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The effects of body weight, temperature, salinity, pH, light intensity and feeding condition on lethal DO levels of whiteleg shrimp, *Litopenaeus vannamei* (Boone, 1931)

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Abstract

Tolerance of whiteleg shrimp *Litopenaeus vannamei* exposed to different temperatures (14.5, 21.5, 24.8, 27.8, 30.8, and 35.0 °C), salinities (9, 15, 26, 35, and 40‰), pH (3.3, 6.5, 7.7, 8.1, and 9.2), and light intensities (strong 2100 lx and weak 60 lx) at various body weights (3.0, 3.7, 4.3, 5.7, 7.8, 9.0, 9.5, 10.7, 11.9, and 13.3 g) and feeding conditions (fed for 3 h, fasted for 12 h, and fasted for 48 h) to hypoxic stress was measured. Regression models for the effects of body weight, temperature, salinity, and pH on lethal dissolved oxygen (DO) levels were derived from the data. Body weight, temperature, salinity, and pH had significant effects on lethal DO levels ($P<0.01$). The estimated body weight (BW), temperature (T), salinity (S), and pH (pH) for minimum lethal DO levels (LDOL) were 9.17 g, 22 °C, 16.6‰, and 7.56 ($\mathrm{LDOL}=0.0076\ \mathrm{BW}^2-0.1394\ \mathrm{BW}+1.1471$, $r^2=0.94$; $\mathrm{LDOL}=2.4291\times10^{-5}\ T^3-0.0008\ T^2+0.6095$, $r^2=0.66$; $\mathrm{LDOL}=-7.8212\times10^{-5}\ S^3+0.0058S^2-0.1280\ S+1.2424$, $r^2=0.98$; $\mathrm{LDOL}=0.1487\ \mathrm{pH}^2-2.2488\ \mathrm{pH}+8.8806$, $r^2=0.99$), respectively. The lethal DO levels of the shrimps exposed to strong light (2100 lx) were 75.1% of those exposed to weak light (60 lx), but there was no significant difference ($P>0.05$) between the two light intensities. The lethal DO levels of the shrimps fed for 3 h were 80.6% of those fasted for 48 h ($P<0.01$), but no significant difference ($P>0.05$) was found between those fed for 3 h and fasted for 12 h. These results indicated that *L. vannamei* cultured at optimum conditions has the best ability to withstand hypoxia. Therefore, it is suggested that water temperature be maintained at 22 °C, salinity 16.6‰, pH 7.56, and strong light conditions for water management practice in *L. vannamei* culture when hypoxia happened.

Keywords: Shrimp; *Litopenaeus vannamei*; Lethal DO levels; Body weight; Temperature; Salinity; pH; Light intensity; Feeding condition

1. Introduction

Dissolved oxygen (DO) is a major limiting factor in aquaculture. The bottom layer of pond waters, where shrimps spend most of their time, may become hypoxic or even anoxic due to organisms' respiration and decomposition of accumulated organic matter of feed remains and feces, particularly at nighttime. These hypoxic

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conditions can certainly threaten shrimps' life. Hence, DO have often been considered an important environmental factor determining the success and intensification of shrimp culture. DO values higher than 5 mg l^{-1} have often been recommended for intensive culture practices (Cheng et al., 2003).

Hypoxia or low DO is defined as DO less than 2.8 mg l^{-1} (Diaz and Rosenberg, 1995). The effect of hypoxia on growth, survival, feeding, molting, behavior, osmoregulatory capacity, and immune response of penaeid shrimps has been well documented by some authors (Clark, 1986; Renaud, 1986; Allan and Maguire, 1991; Charmantier et al., 1994; Moullac et al., 1998; Wannamaker and Rice, 2000; McGraw et al., 2001; Wu et al., 2002; Pérez-Rostro et al., 2004; Mugnier and Soyez, 2005). It has been reported that the lethal DO levels ranged from 0.2 to 1.27 mg l^{-1} for a number of penaeid shrimps. Allan and Maguire (1991) reported that 96-h LC_{50} of DO for juvenile *Penaeus monodon* was estimated to be 0.9 mg l^{-1}. Egusa (1961) found that the lethal DO level for *Marsupenaeus japonicus* lay between 0.5 and 1.0 mg l^{-1}. Martínez et al. (1998) reported that 48-h LC_{50} of DO for postlarvae *Litopenaeus setiferus* was 1.27 mg l^{-1} and 1.16 mg l^{-1} for juveniles at 72-h LC_{50}. Chen and Nan (1992) found that the lethal DO level for *Fenneropenaeus chinensis* weighing from 0.31 to 10.54 g was 0.74 mg l^{-1} on the average. Wu et al. (2002) reported that 8-h LC_{50} of DO for juvenile *Metapenaeus ensis* was 0.77 mg l^{-1}. Pérez-Rostro et al. (2004) indicated that the DO level of 0.2 mg l^{-1} was lethal for the shrimp *Litopenaeus vannamei* after 1 h of exposure, and Hopkins et al. (1991) found that the lethal DO level for *L. vannamei* was about 1 mg l^{-1}.

Although the lethal DO level for *L. vannamei* is reported, there is scarce information about the effects of biotic and abiotic factors on the lethal DO levels and no modeling study has yet been carried out. According to Herreid (1980), the mechanisms involved in response to hypoxia depend on the environment and the physiological state of the animals. In this study, a series of six experiments were carried out to investigate the effects of body weight, temperature, salinity, pH, light intensity and feeding condition on the lethal DO levels of *L. vannamei*. Using the results of laboratory studies, four models for the effects of body weight, temperature, salinity, and pH were described to predict the tolerance of *L. vannamei* to hypoxia that would occur in different environmental conditions. Knowledge of lethal DO levels at different environmental conditions and physiological states could prove beneficial to the improvement of live transportation methods for penaeid shrimps and also provide a scientific basis for water quality regulation in shrimps' culture.

2. Materials and methods

2.1. Source and acclimation of shrimps

The experiments were carried out from October 15, 2004 to January 20, 2005 at the Key Laboratory of Mariculture, Ocean University of China, Qingdao, PR China. The test shrimps weighing from 3 to 15 g were purchased from local farm (Shazikou, Qingdao) and were acclimated in a 2-m^3 recirculating fiberglass tank for 10 days before experiments commenced. During the acclimation, shrimps were fed commercial pellets (43.39±0.22% crude protein, 9.74±0.30% fat, 9.91±0.01% ash, 8.41±0.06% moisture) at 5% of shrimp biomass, twice daily. Temperature, salinity, DO, pH, ammonia-N, and photoperiod were maintained at 22±0.5 °C, 30±2‰, 6.0–7.0 mg l^{-1}, 7.8–8.2, 0.20–0.50 mg l^{-1}, and 14 L/10 D, respectively. Water was exchanged daily at a rate of 5% tank volume.

2.2. Experimental design and procedure

Seawater used in all experiments was prepared the day before the experiments by sand filter and ultraviolet sterilization.

Shrimps at intermolt stage were used for all experiments. The molt stage was determined by examining the uropods in which partial retraction of the epidermis can be distinguished (Wassenberg and Hill, 1984).

2.2.1. Experiment 1 — effect of body weight on the lethal DO levels

In this experiment, temperature, salinity, pH, and incipient DO were maintained at 22±0.5 °C, 30±1‰, 7.45±0.24, and above 7.0 mg l^{-1}, respectively.

Ten sizes of shrimps with body weights of 3.0, 3.7, 4.3, 5.7, 7.8, 9.0, 9.5, 10.7, 11.9, and 13.3 g were selected from a range of 3 to 15 g and 12 weight-selected shrimps were randomly selected for every body weight size. Shrimps fasted for 12 h were dried on absorbent paper, and weighed to the nearest 0.1 g using a digital balance, then transferred to volumetric flasks containing the desired seawater. 500 mL volumetric flasks were used for shrimps weighing up to 4.3 g, 1000 mL for shrimps weighing up to 9.5 g, and 2000 mL for shrimps weighing up to 13.3 g. One shrimp was stocked in each volumetric flask to avoid a sharp drop in oxygen levels. To minimize handling