multiple batches and included both male and female crabs of different sizes. The crab shells were cleaned to remove adhering impurities such as mud, residual meat, and other debris by brushing them under running tap water. The cleaned shells were then oven-dried at 50°C for 24 hrs, resulting in final moisture contents of 7.26% and 8.29% for *S. olivacea* and *S. paramamosain*, respectively. After drying, the shells were ground into fine powder and sieved through a 250 μm (60 mesh) stainless steel wire mesh. The powdered samples were protected from light and immediately subjected to extraction.

### Carotenoid Extraction

Crab shell powder was extracted with food-grade 95% ethanol at a 1:10 (w/v) ratio, as described by Sachindra et al. (2006), with minimized light exposure. The samples were shaken on a shaker incubator (BEING BSI-3C) at 150 rpm for 2 h at 27 °C. The solid residue was removed from the carotenoid-containing extract by filtration through Whatman No. 1 filter paper. The extraction process was repeated for three cycles using fresh 95% ethanol for each cycle on the same solid residue, and each extract was retained separately. An aliquot of each extract was used to determine the total carotenoid content by spectrophotometry. The remaining extracts from the three cycles were then combined and concentrated by rotary evaporation at 40 °C for subsequent HPLC analysis. During evaporation, the round bottom flask

was covered with a black cloth to protect the extract from direct light exposure and minimize carotenoid degradation.

**Determination of Total Carotenoid Content**

The total carotenoid content of the extracts was determined following the method described by Lira et al. (2017). Briefly, 1 mL of each sample extract was placed in a cuvette, and the absorbance was measured at 482 nm using a UV–Vis spectrophotometer (HITACHI U-5100). Ethanol (1 mL) was used as the blank reference. The results will be expressed as total carotenoid content using the following equation:

$$\text{Carotenoid Yield (mg/g dry weight)} = \frac{A \; x \; V \; x \; 1000}{\varepsilon \; (1cm) \; x \; 100}$$

Where:

A = absorbance (470 nm)

V = total volume (mL) used during carotenoid extraction

∑ = extinction coefficient (2500)

**HPLC Analysis**

The extracts from *S. olivacea* and *S. paramamosain* were analyzed. The pooled extracts obtained from the three successive extraction cycles of *S. olivacea* and *S. paramamosain* were analyzed using high-performance liquid chromatography coupled with a diode array detector (HPLC-DAD) according to Lu et al. (2010). Separation was performed using an Eclipse C18 column (4.6 × 250 mm, 5 µm) at 25 °C. The mobile phase consisted of methanol:water:dichloromethane (70:4:13:13, v/v/v/v) and was delivered at a flow rate of 0.8 mL/min. The injection volume was 5 µL, and detection was performed at 480 nm using a diode array detector (DAD). For sample preparation, 20 mg of each concentrated pooled extract was dissolved in 1 mL of acetone, vortexed for 1 min, and filtered through a 0.45 µm membrane filter prior to injection. Astaxanthin (Sigma-Aldrich) at concentrations of 5–20 µg/mL was used as the external standard. The astaxanthin content was expressed on a dried shell weight basis (µg/g).

**Data Analysis**

All data were analyzed using SPSS software (IBM SPSS Statistics version 20). For total carotenoid content, one-way analysis of variance (ANOVA) was performed to determine significant differences among the three successive extraction cycles (Cycle 1, Cycle 2, and Cycle 3) for each crab species. For astaxanthin content, one-way ANOVA was used to determine significant differences between *Scylla olivacea* and *Scylla paramamosain*. Each independent extraction replicate was considered the experimental unit. When significant differences were detected, Tukey's post hoc test was performed for multiple comparisons. Differences were considered statistically significant at $p < 0.05$.

## RESULTS AND DISCUSSION

**Total Carotenoid Content**

The extraction process was conducted through three successive extraction cycles to evaluate the recovery of carotenoids from the shell material of *Scylla olivacea* and *Scylla paramamosain*. The extraction yield obtained from each cycle was compared to determine the efficiency of repeated extraction and to observe the amount of carotenoids recovered during each extraction cycle. The highest carotenoid content among the three extraction cycles was observed in S. olivacea in Cycle 1 (140.6 ± 33.79 µg/g), which was significantly higher than in the other extraction cycles ($p < 0.05$). In contrast, the lowest carotenoid content was observed in *S. paramamosain* Cycle 3 (7.8 ± 0.45 µg/g). No significant difference was found between *S. olivacea* Cycle 3 and *S. paramamosain* Cycle 2 ($p > 0.05$) as shown in Table 1.

Table 1. Determination of carotenoid content obtained from extraction cycles 1, 2, and 3 obtained from *S. olivacea* and *S. paramamosain*

| Carotenoid (µg/g dry weight) | Species | |
|---|---|---|
| Cycle | *S. olivacea* | *S. paramamosain* |
| 1st | 140.6 ± 33.79[a] | 96.1 ± 4.93[b] |
| 2nd | 49.2 ± 3.30[c] | 13.9 ± 1.73[cd] |
| 3rd | 9.2 ± 1.03[d] | 7.8 ± 0.45[d] |

Values are expressed as mean ± SD (n = 3). Different superscript letters indicate significant differences among treatment combinations ($p < 0.05$)

Table 2 shows the visual appearance of liquid extracts and crab shell powders after three extraction cycles. The first cycle produced the darkest extract color for both species, while the color intensity decreased in subsequent cycles. This indicates that repeated extraction reduced the amount of pigments remaining in the crab shell matrix.

The carotenoids extracted from *Scylla olivacea* and *Scylla paramamosain* exhibited a similar extraction pattern, in which the carotenoid content obtained from the first extraction cycle was substantially higher than that obtained from the second and third extraction cycles (Table 1). A similar trend was reported by Sachindra et al. (2006), who found that most carotenoids from crustacean waste were recovered during the initial extraction, while subsequent extraction cycles resulted in only marginal improvements. Likewise, Vicente et al. (2022) reported the same pattern during astaxanthin extraction from shrimp shells using three successive extraction cycles, where the astaxanthin content gradually decreased in the second and third Cycles, and the extracts became nearly colorless, indicating that most of the extractable pigments had already been recovered (Table 2). The decrease in carotenoid content may be explained by the fact that most readily extractable pigments, particularly free astaxanthin, were released from the shell matrix during the first extraction. The remaining carotenoids are more likely to be bound to carotenoproteins, chitin, or other structural components, making them more difficult to extract using the same solvent (Higuera *et al.,* 2006; Ambati *et al.,* 2014).

Table 2. Visual appearance of liquid extract and crab shells powder obtained from extraction cycles 1, 2, and 3 of *S. olivacea* and S. *paramamosain.*

| Species | Cycle 1 | Cycle 2 | Cycle 3 |
|---|---|---|---|
| *S. olivacea* |  | | |
| *S. paramamosain* |  | | |

Visually, the Cycle 1 extract of *S. olivacea* showed a darker orange/red color than that of *S. paramamosain*. This observation agrees with the carotenoid content shown in Table 1, where *S. olivacea* (140.6 ± 33.79 µg/g) contained a higher carotenoid concentration than *S. paramamosain* (96.1 ± 4.93 µg/g). The higher color intensity is associated with a higher carotenoid content because astaxanthin is the main pigment responsible for the red/orange color of crustacean shells (Lim *et al.,* 2018). Similarly, crab shell color is determined by carotenoid deposition, with the intensity of the red to orange color depending on the

concentration and composition of the carotenoids (Wade *et al.,* 2012). For both species, the color of the extracts became lighter from Cycle 1 to Cycle 3, indicating that most carotenoid pigments were extracted during the first cycle. As a result, less pigment remained to be extracted in Cycles 2 and 3. This trend is commonly observed in successive extraction, where the amount of the target compound decreases after the first extraction (Burke & Kerton, 2023). The solid residues (powders) of both species also became whiter from Cycle 1 to Cycle 3. This change suggests that carotenoid pigments were gradually removed from the shell during repeated extraction. As the carotenoid content decreased, the natural white color of the main shell components, calcium carbonate and chitin, became more visible (Hossain & Shahidi, 2024).

**HPLC Analysis**

To further confirm the presence of astaxanthin in the carotenoid extracts, HPLC-DAD analysis was performed on the extracts obtained from *S. olivacea* and *S. paramamosain*. The chromatograms of the samples were compared with that of the astaxanthin standard based on the retention time and UV–V is absorption characteristics of the detected peak. The astaxanthin standard produced a distinct peak at a retention time of approximately 8.5 min. A peak at a similar retention time was also observed in both *S. olivacea* and *S. paramamosain* extracts, indicating the presence of astaxanthin in the extracted samples. As shown in Figure 2, the chromatographic profiles of both species exhibited a major peak corresponding to the astaxanthin standard, although the peak intensity differed between the two samples.

The astaxanthin content of the extracts was confirmed by HPLC-DAD analysis (Table 3). *S. olivacea* showed the highest astaxanthin concentration (20.12 ± 0.36 µg/mL), which was significantly higher than that of *S. paramamosain* (11.31 ± 0.08 µg/mL) ($p < 0.05$). The chromatogram of the astaxanthin standard is presented in Fig. 2C, which shows a single major peak with a retention time of approximately 8.5 min. The chromatograms of the *S. olivacea* and *S. paramamosain* extracts are shown in Fig. 2A and Fig. 2B, respectively. Both extracts exhibited a peak at the same retention time as the astaxanthin standard, confirming the presence of astaxanthin in the carotenoid extracts. Both extracts showed peaks at retention times of 8.567 min for *S. olivacea* and 8.573 min for *S. paramamosain*, which were close to the astaxanthin standard (8.436 min). Based on the similarity in retention times under the same chromatographic conditions, these peaks were tentatively identified as astaxanthin.

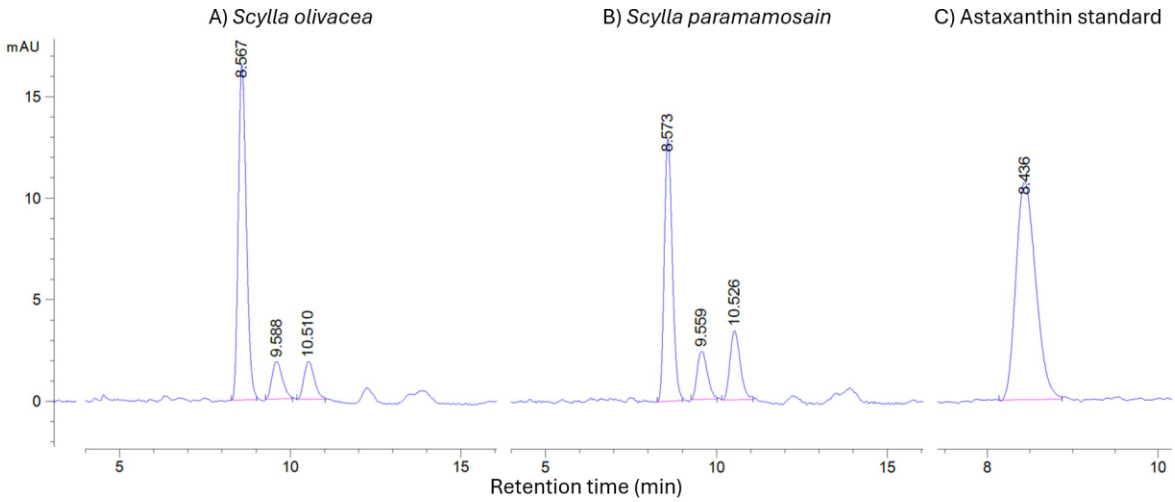



Figure 2. HPLC chromatograms of carotenoids extracted from (A) *Scylla olivacea,* (B) *Scylla paramamosain* and (C) 10 ⌠g/mL Astaxanthin standard

Table 3. Astaxanthin content in *S. olivacea* and *S. paramamosain* confirmed using HPLC analysis

| Sample | Astaxanthin (⌠g/mL) |
|---|---|
| *S. olivacea* | 20.12 ± 0.36 |
| *S. paramamosain* | 11.31 ± 0.08 |

The HPLC chromatograms confirmed the presence of astaxanthin in the extracts of both mud crab species, *S. olivacea* and *S. paramamosain*. This finding is consistent with that reported for the blue crab *Portunus segnis*, in which astaxanthin was identified as the predominant carotenoid in the shell extract (Hamdi *et al.,* 2020). In addition to the major astaxanthin peak, several smaller peaks were observed, which probably correspond to astaxanthin isomers (López *et al.,* 2006). Astaxanthin, in both its free and esterified forms, is recognized as the predominant carotenoid in crustaceans, regardless of whether they are wild caught or farmed (Castillo *et al.,* 1982). Similarly, Montoya et al. (2021) reported astaxanthin contents of 31 ± 0.3 µg/g and 37 ± 0.4 µg/g in the shells of the blue crab (*Callinectes sapidus*) and the brown crab (*Callinectes bellicosus*), respectively, following ethanol extraction.

## CONCLUSION

This study showed that mud crab shell waste contains carotenoids, particularly astaxanthin, and has potential as a natural source of these bioactive compounds. *Scylla olivacea* showed a higher carotenoid extraction yield than *Scylla paramamosain*, with the highest yield obtained during the first extraction cycle in both species. The extraction yield decreased in the subsequent extraction cycles. HPLC-DAD analysis confirmed the presence of astaxanthin in both *S. olivacea* and *S. paramamosain*, with higher astaxanthin content detected in *S. olivacea* compared with *S. paramamosain*. Overall, *S. olivacea* exhibited greater potential as a source of carotenoids and astaxanthin compared with *S. paramamosain*.

## ACKNOWLEDGEMENT

The authors express their sincere gratitude to the Prince of Songkla University (PSU)–Airlangga University Student Exchange Program. Special thanks are extended to the PSU–TUYF Charitable Fund for providing the research grant. The authors also gratefully acknowledge all staff members, as well as the M.Sc. and Ph.D. students of Prince of Songkla University, for their assistance, support, and encouragement throughout this research.

## REFERENCES

Ashraf, S. A., Adnan, M., Patel, M., Siddiqui, A. J., Sachidanandan, M., Snoussi, M., & Hadi, S. (2020). Fish-based bioactives as potent nutraceuticals: Exploring the therapeutic perspective of sustainable food from the sea. *Marine drugs*, *18*(5), 265.https://doi.org/10.3390/md18050265

Babin, A., Moreau, J., & Moret, Y. (2019). Storage of carotenoids in crustaceans as an adaptation to modulate immunopathology and optimize immunological and life-history strategies. *BioEssays*, *41*(11), 1800254. 10.1002/bies.201800254

Burke, H. J., & Kerton, F. (2023). Sequential extraction of valuable bio-products from snow crab (Chionoecetes opilio) processing discards using eco-friendly methods. *Marine Drugs*, *21*(6), 366. https://doi.org/10.3390/md21060366

Castillo, R., Nègre-Sadargues, G., & Lenel, R. (1982). General survey of the carotenoids in Crustacea. In *Carotenoid chemistry and biochemistry* (pp. 211-224). Pergamon. https://doi.org/10.1016/B978-0-08-026224-6.50018-8

Hajisamae, S., Maae, S., Nooseng, S., & Theppanich, A. (2025). Mud crab aquaculture industry in Thailand. In *Status, technological innovations, and industry development needs of mud crab (Scylla spp.) aquaculture: FAO Expert Workshop, 27–30 November 2023, Singapore* (p. 125). Food & Agriculture Org.

Hamdi, M., Nasri, R., Dridi, N., Li, S., & Nasri, M. (2020). Development of novel high-selective extraction approach of carotenoproteins from blue crab (*Portunus segnis*) shells, contribution to the qualitative analysis of bioactive compounds by HR-ESI-MS. *Food chemistry*, *302*, 125334. https://doi.org/10.1016/j.foodchem.2019.125334

Hamdi, S., Elsayed, N., Algayar, M., Ishak, V., Ahmed, M., Ahmed, S., Kamal, M., & Abd El-Ghany (2022). Biological extraction, HPLC quantification and medical applications of astaxanthin extracted from crawfish "*Procambarus clarkii*" exoskeleton by-product. *Biology*, *11*(8), 1215. https://doi.org/10.3390/biology11081215

Hegazy, G. E., Abu-Serie, M. M., Abo-Elela, G. M., Ghozlan, H., Sabry, S. A., Soliman, N. A., & Abdel-Fattah, Y. R. (2020). *In vitro* dual (anticancer and antiviral) activity of the carotenoids produced by haloalkaliphilic archaeon *Natrialba* sp. M6. *Scientific Reports*, *10*(1), 5986. doi: https://doi.org/10.1038/s41598-020-62663-y

Higuera-Ciapara, I., Félix-Valenzuela, L., & Goycoolea, F. M. (2006). Astaxanthin: a review of its chemistry and applications. *Critical reviews in food science and nutrition*, *46*(2), 185-196. https://doi.org/10.1080/10408690590957188

Hooshmand, H., Shabanpour, B., Moosavi-Nasab, M., & Golmakani, M. T. (2017). Optimization of carotenoids extraction from blue crab (*Portunus pelagicus*) and shrimp (*Penaeus semisulcatus*) wastes using organic solvents and vegetable oils. *Journal of food processing and preservation*, *41*(5), e13171. https://doi.org/10.1111/jfpp.13171

Hussein, G.; Sankawa, U.; Goto, H.; Matsumoto, K.; Watanabe, H. Astaxanthin, a carotenoid with potential in human health and nutrition. *J. Nat. Prod*. 2006, 69, 443–449. https://doi.org/10.1021/np050354+

Ikeuchi, M., Koyama, T., Takahashi, J., & Yazawa, K. (2006). Effects of astaxanthin supplementation on exercise-induced fatigue in mice. *Biological and Pharmaceutical Bulletin*, *29*(10), 2106-2110. https://doi.org/10.1248/bpb.29.2106.

Kuddus, M., & Ahmad, I. Z. (2013). Isolation of novel chitinolytic bacteria and production optimization of extracellular chitinase. *Journal of Genetic Engineering and Biotechnology*, *11*(1), 39-46. https://doi.org/10.1016/j.jgeb.2013.03.001

Lim KengChin, L. K., Fatimah Md. Yusoff, F. M. Y., Mohamed Shariff, M. S., & Mohd Salleh Kamarudin, M. S. K. (2018). Astaxanthin as feed supplement in aquatic animals. https://doi.org/10.1111/raq.12200

Linnewiel-Hermoni, K., Khanin, M., Danilenko, M., Zango, G., Amosi, Y., Levy, J., & Sharoni, Y. (2015). The anti-cancer effects of carotenoids and other phytonutrients resides in their combined activity. *Archives of biochemistry and biophysics*, *572*, 28-35. https://doi.org/10.1016/j.abb.2015.02.018

Lira, G. M., Lopez, A. M. Q., Firmino, G. O., Santos, S. D., & Bezerra, R. D. S. (2017). Total carotenoids and antioxidant activity of fillets and shells (in natura or cooked) of "Vila Franca" shrimp (*Litopenaeus schmitti*) in different intervals of storage under freezing. *Ciência e Agrotecnologia*, 41, 94-103. https://doi.org/10.1590/1413-70542017411023616

López-Cervantes, J., Sánchez-Machado, D. I., Gutiérrez-Coronado, M. A., & Ríos-Vázquez, N. J. (2006). Quantification of astaxanthin in shrimp waste hydrolysate by HPLC. *Biomedical chromatography*, *20*(10), 981-984. https://doi.org/10.1002/bmc.676

Lovatelli, A., Shelley, C., Tobias-Quinitio, E., Waiho, K., & Chan, D. (2025). Status, technological innovations, and industry development needs of mud crab (*Scylla* spp.) *aquaculture. https://doi.org/10.4060/cd3976e*

Lu, M., Zhang, Y. E., Zhao, C., Zhou, P., & Yu, L. (2010). Analysis and identification of astaxanthin and its carotenoid precursors from *Xanthophyllomyces dendrorhous* by high-

performance liquid chromatography. *Zeitschrift für Naturforschung C*, *65*(7-8), 489-494. https://doi.org/10.1515/znc-2010-7-812

Martins, N., & Ferreira, I. C. (2017). Wastes and by-products: Upcoming sources of carotenoids for biotechnological purposes and health-related applications. *Trends in Food Science & Technology*, *62*, 33-48. https://doi.org/10.1016/j.tifs.2017.01.014

Montoya, J. M., Mata, S. V., Acosta, J. L., Cabrera, B. E. H., Valdez, L. G. L., Reyes, C., & Cureño, H. J. B. (2021). Obtaining of astaxanthin from crab exosqueletons and shrimp head shells. *Biointerface Res. Appl. Chem*, *11*, 13516-13523. https://doi.org/10.33263/BRIAC115.1351613523

Nunes, A. N., Roda, A., Gouveia, L. F., Fernández, N., Bronze, M. R., & Matias, A. A. (2021). Astaxanthin extraction from marine crustacean waste streams: An integrated approach between microwaves and supercritical fluids. *ACS Sustainable Chemistry & Engineering,* 9, 3050–3059. https://doi.org/10.1021/acssuschemeng.0c06534

Ozogul, F.; Cagalj, M.; Šimat, V.; Ozogul, Y.; Tkaczewska, J.; Hassoun, A.; Kaddour, A.A.; Kuley, E.; Rathod, N.B.; Phadke, G.G. Recent developments in valorisation of bioactive ingredients in discard/seafood processing by-products. *Trends Food Sci. Technol*. 2021, 116, 559–582. https://doi.org/10.1016/j.tifs.2021.08.007

Roy, V. C., Islam, M. R., Sadia, S., Yeasmin, M., Park, J. S., Lee, H. J., & Chun, B. S. (2023). Trash to treasure: An up-to-date understanding of the valorization of seafood by-products, targeting the major bioactive compounds. *Marine Drugs*, *21*(9), 485. https://doi.org/10.3390/md21090485

Sachindra, N. M., Bhaskar, N., & Mahendrakar, N. S. (2006). Recovery of carotenoids from shrimp waste in organic solvents. *Waste Management*, *26*(10), 1092-1098. https://doi.org/10.1016/j.wasman.2005.07.002

Sodsuk, P. 2006. Genetic diversity study of the blue swimming crab (*Portunus pelagicus*) and mud crabs (*Scylla spp*.) populations of Thailand. *Newsletter Aquatic Animals*, 8: 24–25. https://doi.org/10.14456/tjg.2009.13

Vicente, F. A., Ventura, S. P., Passos, H., Dias, A. C., Torres-Acosta, M. A., Novak, U., & Likozar, B. (2022). Crustacean waste biorefinery as a sustainable cost-effective business model. *Chemical Engineering Journal*, *442*, 135937. https://doi.org/10.2139/ssrn.4004674

Wade, N. M., Anderson, M., Sellars, M. J., Tume, R. K., Preston, N. P., & Glencross, B. D. (2012). Mechanisms of colour adaptation in the prawn *Penaeus monodon*. *Journal of Experimental Biology*, *215*(2), 343-350. https://doi.org/10.1242/jeb.064592