Red head syndrome in shrimp aquaculture: Prevention and control

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Abstract

Red head syndrome (RHS) is an emerging concern in shrimp aquaculture, particularly affecting whiteleg shrimp (*Litopenaeus vannam*ei). Characterized by orange to red discoloration of the cephalothorax, RHS reduces marketability and leads to economic losses, especially for head-on shrimp. Although RHS doesn't affect shrimp safety or taste, it negatively impacts perceived quality and increases export rejection rates. Environmental stressors, poor farming and harvesting practices, and inadequate cold chain management are the primary factors inducing RHS. Oxidative stress, increase by elevated water temperatures, low dissolved oxygen levels, and suboptimal nutrition, drives pigment production and causes hepatopancreatic damage. This review examines the physiological, genetic, and pathological factors contributing to RHS and proposes preventative strategies. Maintaining optimal pond conditions, implementing antioxidant supplementation, improving harvesting techniques, and genetic selection are essential for mitigating RHS and enhancing shrimp quality. An integrated approach can reduce the incidence of RHS, thereby improving profitability and ensuring the sustainability of shrimp aquaculture.

Keywords: Shrimp aquaculture; Environmental stressors; Shrimp quality; Harvesting techniques

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Introduction

Redhead syndrome significantly impacts the marketability and economic value of both farmed and wild-caught shrimp. Affecting 20–30% of export-quality farmed shrimp annually, this condition, which was once common in Latin American head-on shrimp, is now more prevalent in Southeast Asian *L. vannamei* farms. Although these changes do not affect the safety, odor, or taste of shrimp, they can negatively impact perceived quality and health, ultimately decreasing market appeal and prices, particularly for head-on shrimp. This issue arises from inadequate processing and transportation, especially due to mismanagement during harvest and transport, which leads to environmental stress. Studies indicate that proper transportation methods, such as insulated boxes, can reduce the occurrence of this syndrome (Mohammadidust *et al*., 2020). Furthermore, the pigmentation of shrimp heads intensifies under poor nutritional and farming conditions, such as elevated water temperatures and low levels of dissolved oxygen (Mobaraki *et al*., 2022). The economic impact of this syndrome extends beyond mere aesthetics. It significantly lowers marketability and consumer acceptance, particularly in head-on shrimp markets where appearance is critical. This decline in quality leads to reduced prices, increased processing costs, and greater risk of export rejection, thereby affecting the entire aquaculture supply chain. RHS in shrimp is often caused by inadequate handling and transportation, particularly when the shrimp experience stress during harvesting and transport. A study show that proper transport methods, such as using insulated boxes, can significantly reduce the incidence of this syndrome (Macusi, 2022). Shrimp pigmentation increases due to factors such as nutritional quality and environmental conditions during farming, such as high water temperatures and low levels of dissolved oxygen (Petesch *et al*., 2021).

This research enhances the understanding of RHS by examining genetic and pathological factors, thereby providing a framework for targeted prevention and control. This comprehensive approach is essential for improving shrimp quality and ensuring the economic sustainability of shrimp aquaculture, representing a significant contribution to both aquaculture and shrimp health management. This article examines the causes, prevention, and control of redhead syndrome, including physiological stressors, genetic influences, pre-harvest and post-harvest interventions, as well as the associated pathological and metabolic changes. Preventing and mitigating RHS in commercial shrimp aquaculture requires a comprehensive, integrated approach that implements best practices throughout all production stages, from pond management to post-harvest processing. This study comprehensively examines the interconnected factors contributing to the incidence across the entire shrimp production chain, from pond to processing. Additionally, it provides new insights into the genetic

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factors influencing RHS susceptibility, specifically focusing on inbreeding and genetic markers associated with pigment metabolism and oxidative stress.

Explanation of the occurrence of RHS in shrimp

RHS is a multifactorial condition that results in orange to red discoloration of the cephalothorax in farmed shrimp, particularly in *L. vannamei*. This condition poses a significant economic threat to the aquaculture industry (Mobaraki *et al*., 2022). Maintaining tissue integrity and consumer appeal relies on proper farming, harvesting, and processing techniques (Mohammadidust *et al*., 2020). Harvesting and transportation stress can further exacerbate the condition by increasing the production of red pigments. Inadequate pond management, including improper slope and rapid reductions in water levels, physically stresses shrimp. Interrupted harvesting concentrates biomass in small areas with high waste, intensifying stress and leading to molting, lethargy, and red head syndrome. Stress-induced respiration increases the production of free radicals, resulting in lipid peroxidation in the hepatopancreas and intensifying discoloration (Mobaraki *et al*., 2022).

Oxidative stress, resulting from imbalances between free radicals and antioxidants due to factors such as ammonia, nitrite, temperature fluctuations, oxygen deficiency, and algal toxins, significantly contributes to red head syndrome. This condition often induces apoptosis in hepatopancreatic tissue. Biomarkers of oxidative stress include altered liver enzyme levels, reduced activity of antioxidant enzymes, elevated concentrations of free radicals, disrupted fatty acid balance, and impaired cell membrane function, all of which indicate hepatopancreatic damage (Han *et al*., 2018; Ardiansyah *et al*., 2020). Although this condition does not compromise safety or taste, it adversely affects the shrimp's appearance, raising concerns about product quality and health. Consequently, this can lead to lower prices in head-on shrimp markets.

RHS in shrimp is characterized by metabolic and inflammatory changes that indicate cellular stress, pigment dysregulation, and oxidative damage. This condition includes the accumulation of lipofuscin and depleted energy reserves in the hepatopancreas due to oxidative stress (Mohammadidust *et al*., 2020). Disruption of carotenoid synthesis results in abnormal tissue discoloration. Evidence of oxidative stress is further demonstrated by reduced antioxidant enzyme activity, which leads to elevated levels of free radicals and damage to the hepatopancreas (Mobaraki *et al*., 2022). Ionic imbalances and pH dysregulation, marked by increased cell membrane permeability and altered calcium and potassium homeostasis, also contribute to discoloration (Mohammadidust *et al*., 2020). Inflammatory responses involve hemocyte infiltration and macrophage accumulation in the hepatopancreas, along with structural changes in capillaries and blood pooling (Mobaraki *et al*., 2022). Elevated levels of

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inflammatory cytokines may harm healthy cells, while reduced lymphocyte counts compromise the organism's ability to resist pathogens (Mohammadidust *et al*., 2020). Ultimately, these changes result in the structural degradation of hepatopancreatic tissues, including alterations in digestive gland architecture, decreased enzymatic activity, increased cellular necrosis, and the accumulation of metabolic waste products (Mobaraki *et al*., 2022).

Pond management and environmental control

To prevent RHS, it is essential to maintain optimal pond conditions through regular monitoring and regulation of water quality parameters, including temperature, dissolved oxygen, pH, and nitrogenous waste. Proactive management of organic matter and sediment, along with consistent aeration, appropriate stocking densities, and the use of probiotics, helps to minimize environmental stressors (Lucien-Brun, 2006; Mobaraki *et al*., 2022). Environmental stress leads to structural alterations in the hepatopancreas, a crucial metabolic regulator, which in turn increases the secretion of digestive enzymes and modifies cellular structure, ultimately causing head discoloration (Mohammadidust *et al*., 2020). Pathogens such as *Vibriosis*, and stressors including high pH, increased organic load, and cyanobacterial blooms further contribute to the syndrome by shifting the pond ecosystem toward a bacteria-dominated state, which induces oxidative stress. Additionally, insufficient light and low dissolved oxygen levels (below 2 ppm) disrupt shrimp metabolism, leading to oxidative stress and hepatopancreas discoloration (Chanratchakool and Phillips, 2002; Mohammadidust *et al*., 2020).

Nutritional strategies

RHS is often associated with poor nutrition. Proper nutrition is essential for enhancing shrimp resilience against RHS. Fortifying feeds with antioxidants such as vitamins C and E, selenium, and carotenoids (e.g., astaxanthin) promotes hepatopancreatic health and reduces oxidative damage (Mobaraki *et al*., 2022). Inappropriate pigments in feed can lead to color changes in shrimp, with certain artificial pigments resulting in excessive carotenoid accumulation in the hepatopancreas. It is crucial to avoid contaminated or oxidized feeds and to source ingredients carefully to limit heavy metal contamination, which is vital for maintaining metabolic stability and minimizing hepatopancreatic pigmentation disorders (Mohammadidust *et al*., 2020). Additionally, it is recommended to stop feeding 24 to 48 hours prior to harvest to facilitate gut clearance, thereby reducing post-mortem discoloration caused by the decomposition of residual feed (Kooloth *et al*., 2021).

Harvest and post-harvest handling

Harvesting practices are essential for preventing RHS. Gentle, rapid harvesting, avoiding crowding near drainage areas, and immediate chilling help minimize stress and tissue degradation. Stress from harvesting and transportation can further aggravate the condition by stimulating the production of red pigments. Physical stress due to poor pond management practices, including insufficient slope and rapid fluctuations in water levels, exacerbates the issue. Disrupted harvesting concentrates biomass, waste, and harmful metabolites, leading to molting issues, lethargy, and red head syndrome. Rapidly chilling shrimp to below 5°C post-harvest inhibits enzymatic reactions that lead to discoloration and softening (Roda International Group, 2025). Maintaining a consistent cold chain from harvest to processing is the most critical post-harvest strategy. Utilizing insulated containers, ice-water slurries, and minimizing handling can reduce temperature fluctuations and mechanical damage, thereby preserving the appearance and quality of the shrimp (Shinn *et al*., 2018).

Processing and packaging standards

To minimize oxidative and microbial spoilage, processing protocols should emphasize speed and hygiene. Techniques such as flash freezing, vacuum packaging, and modified atmosphere packaging (MAP) can effectively preserve the color and texture of shrimp. Strict temperature controls and prompt processing are essential to prevent quality degradation and increased RHS symptoms (Mobaraki *et al*., 2022; Yu *et al*., 2023).

Genetic management

Selective breeding for genetic resistance to RHS is a promising strategy. Introducing robust broodstock lines to prevent inbreeding and promote genetic diversity can reduce susceptibility to environmental and nutritional stressors that trigger RHS (Mohammadidust *et al*., 2020). Marker-assisted selection targeting traits related to oxidative stress resilience and pigment metabolism may provide long-term solutions.

Cold chain deficiencies and improper processing

RHS is exacerbated by inadequate cold chain management and processing. Discoloration of the hepatopancreas is often associated with failures in the cold chain between harvesting and processing. Maintaining a consistent cold chain and rapidly achieving the lowest possible temperature during transportation and handling are essential (Bono *et al*., 2025). Rapidly reducing the body temperature of shrimp post-harvest, ideally below 5°C, minimizes the occurrence of this condition (Selamoglu, 2021). Proper chilling, efficient harvesting, and hygienic practices throughout the entire process significantly reduce the incidence of red head syndrome. Studies confirm that improved transportation methods, such as insulated polystyrene boxes, can reduce the incidence of stress (Shinn *et al*., 2018) (Fig. 1).

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Figure 1: Western white shrimp (*L. vannamei*) with varying degrees of RHS (right) and healthy shrimp (left).

Integrated management of RHS in commercial shrimp farming

Optimal environmental conditions are essential for preventing RHS. Maintaining dissolved oxygen levels above 5 ppm and water temperatures below 32°C helps minimize oxidative stress and hepatopancreatic discoloration. Since temperature and dissolved oxygen are inversely related, increased aeration is necessary during warmer periods, as temperatures exceeding 36°C significantly elevate the risk of RHS risk (Farabi and Latuconsina, 2023). Maintaining a stable pH level (7.5-8.5) and salinity consistent with hatchery conditions minimizes stress-induced syndromes (Ariadi *et al*., 2023).

Nutritional strategies

Effective nutritional management is essential for RHS prevention. Antioxidant supplementation, particularly with vitamin E at a dosage of 85-89 mg/kg of diet, significantly reduces the incidence of RHS and enhances shrimp immunity. When combined with vitamin E, vitamin C provides synergistic antioxidant protection. Furthermore, beta-glucan strengthens the immune system and improves stress resistance. Natural astaxanthin is preferred over synthetic alternatives to maintain hepatopancreatic health and prevent carotenoid accumulation. To maintain metabolic stability and minimize hepatopancreatic pigmentation disorders, it is essential to avoid contaminated or oxidized feeds and to source feeds carefully to reduce heavy metal contamination (Mohammadidust *et al*., 2020). Gut clearance via feed intake 24 to 48 hours before harvest can significantly reduce the risks of post-mortem discoloration caused by the decomposition of residual feed during storage.

Optimized harvest protocols

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Preventing RHS during harvest requires carefully timed harvesting. Pre-harvest feed withdrawal of 48 to 72 hours helps to empty the digestive tract and reduce metabolic stress; however, it also increases vulnerability to pathogens. Gradually reducing pond water levels to one-third of capacity over several days helps to avoid sudden environmental stress. Harvesting during cooler periods, such as late afternoon or early evening, minimizes thermal stress, while rapid harvesting techniques decrease exposure time. Chilled harvest systems that apply ice immediately maintain product temperatures below 5°C, thereby preventing enzymatic and oxidative processes that contribute to RHS (Shinn *et al*., 2018).

Maintaining shrimp quality during harvesting is crucial, as it begins to decline immediately. Employing faster harvesting methods, such as elevators and nets in drainage canals, helps preserve quality. The rate depends on factors such as shrimp temperature, physical damage, and sediment contamination. Therefore, rapid harvesting, hygienic conditions, and a robust cold chain are essential. Extended harvest times, rising temperatures, and environmental stress increase the risk of red head syndrome. Harvesting in the late afternoon or early evening is preferable due to cooler temperatures and reduced bird predation. To minimize damage, avoid overfilling harvest bags and keep shrimp collected from sediment separate. Additionally, clear barnacles and shells from drainage areas to prevent injury. Immediately chill harvested shrimp in an ice-water slurry before transferring them to appropriately sized containers for further handling.

Maintaining a consistent cold chain is essential for preventing post-harvest RHS. Continuous temperature monitoring at critical control points is necessary to ensure that temperature requirements are maintained below 3°C throughout the processing stages. Research indicates that temperature compliance rates below 60% at processing facilities significantly increase the incidence of RHS, highlighting the importance of strict temperature control measures (Samantha and Imroatin, 2025). Maintaining optimal temperatures and quality during the transport of shrimp from the farm to the processing center is essential for preventing red head syndrome. This can be achieved by using sanitized, refrigerated vehicles and hygienic containers, minimizing the openings of storage compartments, and promptly transferring harvested shrimp to refrigerated transport. It is important to avoid unnecessary delays, such as draining water before weighing (Lucien-Brun, 2016) (Fig. 2).

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Figure 2: Maintaining shrimp quality through cooling during farm-to-processing transport.

Design and operation of processing facilities

To minimize RHS development, processing facilities should prioritize temperature control, efficient product flow, and hygiene. Maintaining ambient temperatures below 12°C and limiting processing time to 2 minutes from reception to freezing helps prevent product degradation. The separation of raw and processed products, along with efficient drainage and waste removal, ensures hygienic conditions. Additionally, automated processing further reduces handling time and the risk of contamination (Lucien-Brun, 2016).

Conclusuion

RHS presents a significant challenge to commercial shrimp farming, adversely affecting product quality, marketability, and economic sustainability. This condition is influenced by oxidative stress and inadequate cold chain management, which are affected by environmental, nutritional, genetic, and operational factors. Effective prevention and mitigation strategies depend on integrated management practices, including pond preparation, water quality control, optimized nutrition, biosecurity measures, and careful handling during harvest and post-harvest processes. Proactive measures, such as maintaining optimal oxygen and temperature levels, supplementing diets with antioxidants, and implementing rapid chilling techniques, have been shown to significantly reduce the incidence and severity of RHS. The economic consequences of RHS extend beyond direct losses, impacting processing costs and the industry's reputation. However, investing in comprehensive prevention strategies can yield substantial returns, protecting farm profitability and market access. The future stability of the shrimp aquaculture sector depends on the adoption of integrated, science-based management frameworks, continuous improvement, technological advancements, and industry collaboration to minimize RHS risks and ensure sustainable growth.

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