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The Effect of Low Salinity Water with Different Ionic Composition on the Growth and Survival of *Litopenaeus vannamei* (Boone, 1931) in Intensive Culture

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The effects of four different ionic composition low salinity water (*T₁*, *T₂*, *T₃*, and *T₄*), on growth and survival of *L. vannamei* marine shrimp juveniles were investigated. Shrimp culture in seawater (*T₅*) was used as control treatment. The results indicated that there were no significant difference (*P < 0.05*) in growth, survival, production, and feed conversion ratio (FCR) of *L. vannamei* juveniles reared in the different treatments, but significant differences (*P < 0.05*) were observed between each of them when compared with seawater (*T₅*). After 84 days, culture shrimp grew from 0.02 to 7.58 g in *T₁*. The lowest growth rate was attained in *T₃* (0.57 g/week), in which potassium and calcium ions concentrations were the lowest (0.58 and 28.00 mg/L, respectively). The recorded survival rate (76.35% to 79.55%) is considered well for...
the 84 days growout period, although it was 7.6% lower than that recorded in the control treatment. Although there were no significant differences (P < 0.05) in growth with respect to the ionic composition of the four treatments, there was a trend of increasing growth in relation with the ionic ratio found in the seawater ($T_m$). This aspect should be evaluated more closely in future research.

**KEYWORDS** Low salinity, ionic ratio, well water, growth, L. vannamei

**INTRODUCTION**

Shrimp culture in low salinity water is becoming an important expansion of marine shrimp culture and has been developed in many regions of the world in recent years, such as inland waters in the United States (McGraw et al. 2002), Ecuador, Thailand (Saoud, Davis, & Rouse 2003; Roy et al. 2007), China (Cheng et al. 2005), and Mexico (Tamayo 1998). However, the use of well water from inland locations for shrimp culture faces many challenges (McGraw & Scarpa 2003). Information on essential environmental ions and minimum concentrations necessary for survival and growth of shrimp is lacking (McGraw & Scarpa 2003), although salinity tolerance has been examined (Samocha et al. 1998; Laramore, Laramore, & Scarpa 2001; McGraw et al. 2002). The marine shrimp *L. vannamei* can tolerate a wide salinity range from freshwater (0.5–2.0 psu) to hypersaline water of 60 psu (Stern, Daniels, & Letellier 1990; Bray, Lawrence, & Leung-Trujillo 1994; McGraw et al. 2002; Saoud, Davis, & Rouse 2003). Boyd (1989) considered a salinity of 15–25 psu to be ideal for *L. vannamei*. However, inconsistencies have been found in the published information regarding salinity effects on shrimp growth, and the optimum salinity for *L. vannamei* is still not conclusive (Zhu, Dong, & Wang 2006). It has been determined that the effect of salinity on growth varies with size and age (Laramore, Laramore, & Scarpa 2001). Bray, Lawrence, and Leung-Trujillo (1994) showed that 5 and 15 psu salinities produced significantly greater final weights than other levels tested (25, 35, and 49 psu), and Ponce-Palafox, Martinez-Palacios, and Ross (1997) concluded that the growth of *L. vannamei* was not reduced at a salinity range of 25–45 psu. Likewise, it should be noted that shrimp have been successfully cultivated at lower salinities in commercial operations. Ponds in Mexico, Central and South America are often subjected to heavy rainfall and fresh water influx that decrease the salinity to less than 2 psu (Teichert-Coddington, Rodriguez, & Toyofuku 1995; Tamayo 1998). Shrimp have been cultivated in commercial operations in some inland shrimp farms in the United States and at Harbor Branch Oceanographic Institute (Van Wyk et al. 1999) at salinities as low as 0.5 psu. Aquaculturists still face problems due to mineral deficiencies in the ionic profiles of pond waters.
Although shrimp-farming technology in seawater has reached a high level, it cannot be introduced to inland low salinity water culture directly (Zhu, Dong, & Wang 2006). Compared to seawater, the ion profile has changed a lot, and the rule of constancy of composition of seawater does not apply to inland low salinity water. Furthermore, the ionic composition and salinity of ground water can vary markedly among sites; the natural low salinity water resources in many inland sites cannot be used in shrimp culture directly (Davis et al. 2002; Saoud, Davis, & Rouse 2003; Zhu, Dong, & Wang 2006). The lack of an optimal mix of essential ions, such as K⁺ and Mg²⁺, has been shown to limit growth and survival of shrimp postlarvae (PL) at acclimation (Saoud, Davis, & Rouse 2003), as well as during the growout period (Davis, Samocha, & Boyd 2004).

There is little published information about the growth and survival of *L. vannamei* in well-water or inland surface water. Some of the first reports were from West Texas, where this species was successfully produced in earthen ponds. The shrimp grew from 1.2 to about 20 g in 120 days at a stocking density of 25 shrimp/m² (Samocha et al. 2002). There are also reports of super-intensive culture (109 shrimp/m²) in earthen ponds (0.1 ha) in the Sonora Desert of Arizona, with production as high as 12 tons/ha in low salinity well water of 2.0 psu (Davis, Samocha, & Boyd 2004).

Because of variations in well water and soil, some farmers have had problems rearing shrimp, while others have been successful. In Thailand, where water for inland shrimp culture is prepared by diluting a brine solution (100 to 250 psu) from coastal seawater evaporation ponds, ionic concentrations are similar to those expected from seawater diluted to the same salinity (Davis, Samocha, & Boyd 2004). In the United States, Ecuador, and Mexico, shrimp are cultured mostly in coastal, brackish water ponds. However, in the United States, Ecuador (Boyd, Thunjai, & Boonyaratpalin 2002; Davis, Samocha, & Boyd 2004), and Mexico, many ponds have much lower concentrations of potassium, magnesium, and other ions than expected in diluted seawater.

Research has been done to identify the reasons for the differences in survival and growth among farms, and to develop strategies for producing shrimp under various conditions (Davis, Samocha, & Boyd 2004). The first thing a farmer must determine is whether or not his water is suitable for shrimp culture. In Sinaloa, Mexico, the culture of *L. vannamei* shrimp in inland low salinity well water (about 0.5–7.0 psu) faces several challenges. The ionic composition of this water is sometimes deficient in several key minerals and poor shrimp survival and growth have been achieved. Consequently, the purpose of this research was to determine the effects of four sources with different ionic composition of low salinity well water on growth and survival of *L. vannamei* marine shrimp juveniles at a stocked density of 200 shrimp/m², and thereby to contribute further to the knowledge on shrimp farming with inland saline ground water.
MATERIALS AND METHODS

Production System
The experiment was performed inside a greenhouse in 16 fiberglass tanks (1 m wide, and 0.65 m deep, 650 L) functioning each as an independent tank system for treatment replication. The experimental work was carried out with different sources of ionic composition of low salinity well waters (ICLSWW) located in Guasave City, State of Sinaloa, Mexico. The well water was obtained by means of pumping at four sites: Tamazula (T1), El Pitahayal (T2), El Terahuito (T3), and La Trinidad (T4). The wells were handmade and had a depth of 5 to 7 meters. The aquifer from which the water was obtained corresponds to the Guasave aquifer located on both margins of River Sinaloa. Seawater was used as control (34.0 ± 0.5 psu). The seawater was used on the front of the beach “Las Glorias,” Guasave, Sinaloa. The water quality of each tank was maintained with a daily 20% water exchange. Shrimp were reared under an ambient light regimen (approximately 14 h light/10 h dark). Each tank was aerated with four pieces of air stone suspended in mid-depth of the water column.

Experimental Design
The experiments were designed to compare the effects of four ionic composition low salinity well water (ICLSWW), T1 (Tamazula (25°26′21″ N, 108°26′55″ W)), T2 (El Pitahayal (25°29′36″ N, 108°22′32″ W)), T3 (El Terahuito (25°36′54″ N, 108°24′29″ W)), and T4 (La Trinidad (25°38′43″ N, 108°31′12″ W)) on growth and survival rate of L. vannamei marine shrimp juvenile at a stocked density of 200 shrimp/m². Shrimp culture in seawater (Tm) was used as a control treatment at the same conditions. Four replicate tanks were randomly assigned to each treatment.

Stocking and Rearing Protocols
Commercially produced PL12 (mean weight 0.008 ± 0.002 g) were obtained and held in one 4 m long, 1 m wide, and 0.65 deep fiberglass tank (2,600 L) at 10 shrimp/L with flow-through water (0.6 L/min), 34 ± 0.5 psu, and aeration for three days. After this holding period, shrimp (PL15) were counted on a mesh screen, acclimated, and stocked (PL18, 0.02 ± 0.03 g) into tanks for the corresponding treatments. Shrimps were acclimated to each treatment over a three-day period prior to the start of the experiments. Shrimps were acclimated in a plastic container (20 L) from seawater (34.0 ± 0.5 psu) to the corresponding ICLSWW (0.52 ± 0.09 [T1], 0.88 ± 0.12 [T2], 0.52 ± 0.08 [T3], and 0.72 ± 0.08 psu [T4]) at a rate of change of 0.5 psu/h (Laramore, Laramore, & Scarpa 2001; McGraw et al. 2002; McGraw & Scarpa 2004). Shrimp were fed with a commercially formulated
feed (40% protein, 8% lipid) three times daily at 8:00, 12:00, and 16:00 h. The amount fed was adjusted weekly for each tank depending on the amount of uneaten food observed (Cuadros & Beltrame 1998). The proportion of larger crumbles was increased gradually as shrimp grew. Feed was initially fed at a rate of 18%–23% of the estimated biomass at PL18, and this ration was progressively reduced to 2%–4% at a mean shrimp weight of 8.85 g.

Water Quality and Major Ions Analyses
Temperature, dissolved oxygen (DO), pH, and salinity were recorded in each replicate twice per day (08:00 and 16:00 h) using a standard mercury thermometer, an YSI 55 oxygen meter, and a Hanna 213 potentiometer, respectively. We used a refractometer to monitor salinity and for water temperature an electronic conductivity meter (Yellow Springs Instruments) was used (Boyd, Thunjai, & Boonyaratpalin 2002). Twice a month, water samples were taken from each tank and analyzed for nitrite-N, nitrate-N, and ammonia-nitrogen concentrations, according to the methods proposed by Arredondo-Figueroa and Ponce-Palafox (1998).

During the growth trial, all water quality parameters were similar except the salinity. Mean temperature and dissolved oxygen (DO) were maintained up to 26°C and up to 5.0 mg/L, respectively. Values for pH were constant with near of 8.0. Minimum and maximum mean of total ammonia-nitrogen, nitrite-N, nitrate-N, and reactive phosphorus were between 0.26 to 0.31 mg/L; 0.28 to 0.32 mg/L; 0.73 to 0.77 mg/L; and 1.5 to 1.7 mg/L, respectively. Mean salinity of the control treatment was maintained at 34.00 (± 0.5) psu, while the salinity recorded in the other treatments fluctuated from 0.52 to 0.88 psu. Mean water quality parameters were within levels recommended for culturing juvenile Penaeids (Chien 1992; Arredondo-Figueroa & Ponce-Palafox 1998; Atwood et al. 2003; Saoud, Davis, & Rouse 2003). During growth trial, intermittent evaluations of DO and ammonia-nitrogen levels among treatments were utilized to adjust aeration and water exchanges to maintain equivalent water quality parameters among treatments.

Twice a month, water samples (500 mL plastic bottles) were taken from two tanks per each of the ICLSWW and transported to the laboratory AGUALAB (Reg. CNA. No. CAN-GSCA-440) in Guasave, Sinaloa, for analyses. Samples were analyzed for major ions by the standard protocol recommended by Clesceri and colleagues (1998) as follows: bicarbonates (sulfuric acid titration), chloride (mercuric nitrate titration to diphenylcarbazone endpoint), sulfate (barium chloride turbidimetry), calcium (titration to Eriochrome Black-T endpoint with ethylenediamine tetracetic acid, EDTA), magnesium (titration to murexide endpoint with EDTA), potassium, and sodium (atomic absorption spectrophotometry).
Data Collection for Growth, Survival, Production, and Feed Conversion Ratio (FCR)

A random sample of 50 shrimps from each tank was collected and the shrimps individually weighed every week. After 84 days, each treatment was harvested. At harvest, all shrimps were collected and counted to calculate survival and provide an estimate of production, and the shrimps were individually weighed to obtain a final mean harvest size. The growth results were expressed as the mean weight of shrimps within each ICLSWW at weekly intervals. Specific growth rate (SGR, % body weight/d) was calculated from $\text{SGR} = 100 \times \frac{\ln W_f - \ln W_i}{t}$, where $W_f$ = mean weight at the end of the period, $W_i$ = mean weight at the beginning of the period, and $t$ = time in days of the period (Ricker 1979). Survival rate was calculated as the percentage of remaining shrimps in each tank from the estimated number stocked. Production was calculated from the mean harvest weight of shrimps from each tank multiplied by the harvest density for that tank. Feed conversion ratio (FCR) was calculated from the total amount of feed administered to each tank divided by the total biomass gain for that tank.

Statistical Analysis

Statistical analyses were performed using SAS (Version 6.1, SAS Institute, Cary, NC, USA). Data were analyzed by one-way analysis of variance to determine significant differences at $P < 0.05$. Survival and growth rate of juvenile shrimp at various ICLSWW were compared with survival in the control condition (seawater) using Tukey’s t-test (Steel & Torrie 1980). Means of harvest size, growth, survival, production, and feed conversion ratio (FCR) of juvenile shrimp maintained in the treatments were compared among them using Student-Newman-Keuls multiple range test; major ions in the water-sources were analyzed likewise.

RESULTS

Ionic Composition

Results of water analyses are summarized in Table 1. There were significant differences ($P < 0.05$) in the concentrations of major ions in the ICLSWW except for bicarbonates found at a concentration higher than 250 mg/L, which is the concentration in normal seawater (Goldberg, 1963). The concentrations of the other ions were much lower than those of normal seawater. Bicarbonate concentrations ranged from 314.6 (T4) to 268.4 mg/L (T1). The maximum mean concentration of chloride was recorded in T2 (105.3 mg/L) and the minimum in T1 (22.0 mg/L). The sulfate concentration was almost three times higher in the well water of T2 (173.1 mg/L) than in the
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Other treatments, and the minimum concentration was recorded in T3 (38.4 mg/L). Calcium concentration was different in all treatments and the minimum and maximum concentrations recorded were 28.0 (T3) and 166.5 mg/L (T2), respectively. The highest concentration of magnesium was recorded in treatment T2 (118.9 mg/L) and the minimum in T1 (11.7 mg/L). Contrary to the other major ions, sodium concentration was higher in well water T4 (140.0 mg/L) and lower in T2 (40.7 mg/L). The maximum concentration of potassium was recorded in treatment T2 (4.7 mg/L), and the minimum was recorded in T3 (0.58). The treatments that showed a close Na/K and Mg/K ratio to seawater were T2 and T1, respectively. The maximum differences were exhibited in T3 and T4. All treatment exhibited high Ca/K and K ratios differences with respect to seawater; the highest values were registered in T4 and T1, respectively.

Growth, Survival, Production, Feed Conversion Ratio (FCA)

There were no significant differences (P < 0.05) in growth, survival, production, and feed conversion ratio among L. vannamei juvenile reared in the different sources of low salinity well water treatments (Table 2), but significant differences were found with those reared in seawater (Tm) (P < 0.05), except for the FCR (P > 0.05). After 84 days of culture, the highest values of mean final body weight (8.85 ± 1.11 g), mean weekly weight gain (0.74 ± 0.08 g/week), specific growth rate (7.25%/d), survival (85.55 ± 4.13%), and production (1.51 ± 0.18 kg/m²) were recorded in the control treatment.
Growth Performance

If inland culture of marine shrimp *L. vannamei* is to continue to develop, we must acquire a better understanding of the influence exerted by the salinity or ionic composition of well water on the physiology of shrimp. Present results confirm reports that *L. vannamei* can grow at low salinity well water (0.52–0.88 psu), although the growth rates were lower than recorded with seawater. In the present work, *L. vannamei* was reared in four ICLSWW (T1= 0.52, T2= 0.88, T3= 0.52, and T4= 0.72 psu) at a stocking density of 200 shrimp/m² and grew from 0.02 up to 7.58 g (T1) with growth rates of 0.63 (T1), 0.62 (T2), 0.57 (T3), and 0.61 (T4) g/week; while in the control condition (Tm= 34.00 psu), shrimp grew up to 8.85 g at 0.74 g/week. Some reports indicate that in marine water shrimp can grow until 1.19 g/week at stocking densities of 223–299/m² (Robertson et al. 1992). Under typical semi-intensive pond growout marine conditions, *L. vannamei* grow at a rate of about 1.10 g/week at a stocking density of 7 juveniles/m² (Clifford 1985). In intensive pond growout systems, shrimp growth is comparable; some data indicated that *L. vannamei* grew 1.26 g/week when stocked at a density of 25/m² (Huang 1990), 0.70 to 1.80 g/week at 45/m² (Wyban & Sweeney 1989), and 1.4 to 1.5 g/week at 75 to 100/m² (Wyban et al. 1987). In marine and stuarine waters, shrimp is capable of growing 1.4 g/week at densities of 2–3/m² (Menz & Blake 1980, cited by Wyban and Sweeney 1989).

**TABLE 2** Mean (± SD) Values of the Bio-Indicators of *L. vannamei* Reared in Four Different Sources of Low Salinity Well Water and Seawater (Control) Using PL₁₈ (0.02 g) Socked at Density of 200 Shrimp/m² for 84 days

<table>
<thead>
<tr>
<th>Bioindicators</th>
<th>T₁</th>
<th>T₂</th>
<th>T₃</th>
<th>T₄</th>
<th>Tm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean initial body weight (g)</td>
<td>0.02 ± 0.03</td>
<td>0.02 ± 0.03</td>
<td>0.02 ± 0.03</td>
<td>0.02 ± 0.03</td>
<td>0.02 ± 0.03</td>
</tr>
<tr>
<td>Mean final body weight (g)</td>
<td>7.58 ± 1.53a</td>
<td>7.25 ± 1.60a</td>
<td>6.78 ± 1.65a</td>
<td>7.20 ± 1.55a</td>
<td>8.85 ± 1.11b</td>
</tr>
<tr>
<td>FCR</td>
<td>1.35 ± 0.24a</td>
<td>1.51 ± 0.23</td>
<td>1.58 ± 0.15</td>
<td>1.48 ± 0.19</td>
<td>1.38 ± 0.10</td>
</tr>
<tr>
<td>Production (kg/m²)</td>
<td>1.19 ± 0.28a</td>
<td>1.12 ± 0.35a</td>
<td>1.08 ± 0.15a</td>
<td>1.10 ± 0.31a</td>
<td>1.51 ± 0.18b</td>
</tr>
<tr>
<td>Mean weekly weight gain (g/week)</td>
<td>0.63 ± 0.16a</td>
<td>0.62 ± 0.15a</td>
<td>0.57 ± 0.13a</td>
<td>0.61 ± 0.31a</td>
<td>0.74 ± 0.08b</td>
</tr>
<tr>
<td>Specific growth rate (%/d)</td>
<td>7.07 ± 0.93</td>
<td>7.02 ± 0.81</td>
<td>6.94 ± 0.56</td>
<td>7.01 ± 1.0</td>
<td>7.25 ± 0.23</td>
</tr>
<tr>
<td>Survival (%)</td>
<td>78.36 ± 3.7a</td>
<td>77.55 ± 3.4a</td>
<td>79.55 ± 4.3a</td>
<td>76.35 ± 3.69a</td>
<td>85.55 ± 4.13b</td>
</tr>
</tbody>
</table>

T₁ = Tamazula; T₂ = El Pitahayal; T₃ = El Terahuito; T₄ = La Trinidad; Tm = Seawater (control). Different superscripts letters within rows indicate significant differences ($P < 0.05$).

**DISCUSSION**

Growth Performance

If inland culture of marine shrimp *L. vannamei* is to continue to develop, we must acquire a better understanding of the influence exerted by the salinity or ionic composition of well water on the physiology of shrimp. Present results confirm reports that *L. vannamei* can grow at low salinity well water (0.52–0.88 psu), although the growth rates were lower than recorded with seawater. In the present work, *L. vannamei* was reared in four ICLSWW (T₁= 0.52, T₂= 0.88, T₃= 0.52, and T₄= 0.72 psu) at a stocking density of 200 shrimp/m² and grew from 0.02 up to 7.58 g (T₁) with growth rates of 0.63 (T₁), 0.62 (T₂), 0.57 (T₃), and 0.61 (T₄) g/week; while in the control condition (Tm= 34.00 psu), shrimp grew up to 8.85 g at 0.74 g/week. Some reports indicate that in marine water shrimp can grow until 1.19 g/week at stocking densities of 223–299/m² (Robertson et al. 1992). Under typical semi-intensive pond growout marine conditions, *L. vannamei* grow at a rate of about 1.10 g/week at a stocking density of 7 juveniles/m² (Clifford 1985). In intensive pond growout systems, shrimp growth is comparable; some data indicated that *L. vannamei* grew 1.26 g/week when stocked at a density of 25/m² (Huang 1990), 0.70 to 1.80 g/week at 45/m² (Wyban & Sweeney 1989), and 1.4 to 1.5 g/week at 75 to 100/m² (Wyban et al. 1987). In marine and stuarine waters, shrimp is capable of growing 1.4 g/week at densities of 2–3/m² (Menz & Blake 1980, cited by Wyban and Sweeney 1989).
On the other hand, Bray, Lawrence, and Leung-Trujillo (1994) and Samocha and colleagues (1998) reported that *L. vannamei* maintained in seawater grew better at low salinities (2–10 psu) than at high salinities (>15 psu). However, since the rule of constancy of composition of seawater does not apply to aquifer water, the salinity of well water in not a major factor in predicting its suitability for shrimp culture (Saoud, Davis, & Rouse 2003). Results of the present work demonstrated that not all the treatments of low salinity well water are equal, even if they originate from the same aquifer but at different locations. The T1 (Tamazula) water and the T2 (El Pitahayal) water are from wells that are less than 5 km apart and drilled into the same aquifer, yet they have different salinities and chloride, sulfate, calcium, magnesium, and sodium concentrations, although shrimp growth reared in that well water was not different. However, the lowest growth rate was reached in T3 (0.57 g/week), where potassium and calcium concentrations were the lowest (0.58 and 28.00 mg/L, respectively). In the present work, the lower shrimp growth as compared to seawater culture could have been influenced by the ionic composition of well water, since the concentrations of all major ions were much lower than those of normal seawater, except for bicarbonates. Although shrimp growth reared in the fourth treatment well water was not different, we found a tendency to have a bigger growth rate where the proportion of Na/K and Mg/K ratios (T1; 37.91 and 3.68, respectively) is closest to seawater (Tm; 14.8 and 2.4, respectively). Chang-Bo, Shuang-Lin, and Wang (2006) determined that good growth could always be obtained within a Na/K range of 34.1 to 47.3 (mmol/mmol) regardless of salinity. Although there were not significant differences in growth with the treatments of well water, there was a trend of increasing growth with the ionic proportions found in seawater (Tm) that should be investigated more closely.

Survival Rate

Few studies have focused on survival of juvenile *L. vannamei* at low salinities. Bray, Lawrence, and Leung-Trujillo (1994) found no differences in survival rates of 2 g juveniles reared between 5 and 40 psu. Samocha and colleagues (1998) found no difference in survival of 2 g juveniles between 2 and 8 psu. Ogle, Beaugez, and Lotz (1992) assessed the effects of salinity on survival of 22 day old *L. vannamei* postlarvae over 30 days, and no significant differences were found in survival between 4 and 16 psu, although a significant difference was obtained between 2 and 16 psu. Laramore, Laramore, and Scarpa (2001) performed a fourth experiment comparing juveniles (8 g) and postlarvae (0.05 and 0.35 g) cultured at salinities of 0, 2, 4, and 30 psu for 40 days and they reported that there was no postlarvae survival at 2 psu. Postlarvae survival at 4 psu (86%) was no significantly different from that at 30 psu (100%). Juveniles exhibited better survival at lower salinities
(100% at 2 psu) than 0.05 g and 0.35 g postlarvae (29% and 14%, respectively, at 2 psu). In the present study, only slight differences (there were no significant difference, \( P > 0.05 \)) in survival were observed among shrimp juveniles of 0.02 to 7.58 g (Table 3). Survival recorded in the present study (76.35% to 79.55%) is considered good for the 84-day growout period, although it was 7.6% lower than that recorded with the control treatment (Tm). In marine intensive pond trials, survival of *L. vannamei* is typically above 80% (Sandifer, Hopkins, & Stokes 1988; Wyban & Sweeney 1989).

As reported by Davis and colleagues (2002), Saoud, Davis, and Rouse (2003), and Zhu and colleagues (2004, 2006), the results from the present study confirm that the ionic composition of the well water is more important than salinity. Since salinity and the concentrations of most of the major ions of well water were much lower than those of normal marine water, the survival in well water was only 7.6% lower than that recorded in marine water (Tm) (Table 2).

Cawthorne and colleagues (1983) demonstrated that single salt solutions (NaCl) were not suitable for shrimp culture at any salinity. Additionally, Atwood and colleagues (2003) found that *L. vannamei* larvae could survive well in the solution containing 1 g/L sea salt, and they could survive fairly well after adding 4 g CaCl\(_2\) or 2 g CaCl\(_2\) and 2 g NaCl and the salinity reached 5 psu, but no survival would have resulted if 4 g NaCl had been added. They speculated that the sodium ratio to some other ion in the solution might be too high. Zhu and colleagues (2004) demonstrated that a high Na/K ratio in seawater resulted in poor survival of *L. vannamei*. However, in the present study, all Na/K ratios of the four treatments of well water were higher than that of seawater (Tm), except the well water T2, but survival was not affected significantly.

Even though in T2, the Na/K ratio was lower than in marine water and in the other well water treatments, shrimp survival in T2 was only 8% lower than in Tm and 0.61% lower than in the others. It is necessary to clarify that, in T2, the chloride, sulfate, calcium, and magnesium concentrations were higher than in the other well water treatments (Table 2), confirming that, aside from the Na/K ratio, the concentration of each one of the other major ions is important. However, further research is needed to confirm the proper range of the Na/K ratio and of the major ion concentrations for growth and survival of *L. vannamei* at low salinities (≤0.5 psu).

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