6.1 Beyond the frame: leveraging complementary studies to develop value-added products from giant freshwater prawn discards

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Abstract

This study explores the extraction of chitin from the shells of giant freshwater prawns (GFP) and the production of high-purity chitosan, which is then utilised for value-added applications in the food and cosmetic industries. Chitosan beads were developed as an alternative to microplastic beads in face wash products, demonstrating similar exfoliating properties. An edible, biodegradable and transparent food packaging film was also fabricated, serving as a sustainable alternative to polyethylene, with properties suitable for 'heat-and-eat' food products. The film's antimicrobial activity was evaluated, showing its potential as an active packaging material. Furthermore, a smart film was developed to indicate food spoilage, enhancing the functionality of food packaging. Additionally, the research focuses on the community empowerment potential of utilising discarded soft-shelled GFP. A simple cheese-making process incorporating soft-shelled GFP meat was developed, along with a 'heat-and-serve' soup using discarded whey, providing nutritional and economic benefits to rural communities.

Keywords: *culture-based fisheries, Macrobrachium rosenbergii, post-harvest*

Introduction

The GFP (*Macrobrachium rosenbergii*) is increasingly recognised as a key component in improving the livelihoods of rural fisheries in Sri Lanka. Known for its tender and flavourful meat, the GFP is predominantly marketed for export or to local restaurants. However, approximately 55% of the prawn, including shells and heads, is discarded after meat extraction. The shells, primarily composed of chitin, offer significant potential for value-added products; however, their rigid structure limits utilisation (Ju et al. 2021). Deacetylating chitin to form chitosan opens opportunities for its application in industries such as food, cosmetics and biomedical.

Microplastic pollution, particularly from the cosmetic industry, has emerged as a global environmental challenge (Laskar and Kumar 2019; Wang et al. 2021). Microplastic beads, commonly used as exfoliants in face washes, contribute significantly to environmental contamination. As a result, several countries have enacted bans on the use of microplastic beads (Kentin and Kaarto 2018). Likewise, the widespread use of polyethylene-based food packaging materials has raised concerns due to their environmental and health implications (Agarwal et al. 2023). These issues underscore the necessity for biodegradable and non-toxic alternatives. Chitosan, derived from natural sources, offers promising properties such as antimicrobial activity, antioxidant effects and biodegradability (Abd El-Hack et al. 2020; Muzzarelli 2009; Sharma and Batra 2019), positioning it as an ideal candidate for replacing microplastic beads and polyethylene packaging.

In many rural communities, discarded GFP shells – including soft-shelled and damaged prawns –result in both financial and nutritional losses. Additionally, cooked prawn shells from restaurants are frequently discarded. Developing simple, cost-effective technologies to utilise these waste materials could significantly contribute to the economic and nutritional wellbeing of rural communities engaged in GFP fisheries.

Development of value-added products from GFP shell waste and soft-shelled GFP

Chitosan extraction from GFP shell waste

Chitin, a natural polymer found in crustacean shells, has limited direct application due to its rigid structure. However, chitosan, its deacetylated derivative, offers greater versatility for value-added applications. In this study, chitosan was extracted from GFP shell waste discarded by restaurants, achieving a yield of 10.15% (dry weight basis), comparable to chitosan extracted from blue swimming crab shells (11.39%). Characterisation of chitosan was performed using Infrared Spectroscopy (FTIR), X-ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDS), confirming its purity and suitable physicochemical properties for use in cosmetics and food applications (Figure 6.1.1 A, B, C). Additionally, the extracted chitosan exhibited thermal stability up to 310 °C (Figure 6.1.1 D), with favourable viscosity, colour and antioxidant properties.

Value-added products from GFP shell waste

Chitosan beads as an alternative to microplastic beads in face wash

In our study, chitosan extracted from GFP shell waste was used to make beads in similar size to microplastic beads (Figure 6.1.2 A, B). This was a green approach as only the green chemicals were used in the preparation process and the chitosan beads are biodegradable. The structural change of chitosan to chitosan beads was confirmed using FTIR (Figure 6.1.2 C). Properties of chitosan beads were compared with that of microplastic beads and apricot granules to test the effectiveness. Beads should be stable in water without breaking, otherwise beads will be dissolved in liquid face wash with time. Results revealed an acceptable level of water stability (96.23±0.01) which is not significantly different from the reference value (94.60±0.02) ($p=0.240$) (Song et al. 2021).

The cleansing effectiveness of chitosan beads was tested by comparing the time taken to remove eyeliner marks on the skin after applying beads containing face wash to that of microplastic beads and apricot granules. According to the Figure 6.1.3 A, after 30 seconds of rubbing, chitosan

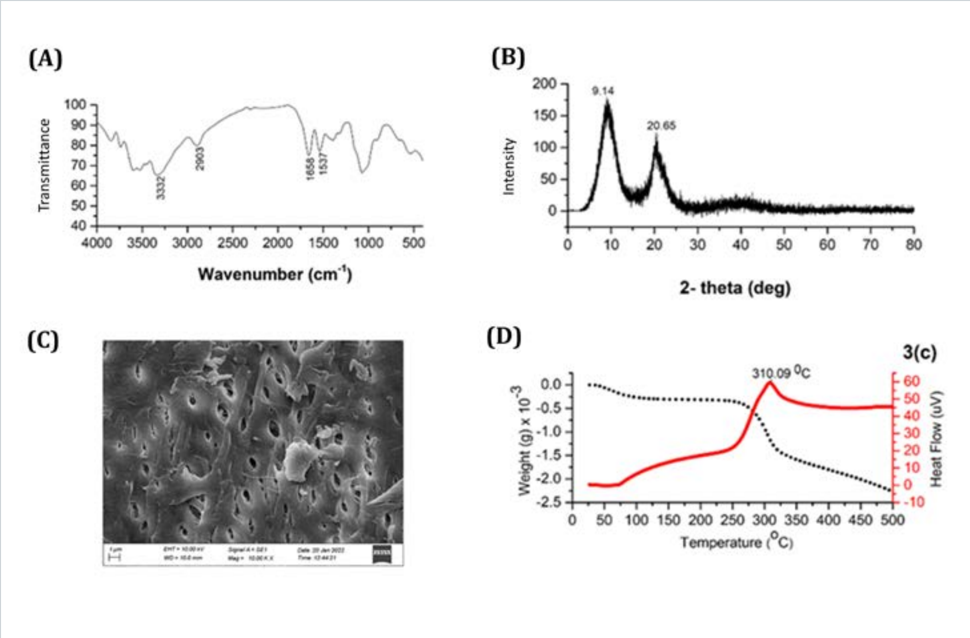

Figure 6.1.1: Characteristics of extracted chitosan

Note: (A) FTIR spectrum; (B) XRD spectrum; (C) SEM image; (D) Thermal degradation temperature.

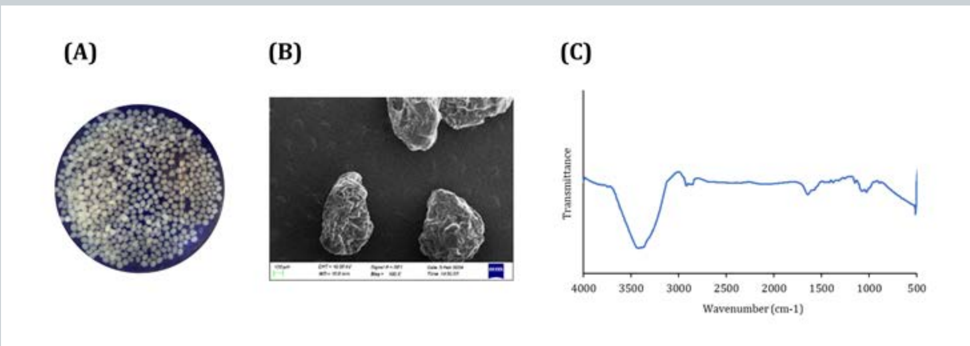

Figure 6.1.2: (A) Photograph of prepared chitosan beads; (B) SEM image; (C) FTIR spectrum

beads showed the highest cleansing effect compared to microplastic beads and apricot granules. This finding was further confirmed by the shortest time duration taken to remove eyeliner marks compared to microplastic beads and apricot granules as shown in Figure 6.1.3 B. According to the sunblock removal test (Figure 6.1.3 C), the highest effectiveness was shown by the chitosan beads.

Sensory evaluation revealed that the face wash containing chitosan beads was preferred over alternative apricot beads for its moisturising, cleansing and oil retention properties (Figure 6.1.4). However, textural and colour properties of chitosan beads were ranked second to microplastic beads, suggesting further experiments to improve texture and colour of chitosan beads.

Edible and biodegradable food packaging film for 'heat-and-eat' foods

An edible, biodegradable food packaging film was developed from GFP-derived chitosan (Figure 6.1.5 A). This was a green approach as only green chemicals were used and the film is biodegradable. The structure of the chitosan film was confirmed by FTIR and XRD spectra (Figure 6.1.5 B, C). The properties of this

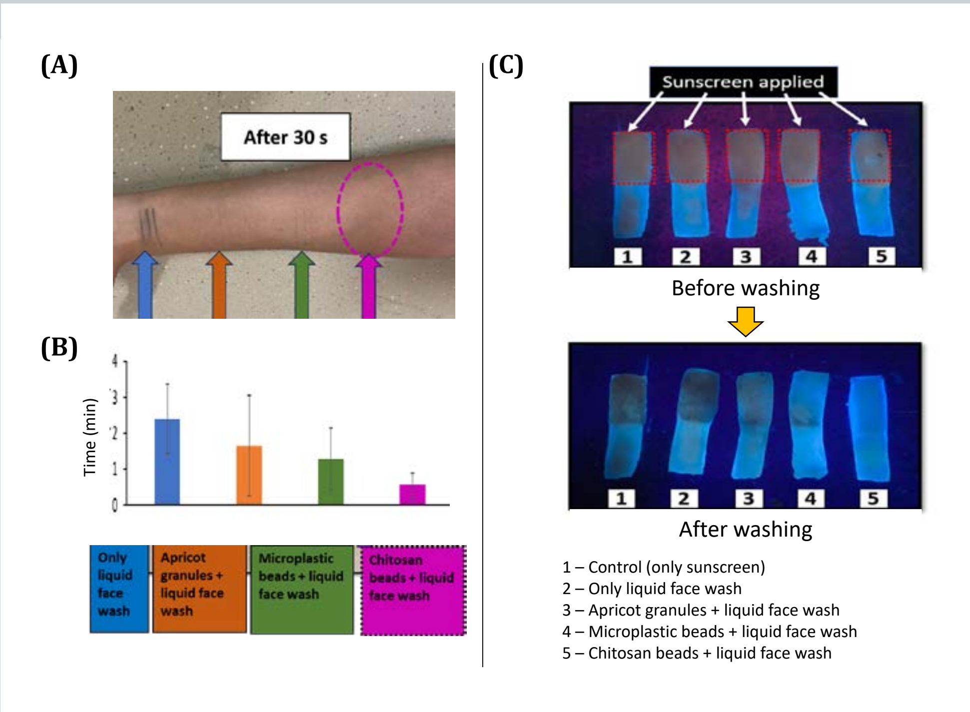

Figure 6.1.3: Cleansing efficiency tests of chitosan beads

Note: (A) Photograph showing remaining eyeliner marks on the skin after 30 min of rubbing; (B) Time taken to completely remove eyeliner marks on the skin; (C) Photograph under UV 365 nm light source showing remaining sunblock on the porcine skin taken as the model skin.

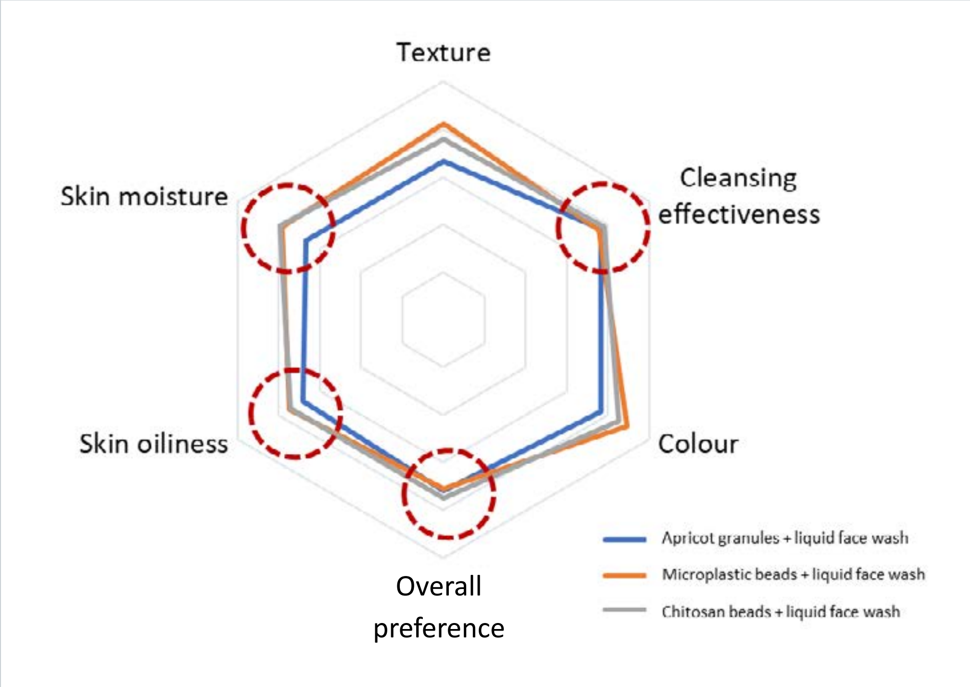

Figure 6.1.4: Sensory evaluation results of 6 attributes of 3 different bead types

film include thickness of 0.04 mm, density of 0.65 gcm^{-3}, grammage of 0.03 gm^{-2}, tensile strength of 37 MPa, antioxidant activity of 85% and biodegradability within 9 days. It remained intact in boiling water for one hour (not tested beyond this), and did not degrade or change colour in microwave oven for 45 minutes, and was heat resistance up to 225 °C as tested by thermal gravimetric analysis (Figure 6.1.5 D) film is suitable for 'heat-and-eat' food products, offering an environmentally friendly alternative to polyethylene. Additionally, the film can be consumed with the food it packages, reducing waste, and is suitable for applications such as instant noodle sachets containing oil and spices (Figure 6.1.5 E).

Active packaging film for fish fillets

Due to their high moisture content, fish fillets are highly perishable, often packaged in polyethylene films under refrigerated conditions. Chitosan-based active packaging films, developed in this study, demonstrated antimicrobial properties (Liyanage et al. 2023) that significantly reduced microbial load on packaged fish fillets under refrigeration. In our research, the previously developed edible food packaging film was further evaluated as an active food packaging film for fish fillets stored at 4 °C. The total plate count of the packaged fish fillets, and in inside and outside surfaces of the package were determined. The results proved that chitosan film had a positive effect on reducing microbial load in fish fillets (Figure 6.1.6).

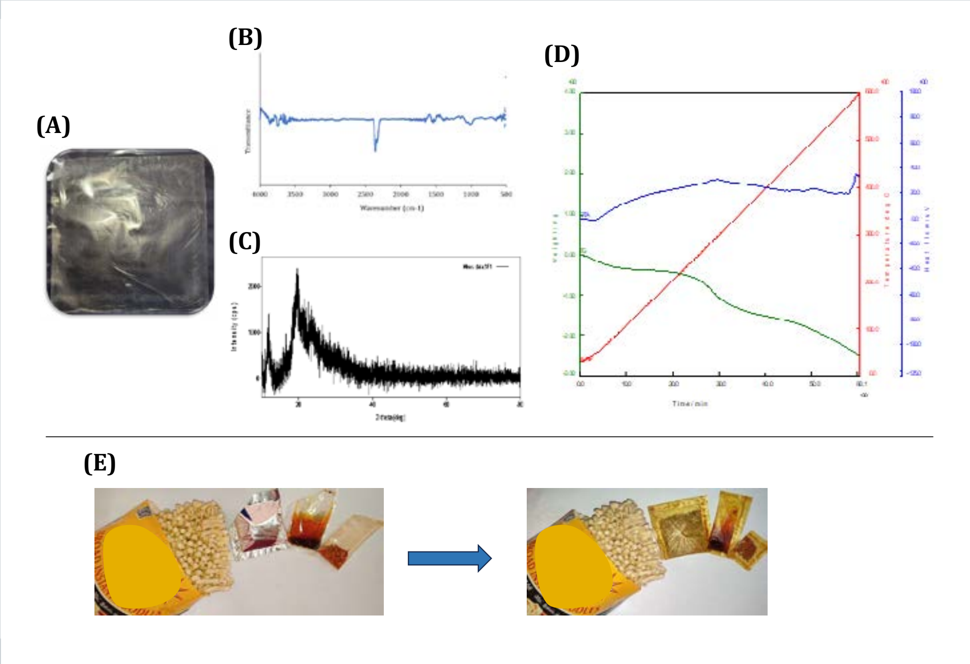

Figure 6.1.5: (A) Photograph of prepared chitosan film; (B) FTIR spectrum; (C) XRD spectrum; (D) Thermal degradation temperature; (E) Representation of the proposed use as sachets (left side – original sachets from polythene, right side – prepared sachets from chitosan)

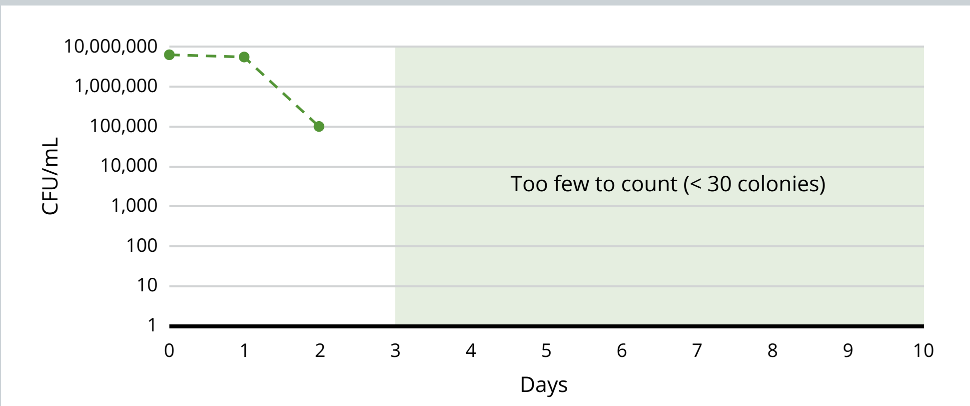

Figure 6.1.6: Total bacterial count of fish fillets packed in chitosan films at 4 °C

Note: The number of colonies in agar plates from 10_{-1} dilution was less than 30, therefore cannot present the values in CFU/mL.

Further, the films also showed promise in extending the shelf life of fish nuggets stored under frozen conditions, providing a biodegradable and non-toxic alternative to synthetic antimicrobial agents. In addition, due to the heat stability up to 225 °C as confirmed by our previous research, these chitosan films can be used for packaging of 'heat-and-eat' food, for example fish nuggets can be deep fried in cooking oil conveniently, without removing the package.

Intelligent and smart food spoilage sensor film

Consumers mainly depend on 'expiry date' given in the packaging as a measure of freshness and safety. However, perishable items like fish fillets spoil fast due to fluctuations in storage temperature although it is still within the expiry date. In addition to expiry date, consumers rely on colour and smell of the fish fillets as a measure of freshness. However, for the vacuum packed fish fillets, the colour alone cannot be taken as a reliable measure of freshness and safety.

Hence, to enhance food safety, a smart spoilage sensor film was developed by incorporating anthocyanins from red cabbage into GFP-derived chitosan to cause structural modifications as evident by the FTIR spectrum (Figure 6.1.7). This pH-responsive (pH 1-pH 13) film exhibited a colour change from purple to blue to green as fish fillets spoiled over a 9-day period under refrigerated conditions (Figure 6.1.8 A). The film also displayed pH-responsive colour changes in apple juice and milk. The colour of smart films changed from purple to yellowish red over a 5-day period for apple juice (Figure 6.1.8 B), and from purple to yellowish red over a 6-day period for milk (Figure 6.1.8 C) at refrigerated storage conditions. These results suggest its potential for broader application in food products.

Value-added products from soft-shelled GFP meat for community empowerment

Soft-shelled GFP-incorporated fresh cheese

A fresh cheese was developed by incorporating soft-shelled GFP flesh using a simple, household-level technology. Two coagulants were used: commercial citric acid and lime juice. Two cheese types under each coagulant were made by incorporating prawn flesh in 2 forms: cube form and ground form (Figure 6.1.9). Properties of these cheeses were compared to cheese made using only milk by adding 2 coagulants separately. Hence, there were 6 cheese types: milk only – citric, cube prawn – citric, ground prawn – citric, milk only – lime, cube prawn – lime, ground prawn – lime. Textural properties of hardness, chewiness and gumminess were significantly different among all 6 cheese types (Figure 6.1.10). However, there were no significant differences in textural properties among 3 cheese types made with lime juice. Sensory attributes were evaluated using the lexicon method and hedonic scale test with the participation of 30 panellists. The results indicated that prawn incorporated cheese types scored higher ranks for sensory attributes; however, there is more room for further improvement of cheese made with lime (Figure 6.1.11 A). The most preferred cheese type was the ground-prawn flesh incorporated cheese made using lime juice as the coagulant (Figure 6.1.11 B). These findings suggest potential for local communities to utilise soft-shelled GFP in value-added food products. Further, this study suggested developing another product from leftover whey as nearly 70% of milk is discarded as liquid whey.

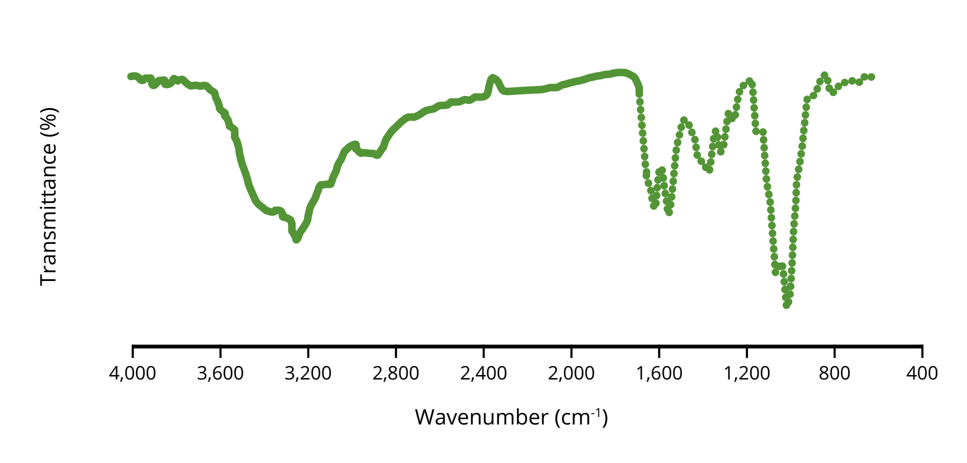

Figure 6.1.7: FTIR spectrum of pH responsive smart film made of chitosan

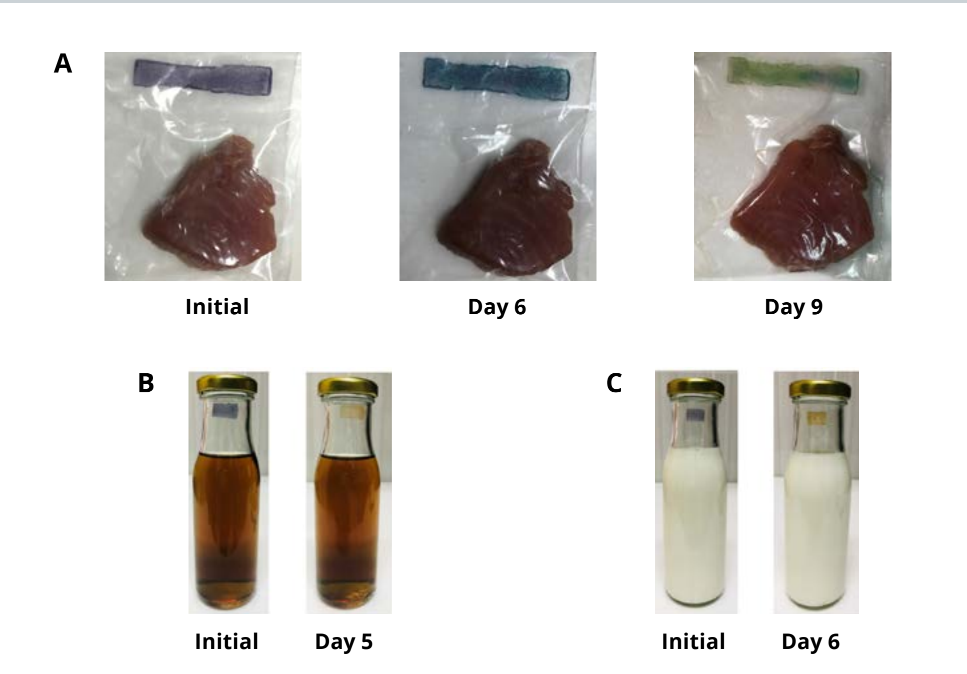

Figure 6.1.8: Photographs showing the colour changes of pH responsive smart films with spoilage

Note: (A) Fish fillet; (B) Apple juice; (C) Milk.

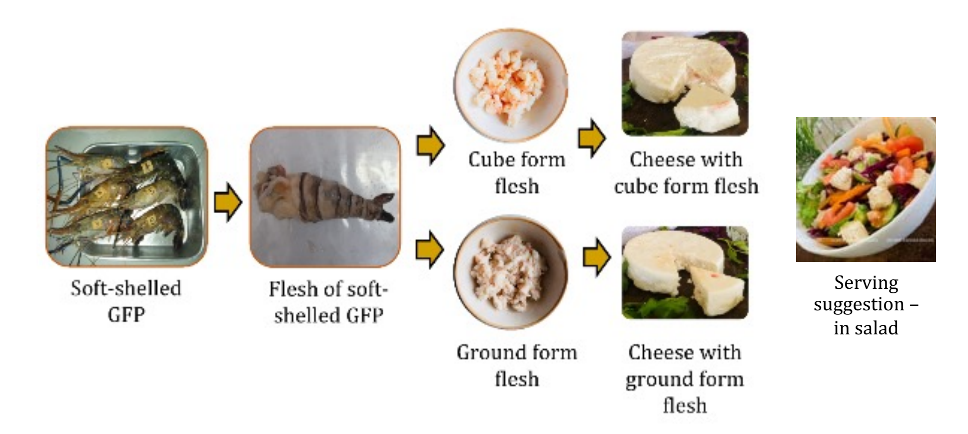

Figure 6.1.9: Photographs showing the use of soft-shelled GFP in cheese making

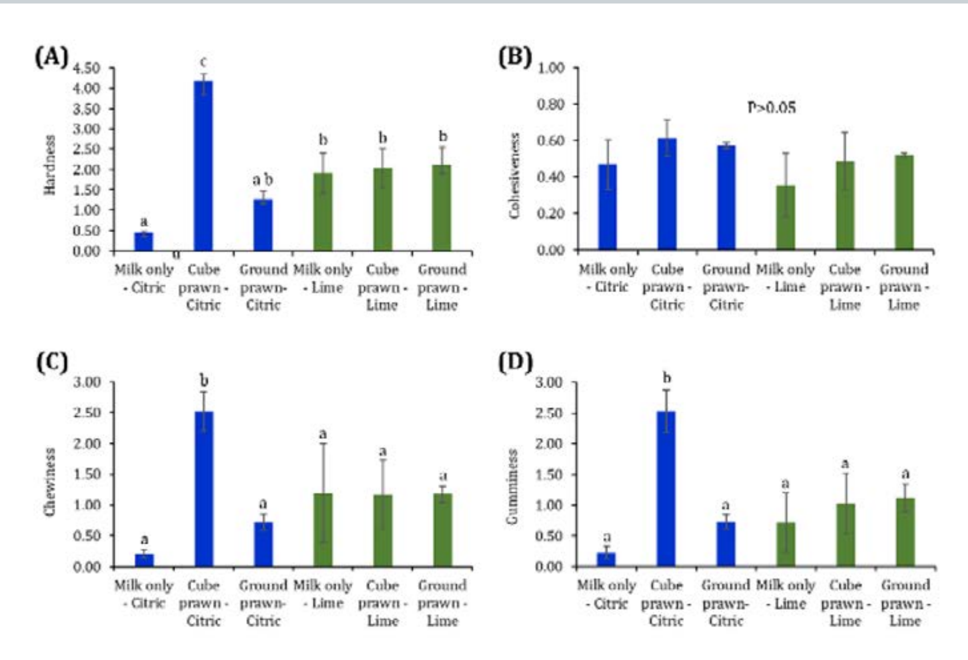

Figure 6.1.10: Textural properties of 6 different cheese types

Note: (A) Hardness; (B) Cohesiveness; (C) Chewiness; (D) Gumminess.

Whey-incorporated 'heat-and-serve' soup
According to the method of cheese preparation in our previous study, nearly 70% of milk is discarded as liquid whey. This liquid whey contains nearly 10% of whey in wet weight basis. To utilise this by-product of cheese preparation, a 'heat-and-serve' soup was developed which can also be prepared at household level. In this research, carrageenan extracted from a seaweed, *Kappaphycus alvarezii*, was used as the thickening agent. Different ratios of liquid whey, tomato pulp and carrageenan powder were tested to select the best ingredient ratio. The proximate composition, viscosity, soluble fibre content and titratable acidity were compared. A sensory test was conducted using a hedonic scale test with the participation of 30 panellists. According to the sensory analysis results, the ingredient ratio of the most preferred soup was whey (20): tomato (80): carrageenan (0.1) (Figure 6.1.12). This simple, nutritious product can be easily prepared at the household level, offering another avenue for rural communities to capitalise on underutilised prawn and dairy by-products.

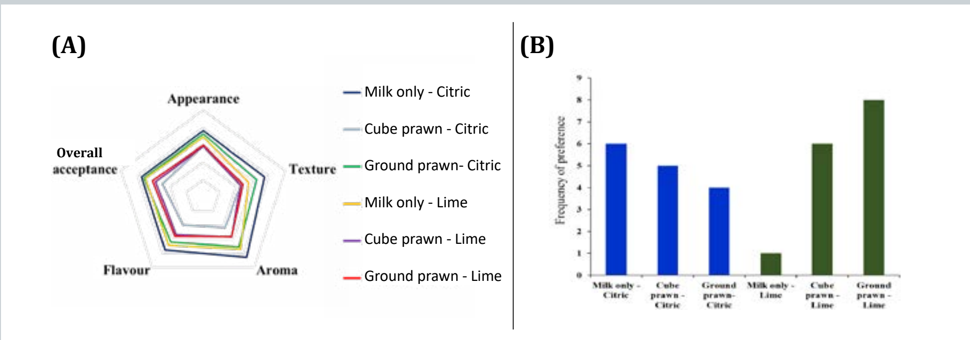

Figure 6.1.11: (A) Sensory evaluation results of 5 attributes of 6 different cheese types; (B) Frequency of preference for 6 cheese types by sensory panellists

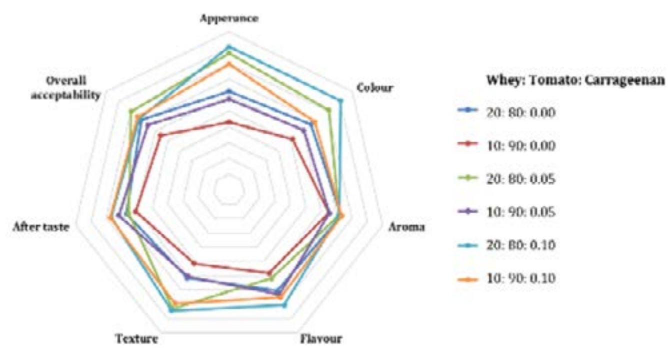

Figure 6.1.12: Sensory evaluation results of 7 attributes of 6 different soup types

Conclusion

This research demonstrates the potential for developing value-added products from the by-products of GFP fisheries, benefiting both the environment and rural communities. The successful extraction of chitosan from GFP shells and the development of biodegradable alternatives to microplastics and polyethylene packaging contribute to sustainability efforts. Furthermore, the innovative use of discarded soft-shelled GFP for food products offers an opportunity for economic and nutritional improvement in rural communities.

Contributors:

Contributor	Contribution
MNS Weerasekara	Preparation of chitosan beads as an alternative to microplastic beads to use in face wash.
KGY Ravihari	Preparation of edible and biodegradable food packaging film for 'heat-and-eat' foods as an alternative to polyethylene.
JAIPU Jayakody	Carrying out testing of active packaging film for fish fillets.
PLH Amandya	Preparation of intelligent and smart food spoilage sensor film.
AADAI Amarasinghe	Preparation of soft-shelled GFP-incorporated fresh cheese.
S Neeraja	Preparation of soft-shelled GFP-incorporated fresh cheese.
PGUS Ranasinghe	Preparation of whey-incorporated 'heat-and-serve' soup.

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