Ciencias Marinas Journal/Revista

# Effect of the water exchange system on the development, survival, and performance of *Argopecten purpuratus* larvae culture (Pectinidae, Mollusca)

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ARTICLE INFO

*Article history:*
Received 15 September 2023
Accepted 03 August 2024
Published 21 Novembre 2024

LEER EN ESPAÑOL:
https://doi.org/10.7773/cm.y2024.3437

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**ABSTRACT.** Scallop cultivation on the coasts of Peru and Chile is continuously expanding, leading to increased larval production and the mounting need to enhance efficiency to boost sector productivity. This study focused on investigating how the water exchange system affects the development, survival, and performance of *Argopecten purpuratus* larvae. Three static water exchange systems (T1 [12-h exchange], T2 [24-h exchange], and T3 [48-h exchange]) and 2 recirculation systems (RAS 1 and RAS 2) were evaluated, with 3 replicates per treatment. The feed supplied in each treatment consisted of a mixture of the microalgae *Isochrysis galbana*, *Diacronema lutheri*, *Chaetoceros calcitrans*, *Chaetoceros gracilis*, and *Nannochloropsis* sp. at a concentration of $5 \times 10^4$ cell·mL$^{-1}$·d$^{-1}$. The results showed that survival was higher in T1 (80.49%) than in T2 (68.49%) or T3 (67.17%); lower survival was observed in RAS 2 (52.94%) and RAS 1 (6.34%). Furthermore, T1 resulted in significantly greater growth (shell height: 192.2 ± 9.03 µm; growth rate: 3.7 µm·d$^{-1}$) than that of T2 or T3. Although RAS 1 was discarded due to high mortality, RAS 2 showed similar performance to that of T1 with regard to larval growth. Considering commercial factors and energy efficiency, T2 and T3 yielded the most favorable results in terms of larval survival and growth.

*Key words*: larviculture, cultivation systems, feeding, survival, performance, scallop, recirculation system, water exchange.

## INTRODUCTION

From ancient times to the present day, bivalve mollusks have been important coastal resources for human livelihoods, with their commercialization occupying a notable role in economic activities worldwide (Wolff 1988, Alvarado 2017, López de la Lama et al. 2018). In aquaculture settings, mollusks are ideal organisms to cultivate due to their feeding capacity, which is based on filtering the primary producers that grow in the cultivation tanks. In addition, the costs associated with their production, which include purchasing and maintaining nets and suspended systems, are easily accessible and relatively low, making bivalve mollusk aquaculture a business with a constant return on investment (Helm et al. 2004, Torkildsen and Magnesen 2004, Kluger et al. 2019). In Peru, the scallop *Argopecten purpuratus* has become the most commercially important bivalve mollusk, with its production accounting for 33.1% of all aquaculture production in the country (López de la Lama et al. 2018, PRODUCE 2022).

Bivalve mollusk aquaculture production involves several processes, including supplying or "seeding" larvae. This process is critical, as overall production depends directly on the supply of optimal larval seeds. Although there are various methods to obtain these larvae, 2 methods are commonly used in the industry. The first method involves placing collector units in the sea to gather larvae or post-larvae in the water column (Wolff 1988, Bandin and Mendo 1999, Galeno and Barbieri 1999, Pérez et al. 2012, Carvalho et al. 2013). Notably, this method is highly dependent on environmental conditions and recruitment capacity, which can vary greatly

Open Access
Online ISSN: 2395-9053
Screened via Similarity Check powered by iThenticate
https://doi.org/10.7773/cm.y2024.3437

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(Helm et al. 2004; Cantillanez et al. 2005; Lagos et al. 2015; Ramajo et al. 2016, 2019, 2020).

The second method involves the controlled production of larvae in specialized laboratories known as hatcheries (Spencer 2002, Kamermans et al. 2016, Pérez et al. 2016, López de la Lama et al. 2018). Hatchery production is a complex and integral process that requires the meticulous selection of broodstock individuals with optimal phenotypic and developmental characteristics, followed by induced spawning (Merino et al. 2009, Soria et al. 2010, Pérez et al. 2012). After fertilization, the resulting larvae occupy the water column, and their development depends on factors such as temperature, water quality, and the cultivation system.

Traditionally, static systems have been the most commonly used for larval hatchery production. These systems were introduced in the 1960s, with the first experiments conducted with species such as *Crassostrea virginica* (Loosanoff and Davis 1963) and *Ostrea edulis* (Walne and Spencer 1974). The use of static systems then spread, as they were modified for other species such as *A. purpuratus* (Pérez et al. 2012). However, the use of static systems was restricted to low-density larval cultivation and required a substantial amount of physical space. In addition, these systems required large volumes of water for production, the daily selection of larvae using mesh sieves, and constant pumping, which elevated energy costs. In addition, the physicochemical parameters of the seawater used for cultivation fluctuated continually due to changing environmental conditions, including variations in temperature, oxygen saturation, and nitrogen compounds, which increased the risk of pathogens and contaminants being introduced into the systems. These factors have been shown to negatively impact larval development and survival within static systems (Avendaño et al. 2001, Helm et al. 2004, Supan 2014, Kamermans et al. 2016, Ramos et al. 2021).

In recent decades, the production of bivalve mollusks in recirculating aquaculture systems (RAS) has proven to be a promising technology (Magnesen and Jacobsen 2012, Blanco and Kamermans 2015, Kamermans et al. 2016, Holbach et al. 2017, Pauletto et al. 2018), as it allows for high-density larval cultivation with low water exchange. However, RAS require notable investments and operational capital, as well as highly skilled personnel for their maintenance and operation (Vinatea and Andreatta 1997, Merino et al. 2009, Ramos et al. 2021). Therefore, the objective of this study was to evaluate the effects of water exchange systems on the development, survival, and performance of *A. purpuratus* larvae under cultivation.

## Materials and methods

### *Agropecten purpuratus* broodstock

Broodstock were sourced from the suspended cultivation systems of SeaCorp S.A.C. (Lima, Peru). Traceability was monitored per batch, which allowed for the broodstock to be carefully selected (7.8 ± 1.7 cm) and for their gonadal maturity stage to be determined (Sanjinez et al. 2016).

### Production of *Argopecten purpuratus* larvae under controlled conditions

After transporting the broodstock to the hatchery, epibionts were removed from their shells. Then, the broodstock were subjected to a purging process in an open system to minimize the presence of excretions during spawning. Spawning was induced through desiccation; the scallops were removed from the water and left exposed at the water surface for ~15 min (Velasco et al. 2007). Individuals that released oocytes were identified by their reddish color, selected, and placed in 20-L containers. The population size was estimated using a Nexcope NE620W (Ningbo Yongxin Optics Co., Zhejiang, China) binocular microscope and Sedgewick-Rafter counting chamber. Individuals that released spermatozoa were selected based on their size (Avendaño et al. 2001). After obtaining the gametes, fertilization took place at a spermatozoa:oocyte ratio of 4:1 (Gruffydd and Beaumont 1970, Winkler and Estévez 2003). After obtaining the zygotes, the larvae were allowed to complete embryonic development over ~2 d before the experimental stage began.

### Experimental design

#### *Static system*

Three static water treatments were established with the following water exchange regimes: T1 (every 12 h at 6 a.m. and 6 p.m.), T2 (every 24 h at 6 p.m.), and T3 (every 48 h at 7 p.m.). All of the water was removed from each tank during each exchange. No changes were made to these treatments during the experimental period. During each water exchange, the larvae were removed through a tube (5.08-cm diameter) located on the lower side of the tank, and sieved through various mesh sizes (75 µm, 100 µm, 125 µm, and 150 µm), according to larval size. Each treatment was replicated in triplicate (Fig. 1).

#### *Recirculation system*

Two RAS treatments (RAS 1 and RAS 2) were established that employed 2 types of sieves. The prototype for RAS 1 employed a sieve with 4 diagonally cut, 2.54-cm tubes (10% slope over 20 cm), which provided an effective area of ~285 $cm^2$ to retain the larvae in the system (Fig. 2). The prototype for RAS 2 utilized a tube-like structure (30.48-cm diameter) that allowed the sieve to be placed on both sides to maximize the area (1,400 $cm^2$) (Fig. 2). The sieves were replaced as the larvae developed (75–150 µm). The RAS system involved adapting the water outlet to the center of the tank, passing the water through a mechanical filter composed

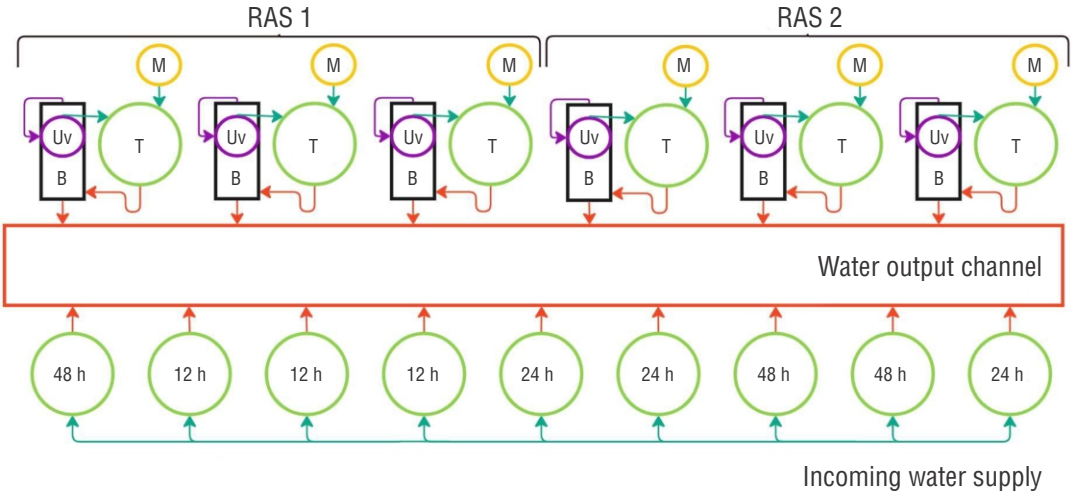


**Figure 1.** Experimental design and treatment distribution. The upper section shows the distribution of the 2 recirculation systems (RAS 1 and RAS 2). The RAS were composed of a larval tank (T) (experimental unit), microalgae container (M), biofilter (B), and ultraviolet lamp (Uv). The lower section shows the distribution of the static water exchange systems T1 (water exchange every 12 h at 6 a.m. and 6 p.m.), T2 (water exchange every 24 h at 6 p.m.), and T3 (water exchange every 48 h at 7 p.m.). The turquoise lines represent the inlets; the red lines represent the seawater outputs.

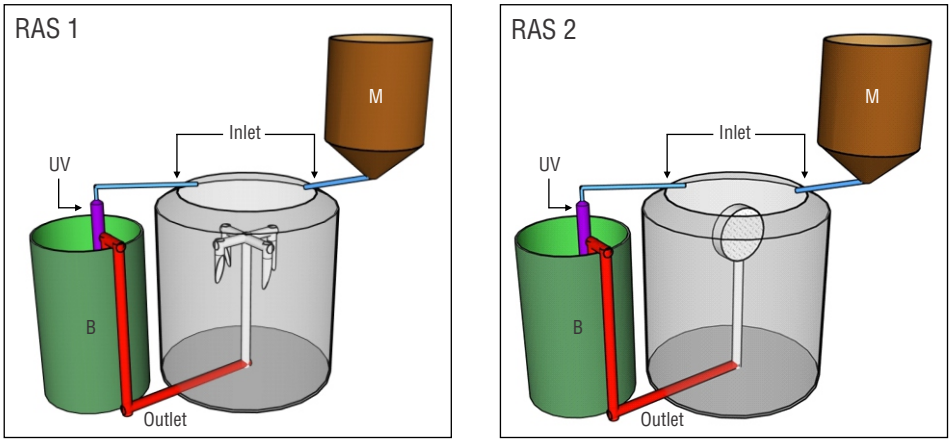


**Figure 2.** Simplified 3-D schematics of the 2 water recirculation system (RAS) prototypes: RAS 1 (left) and RAS 2 (right). Each RAS included a microalgae container (M), biofilter (B), and ultraviolet lamp (UV). The seawater inlets and outlets in RAS 1 and RAS 2 are represented by light blue and red tubes, respectively.

of black sponges and a 10-L mature biological filter (Krüger Kaldnes, Sandefjord, Norway), and sterilizing the water via UV radiation (Fig. 2) (Merino et al. 2009, Holbach et al. 2017, Silveira et al. 2023).

*Response variables*

The response variables of shell height (µm), specific growth rate (SGR), and survival were analyzed. To determine larval density during the course of the experiment (Table 4), 3 aliquots (1 mL) were collected per treatment each day, and the larvae in each sample were counted in a Sedgewick-Rafter chamber. Subsequently, shell height was measured in 12 randomly selected individuals per treatment (Fig. 3). Measurements were collected using a NE620W microscope (Nexcope, Ningbo Yongxin Optics Co.) and TouchScope Pro (Novel Optics, Ningbo Yongxin Optics Co.) calibrated at 4× magnification. The distance from the umbo region to the ventral valve (dorsoventral) was measured (Fig. 4), according to the methods of Sühnel et al. (2024). Mean shell height was used to calculate SGR (Avendaño et al. 2001):

$$SGR = \frac{Mean\ shell\ height(t_x) - Mean\ shell\ height\ (t_0)}{(t_x) - (t_0)}, \quad (1)$$

where $t_x$ is the final time, and $t_0$ is the initial time.

Larval survival ($S$) was estimated for each treatment (Angel-Dapa et al. 2021):

$$S = \left(\frac{D_f}{D_0}\right) \times 100, \quad (2)$$

where $D_f$ is the density of living larvae at the end of the experimental period for each treatment, and $D_0$ is the number of larvae at the beginning of the experiment.

*Experimental management and larval cultivation*

The experiment was conducted at the SeaCorp S.A.C. seed production laboratory in Sechura Bay (Piura, Peru). Twelve white polyethylene tanks (1-m diameter, 1-m$^3$ capacity) were used as experimental units. The seawater was passed through a sand filter, UV lamp, and nylon mesh to filter particles larger than 10 µm.

A mixture of microalgae, including *Isochrysis galbana*, *Diacronema lutheri*, *Nannochloropsis* sp., *Chaetoceros gracilis*, and *Chaetoceros calcitrans*, was used to feed the larvae, with the proportions varying during the experiment (Table 1). In treatment T1, half of the food dose was provided after each water exchange to prevent overfeeding and to maintain the experimental conditions. Physicochemical parameters, such as temperature, pH, and nitrogen compounds (nitrites, nitrates, and ammonia), were monitored daily. Temperature was measured with a TP101 digital thermometer (WMETERS, China), and pH measurements were taken with a research grade HI 5521 bench meter (Hanna Instruments, Woonsocket, USA) calibrated with a seawater scale (Dickson 1984). Test kits for nitrite, nitrate, and ammonia were employed to evaluate nitrogen compounds (API Fish Care, Chalfont, USA).

Performance was assessed based on the presence of larvae suitable for settlement, specifically those with an eye spot. In the static system, water exchanges were performed using filters that were appropriate for the stage of larval development (75–150 µm). In both RAS, 2 mesh sieves were installed to prevent the larvae from leaking out excessively from the water outlet and mechanical filter (discharge).

*Energy consumption*

The static cultivation system required a 1,492-W electric pump and a 180-W UV sterilization unit for water exchange. In contrast, both RAS required a 45-W pump and a 9-W UV filter. The usage time and energy consumption are given in Table 2. It is worth noting that this experiment did not consider energy consumption related to microalgae production.

**Statistical analysis**

Statistical analyses were conducted in RStudio v. 4.0.3 (Posit Team 2024). The response variables of shell height, density, survival rate, and growth rate were normally distributed and exhibited variance homogeneity, as assessed by the Jarque-Bera and Bartlett tests, respectively. An analysis of variance (ANOVA) was used to identify significant differences based on the water exchange factor. Subsequently, a post-hoc Tukey test was used to evaluate significant differences between groups.

## Results

**Cultivation conditions**

Temperature (17.65 ± 0.48 °C) and pH (7.54 ± 0.1) varied among treatments and remained consistent with natural conditions (Sicard et al. 1999, Martínez and Pérez 2003,

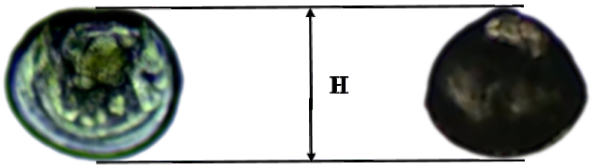


**Figure 3.** Schematization of a shell height (H) measurement for a D-larva (left) and an eyed veliger larva (right) observed under a microscope.

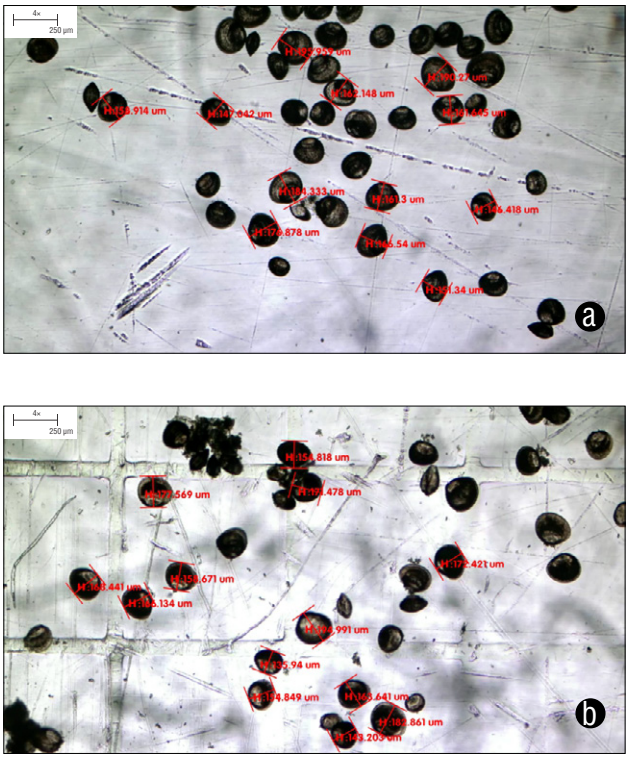


**Figure 4.** Shell height (H) measurements of *Argopecten purpuratus* larvae on the final evaluation day: (**a**) sample from T2 (water exchange every 24 h at 6 p.m.) and (**b**) sample from T3 (water exchange every 48 h at 7 p.m.).

**Table 1.** Composition and concentration (cell·mL$^{-1}$) of the microalgae feed supplied to *Agropecten purpuratus* larvae during the experiment (day 1 to day 19) in the static water exchange and recirculating aquaculture systems (RAS).

| Microalgae species | Day 1–5 (20,000 cell·mL$^{-1}$) | Day 6–9 (30,000 cell·mL$^{-1}$) | Day 10–15 (40,000 cell·mL$^{-1}$) | Day 16–19 (50,000 cell·mL$^{-1}$) |
|---|---|---|---|---|
| *Isochrysis galbana* | 10,000 | 10,000 | 10,000 | 10,000 |
| *Diacronema lutheri* | 10,000 | 10,000 | 10,000 | 10,000 |
| *Nannochloropsis* sp. | | 10,000 | 10,000 | 10,000 |
| *Chaetoceros gracilis* | | | 5,000 | 10,000 |
| *Chaetoceros calcitrans* | | | 5,000 | 10,000 |

**Table 2.** Energy consumption per cubic meter of water of the static water exchange systems (T1 [every 12 h at 6 a.m. and 6 p.m.], T2 [every 24 h at 6 p.m.], and T3 [every 48 h at 7 p.m.]) and recirculating aquaculture systems (RAS 1 and RAS 2) employed to culture *Agropecten purpuratus* larvae.

| System | Power (kW) | Usage (min·d$^{-1}$) | Energy consumption (kWh·d$^{-1}$) |
|---|---|---|---|
| T1 | 1.792 | 40 | 1.115 |
| T2 | 1.792 | 20 | 0.557 |
| T3 | 1.792 | 10 | 0.279 |
| RAS 1 and RAS 2 | 0.06 | 960 | 0.864 |

Merino et al. 2009). A rising trend in temperature was observed in T3 (48-h water exchange) and in RAS 1 and RAS 2 (continuous water exchange systems), which was not observed in T1 (12-h water exchange) or T2 (24-h water exchange) (Table 3). The recorded nitrogen compound values were lower than the detection limits of the kits used in the study (<0.01 mg·L$^{-1}$).

### Larval survival

Survival was significantly different ($P < 0.05$) between the static water exchange treatment of T1 (80.49%) and those of T2 (68.49%) and T3 (67.17%). This pattern was supported by the results of the Tukey analysis, which demonstrated that the water exchange system of T1 provided the most favorable conditions for larval survival. Additionally, a higher mortality rate was observed in both RAS, with 93.66% mortality in RAS 1 and 52.94% survival in RAS 2 (Table 4, Fig. 5).

### Shell height and the growth rate

Final shell height was statistically different ($P < 0.05$) among treatments, with the highest value (192.2 ± 9.03 µm) in treatment T1 (Fig. 6). It is important to note that larval size is a key indicator of their quality and ability to survive and develop. Significant differences in the growth rate were also observed among the different treatments (Table 4). It is worth mentioning that for RAS 1, data are only available until day 11, as this treatment concluded before the others due to its high mortality rate. On the other hand, the growth rate of RAS 2 was similar to that of T1 (Table 4). This suggests that RAS 2 was equally as effective in supporting larval growth as the other treatments employing static water exchange systems.

## Discussion

### Density and survival

Notably higher survival was observed in T1 (80.49%), which employed the static water exchange system (total exchange every 12 h). This result was mainly attributed to the water exchange regime of T1, which involved replenishing the tank with water and food twice a day. In this treatment, fresh food (half a ration) was provided to the larvae after each water exchange (Martínez et al. 1995, Torkildsen and Magnesen 2004, Turini et al. 2014, Arfken et al. 2021, Sarkis and Lovatelli 2022). In contrast, the larvae in treatments T2

(24-h water exchange) and T3 (48-h water exchange) were supplied with an entire food ration after each water exchange. These treatments showed similar survival values, which were inferior to that of T1.

Feeding plays a crucial role in larval development (Carvalho et al. 2013, Ran et al. 2020, Rojas et al. 2023). In particular, the timely supply of food with adequate characteristics greatly contributes to the health and survival of larvae in these cultivation systems (Martínez et al. 1995, Arfken et al. 2021, Rojas et al. 2021). In static systems in which water is completely replaced, it is essential to provide food promptly after each water exchange (Martínez et al. 1995; O'Connor and Heasman 1997; Nevejan et al. 2003a, b; Cheng et al. 2020) to ensure that larvae have access to the nutrients necessary for proper growth (Martínez et al. 2000, Cheng et al. 2020, Rojas et al. 2023).

In previous studies, the provision of food in 2 daily feedings resulted in better growth for *A. purpuratus* and *Mimachlamys asperrima* compared to that obtained with a single feeding but lower performance when compared to that obtained with continuous feeding (Martínez et al. 1995, O'Connor and Heasman 1997, Tidwell 2012, Qiu et al. 2015). It is important to note that Martínez et al. (1995) did not mention the use of a recirculation system. These results are similar to those of the present study; larvae in T1, which were fed twice a day, achieved the highest survival and growth. Furthermore, cell density was gradually increased from 20 cell·µL$^{-1}$ to 50 cell·µL$^{-1}$, using a mix of *I. galbana*, *D. lutheri*, *Nannochloropsis* sp., *C. gracilis*, and *C. calcitrans* (Table 1). This feeding strategy was implemented to ensure comprehensive coverage based on the nutritional characteristics of each type of microalgae (Martínez et al. 1995, Brown et al. 1997, Narvarte and Pascual 2001, Kuhn et al. 2013, Rojas et al. 2021).

**Table 3.** Average physicochemical parameters of the static water exchange systems (T1 [every 12 h at 6 a.m. and 6 p.m].), T2 [every 24 h at 6 p.m.], and T3 [every 48 h at 7 p.m.]) and recirculating aquaculture systems (RAS 1 and RAS 2) during the experimental phase.

| Treatment | Temperature (°C) | pH | Nitrogen compounds |
|---|---|---|---|
| T1 | 17.54 ± 0.42 | 7.57 ± 0.15 | <0.01 |
| T2 | 17.49 ± 0.36 | 7.52 ± 0.07 | <0.01 mg·L$^{-1}$ |
| T3 | 17.57 ± 0.32 | 7.53 ± 0.08 | <0.01 mg·L$^{-1}$ |
| RAS 1 | 18.22 ± 0.61 | 7.53 ± 0.07 | <0.01 mg·L$^{-1}$ |
| RAS 2 | 18.15 ± 0.67 | 7.53 ± 0.08 | <0.01 mg·L$^{-1}$ |

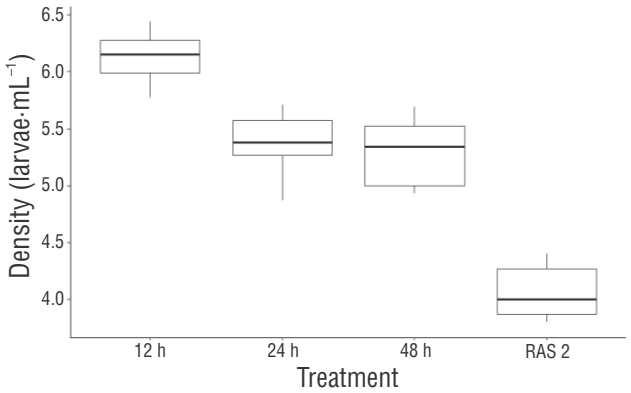


**Figure 5.** Density of *Argopecten purpuratus* larvae at the end of the experimental stage for each treatment: T1 (water exchange every 12 h at 6 a.m. and 6 p.m.), T2 (water exchange every 24 h at 6 p.m.), T3 (water exchange every 48 h at 7 p.m.), and RAS 2 (recirculation system 2).

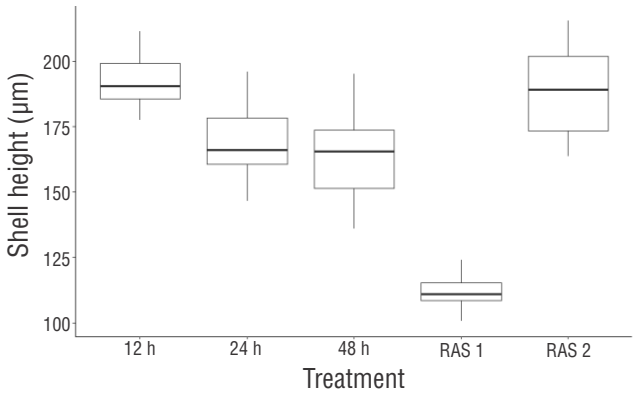


**Figure 6.** Shell height of *Argopecten purpuratus* larvae at the end of the experimental stage for each treatment: T1 (water exchange every 12 h at 6 a.m. and 6 p.m.), T2 (water exchange every 24 h at 6 p.m.), T3 (water exchange every 48 h at 7 p.m.), RAS 1 (recirculation system 1), and RAS 2 (recirculation system 2).

**Table 4.** Survival and specific growth rate (SGR) of *Argopecten purpuratus* larvae.

| Treatment | Survival (%) | Initial density (larvae·mL$^{-1}$) | Final density (larvae·mL$^{-1}$) | Initial shell height (µm) | Final shell height (µm) | SGR (µm) |
|---|---|---|---|---|---|---|
| T1 | 80.499$^{a}$ | 7.6 ± 0.28 | 6.11 ± 0.21 | 95.24 ± 7.76 | 192.2 ± 9.03$^{a}$ | 3.7 |
| T2 | 68.498$^{b}$ | 7.84 ± 0.41 | 5.36 ± 0.27 | 95.16 ± 7.19 | 169.19 ± 13.83$^{b}$ | 3.02 |
| T3 | 67.172$^{b}$ | 7.85 ± 0.29 | 5.27 ± 0.29 | 95.61 ± 7.97 | 163.46 ± 15.07$^{b}$ | 2.81 |
| RAS 1* | 6.343$^{d}$ | 7.58 ± 0.35 | 0.48 ± 0.15 | 95.17 ± 8.27 | 112.2 ± 6.56$^{c}$ | 0.87 |
| RAS 2 | 52.94$^{c}$ | 7.68 ± 0.28 | 4.07 ± 0.23 | 98.59 ± 8.02 | 189.01 ± 17.6$^{a}$ | 3.42 |

* Treatment withdrawn on day 11 of the experimental period. Letters indicate significant differences.

Treatments RAS 1 and RAS 2 showed low survival due to the mechanical stress caused by the inherent water recirculation in these systems (Table 4, Fig. 6) (Merino et al. 2009, Badiola et al. 2012, Ramos et al. 2021). Due to the observed mortality and sieve obstruction, RAS 1 had to be eliminated from the experiment on day 11. The difference in filtering area between RAS 1 (285 cm$^2$) and RAS 2 (1,400 cm$^2$) was notable and improved sieving by reducing the suction force and the damage caused by friction between the larvae and the sieve.

Despite the improvement in filtering area, RAS 2 was unable to match the survival rates of the static system treatments. This underscores the importance of considering not only the filtering area but other factors, such as the suction force and overall system conditions, in RAS. Daily sieve cleaning is required to prevent water flow obstructions, which can contribute to creating an environment conducive to the proliferation of bacteria and other microorganisms, thus promoting larval mortality (Andersen et al. 2000, Supan 2014, Ramos et al. 2021). Therefore, to optimize survival, adjustments to the sieving, cleaning, and maintenance processes are necessary (Vinatea and Andreatta 1997, Badiola et al. 2012, Hua et al. 2013, Kuhn et al. 2013, Cortés and Merino 2020, Yu et al. 2020, Arfken et al. 2021, Ramos et al. 2021).

These findings highlight the importance of the feeding frequency and regimen in static cultivation systems, as studies have conclusively demonstrated that providing food more frequently significantly improves larval survival (Martínez et al. 1995, O'Connor and Heasman 1997, Soria et al. 2007, Merino et al. 2009). The RAS presented additional challenges due to the inherent mechanical stress. Thus, implementing these systems will require specific adjustments to cleaning and maintenance processes to optimize larval survival (Smaal et al. 2019, Morris 2020, Sarkis and Lovatelli 2022). Unlike static systems, RAS are operationally more complex because they must be monitored and additional variables must be controlled, such as water quality and oxygen levels (Congrove 2012, Blanco and Kamermans 2015, Pauletto et al. 2018, Silveira et al. 2023).

**Shell height and the growth rate**

The obtained values for SGR fall (Table 4) within the range reported by Martínez et al. (1995) (6.06–6.88 µm·d$^{-1}$), Avendaño et al. (2001) (2.88–7.61 µm·d$^{-1}$), and Nevejan et al. (2003b) (1.38–7.5 µm·d$^{-1}$); it is important to highlight that all of the aforementioned authors conducted their bioassays with *A. purpuratus*. Merino et al. (2009) reported higher growth rates of 9.56–13.15 µm·d$^{-1}$, considering temperatures of 18.2–20.8 °C, which were slightly higher than those of the current study. However, in terms of survival, the static system achieved better results and was able to produce larvae suitable for settlement in a shorter period of time (~15 d) compared to RAS (~20 d). These results are very similar to those of the present study, with larvae ready for settlement on day 19 of culture, in addition to higher survival and a greater percentage of competent larvae produced in T1 (2-h water exchange). In contrast, significantly lower survival was observed in T3 (48-h water exchange) and RAS 2.

Furthermore, it is important to discuss the energy consumption of each system (Table 2). When considering the equipment and operating times per cubic meter of water per day of operation, it was observed that the energy demand was highest in T1 (12-h water exchange), followed by RAS 1 and RAS 2. Thus, the high energy investment required to operate T1 may impact production costs. On the other hand, the yields of T2 and T3 can be considered optimal from a commercial perspective. Indeed, if we evaluate the yields obtained in T2 and T3 as a reference for commercial consideration, these treatments were the most suitable. RAS 2 achieved higher growth rates; however, it also negatively affected larval survival, limiting its viability in terms of performance and efficiency (Badiola et al. 2012). Kamermans et al. (2016) determined that both conventional water exchange and recirculation systems produced similar yields of *Crassostrea gigas*, *Pecten maximus*, *Mytilus edulis*, and *Ruditapes decussatus*, without considering the energy costs associated with production and the risks associated with complete water exchange in conventional systems.

## Conclusions

The mechanical stress and the need to adjust cleaning and maintenance processes are crucial aspects that must be considered when optimizing larval survival in recirculation systems. On the other hand, the static water exchange system demonstrated that a higher feeding frequency significantly improved larval survival, highlighting the importance of designing appropriate feeding regimens for this type of cultivation system. In terms of performance, an optimal balance lies between the water exchange regimes of 24 h and 48 h. These intervals allow for acceptable larval survival to be maintained while reducing the associated energy demand, making them preferable to a 12-h water exchange regime.

## Declarations

### *Supplementary Material*

This work includes no supplementary material.

### *Acknowledgments*

The authors would like to thank the entire SeaCorp S.A.C. laboratory team, with special recognition for Hugo Inga, whose willingness was crucial to realize the operational portion of this study. Furthermore, we extend our sincere gratitude to BSc Arturo Mires for his invaluable feedback and constructive suggestions.

### *Funding*

This study was funded by *Programa de Innovación en Acuicultura y Pesca* (PNIPA) through the project "*Adaptación de un Sistema de Producción Innovador* y *Eco-amigable en un Hatchery de Concha de Abanico*, *Utilizando Energías Limpias e Incrementando la Eficiencia Energética para Reducir Costos y Asegurar el Suministro de Semilla en la Bahía de Sechura*" (grant no. SP-2020-00595).

### *Conflict of interest*

The authors declare they have no conflict of interest.

### *Author contributions*

Conceptualization: LRC, GA, EH (equal); Data curation: LRC; Formal analysis: LRC; Funding acquisition: EH; Investigation: LRC; Methodology: LRC; Project administration: LRC, EH; Resources: LRC; Software: LRC; Supervision: LRC, GA; Validation: LRC; Visualization: LRC; Writing–original draft: LRC; Writing–review & editing: LRC, GA.

### *Data availability*

The data for this study are available from the corresponding author by reasonable request.

### *Use of AI tools*

The authors did not employ any AI tools in this work.

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