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Performance of Pacific White Shrimp, *Litopenaeus vannamei*, Reared in Zero-Exchange Tank Systems Exposed to Different Light Sources and Intensities

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Abstract

The development of biofloc production technology has generated significant commercial and research interest directed toward the inland culture of Pacific white shrimp, *Litopenaeus vannamei*. Most work to date has been conducted in greenhouses, where photoautotrophic organisms are significant contributors to system functionality. In more temperate locations, operations in insulated buildings would reduce heating costs. This experiment was designed to evaluate the effect of light on shrimp cultured in intensive biofloc systems. A 92-d experiment was conducted in 3.8-m^3 tanks. There were five light treatments: (1) natural sunlight (SUN) as a control (midday: 718 lx); (2) one metal halide light (MHL) (1074 lx); (3) one fluorescent light (1FL) (214 lx); (4) two fluorescent lights (2FL) (428 lx); and (5) three fluorescent lights (3FL) (642 lx). Artificial light treatments operated on a 12:12 daily cycle. There were three replicate tanks per treatment and each was separated by black plastic to prevent light transmission between replicates. Each tank was stocked at 465 shrimp/m^2 of tank bottom (initial mean weight = 0.4 g). Light treatment had a significant ($P \leq 0.05$) impact on average individual weight, survival, harvest yield (kg/m^2), and feed conversion ratio (FCR). Harvest yield and survival among shrimp in the SUN, MHL, and 1FL treatments were not significantly different. However, there was an inverse linear relationship ($P \leq 0.05$; $R^2 = 0.76$) between the number of fluorescent fixtures and survival, which was related to greater concentrations of filamentous bacteria as the intensity of fluorescent light increased, causing gill fouling. Natural light and MHL did not result in high concentrations of filamentous bacteria. These results indicate that natural light, metal halide lighting, and/or relatively low levels of fluorescent lighting are suitable for indoor production of Pacific white shrimp in biofloc systems. Light spectrum and intensity can affect bacterial community structure, which has a profound effect on shrimp survival and production.

Indoor recirculating aquaculture systems (RAS) are being evaluated for the production of penaeid shrimp and offer several advantages compared to earthen ponds. These systems significantly reduce water requirements, which also improve biosecurity (Browdy et al. 2001). These systems can reduce or eliminate biological pollution of the surrounding environment (Moss et al. 2001). In addition, indoor production of shrimp provides the opportunity for producers to move inland and take advantage of a wider array of markets and reduce competition for land in coastal areas (Neal et al. 2010).

Recirculating systems can be differentiated or classified by the primary method of waste nitrogen removal (Hargreaves 2006). The three naturally occurring pathways include phototrophic assimilation by algae, autotrophic bacterial nitrification of ammonia-nitrogen to nitrate-nitrogen, and heterotrophic bacterial conversion of ammonia-nitrogen to microbial biomass (Ebeling et al. 2006). In most cases, all three pathways exist to a varying degree.

Traditional RAS use "fixed film" technology whereby autotrophic bacteria attached to media inside a bioreactor (biofilter) convert ammonia into less toxic forms (nitrate). A production technology based on suspended biofloc has been implemented in penaeid

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shrimp production (Avnimelech 2009). Such systems use carbon inputs (sugar or molasses) to increase the C/N ratio and promote the growth of heterotrophic bacteria (Avnimelech 1999; McIntosh 2001). Biofloc production systems require less infrastructure by eliminating or reducing the need for external components such as biofiltration, solids filtration, and disinfection systems (Neal et al. 2010).

Research on heterotrophic aquaculture systems has been conducted in greenhouses in tropical or sub-tropical areas such as Hawaii and South Carolina (Browdy et al. 2001; Moss et al. 2001). Greenhouses provide natural light and can reduce heating costs in sub-tropical climates. Water temperature for Pacific white shrimp, *Litopenaeus vannamei*, must be maintained between 24 and 30 C for optimal health and growth (Lu-Qing et al. 2007). In temperate climates, energy requirements to maintain these temperatures year-round are substantial. Greenhouses, with relatively poor insulation, are too expensive to heat during winter months. Agricultural buildings, such as those used for growing poultry or swine, are highly insulated and are less costly to heat in these areas. However, a potential drawback of these buildings is the incapacity to provide natural sunlight.

Survival and growth of crustaceans can be affected by light (Hillier 1984) and light intensity also affects ovarian maturation and reproduction of crustaceans (Emmerson 1980; Kelemec and Smith 1980; Emmerson et al. 1983; Hillier 1984; Primavera and Caballero 1992; Wang et al. 2004). Relatively few studies have evaluated the effect of light spectrum on crustaceans. Blue-spectrum lighting promotes maturation and spawning of white shrimp, *Penaeus setiferus* (Wurts and Stickney 1984). Growth and feed conversion efficiency in Chinese shrimp, *Fenneropenaeus chinensis*, reared under blue light is reduced compared to full-spectrum, white or green light (Wang et al. 2003). Exposure of Pacific white shrimp to metal halide lighting resulted in greater growth rate than shrimp exposed to florescent lighting, although growth differences were small (You et al. 2006). These studies were conducted in clear-water systems with >25% daily water exchange and presumably high light penetration.

In a previous experiment, natural light increased production by >48% compared to a low-light treatment (50 lx) using incandescent lighting in zero-exchange biofloc systems (Neal et al. 2010). Natural light had a direct positive impact on the availability of rotifers and other zooplankton (Neal et al. 2010) that are natural food sources for shrimp (Thompson et al. 1999). Differences in the abundance of microalgae between natural-light and low-light treatments were minimal. This may have been caused by rapid grazing of microalgae by the greater number of zooplankton in natural-light systems (Neal et al. 2010).

Fluorescent lighting is widely used in industrial, commercial, and residential applications because it is economical, versatile, and readily available in three basic types: white, full-spectrum, and actinic blue. Metal halide lighting (MHL) is particularly popular in situations where high light intensity is needed and for use in indoor horticulture and saltwater aquariums because they emit light in the most photosynthetically active wavelengths (Wurts and Stickney 1984).

Research is needed to investigate different wavelengths and intensities of artificial lighting to improve production efficiencies in biofloc systems. This is especially important for temperate zone production because natural light sources may not be available in closed buildings. The objective of this study was to evaluate the effects of different light sources and intensities on the performance of Pacific white shrimp in biofloc systems.

Materials and Methods

Shrimp Performance

The trial was conducted in a 24 × 30 m double-walled plastic greenhouse using 15 conical-bottom polyethylene tanks with a working volume of 3.8 m^3, a diameter of 2.44 m at the top of the tank, a diameter of 2.13 at the bottom of the tank, and a depth of 1.35 m (Polytank, Inc., Litchfield, MN, USA). Black plastic sheeting was attached to the walls and ceiling

of two-thirds of the greenhouse to block outside light in artificial light treatments. There were three replicate tanks per treatment and each tank within the artificial light section was separated by vertical curtains of black plastic sheeting to prevent light transmission between treatments. Water temperatures were maintained near 30 C by a combination of ambient greenhouse temperatures and in-tank immersion heaters (Process Technology, Mentor, OH, USA).

There were five light treatments: (1) natural sunlight (SUN) as the control (midday: 718 lx); (2) one metal halide light (MHL) (1074 lx); (3) one fluorescent light (1FL) (214 lx); (4) two fluorescent lights (2FL) (428 lx); and (5) three fluorescent lights (3FL) (642 lx). Light intensity measurements are the average of recordings for each tank made at the beginning and conclusion of the trial with a light intensity meter (Model 840022 Broad Range LUX/FC Meter, SPER Scientific, Scottsdale, AZ, USA) held by hand over the center of the tank at the water surface. In the MHL treatment, one metal halide light fixture (Lithonia Lighting, Conyers, GA, USA) was suspended 0.8 m over the center of each of three replicate tanks. Type R metal halide bulbs were used (MH400/U, Philips Electronics North America Corporation, Andover, MA, USA) and reportedly provided a color temperature of 4000 K, color rendering index (CRI) of 65, and design lumens of 36,000. The fluorescent light treatments used 1.2 m, wet location, two-bulb light fixtures (GE Lighting Manufacturing Company, LLC, Cleveland, OH, USA) suspended 0.8 m over the center of each of nine tanks. One, two, or three fixtures were suspended, based on treatment. Full-spectrum fluorescent bulbs were used (F40/DAY PLUS, Philips Electronics North America Corporation) and reportedly provided a color temperature of 6500 K, CRI of 84, and design lumens of 2325. Artificial light treatments were maintained on a 12:12 h light : dark cycle for the duration of the study. Water was circulated within each tank by vigorous diffused aeration to keep solids suspended. Pure oxygen was provided to each tank at 0.25 L/min through ultra-fine pore ceramic plate diffusers supplied from a liquid oxygen tank.

Two days prior to stocking shrimp, water from a previous trial was mixed and equally distributed to fill each experimental tank approximately 50%. The remaining 50% was de-chlorinated municipal water. At the start of the trial, total suspended solids (TSS) ranged from 150 to 173 mg/L among all tanks. Initially salinity was adjusted to 16 ppt with a commercially available marine pre-mix (Crystal Sea® Marine mix, Marine Enterprises International, Baltimore, MD, USA) and was maintained at 15–20 ppt throughout the study.

Approximately 100,000 specific pathogen-free *L. vannamei* post-larvae (PL-8) were transported by air from a commercial supplier (Ocean Boy Farms, Clewiston, FL, USA) and nursed in a greenhouse at the Aquaculture Research Center, Kentucky State University, Frankfort, KY, USA, for 60 d. During this nursery phase, shrimp were fed a 45% protein shrimp diet (Zeigler Brothers, Inc., Gardners, PA, USA) four times daily according to a feed chart (Van Wyk 1996b). Prior to stocking, *L. vannamei* from the nursery tank were graded to a similar size and a sample of 100 shrimp was blotted free of surface water and individually weighed to determine average weight ($\overline{x} \pm SD$; 0.40 ± 0.28 g). Each tank was stocked by manual counting until a density of 465 shrimp/m^2 (344 shrimp/m^3) was achieved.

After stocking, average weights of shrimp in each experimental tank were determined weekly by group weighing a drained sample of $\geq$30 shrimp to the nearest 0.1 g, and dividing the drained weight by the number of shrimp in the sample.

After 13 wk, all tanks were drained to 0.5-m depth, and shrimp were removed by dip-net, bulk weighed, and counted. One hundred shrimp per tank were individually weighed and examined for disease signs.

Feeds and Feeding

Shrimp were fed daily at 0800 and 1600 h with extruded sinking pellets (2.4 mm) (Hyper-Intensive Shrimp Grower, Zeigler Brothers, Inc.) containing 35% protein and 9% fat. Feeding rates were based on a feed table (Van Wyk

1999b) beginning at 10% of estimated biomass of shrimp and gradually decreasing to 3% of estimated biomass. Feed inputs were adjusted weekly according to average sample weights and estimated survival (1% mortality per week) and were considered to be in slight excess of consumption based on the presence of feed on the tank bottom during routine sampling. Sodium bicarbonate (baking soda) was applied daily to each tank at the time of feeding as a source of alkalinity to promote the growth of autotrophic bacteria. Baking soda inputs were 5% (by weight) of the daily feed allotment throughout the study.

Sucrose (pure cane sugar) was applied daily to each tank at the time of feeding as a source of carbon to promote the growth of heterotrophic bacteria. Sugar inputs were based on a percentage of the daily feed allotments (by weight) with application rates of 15% for Days 1–69 and 12% for Days 70–92. Sugar application rates were decreased to 12% on Day 70 based on increasing TSS levels and stable total ammonia-N (TAN) concentrations. Sugar addition was based on previous production experiments and stoichiometry calculations (Avnimelech 1999; Hari et al. 2004; Ebeling et al. 2006; Schneider et al. 2006; Crab et al. 2007; De Schryver et al. 2008). In this study, the 35% protein feed has a C/N ratio of approximately 2.2. The optimal C/N ratio of inputs should be 6.1 in a purely heterotrophic system (Ebeling et al. 2006). The feed plus the 15% application rate of sugar in this study provided a combined C/N ratio of 3.4. To reduce TSS and solid waste production, this rate was chosen as a modification of the protocol from a previous experiment in which sugar was added at 20% of the daily feed allotment (Neal et al. 2010). On the basis of the C/N ratio of inputs, approximately 50% of the ammonia-nitrogen in the system was removed by autotrophic bacteria (Ebeling et al. 2006), in which addition of baking soda at 5% of the daily feed allotment was used as the inorganic carbon source.

Water Quality Management

Dissolved oxygen concentration, temperature, pH, and salinity were measured twice daily (0830 and 1630 h) with a YSI 556 dissolved oxygen meter (YSI Inc., Yellow Springs, OH, USA). TAN and nitrite-N (NO_2-N) concentrations were determined with a spectrophotometer (Hach Odyssey DR 2400, Hach Company, Loveland, CO, USA). Levels of TAN and NO_2-N were measured once daily at 1000 h during the first 4 wk of the study. As levels decreased, monitoring was decreased to three times per week for the remainder of the trial. Alkalinity was determined twice weekly by titration (Hach digital titrator, Hach Company). In addition to daily calculated applications of baking soda, weekly additions were made to maintain alkalinity >150 mg/L if indicated by analysis.

Total suspended solids (TSS) were measured once daily with an Insite IG® 3150 suspended solids analyzer (Insite Instrumentation Group, Inc., Slidell, LA, USA). Levels of TSS were maintained within target ranges during the study using a bag filter system described by Neal et al. (2010). Avnimelech (2009) recommended increased solids removal or water exchange at TSS greater than 200–500 mg/L in heterotrophic shrimp systems. The threshold level of TSS in this study was set at 300 mg/L. Excess solids were removed with a bag filter operated by an airlift. The bag filter contained 300–1000 μm mesh bags, with mesh size adjusted to floc characteristics. Bags were hung to drain overnight, and then weights of harvested floc (sludge) were recorded.

Total chlorophyll and algae classes: green algae, blue-green algae, brown algae (diatoms and dinoflagellates), and cryptophyceae, were determined weekly for each tank using a bbe Algae Lab Analyzer (bbe Moldaenke, Kiel-Kronshagen, Germany).

Statistics

The FCR was calculated as weight of feed fed divided by live weight gain (g). Data on shrimp growth, survival, FCR, harvested biomass, water quality, and algae class were analyzed by ANOVA using Statistix version 7 (Statistix Analytical Software 2000, Tallahassee, FL, USA). If significant differences

TABLE 1. *Treatment means*[1] *of water quality variables measured during the 13-wk grow-out of* Litopenaeus vannamei *reared under either natural sunlight (SUN), metal halide light (MHL), or three different intensities of fluorescent light (1FL, 2FL and 3FL).*

	Treatment				
Variable	SUN	1FL	2FL	3FL	MHL
Temperature (C)	30.3 ± 0.1^{a}	29.8 ± 0.0^{b}	29.7 ± 0.1^{b}	29.9 ± 0.2^{b}	29.7 ± 0.1^{b}
DO am (mg/L)	7.8 ± 0.2^{b}	7.1 ± 0.1^{b}	8.2 ± 0.1^{a}	7.4 ± 0.1^{b}	7.7 ± 0.1^{ab}
DO pm (mg/L)	7.5 ± 0.2^{bc}	7.7 ± 0.0^{ab}	8.1 ± 0.2^{a}	7.2 ± 0.2^{c}	7.5 ± 0.1^{bc}
TSS (mg/L)	276.8 ± 6.9^{ab}	268.3 ± 7.3^{b}	315.7 ± 28.1^{a}	238.4 ± 7.5^{b}	260.4 ± 1.6^{b}
Alkalinity (mg/L)	152.7 ± 3.9^{a}	149.7 ± 3.3^{a}	153.3 ± 1.2^{a}	147.0 ± 3.5^{a}	151.4 ± 2.6^{a}
TAN (mg/L)	0.19 ± 0.03^{a}	0.13 ± 0.06^{a}	0.20 ± 0.06^{a}	0.20 ± 0.07^{a}	0.10 ± 0.02^{a}
pH	7.5 ± 0.0^{a}	7.6 ± 0.0^{a}	7.5 ± 0.1^{a}	7.5 ± 0.0^{a}	7.5 ± 0.0^{a}
Nitrite-N (mg/L)	0.1 ± 0.0^{a}	0.1 ± 0.0^{a}	0.1 ± 0.0^{a}	0.1 ± 0.0^{a}	0.1 ± 0.0^{a}
Sludge (kg/m^2)	15.1 ± 0.8^{a}	23.2 ± 5.5^{a}	30.1 ± 10.9^{a}	11.3 ± 2.3^{a}	11.7 ± 0.9^{a}
Salinity (ppt)	17.4 ± 0.7^{a}	16.7 ± 0.3^{a}	17.1 ± 0.2^{a}	16.2 ± 0.2^{a}	16.8 ± 0.6^{a}

DO = dissolved oxygen; TAN = total ammonia-N; TSS = total suspended solids.

[1]Means (±SE) of three replicate tanks; means within a row followed by different superscripts are significantly different ($P \leq 0.05$).

($P \leq 0.05$) were indicated, means were separated using Fisher's LSD test. All percentage and ratio data were transformed to arc sin values prior to analysis (Zar 1984). Summary statistics are presented in the untransformed form to facilitate interpretation.

Results and Discussion

Water Quality

There were no significant differences in TAN, NO_2-N, pH, total alkalinity, salinity, or sludge removed among treatments (Table 1). Overall means (±SE) were TAN, 0.19 ± 0.02 mg/L; NO_2-N, 0.11 ± 0.01 mg/L; pH, 7.51 ± 0.02; total alkalinity, 150.8 ± 1.2 mg/L; salinity, 16.8 ± 0.2 ppt; and sludge, 18.3 ± 4.1 kg/m^2.

Dissolved oxygen and temperature remained within recommended ranges for the growth of Pacific white shrimp throughout the course of the experiment (Van Wyk and Scarpa 1999; Whetstone et al. 2002; Jory and Cabrera 2003). Statistical differences in water quality parameters were not considered sufficient to impact growth.

TSS differences were primarily a function of managing TSS by cropping with filter bags and were not necessarily a function of lighting.

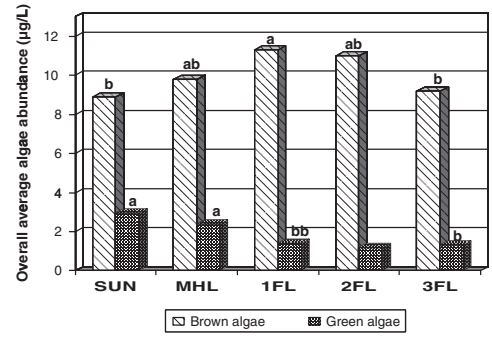

FIGURE 1. *Abundance for brown and green algae groups, measured by transmittance, in heterotrophic systems containing* Litopenaeus vannamei *reared under either natural sunlight (SUN), metal halide light (MHL), or three different intensities of fluorescent light (1FL, 2FL, and 3FL).*

Algae Analysis

There were no blue-green algae or cryptophyceae measured in any sample during the experiment. There were significant differences in overall means for green algae and brown algae between treatments (Fig. 1). The SUN and MHL treatments resulted in an overall greater abundance of green algae than the fluorescent light treatments. Brown algae dominated all tanks in the experiment.

In this study, large differences in the numbers of microalgae between the natural-light and

TABLE 2. *Treatment means*[1] *of average harvest weight, growth rate, survival, harvest yield, and feed conversion ratio (FCR) measured during the 13-wk grow-out of* Litopenaeus vannamei *reared under either natural sunlight (SUN), metal halide light (MHL), or three different intensities of fluorescent light (1FL, 2FL, and 3FL).*

	Treatment				
Variable	SUN	MHL	1FL	2FL	3FL
Harvest wt. (g)	10.7 ± 0.4^{b}	10.7 ± 0.2^{b}	11.0 ± 0.1^{b}	11.9 ± 0.1^{ab}	12.5 ± 0.8^{a}
Growth rate (g/wk)	0.8 ± 0.0^{b}	0.8 ± 0.0^{b}	0.8 ± 0.0^{b}	0.9 ± 0.0^{ab}	0.9 ± 0.1^{a}
Survival	88.7 ± 1.9^{a}	87.2 ± 2.3^{a}	75.6 ± 7.1^{ab}	59.8 ± 8.0^{b}	31.9 ± 5.1^{c}
Harvest yield (kg/m^2)	4.4 ± 0.1^{a}	4.3 ± 0.1^{a}	3.9 ± 0.3^{ab}	3.3 ± 0.4^{b}	1.8 ± 0.2^{c}
FCR	2.1 ± 0.0^{b}	2.1 ± 0.0^{b}	2.4 ± 0.2^{b}	2.9 ± 0.4^{b}	5.3 ± 0.7^{a}

[1]Means (±SE) of three replicate tanks; means within a row followed by different superscripts are significantly different ($P \leq 0.05$).

low-light treatments were not indicated. Neal et al. (2010) reported similar findings and suggested rapid grazing of microalgae by the greater number of zooplankton measured in the natural-light systems in that study.

Shrimp Performance

At harvest, significant differences were observed in final average weight, growth rate, survival, harvest yield, and FCR of shrimp among the five treatments (Table 2). Mean average weight of shrimp were similar to average weights reported in other studies where shrimp were stocked at similar densities (Van Wyk 1999a; Samocha et al. 2004; Browdy and Moss 2005). Shrimp FCR and harvest yield were within optimal range in the SUN, MHL, and 1FL treatments (Browdy and Moss 2005).

There was a significant inverse linear relationship ($r^2 = 0.76$; $P \leq 0.05$) between survival and intensity of fluorescent light (Fig. 2). Significant differences in growth performance variables were primarily related to differences in survival. Decreased survival in the 2FL and 3FL treatments largely accounts for the greater average harvest weights in those treatments, which is clearly a result of a decrease in density. Similarly, greater harvest yield in the SUN and MHL treatments, compared to the 2FL and 3FL treatments, are due to greater survival in the SUN and MHL treatments. Differences in FCR are also a result of differences in survival as all tanks were fed the same amount, according to a feed chart; therefore, differences should not be interpreted as a function of light treatment.

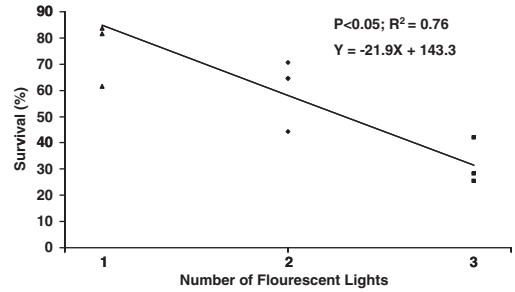

FIGURE 2. *Linear regression of survival on amount of fluorescent light (1FL, 2FL, and 3FL) after 13 wk for* Litopenaeus vannamei *reared in static heterotrophic systems.*

Modeled production of juvenile shrimp stocked at 300/m^2 in a heated greenhouse over a 84-d production cycle projected survival of 85% and yield of 4.3 kg/m^2 of 17-g shrimp (Browdy and Moss 2005). In a previous trial, harvest yields were 4.1 kg/m^{2}of 13.6 g shrimp; these were stocked at 364/m^2 after 84 d in a natural sunlight treatment (Neal et al. 2010). In this study, the natural-light treatment resulted in the production of 4.4 kg/m^2 of 10.7-g shrimp with 89% survival after 91 d when stocked at 465/m^2. The greater stocking density likely resulted in a smaller average size shrimp in this study, although overall conditions during this study were favorable to good growth and survival.

Previous reports on the effect of light type and intensity have been conducted in clear-water aquaria. Growth rates of Chinese shrimp raised under low-intensity light (0–1300 lx) were greater than those raised under

high-intensity light (5500 lx) using fluorescent bulbs (Wang et al. 2004). Exposure to full-spectrum fluorescent light resulted in greater specific growth rates than shrimp reared under blue light (Wang et al. 2003). Blue light induced increased activity, resulting in lower feed conversion efficiency and reduced growth (Wang et al. 2003). Growth of Pacific white shrimp exposed to metal halide light (2500 lx) was greater than that of shrimp exposed to fluorescent light (210 lx) (You et al. 2006).

Filamentous Bacteria

Beginning in Week 2, filamentous bacteria identified as *Leucothrix mucor* (Dr. Donald Lightner, Department of Veterinary & Microbiology and Wildlife & Fishery Science, University of Arizona, Tucson, AZ, USA) was observed in several 2FL and 3FL tanks. By Week 7, significant accumulation of the filamentous bacteria was observed in 2FL and 3FL tanks only. Greater TSS levels measured in the 2FL treatment were caused by increased concentration of filamentous bacteria, as the presence of filamentous bacteria made cropping of TSS more difficult because bag filters clogged, impeding water flow.

High concentrations of *L. mucor* can attach to gill lamellae of shrimp, block respiration, and potentially result in suffocation (McKee and Lightner 1982). Decreased survival in the 2FL and 3FL shrimp populations was likely related to higher concentrations of filamentous bacteria (*L. mucor*) observed in those tanks. Natural light, metal halide lighting, and low levels of fluorescent lighting did not promote high concentrations of filamentous bacteria. Mortality associated with the proliferation of filamentous bacteria in tanks illuminated with incandescent lighting has been reported previously (Neal et al. 2010). Gill clogging caused by high concentrations of filamentous bacteria is a potential problem in biofloc systems (De Schryver et al. 2008), and this was a problem in treatments with high levels of fluorescent light in this study and in low levels of incandescent light in a previous study (Neal et al. 2010).

To date, little is known about the population structure of bioflocs and the ability to select for favorable microorganisms (Hargreaves 2006). The composition of microbial cells in suspended flocs varies widely depending on environmental conditions (Avnimelech 2009). No published studies were found that suggest specific wavelengths or spectral qualities of light favor or inhibit filamentous bacteria. Low dissolved oxygen concentration and low availability of organic carbon (substrate) can affect floc structure and encourage the dominance of filamentous bacteria in biofloc systems (De Schryver et al. 2008).

Filamentous bacteria are responsible for "bulking sludge" in activated sludge systems (Martins et al. 2004). Despite significant research, bulking sludge problems occur worldwide and a comprehensive solution is currently not available (Martins et al. 2004). In activated sludge systems, filamentous bacteria are often classified by their mechanism of competition with floc-forming bacteria as either low dissolved oxygen filaments or low food microorganism filaments (F/M) (Takacs and Fleit 1995). Filamentous bacteria may be better adapted to these conditions based on their higher surface to volume ratio and ability to extend filaments outside the floc structure. These characteristics may increase access to greater substrate and oxygen concentrations than non-filamentous bacteria, which are largely confined within flocs (Martins et al. 2004).

Conclusion

These results indicate that natural light, metal halide lighting, and/or relatively low levels of fluorescent lighting are suitable for indoor production of Pacific white shrimp in biofloc systems. In terms of upfront capital and operating costs, fluorescent lighting may be preferable. These results also suggest that light spectrum and intensity may affect floc community structure, which has a profound effect on shrimp survival and production.

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