2.9 Post-harvest quality loss in giant freshwater prawns: effects of storage conditions and duration

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Abstract

The GFP (*M. rosenbergii*) is a commercially valuable species in Sri Lanka; however, post-harvest quality deterioration presents a significant challenge. This study aimed to assess post-harvest losses, identify critical control points and evaluate storage methods to enhance the quality of GFP products. A structured questionnaire survey was conducted among 286 stakeholders in the GFP market chain, supplemented by focus group discussions and verification of export data. Freshly harvested GFP samples were subjected to various storage conditions: chilled (ice storage), frozen at -20 °C, and blast-frozen at -35 °C for 21 days, with periodic assessments of colour, texture and sensory attributes. Instrumental analyses included CIELAB colour measurements, total colour change (ΔE), texture profiling, and sensory evaluation by trained panelists. Results indicated substantial post-harvest losses, with an average of 31.9% lost before reaching the exporter, primarily due to physical damage. Additionally, predation and soft-shell occurrences at the fisher level contributed to both harvest and quality losses. Colour, texture and sensory assessments demonstrated that ice storage effectively preserved GFP quality for up to 9 days, outperforming frozen GFP, which exhibited significant deterioration before this period. In contrast, both freezing and blast-freezing initially induced rapid colour changes that later stabilised, with no significant differences between these 2 methods. Texture parameters varied among storage conditions, with both freezing and blast-freezing effectively maintaining sensory attributes over prolonged storage. However, while blast-freezing preserved product quality for an extended period, it did not retain the original organoleptic characteristics as effectively as ice storage during the initial 9 days. Based on these findings, ice storage is recommended for short-term market distribution, whereas blast-freezing remains the preferred method for long-term storage, particularly for the export market.

***Keywords**: storing duration, ice, freeze, blast-freeze, texture parameters, instrumental measurements, export market*

Introduction

Fisheries and aquaculture sectors are increasingly recognised for their vital role in global food and nutrition security in the 21st century (FAO 2022). In 2020, global fisheries and aquaculture production reached 214 mt, with 122.6 mt valued at USD281.5 billion, derived primarily from aquaculture. Global inland aquaculture production accounts for 44.4% of total aquaculture production, totalling 54.4 mt. The major aquaculture commodities that account for nearly 99% of inland aquaculture production include Indian and Chinese carp, tilapia, catfish, shrimp, crawfish, crabs and prawns (FAO 2022). The GFP, *M. rosenbergii*, plays a significant role in the growth of global freshwater prawn production, contributing up to 2.6% of total aquaculture crustacean production in 2020 (FAO 2022). In Sri Lanka, GFP production, an indigenous species, is primarily obtained through CBF in reservoirs of the dry zone. The introduction of GFP to inland reservoirs has increased rural income, enhancing the overall economic and social wellbeing of rural fisher communities engaged in CBF in Sri Lanka (Jones et al. 2021; Amarasinghe et al. 2022; Digamadulla et al. 2023). Among the commodities utilised in CBF in Sri Lanka, GFP offers immense export potential and significant market value, making it essential to boost production while maintaining quality and safety standards to meet consumer expectations and achieve global competitiveness.

The quality of GFP is assessed through various parameters, including colour, texture and sensory characteristics, which are essential attributes that significantly influence consumer preferences and product valuation (Ottestad et al. 2011; Chéret et al. 2007). The quality of GFP products directly affects consumer preferences and acceptability, with freshness, texture and appearance being key factors that consumers consider when purchasing aquatic foods (Verbeke and Vackier 2005). Therefore, preserving original qualities throughout the supply chain ensures consumer satisfaction and marketability. As a highly valued product in international markets, the demand for GFP hinges on its ability to meet consumer expectations for quality. This research evaluates the post-harvest quality of GFP in Sri Lanka, focusing on changes in physical parameters (colour and texture) and sensory evaluation. It aims to propose solutions for improving quality by optimising storage conditions and duration. Understanding the factors that influence post-harvest losses and implementing best practices can enhance marketability and economic returns. The findings will contribute to the sustainable development of Sri Lanka's CBF, ensuring food security and economic benefits for stakeholders in the supply chain.

Materials and methods

Post-harvest quality loss through market chain

A questionnaire was developed to identify stakeholders in the GFP market chain and gather insights into harvesting and post-harvest practices. Interviews were conducted with fishers, collectors, factory agents, exporters and aquaculture extension officers using a snowball sampling technique (Biernacki and Waldorf 1981; Deepananda et al. 2015; Naderifar et al. 2017). A total of 286 questionnaires were administered across 7 stakeholder groups. The collected data focused on GFP collection, grading, icing, packing, storage, pricing and transportation. Additional information was gathered through focus group discussions and key informant interviews. Export data was obtained from Sri Lanka Customs, and the accuracy of the data was verified through further assessments when discrepancies arose.

Fresh GFP was collected from the Ridiyagama reservoir in Sri Lanka (440±38 g), immersed in a chilling water bath at 5 °C for 30 minutes, and then transported in Styrofoam containers with flake ice to the laboratory within one hour. After washing with cold distilled water, the samples were processed by dividing them into 3 groups:

1. chilled in Styrofoam boxes with a 1:1 GFP-to-ice ratio
2. directly frozen at -20 °C
3. blast-frozen at -35 °C for 4 hours before being stored at -20 °C.

Storage was maintained for 21 days, and analyses were conducted at regular intervals. Frozen samples were thawed at 4±0.5 °C prior to assessment.

Instrumental analysis

Colour measurements were conducted at the midline of the carapace, across all 6 abdominal segments, the telson, and the flesh of the second abdominal segment of GFP stored under different conditions on days 0, 3, 6, 9, 12, 15, 18 and 21. A chromometer (Model CR-400, HunterLab, Miniscan XE Plus, Osaka, Japan) was used to assess colour based on the CIE colour space, measuring L* (lightness), a* (red/green chromaticity) and b* (yellow/blue chromaticity).

Total colour change (ΔE) was calculated as:

$$\Delta E = \sqrt{(\Delta L^*)^2+(\Delta a^*)^2+(\Delta b^*)^2} \text{ (Wright 1971)}$$

Texture measurements followed the method established by Sigurgisladottir et al. (1999). Fresh GFP from 3 experimental groups was analysed before storage (day 0) and reassessed on days 3, 6, 9, 12, 15, 18 and 21 under various storage conditions. The second abdominal segment was chosen for texture profile analysis, which involved 2 compression cycles using a TA.XT Plus texture analyser (Brookfield, UK) with a TA3/100 probe. Hardness, springiness, chewiness and cohesiveness were evaluated in 10 replicates and analysed using Texture Expert software (version 1.22, Stable Micro Systems, UK).

Sensory evaluation

A trained panel of 10 individuals (5 males and 5 females, aged 23–26) was employed to conduct sensory assessments of GFP quality. Panelists were selected based on health criteria, ensuring that they had no sensory impairments. Evaluations were performed separately for raw and cooked GFP samples stored under different conditions. Initially, raw samples were assessed for colour, appearance, texture and odour and then cooked at 175 °C for 15 minutes with 1% salt, after which they were evaluated for odour, flavour and texture. Panelists rinsed their mouths with water and refreshed their sense of smell with coffee between samples.

The Modified Quality Index Method (QIM), based on the approaches of Khodanazary (2019) and Begum et al. (2011), was employed to evaluate quality by assigning demerit scores ranging from 0 (indicating the best quality) to 3 for raw samples or 5 for cooked samples, depending on the observed changes. Sensory tests were carried out in individual evaluation booths.

Results

Post-harvest quality loss

The export-oriented GFP market chain consists of 4 major actors, spanning from the producer (fisher) to the consumer: local collector, central collector, factory agent and exporter. One significant source of loss occurs at the fisher level, where an average of 22.9% of the total harvest was lost due to predation while GFP remained entangled in gillnets. Key predators include eels, tortoises and spiny eels (*Mastacembelus armatus*). Then, from the rest of the harvest, an average of 7.1% consists of soft-shelled GFP, which are categorised as low-quality at the fisher level. Physical damage, particularly head detachment (head loose) and appendage breakage, was a major contributor to the loss of GFP quality, resulting in post-harvest losses across the market chain. These physical quality attributes are critical factors in determining the suitability of GFP for export. Along the market chain, notable post-harvest losses occur at various stages, with an average total loss of 31.9% by the time the harvest reaches the exporter. These post-harvest losses are distributed among different actors in the market chain. Fishers account for 8.7% of the total loss, while local collectors are responsible for the highest proportion at 12.7%, and central collectors contribute the lowest at 2.9%. As a result of these cumulative post-harvest losses, only 61.1% of the total GFP harvested from reservoirs is classified as good quality and deemed suitable for export. The distribution of GFP harvest and associated post-harvest losses across different phases (a) and the proportional contribution of each market actor to the total post-harvest loss (b) is presented in Figure 2.9.1.

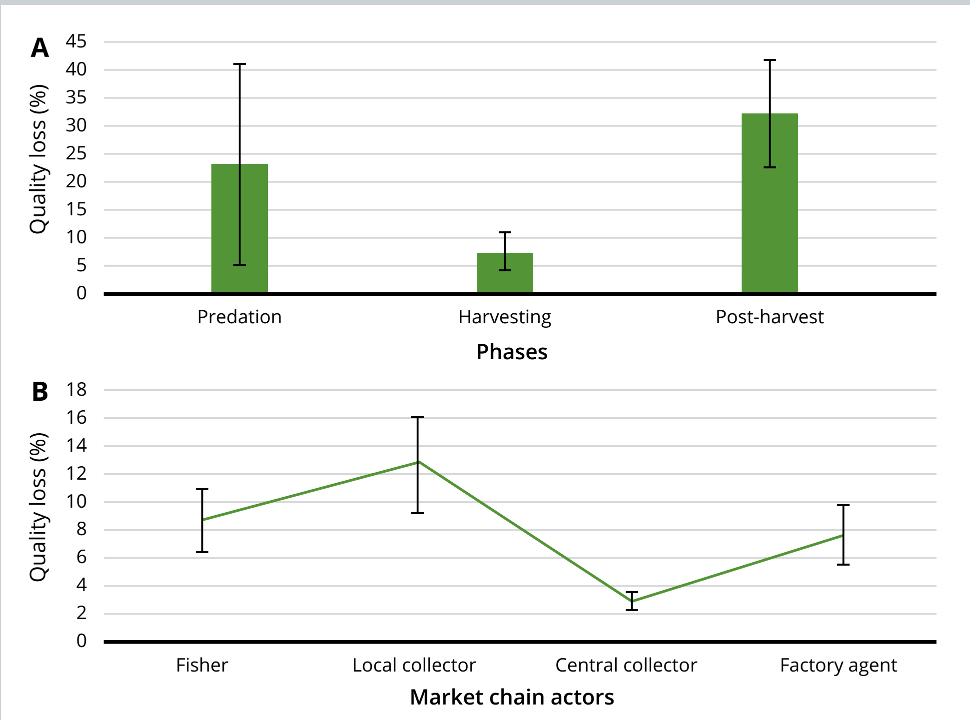

Figure 2.9.1: Harvest and post-harvest losses across different phases (a) and the percentage of post-harvest loss at each market chain actor (b)

Instrumental analysis (colour, texture)

The external shell and flesh color of GFP act as primary indicators of its quality, which is closely linked to freshness. The CIELAB colour parameters (L*, a* and b* values) measured across different body segments (carapace, abdominal segments 1–6 and tail) exhibited significant variations ($p<0.05$). The carapace demonstrated the highest positive a* (reddish) and b* (yellowish) values. In contrast, the abdominal segments displayed considerably lower a* and b* values compared to the carapace, revealing near-zero or negative a* values, indicating a shift from reddish to greenish tones. Lower b* values also suggested a trend toward bluish tones. The L* values, representing lightness, progressively decreased along the abdominal segments and tail, indicating a reduction in brightness, with the lowest CIELAB values documented at the tail (L*: 22.96; a*: -0.17; b*: 4.3). In terms of colour visualisation, a distinct contrast was observed between the carapace and the rest of the body, while minimal colour variation was noted among the abdominal segments and tail. Lab* colour changes across different body segments of GFP (i) and the corresponding visual colour representation based on Lab* values (ii) are shown in Figure 2.9.2.

The colour difference (ΔE) between the outer shell and flesh of GFP stored in ice was relatively lower compared to that of frozen GFP during the initial storage period. However, ΔE in ice-stored GFP increased rapidly, with noticeable changes in the outer shell and flesh after days 12 and 6, respectively. In contrast, the total colour change ΔE in the outer shell and flesh of freeze-stored and blast-freeze GFP did not show a significant difference ($p>0.05$). Nevertheless, a significant difference was observed between frozen and ice-stored GFP in terms of outer shell and flesh colour changes. The outer shell and flesh of frozen GFP exhibited a rapid increase in ΔE within the first 3 days of storage, followed by a decline and stabilisation after day 9. The total colour change (ΔE) in the outer shell

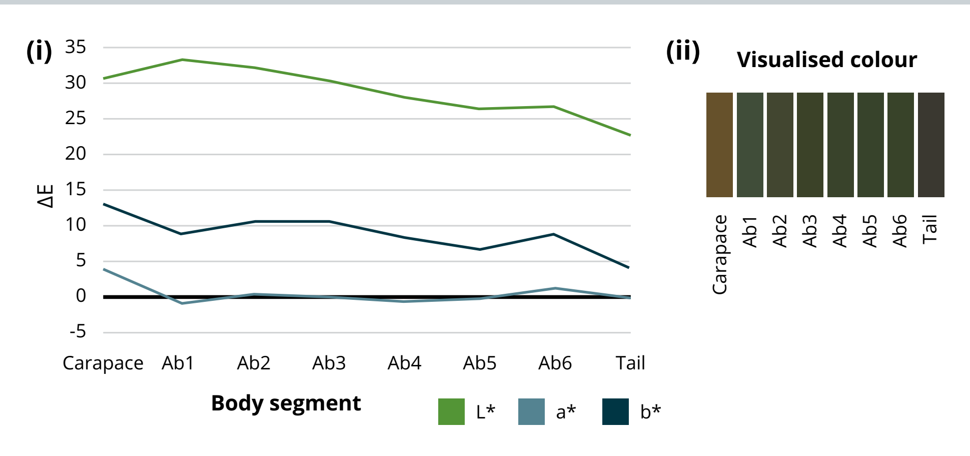

Figure 2.9.2: Lab* colour changes across different body segments of GFP (i) and corresponding visualised colour representation based on Lab* values (ii)

of the GFP body segments (carapace and abdomen) and the flesh of the second abdominal segment over the storage period under ice and frozen conditions is shown in Figure 2.9.3.

Texture

Throughout the storage period, the hardness, springiness, cohesiveness and chewiness of fresh GFP underwent significant changes, differing based on the storage conditions. During iced storage, the texture parameters remained relatively stable for the first 6 days, followed by a sharp decline over the next 15 days. In frozen storage, however, a rapid decrease was observed within the initial 6 days, after which the rate of decline stabilised for the remainder of the storage period. In both freezing methods, these texture parameters declined sharply during the early storage days, followed by a slower rate of change. In contrast, GFP stored under chilled conditions exhibited a continuous decline throughout the storage period. Notably, frozen samples experienced the most significant texture alterations during the early storage phase, whereas ice-stored GFP exhibited pronounced changes in the later stages. Among the storage methods, blast-frozen GFP showed the least variation in texture parameters, while ice-stored GFP exhibited the most substantial deterioration by the end of storage. The changes in instrumental texture parameters of GFP muscles over the storage time and conditions are presented in Table 2.9.1.

Sensory evaluation of GFP stored under ice, freezing and blast-freezing conditions revealed significant differences ($p<0.05$) in odour, texture, colour and flavour across the various storage methods and durations. Ice-stored raw GFP experienced progressive deterioration, with the fresh

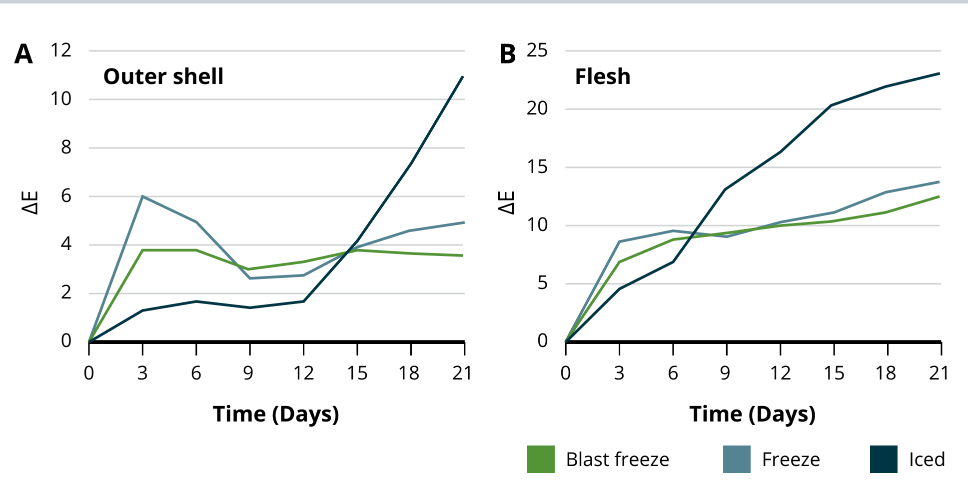

Figure 2.9.3: Total colour change (ΔE) in the outer shell and the flesh of the second abdominal segment of GFP over the storage period under ice and frozen conditions

Table 2.9.1: The changes in instrumental texture parameters of GFP muscles over the storing time and condition

Textural parameters	Storing condition	Storage duration (days)							
		0	3	6	9	12	15	18	21
Hardness (g)	Ice	99.02±3.68	93.12±4.23	86.14±3.22	77.48±3.81	66.55±2.03	53.19±1.98	38.87±3.67	21.71±3.2
	Freeze	99.02±3.68	88.30±3.77	85.32±1.58	78.65±1.65	73.42±2.40	69.34±2.33	66.36±4.38	61.81±.4.3
	Blast-freeze	99.02±3.68	93.04±4.56	89.64±2.98	86.51±2.67	80.94±4.11	79.11±2.76	78.27±5.90	76.33±3.9
Springiness (mm)	Ice	0.98±0.01	0.94±0.03	0.87±0.07	0.78±0.01	0.64±0.03	0.50±0.07	0.39±0.06	0.24±0.03
	Freeze	0.98±0.01	0.82±0.02	0.74±0.03	0.69±0.05	0.64±0.06	0.63±0.04	0.61±0.05	0.57±0.06
	Blast-freeze	0.98±0.01	0.92±0.04	0.89±0.02	0.86±0.07	0.84±0.03	0.83±0.01	0.81±0.04	0.80±0.09
Cohesiveness	Ice	0.70±0.01	0.66±0.04	0.62±0.01	0.55±0.03	0.48±0.01	0.40±0.03	0.32±0.01	0.25±0.03
	Freeze	0.70±0.01	0.67±0.06	0.62±0.02	0.59±0.02	0.54±0.02	0.51±0.02	0.49±0.02	0.47±0.02
	Blast-freeze	0.70±0.01	0.68±0.02	0.64±0.02	0.62±0.03	0.62±0.01	0.59±0.03	0.58±0.04	0.57±0.03
Chewiness (g)	Ice	67.91±2.70	57.08±3.10	46.39±1.54	33.03±2.65	20.27±1.99	10.6±2.61	4.74±1.44	1.26±2.13
	Freeze	67.91±2.70	48.35±2.44	44.99±2.08	39.75±2.56	38.23±3.01	32.17±1.40	30.73±2.10	29.34±2.56
	Blast-freeze	67.91±2.70	58.18±1.54	57.69±1.97	52.79±2.12	49.14±2.43	49.34±1.80	48.82±2.91	46.46±3.20

odour transitioning to neutral by day 3, weak ammonia by day 12, and putrid by day 18. In contrast, freeze- and blast-freeze GFP maintained a neutral odour throughout the storage period. Texture changes were also pronounced in ice-stored samples, which softened progressively from slightly firm and elastic by day 3 to soft and watery by day 15. Frozen samples stabilised after initial softening, while blast-frozen samples retained their firm, chewy texture. Additionally, the colour of ice-stored GFP dulled over time, with the flesh turning yellowish, whereas frozen and blast-frozen samples maintained a stable lime hue. The head-abdomen attachment weakened significantly in ice-stored GFP after 12 days, while frozen samples showed moderate detachment, and blast-frozen samples maintained a firm attachment. The sensory attributes of cooked GFP underwent noticeable changes during the storage period, depending on the preservation method used. In ice-stored samples, the initial 'milky sweet' flavour progressively deteriorated into a sour, bitter taste by day 21. In contrast, frozen samples retained a slightly sweet, greasy flavour, whereas blast-frozen GFP preserved its original 'milky sweet', creamy and meaty taste throughout the storage period. The odour of cooked GFP also evolved; fresh samples initially exhibited a milky, boiled milk or mushroom-like odour by day 3, which gradually changed to a boiled vegetable odour by day 12, a musty odour by day 15, and an ammoniacal odour by day 18. Both frozen and blast-frozen samples maintained a milky, boiled milk or mushroom-like odour throughout the entire storage period. Texture analysis revealed further quality changes as well; the initially firm and chewy texture of cooked GFP softened over time, becoming very soft and pulpy by day 15 in ice-stored samples. Frozen samples developed a lumpy texture from day 6 onward, while blast-frozen samples consistently maintained their firm and chewy texture throughout the storage period. The sensory evaluation of raw and cooked GFP stored under ice, freeze and blast-freeze conditions over a 21-day storage period is summarised in Table 2.9.2.

Discussion

The key actors in the export-oriented GFP market chain play a crucial role in determining product quality and minimising post-harvest losses. These essential players in this market chain hold pivotal positions, with the number of intermediaries varying based on harvesting quantities, reservoir-to-trader distances and transportation availability. Understanding these distinct market channels provides valuable insights into the GFP flow from fishers to consumers, helping to reduce post-harvest losses, enhance competitiveness and optimise marketing systems.

Predation during the harvesting phase significantly contributes to losses because the high abundance of predatory species in Sri Lankan reservoirs poses a considerable threat to GFP harvests. This issue is exacerbated by the practice of setting fishing nets overnight, which increases both post-harvest quality loss and predatory pressure. Implementing innovative strategies to mitigate predation is essential for reducing harvesting losses. Additionally, GFP undergoes periodic molting, shedding its exoskeleton and leaving soft-shelled prawns vulnerable to damage. Soft-shelled GFP is often rejected in export markets, leading to economic losses throughout the supply chain.

Harvest losses occur in fisheries worldwide, affecting every stage from production to consumption. Post-harvest losses can be classified into several key types, including

Table 2.9.2: Sensory evaluation of raw and cooked GFP stored under ice, freeze and blast-freeze storage conditions over the 21 days

GFP product	Sensory modality		Storage method																							
			Ice								Freeze								Blast-freeze							
			Storing duration (days)								Storing duration (days)								Storing duration (days)							
			0	3	6	9	12	15	18	21	0	3	6	9	12	15	18	21	0	3	6	9	12	15	18	21
Raw GFP	Colour	Carapace	0	1	1	3	3	3	3	3	0	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2
		Abdomen	0	1	1	2	3	3	3	3	0	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2
		Tail	0	1	1	2	2	3	3	3	0	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2
		Flesh	0	1	1	2	2	2	3	3	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
	Appearance		0	1	1	1	2	2	3	3	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
	Texture		0	1	1	2	3	4	4	4	0	1	1	1	2	2	2	2	0	1	1	1	1	1	1	1
	Odour		0	1	1	1	2	2	3	3	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
Total Score			0	7	7	13	17	19	22	22	0	9	10	10	11	11	11	11	0	9	9	9	9	9	9	9
Cooked GFP	Odour		0	1	1	1	2	3	4	4	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1
	Flavour		0	1	1	2	3	4	4	5	0	1	2	2	2	2	2	2	0	1	1	1	1	1	1	1
	Texture		0	0	1	2	2	3	3	3	0	0	1	1	1	1	1	1	0	0	0	0	0	0	0	0
Total Score			0	2	3	5	7	10	11	12	0	2	4	4	4	4	4	4	0	2	2	2	2	2	2	2

Note: Raw GFP: Colour (outer): 0- Fresh, bright, shining greenish blue, 1- Slightly loss of brightness, 2- Loss of brightness, 3- Dull in colour, Colour(flesh): 0- Translucent and shiny, 1- Lime colour, 2- Slightly yellowish, Light yellow, Appearance: 0- Shape intact & head firmly attached to the abdomen, 1- Shape intact & head slightly loose from the abdomen, 2- Flesh loosely attached to the shell & head loosely attached to the abdomen, 3- Flesh loosely attached to the shell & head very loosely attached to the abdomen, Texture: 0- Hard & elastic, 1- Slightly hard & elastic texture, 2- Slightly soft & slightly elastic texture, 3- Moderately soft & loss of elastic texture, 4- Soft and watery texture, Odour: 0- Fresh, 1- Neutral, 2- Weak ammonia, 3- Putrid.

Cooked GFP: Odour: 0- Fresh, 1- Milky/Boiled milk /mushroom shed, 2- Boiled vegetables, 3- Musty, 4- Ammonical, Flavour: 0- Milky sweet, 1- Milky sweet, creamy meaty, 2- Slightly sweet, sweet greasy/fatty aftertaste, 3- Slightly sour & very slight sweetness, 4- Sour/bland/ fishy, 5- Soapy, bitter, Texture: 0- Firm, chewy, 1- Lumpy, breaking into firm segments easily, 2- Lumpy, but the segments are softer than the above, 3- Very soft/ pulpy.

physical loss, quality deterioration, nutritional decline and losses driven by market forces (Cheke and Ward 1998). These losses occur throughout the GFP market chain, with physical damage to appendages often resulting from improper handling, storage and transportation practices. The issue of 'head looseness' significantly affects export quality, while mishandling prawns during gillnet retrieval further contributes to quality degradation. In the studied reservoirs, most fishers deliver live GFP to landing sites and allow them to die while waiting for collectors, which further deteriorates quality. The 'chill-killing' method, which involves submerging live prawns in an ice-water slurry, is recommended to enhance product quality (D'Abramo et al. 2009). However, its adoption remains limited due to fishers' reluctance to exert additional effort beyond harvesting.

Contrary to the global trend, which indicates that the highest losses occur at the producer level (Acharjee et al. 2021), local collectors are identified as hotspots of post-harvest losses, primarily due to prolonged storage without sufficient ice, improper packing and suboptimal transportation techniques. These collectors, often fishers or nearby villagers, lack access to adequate ice supplies and depend on buyers for ice delivery, which is often insufficient. In some instances, GFP is stored in freezers instead of ice, further accelerating quality deterioration. In contrast, central collectors experience the least quality loss due to improved handling practices, while factory agents encounter unexpected quality losses, despite better packing and grading, which may be attributed to mechanical damage during transportation and unloading. This issue may stem from factory agents receiving fixed salaries with additional commissions, which can lead to a lack of motivation to maintain product quality. Enhancing transportation infrastructure and road systems can significantly reduce post-harvest losses, as extended transport times from rural reservoirs to central collectors negatively impact quality. Raising awareness among market-chain actors about proper handling and quality maintenance directly decreases post-harvest loss, highlighting the need to close the knowledge gap across all stages of the market chain.

The colour of fish is primarily influenced by the protein-water binding properties and pigments present in the skin or surface of the flesh (Xie et al. 2023). In prawns, colour changes have been linked to lipid oxidation, which leads to the degradation of the carotenoid pigment astaxanthin (Cruz-Romero et al. 2007). Lab* values serve as indicators of colour, protein-water binding capacity, pigments in the outer shell or meat surface, lipid oxidation rates, and variations in astaxanthin content across different GFP body segments. These factors may contribute individually or collectively to the notable differences in Lab* values observed among GFP segments. Additionally, the shifts in a* values in GFP segments could be linked to reactions between phenol oxidase and deoxy phenylalanine, which trigger melanin production (Savagaon and Sreenivasan 1978).

The colour of food plays a crucial role in shaping consumers' perceptions of quality, significantly influencing their purchasing decisions (Sun et al. 2019). In prawns, colour changes are key indicators of quality deterioration, driven by enzymatic and bacterial activities during storage that lead to discolouration as well as various biological and physicochemical alterations (Yu et al. 2018). Research by Tsironi et al.

(2009) and Jin et al. (2018) has shown that colour degradation occurs more rapidly at higher freezing temperatures. Similarly, the present study found that fresh colour degradation in GFP was more noticeable and pronounced during frozen storage compared to ice storage, particularly in the initial storage period. The initial low bacterial count may be attributed to the inability of mesophilic bacteria present in fresh prawns to survive prolonged exposure to low temperatures, as noted by Rodrigues et al. (2000). However, after a lag phase in the GFP body and flesh, psychrophilic bacteria that were initially present are likely to multiply, contributing to the rapid changes in ΔE values observed during the later stages of ice storage. In contrast, frozen storage resulted in more rapid colour changes early on, potentially due to physical and biochemical alterations caused by sudden exposure to freezing temperatures and temporary freeze burns. Over time, these colour changes appeared to stabilise, possibly due to the disruption of various molecular bonds in native protein structures during freezing and frozen storage, as protein denaturation tends to occur more prominently at the onset of the freezing process. This structural alteration may weaken the connection between the outer shell and the prawn's meat, leading to visible colour differences compared to fresh GFP. Lower storage temperatures may slow the deterioration of quality, maintaining more stable colour changes over the 21-day storage period. The hepatopancreas, a central metabolic organ and primary lipid storage site (Liu et al. 2021), likely contributes to the faster quality degradation observed in the carapace region due to its higher nutrient content compared to the abdomen and tail. Furthermore, variations in nutrient availability and pigment concentrations across different body segments may influence the rate of colour changes. Although the factors affecting colour change might initially impact all body segments, differing rates of degradation over time could be attributed to a combination of external environmental conditions and internal physiological factors.

Texture is a key quality parameter for assessing the flesh of prawns and fish in aquaculture industries (Bjørnevik et al. 2002). In the present study, the texture parameters of GFP remained relatively stable during the first 6 days of ice storage, after which a noticeable decline was observed. This pattern aligns with findings by Jain et al. (2007), who reported significant texture loss in fish muscles beginning around day 6 of ice storage. Similar trends have also been noted by Love (1983) and Rhee et al. (1984), further supporting these observations. Under freezing conditions, the formation of ice crystals and protein denaturation play crucial roles in altering texture, driven by endogenous enzymes and microbial activity (Ocaño-Higuera et al. 2011; Badii and Howell 2002). In the early stages of frozen storage, a rapid decline in texture parameters may be attributed to tissue damage caused by ice crystal formation during freezing and blast-freezing. In contrast, GFP stored in ice exhibited a more gradual decline in texture throughout the storage period, consistent with the findings of Jain et al. (2007), who reported a similar decrease in stiffness for raw Nile tilapia fillets stored at ice temperature. Interestingly, blast-frozen GFP experienced minimal texture changes, while ice-stored samples showed the most pronounced deterioration by the end of the storage period. This aligns with Ninan (2021), who identified texture changes as a reliable indicator of spoilage, closely linked to storage temperature due to the temperature-dependent nature of enzymatic and microbial activities. Additionally, the composition of fat and collagen influences fish texture, as microbiological processes and autolysis after death lead to the degradation of myofibrillar proteins, resulting in muscle softening (Li et al. 2012, 2013). The combined effects of temperature fluctuations, enzymatic activity and microbial processes throughout the 21-day storage period contributed to the texture changes observed in this study.

Sensory evaluations conducted on both raw and cooked GFP covered multiple modalities, including appearance, texture, odour and flavour, following the methods used by Khodanazary (2019) and Azam et al. (2013). GFP stored on ice maintained 'very good' quality for up to 6 days, consistent with Begum et al. (2011), but contrasting with Haider et al. (2011), who observed this quality only for 3 days. GFP remained commercially acceptable for up to 9 days, likely due to effective post-harvest handling, which included chill-killing and suitable ice-to-GFP ratios. These findings diverge from reports of quality deterioration by day 9 (Khodanazary 2019; Rahman et al. 2001), with the variability attributed to differences in species, chemical composition and storage practices (Saidi et al. 2023; Cantillo et al. 2020). Additionally, GFP stored under freezing and blast-freezing conditions preserved its organoleptic quality for up to 21 days, aligning with the results of Azam et al. (2013), who reported similar findings for GFP stored at -20 °C for up to 56 days. The methodology of employing sensory modalities and a structured scoring system provides an accurate and species-specific framework for evaluating the quality of export-oriented GFP, which is essential for maintaining high export standards. These findings underscore the significance of improving post-harvest handling practices to minimise quality loss. Strategies such as training fishers in proper handling techniques, using appropriate ice-to-product ratios and adopting chill-killing practices can significantly reduce post-harvest losses and extend the shelf life of GFP, benefiting the export market and ensuring higher quality standards.

Conclusion

The current study revealed that harvesting losses of soft-shelled GFP are unavoidable for fishers, with additional physical and quality losses occurring throughout the market chain, peaking at the final intermediate stage. Predation during harvesting further reduces yields, particularly in reservoirs with an abundance of predators. Local collectors experience the highest post-harvest quality losses due to poor handling and storage practices. Contributing factors include inadequate infrastructure, limited technical resources, suboptimal packaging, disorganised transport and insufficient cooling facilities. These losses diminish income at every stage and impact the food and income security of rural fishing communities. The study found that ice storage effectively preserved the colour, texture and organoleptic qualities of GFP for up to 9 days, after which significant deterioration occurred. In contrast, both freezing and blast-freezing initially caused rapid colour changes that later stabilised, with no notable differences between the 2 methods. Texture properties varied among storage conditions, with ice-stored GFP showing noticeable changes in the later stages compared to frozen samples. While ice storage maintained superior organoleptic qualities and consumer preference in the short term, it proved inadequate for long-term preservation after 9 days. Conversely, freezing and blast-freezing effectively sustained organoleptic properties over extended periods, with blast-freezing emerging as the most suitable method for preserving sensory quality and maintaining consumer preference. Based on these findings, ice storage is recommended for short-term market chains, whereas blast-freezing is the preferred method for long-term storage, particularly for the export market.

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