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Evaluating Water Temperature Changes in Greenhouse and Non-Greenhouse Aquaculture Pond

Ünal Öz[1]*

Abstract: Greenhouse aquaculture is the subject of research for developing economic and applicable methods. This study was carried out to determine the water temperature changes in-greenhouse and out-greenhouse ponds used in aquaculture. The determined water temperature values were evaluated in terms of the cultivation of tropical freshwater aquarium fish. The research was conducted in a production facility where edible and ornamental fish were cultivated, with in-greenhouse and out-greenhouse ponds, for 48 days during the cold season. Water temperature values were measured daily. During the 48-day period between February and April in the Antalya region, the average water temperatures in-greenhouse and out-greenhouse ponds were determined as 23.53±0.16 °C and 15.37±0.16 °C, respectively, while the average in greenhouse air temperature was recorded as 28.15±0.56 °C. Statistical analysis indicated a significant difference between the average water temperatures. Considering these findings, it was determined that greenhouse-based systems play a crucial role in aquaculture, particularly for the cultivation of tropical aquarium fish.

Keywords: Aquaculture, Fish pond, Greenhouse, Water temperature

Sera ve Sera Dışı Su Ürünleri Yetiştirme Havuzlarında Su Sıcaklığı Değişimlerinin Değerlendirilmesi

Özet: Sera içi su ürünleri yetiştiriciliği ekonomik ve uygulanabilir yöntemlerin geliştirilebilmesi için araştırmalara konu olmaktadır. Bu araştırma, su ürünleri yetiştiriciliğinde kullanılan sera içi ve sera dışı havuzlardaki su sıcaklık değişimlerinin belirlenmesi için yapılmış ve belirlenen su sıcaklık değerleri tropical tatlı su akaryum balıklarının yetiştiriciliği açısından değerlendirilmiştir. Araştırma, sera içi ve sera dışı havuzları bulunan yemeklik ve süs balıkları yetiştiriciliği yapılan bir üretim tesisinde 48 gün süreyle, soğuk dönemde yürütülmüş ve günlük olarak su sıcaklık değerleri belirlenmiştir. Antalya bölgesinde Şubat ve Nisan ayları arasında 48 gün süreyle sera içi ve sera dışı havuzlarda ortalama su sıcaklık değerleri sırasıyla 23.53±0.16 °C ve 15.37±0.16 °C olarak, sera içi hava sıcaklığı ise 28.15±0.56 °C olarak belirlenmiştir. İstatiksel analiz sonucu ortalama su sıcaklıkları arasındaki farkın önemli olduğu saptanmıştır. Bu değerler göz önüne alındığında özellikle tropical akvaryum balığı türlerinin yetiştiriciliğinde sera sistemlerinin su ürünleri yetiştiriciliği için önemli bir üretim uygulaması olduğu bulgusunun desteklendiği belirlenmiştir.

Anahtar Kelimeler: Su ürünleri yetiştiriciliği, Balık havuzu, Sera sistemi, Su sıcaklığı

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[1]Sinop University, Faculty of Fisheries, Department of Hydrobiology, Sinop/Türkiye
***Corresponding Author:**
unaloz@sinop.edu.tr

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1. Introduction

Aquaculture is a highly valuable commercial sector. Fish farming, which dates back to ancient times, has evolved with increasing demand and technological advancements. In both edible fish and aquarium fish farming, two critical factors are the regulation of water and feeding protocols specific to the cultivated species. The fundamental criterion in managing water parameters and feeding practices is to meet the biological requirements of the target species. Water parameters and feeding procedures are interdependent and significantly influence the success of aquaculture, aiming for sustainable production conditions. Water temperature is a key factor that affects other water parameters such as pH, dissolved oxygen, and nitrogenous compounds (NH_3/NH_4+, NO_2, NO_3). Additionally, since fish are ectothermic organisms, water temperature plays a crucial role in the cultivation of aquatic species. The ornamental fish trade, a major branch of aquaculture, has grown into a multibillion-dollar industry across more than 125 countries. There are over 2.500 fish species involved in this trade, with more than 60% originating from freshwater habitats. Species such as koi and goldfish (carp species), guppy, molly, and platy (livebearers), ahli, yellow lab, and angelfish (cichlids), as well as crayfish species and various aquatic plants, are commonly produced on a commercial scale. Greenhouse ponds are particularly utilized for the cultivation of tropical species (Watson and Shireman, 2002; Li et al., 2009; Srinivasan, 2013; Mamun Siddiky and Mondal, 2016; Sirimanna and Dissanayake, 2019; Sharma, 2021).

Yongphet et al. (2016) investigated the heat preservation system of ponds inside and outside the greenhouse and the heat preservation system of the pond inside the greenhouse and determined that it is possible to increase the water temperature by integrating the greenhouse fish pond with the system that reduces heat loss.

Traditional greenhouses are primarily constructed using plastic film and wooden columns. This system is currently recognized as one of the most effective methods for improving operational performance. Research is ongoing to enhance optimal conditions in greenhouse systems, and new greenhouse techniques are being developed to regulate temperature more effectively in traditional aquaculture systems. Successful greenhouse-based aquaculture requires high wind resistance, efficient heat conservation, and reasonable costs. These requirements dictate the choice of construction materials and operational procedures (Peng et al., 2014).

Zhu et al. (1998) studied a greenhouse model to determine the thermal properties of greenhouse-covered small lake systems. This model was used to track small lake water temperature increases, compare the performance of different covering materials, and identify the primary heat flows within the system.

Sarkar and Tiwari (2006) reported their research on a thermal model for greenhouse pond systems. Klemetson and Rogers (1985) stated that a greenhouse or plastic-covered pond could increase water temperature by 2.8–4.4 °C compared to outdoor ponds throughout the year.

Greenhouse systems contribute to maintaining water temperatures within optimal ranges, particularly for the cultivation of tropical and temperate species. These systems help regulate the production cycle in terms of duration, quantity, and quality to meet market demands. As research on this topic increases, existing gaps in knowledge can be addressed, leading to more efficient production practices. In the coming years, climate changes driven by global warming are expected to heighten the demand for farmed aquatic products, thereby increasing the importance of aquaculture. Greenhouse systems, which offer advantages in controlling and optimizing environmental conditions, are also expected to play a crucial role in mitigating the impacts of climate change by maintaining stable production conditions (Öz, 2012).

Various construction materials, such as glass or plastic roofs and walls, are used in greenhouse structures. The glass or plastic covering acts as a barrier to airflow, helping retain energy within the greenhouse. While traditionally used for cultivating plants, vegetables, and flowers, greenhouses are now increasingly being utilized in aquaculture and aquaponic systems. These greenhouses require installation with heating, cooling, and lighting equipment to ensure optimal conditions. In fish farming, extremely low temperatures (e.g., 9°C) can lead to significantly reduced metabolic activity due to the ectothermic nature of fish, whereas excessively high temperatures (e.g., 45°C) can result in increased evaporation rates. Such extreme temperature variations highlight the necessity of maintaining water temperatures within ideal ranges to ensure successful aquaculture operations (Li et al., 2009; Omorodion and Madu, 2013; Mashaii et al., 2021).

Greenhouse-based aquaculture, including fish and shrimp farming, provides several advantages by mitigating adverse climatic conditions that may prevent the maintenance of optimal water temperatures for tropical and subtropical species. This system enables continuous or seasonal production, regardless of external weather conditions. Research is also being conducted to enhance the structural applications of traditional greenhouse systems to further improve their benefits (Peng et al., 2014; Akidiva et al., 2020; Mashaii et al., 2021).

Recent studies indicate that changes in rainfall, wind patterns, and temperature fluctuations can directly or indirectly impact disease outbreaks in aquatic species. Climate variability poses a significant risk to shrimp farmers, affecting production success and profitability. Compared to traditional outdoor shrimp farming, greenhouse-based shrimp farming can yield up to three production cycles per year. This makes greenhouse systems a viable option for maintaining a steady production flow throughout the year. Additionally, greenhouses can effectively protect shrimp from rainfall, reduce disease incidence, and enhance product quality. By preventing water temperatures from dropping below 18°C during winter and early spring, greenhouse systems can extend the shrimp farming season and ultimately increase profitability for aquaculture producers (Peng et al., 2014).

It is well established that fish metabolic rates and food consumption increase with water temperature. Previous studies have documented this finding (Likongwe et al., 1996; Tribeni et al., 2010; Musal et al., 2012; Hamed et al., 2021). This theory has been further validated by the observation that fish harvested from greenhouse ponds tend to be larger. Harrahy et al. (2001) suggested that lysozyme levels in most teleost fish are directly correlated with water temperature and that lower water temperatures reduce lysozyme activity. This indicates that fish raised at higher temperatures in greenhouse systems may benefit from improved immune function. Variations in greenhouse design, such as covering a larger surface area or positioning the structure closer to the water surface, may lead to more pronounced differences in temperature regulation. Consequently, further research on modifications to indoor fish pond designs, which could create thermal gradients, would be beneficial. Ideally, such interventions should be easy to implement and cost-effective, particularly for small-scale farmers in developing countries (Emam et al., 2023).

Research and experimental studies have demonstrated that greenhouses can be successfully and profitably constructed using cost-effective materials such as polyethylene, depending on their durability. Aquaculture practices are often conducted in greenhouses in arid regions where temperatures drop significantly and in extremely cold climates with harsh winters. It has been reported that, even during such unfavorable periods, fish farming and other aquaculture activities can be successfully maintained with minimal investment in greenhouse construction.

Since fish metabolic activities are directly influenced by environmental temperature, greenhouse systems must be regularly monitored to prevent extreme heating or cooling, which could negatively impact fish performance. Additionally, greenhouse systems play a dual role in mitigating extreme weather conditions: they help control excessive evaporation rates during hot seasons and maintain stable temperatures during extremely cold seasons (Omorodion and Madu, 2013).

Water temperature is the primary environmental factor influencing the growth and development of aquatic organisms. To sustain aquaculture production year-round, water temperature must be maintained within physiologically acceptable ranges. A common approach to achieving this is placing production units within enclosed structures where air and water are less affected by external climatic conditions. Greenhouse structures, which are typically used for vegetable and flower production, serve as cost-effective solutions for indoor aquaculture, as they are generally inexpensive to construct (Li et al., 2009).

The results show that construction of greenhouses in guadua for ponds using *Guadua angustifolia*, is an economical choice for fish farmers; the plastic covers of the ponds allow adequate control of the temperature of the water in the ponds and controls 100% fish predation by piscivorous birds. It is concluded that ground-floor ponds and plastic cover were the more efficient presenting ease of use, increased production of plankton, better productive and economical yield, coinciding with a greater thermal stability, followed by the ground-floor ponds without plastic cover, making it a viable alternative to optimize fish production. (Hahn-Von-Hessberg and Grajales-Quintero, 2016).

Maintaining optimal water temperature is essential for the growth, reproduction, and disease control of aquatic animals. One of the key advantages of greenhouse systems in aquaculture is their ability to reduce environmental variability. In regions where installation and heating costs are economically feasible, greenhouse-based aquaculture presents a highly advantageous production method (Öz, 2012).

This research was carried out to determine the effects of in-greenhouse and outdoor greenhouse ponds used in aquaculture on water temperature changes, and the determined water temperature values were evaluated in terms of ornamental aquaculture.

2. Materials and Methods

The research was carried out in a production facility with in-greenhouse and out-greenhouse ponds for aquaculture of edible and ornamental fish in Antalya province between February-April 2016 for 48 days in the cold period.

The study aimed to determine the differences in water temperature between fish ponds located outside and those inside a polyethylene-covered greenhouse. No heating system was utilized inside the greenhouse. The water depth in the ponds was 80 cm. The greenhouse had a length of 3 meters and a height of 1 meter. Daily measurements were conducted, recording the air temperature inside the greenhouse as well as the water temperature in both the greenhouse and outdoor ponds in the morning, noon, and evening (Li et al., 2009;

Omorodion and Madu, 2013).

2.1. Statistical Analyses

Statistical analyses were performed using Minitab Release 17 for Windows at a 5% level of significance. Data are presented as mean ± standard error (SE). The normality of the data obtained from different groups was investigated and ANOVA was used since the distribution was normal. One-way analysis of variance (ANOVA) was applied to analyze data from different experimental groups for each sampling period, followed by Tukey's HSD post hoc test for multiple comparisons, with significance set at $p < 0.05$.

3. Results and Discussion

In the Antalya region, over 48 days between February and April, the average water temperature in the greenhouse and outdoor ponds was determined to be 23.53±0.16 °C and 15.37±0.16 °C, respectively, while the average air temperature inside the greenhouse was recorded as 28.15±0.56 °C. Statistical analysis indicated that the difference between the average water temperatures was significant ($p<0.05$).

The minimum and maximum water temperatures recorded in the greenhouse ponds were 19°C and 27°C, while in the outdoor ponds, these values were 10°C and 19°C, respectively. The temperature difference between indoor and outdoor ponds was approximately 8.2 °C. Moreover, the average water temperature values recorded at morning, noon, evening, and night are presented in Table 1 and Figure 1.

Table 1. Average water temperature values (°C) recorded at different times of the day

Water Temperature (°C)	Morning	Noon	Evening	Night	Overall Average
Indoor Greenhouse Pond	22.57±0.20	24.37±0.29	24.08±0.29	22.53±0.40	23.53±0.16[a]
Outdoor Greenhouse Pond	14.62±0.25	16.22±0.25	15.81±0.31	14.55±0.44	15.37±0.16[b]

Different superscripts ([a], [b]) indicate a statistically significant difference between indoor and outdoor pond temperatures ($p<0.05$).

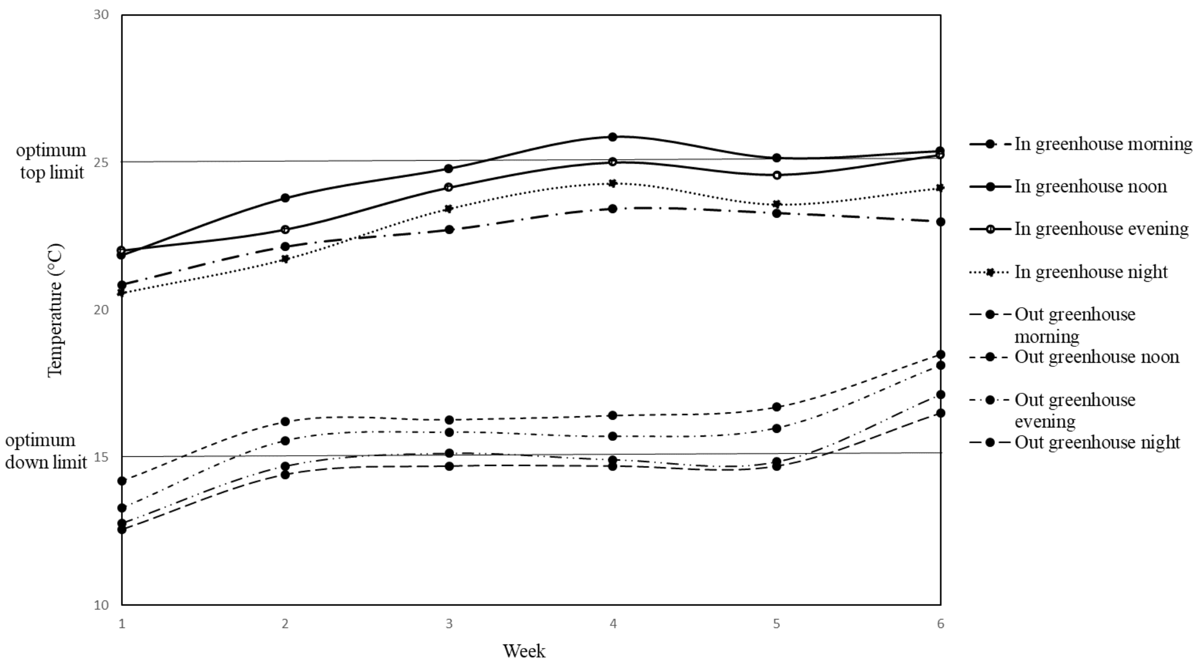

Figure 1. Average water temperature values (°C) recorded at weekly

The finding of this study, which indicates that the water temperature inside the greenhouse is higher than that outside, is consistent with the results of previous research (Omorodion and Madu, 2013; Josiah et al., 2014; Akidiva et al., 2020; Emam et al., 2023; Yongphet et al., 2016) (Table 2).

Table 2. Water temperature values in fish ponds inside and outside the greenhouse in different research and this research

Research	Inside greenhouse (°C)	Outside greenhouse (°C)	Temperature difference (°C)
Li et. al., 2009	min. 16-max. 18	min.6-max. 8	10
Akidiva et al., 2020	23.56	18.72	4.84
Omorodion and Madu, 2013	31-41	25-38	6-3
Yongphet, et al., 2016	26.7	26.4	0.3
Emam et al., 2023	28.06	26.12	1.94
Josiah et al., 2014	24.2	20.5	3.7
This research	23.53	15.37	8.16

Previous studies have also determined that temperature values inside the greenhouse are higher than those outside. This phenomenon is attributed to the greenhouse's ability to trap solar radiation, retain heat, and maintain temperature stability. Therefore, the proper management of temperature and humidity within the greenhouse is a critical factor for the success of greenhouse-based systems. In a study that monitored air temperature, water temperature, and evaporation readings over two weeks, the recorded temperatures inside the greenhouse were found to be 25–27 °C at 6:00 and 26–32 °C at 18:00, whereas the corresponding temperatures outside the greenhouse were 22–25 °C at 6:00 and 24–28 °C at 18:00 (Omorodion and Madu, 2013).

In aquaculture, the recommended optimal water temperature range for the production of many species is between 21–29 °C (Li et al., 2009). It has been reported that lower temperatures outside this range are not suitable for the optimal growth of warm-water fish species such as Nile tilapia. In such environments, greenhouse systems are among the technologies used in aquaculture to regulate water temperature and ambient humidity, as well as to prevent sudden drops or increases in temperature. There was a significant difference in the mean daily temperature recorded in the two pond systems. Greenhouse recorded a mean daily temperature of 23.56±1.74 ˚C with a maximum temperature of 27.13 ˚C and minimum of 20.90 ˚C while the open pond had mean temperature of 18.72±2.09 ˚C with maximum temperature of 24.40 ˚C and minimum of 15.60 ˚C recorded (Akidiva et al., 2020).

Akidiva et al. (2020) reported that the greenhouse pond temperature was within the recommended range of 22-28°C, which is suitable for Nile tilapia, and that the higher average temperature recorded in the greenhouse pond, as opposed to the open pond, was due to the "greenhouse effect". During sunlight exposure, the total solar radiation received by the greenhouse cover is partially reflected, absorbed, and transmitted into the greenhouse through the walls and roof. A significant portion of this transmitted radiation is absorbed by the water, leading to an increase in temperature. In the greenhouse pond, Nile tilapia exhibited a specific growth rate (SGR) mean value of 1.15±0.01 compared to 0.82±0.01 in the open pond.

According to Yongphet et al. (2016), generally, farmers must grow fish until they reach marketable size within approximately 6-8 months. However, in climbing perch (*Anabas testudineus*) aquaculture, controlling the water temperature between 28-32°C during winter and rainy seasons can shorten the required culture period to approximately 3-4 months. This approach can reduce production costs and save time. The average water temperature was determined as 26.4 °C during the day and 26.2 °C at night in the non-greenhouse fish cage, 26.7 °C during the day and 26.4 °C at night in the greenhouse fish cage, and 27.6 °C during the day and 26.5 °C at night in the fish cage integrated with a greenhouse heat loss reduction system. These results support the use of plastic film covering ponds, promoting higher growth performance and lower production costs. This study confirmed that the greenhouse system could be a promising method for climbing perch (*Anabas testudineus*) farming during cold seasons. The experimental results suggest that an insulated fish cage integrated with a greenhouse and a warm air ventilator could be beneficial for achieving higher fish growth rates and advantageous for fish farmers.

Zhu et al. (1998) indicated that simulation results showed that in a 1-meter-deep small lake, passive polyethylene greenhouse small lake systems could achieve a 5.2 °C increase in water temperature compared to the external air temperature. Water temperature values were recorded as 28.06±2.34 °C in the greenhouse and 26.12±2.91 °C in the control. Dissolved oxygen concentrations were also significantly higher in greenhouse small lakes compared to control ponds, recorded as 13.02±2.12 mg/L in the was reported between greenhouse and 11.38±1.36 mg/L in the control. However, no significant difference greenhouse and control ponds in terms of pH or total ammonia nitrogen (Emam et al., 2023).

According to Josiah et al. (2014), water temperatures in Kenya's high-altitude regions range between 16.5 °C and 22.5 °C, which is significantly lower than the optimal range of 24 °C to 32 °C known to be suitable for most tropical freshwater fish. Maintaining the required temperature for optimal metabolic range remains a challenge for many small-scale rural farmers. Greenhouses have been found effective in regulating temperatures within the required range with minimal fluctuations. Some studies have demonstrated that water temperature in a greenhouse can be increased by 3-9 °C (Zhu et al., 1998; Ghosal et al., 2005). The greenhouse treatment showed an average increase of 3.67 °C in water temperature compared to the outside treatment. Given that the growth of *Clarias gariepinus* in Kenya's high-altitude regions is largely constrained by low temperatures, adopting this technology could help achieve better growth and production in these areas. Greenhouses provide a relatively inexpensive supplementary heating technology to raise water temperature, thereby enhancing fish growth. Such a simple technology offers an additional advantage in cost reduction, ultimately increasing the profits of small-scale rural fish farmers. Consequently, the present study demonstrated that greenhouse use significantly increased internal greenhouse temperatures and enhanced the growth of African catfish juveniles. Stocking density and greenhouse-reared juveniles influenced fish growth performance, resulting in higher growth rates in terms of SGR, mean length, and weight gain. Greenhouse cultivation also improved the survival rate of *C. gariepinus* juveniles, as the recorded survival percentage inside the greenhouse was higher than outside.

Das et al. (2010) showed that water temperature increases of 4.13-6.92 °C could be achieved in greenhouse ponds with two collectors, while increases of 3.12-5.64 °C could be achieved in greenhouse ponds without collectors. Fish production in greenhouses was also significantly higher than in open ponds. In the study, *Cyprinus carpio* juveniles initially weighing 13.5 g reached weights of 53.8 g inside the greenhouse and 27.9 g outside, with the difference being statistically significant.

Ghosh et al. (2008) reported that the amount of fish produced in greenhouse and open ponds was 1.273 kg and 0.636 kg, respectively, while water temperature ranged from 18.5-21.5 °C in greenhouses and 13.0-15.5 °C in open ponds.

A model by Klemetson and Rogers (1985) describes the heat balance of open ponds by taking into consideration evaporation, convection and thermal radiation from the pond surface and the solar radiation absorbed by the water. The effects of greenhouses on the heat balance of ponds were modeled by assuming the air surrounding the ponds is saturated and wind speed is zero. The simulation study of Klemetson and Rogers (1985) predicted rise of water temperature by 2.8–4.4 °C. Little and Wheaton (1987) suggest using a computer model that a water temperature rise of 9–10 °C is achievable by placing a greenhouse cover. The experiment by Gaigher and Leu (1985) shows the water temperature of a pond using solar heating was about 6 °C above open pond water temperature (Li et al., 2009).

The numerical differences in findings obtained in research on this subject are believed to be the natural result of variations in environmental conditions such as seasonal characteristics specific to regions, water depth, pond location, and the structural material of the greenhouse and greenhouse cover. When evaluating the overall results, previous studies have indicated that water temperature differences between greenhouse and non-greenhouse ponds could increase by approximately 10°C during cold seasons, while in this study, an increase of up to 8°C was observed.

4. Conclusion

Based on the data obtained from this study, it has been determined that in regions with temperate climates where aquaculture is practiced, greenhouse systems significantly contribute to maintaining water temperature values during the winter season. This ensures the uninterrupted and targeted production of tropical and temperate aquatic species throughout the year. Many freshwater aquarium fish require water temperatures of 23 °C to 28 °C. For instance, species of the Poecilidae family, such as guppy, swordtail, molly, and platy, as well as species of the Cichlidae family, such as angelfish, discus, ahli, and demasoni, and labyrinth fish species like betta, gourami, and paradise fish, are classified as tropical species. Additionally, species such as goldfish and koi, known as warm-water species, have ideal water temperature ranges of 15-25 °C. In Türkiye, a significant portion of aquarium fish trade involves imported species. Although aquarium fish farming is developing domestically, production remains limited in meeting demand. Antalya and its surroundings provide favorable conditions for aquarium fish farming and are among the leading regions for this activity. The results of this study indicate that while the average outdoor pond water temperature was around 15 °C, the greenhouse pond water temperature was approximately 23.5 °C during the 48-day period between February and April in the Antalya region. These findings support the conclusion that greenhouse systems are a crucial production practice for aquaculture, particularly for tropical aquarium fish species.

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6. Compliance with Ethical Standards

a) Authors' Contributions

Ü. Ö.: designed, performed the experiment and data analysis, data collection and wrote the work.

b) Conflict of Interest

The authors declare that there is no conflict of interest.

c) Statement on the Welfare of Animals

Ethics committee approval is not necessary for this study.

d) Statement of Human Rights

This study does not involve human participants.

e) Funding

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