

Red Pepper Powder Enhances Antioxidant and Immune Functions in the Sea Urchin *Strongylocentrotus intermedius*: Potential as a Functional Feed in AquacultureJiadong Guo¹, Yuntian Zhang¹, Yi Chen¹, Yupeng Zhang¹, Rongwei Zhang¹, Yuzhe Han^{1, 2}, Xiaoran Zhao^{1, 2}, Tongjun Ren^{1, 2,*}¹Dalian Key Laboratory of Breeding, Reproduction and Aquaculture of Crustaceans, Dalian Ocean University, Dalian116023, China²College of Fisheries and Life Sciences, Dalian Ocean University, Dalian 116023, China

Abstract

Driven by sustainable aquaculture goals, this study evaluated dietary red pepper powder (*Capsicum annuum*) supplementation (0–2%) over 50 days on *Strongylocentrotus intermedius*. Red pepper powder significantly promoted growth and reduced FCR ($P < 0.05$), with 1.0% showing optimal results. It improved gonadal color, increased protein and lipid content, and enhanced digestive, immune, and antioxidant enzyme activities while lowering MDA levels. The 1.0% group had the highest microbial diversity and a higher abundance of beneficial bacteria (e.g., *Firmicutes*), with fewer pathogens. Immune- and antioxidant-related genes were upregulated, and pro-inflammatory genes downregulated. Overall, 1.0% supplementation optimized intestinal microbiota, improved antioxidant and immune functions, reduced oxidative stress, and enhanced growth and gonadal quality in *S. intermedius*.

Experimental design



Figure 1. Schematic diagram of the recirculating aquaculture system

Water quality was stabilized through mechanical and biological filtration combined with ultraviolet disinfection, ensuring physicochemical consistency and biosecurity. Each tank was equipped with separate inlet and outlet systems to guarantee water independence and improve the reproducibility of the results.

Results

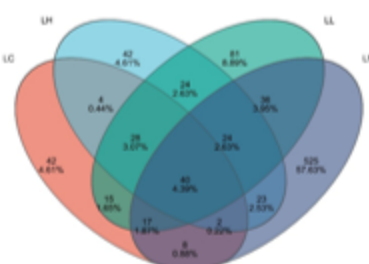
Growth performances

Table 1 Effects of different red pepper powder additive levels growth performance of *Strongylocentrotus intermedius* (*S. intermedius*).

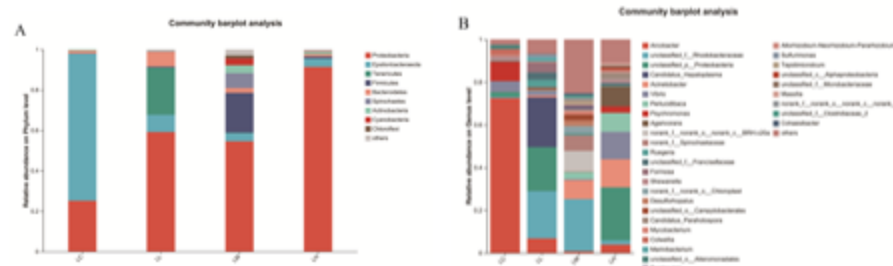
Growth Parameters	LC	LL	LM	LH
IBW (g) ¹	24.32 ± 0.14 ^a	23.97 ± 0.2 ^a	24.27 ± 0.32 ^a	23.34 ± 0.1 ^a
FBW (g) ²	34.35 ± 0.26 ^c	35.86 ± 0.27 ^b	38.12 ± 0.52 ^a	36.44 ± 0.5 ^b
WGR (%) ³	41.28 ± 1.74 ^c	49.59 ± 0.22 ^b	57.1 ± 3.4 ^a	49.69 ± 2.6 ^b
SGR (% day ⁻¹) ⁴	0.69 ± 0.02 ^c	0.81 ± 0.00 ^b	0.9 ± 0.04 ^a	0.81 ± 0.03 ^b
DTW (g) ⁵	1.44 ± 0.06 ^b	1.47 ± 0.15 ^{ab}	1.61 ± 0.08 ^a	1.45 ± 0.05 ^b
DTI (%) ⁶	4.2 ± 0.15 ^a	4.09 ± 0.06 ^a	4.22 ± 0.24 ^a	3.97 ± 0.16 ^a
GWG (g) ⁷	7.64 ± 0.19 ^c	8.53 ± 0.12 ^b	9.3 ± 0.11 ^a	8.68 ± 0.13 ^b
GSI (%) ⁸	22.24 ± 0.4 ^b	23.8 ± 0.24 ^a	24.39 ± 0.41 ^a	23.82 ± 0.34 ^a
FCR ⁹	2.05 ± 0.07 ^a	1.81 ± 0.01 ^b	1.69 ± 0.08 ^b	1.82 ± 0.08 ^b
SR (%) ¹⁰	100 ± 0.00 ^a	100 ± 0.00 ^a	100 ± 0.00 ^a	100 ± 0.00 ^a

Values (mean ± SE; n = 3) with different superscripts differ significantly ($P < 0.05$). ¹IBW, initial body weight. ²FBW, final body weight. ³WGR, weight gain rate. ⁴SGR, specific growth rate. ⁵DTW, digestive tract weight. ⁶DTI, digestive tract index. ⁷GWG, gonad wet weight. ⁸GSI, gonadosomatic index. ⁹FCR, feed conversion ratio. ¹⁰SR, survival rate.

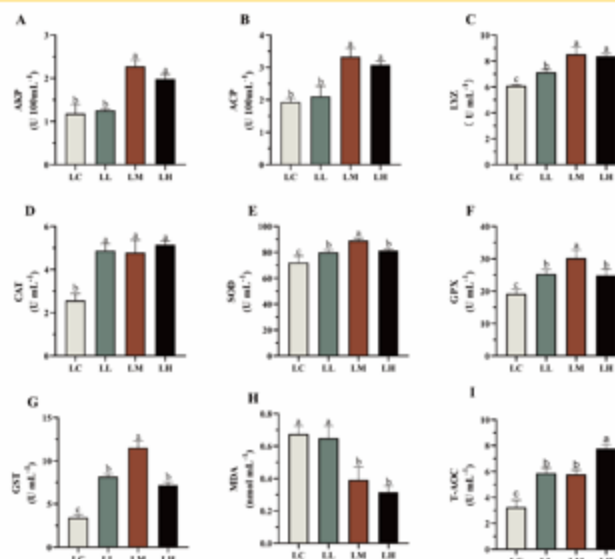
Gut microbiota

Figure 2. Venn diagram representation of operational taxonomic units (OTUs) in the intestinal microbiota of *S. intermedius* with varying red pepper powder supplementation.

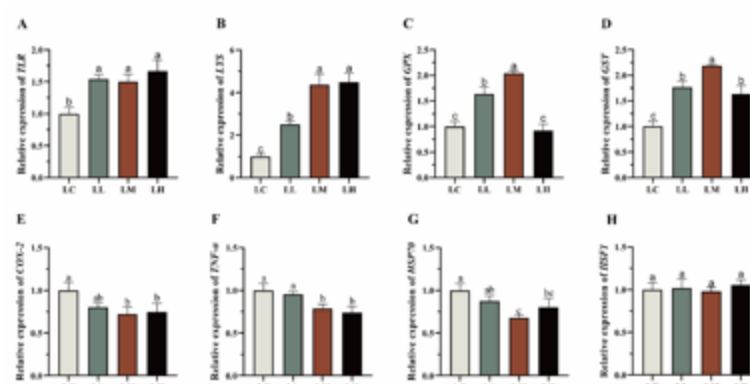
Gut microbiota

Figure 3. Influence of red pepper powder on the intestinal microbiota composition in *S. intermedius* at phylum (A) and genus levels (B).

Immune and Antioxidation Related Parameters

Figure 4. Immune and antioxidant parameters of *S. intermedius* supplemented with different levels of red pepper powder

Physiological response-related genes

Figure 6. Relative expression of immune, antioxidant, inflammatory, and stress-related genes in *S. intermedius* after 50 days of feeding with different levels of red pepper powder. The LC (control) group transcript levels were normalized to 1, using 18S as the internal control gene.

Conclusion

In conclusion, dietary supplementation with red pepper powder significantly improved the growth performance of *S. intermedius*, with its beneficial effects primarily linked to enhanced antioxidant defenses, improved immune function, and modulation of intestinal microbiota. At the molecular level, these improvements were associated with the upregulation of antioxidant- and immunity-related genes and the downregulation of stress-response and pro-inflammatory genes, thereby contributing to physiological homeostasis under intensive aquaculture conditions. Furthermore, red pepper powder improved gonadal pigmentation, promoted nutrient deposition, and enhanced gonadal quality. These findings not only highlight red pepper powder as a potent natural antioxidant but also underscore its promise as a green, safe, and sustainable feed additive in sea urchin farming. Importantly, its stress-mitigating capacity carries global significance for sustainable aquaculture. Under the present experimental conditions, ~1% inclusion was identified as the optimal dosage.