Colegio de Postgraduados

Thermal Variations and the Viability of Nile Tilapia (*Oreochromis niloticus*) Cultivation in Aquaculture Production Units in Zacatecas, Mexico

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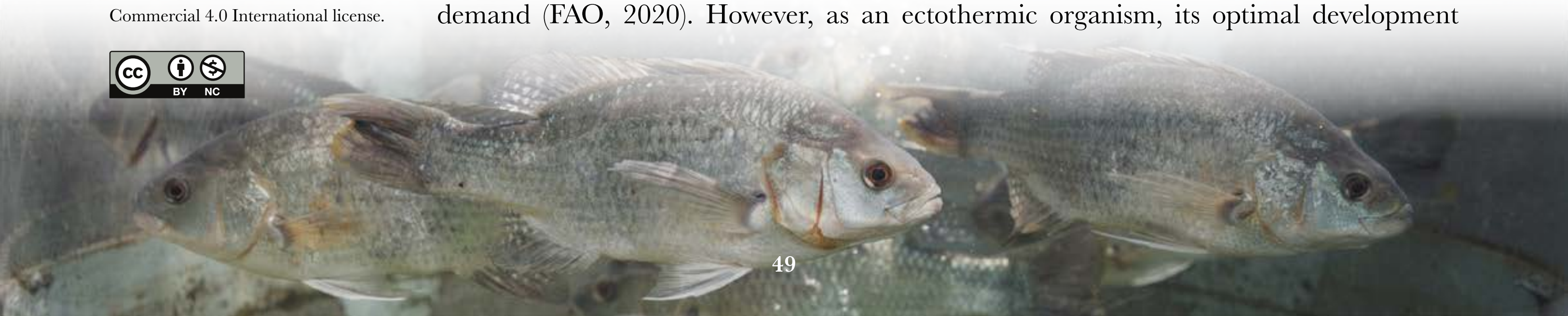
ABSTRACT
Objective: To analyze variations in ambient and water temperature in order to evaluate their impact on the viability of tilapia farming in Zacatecas.
Methodology: Variations in maximum and minimum ambient temperatures recorded at 14 meteorological stations located near Aquaculture Production Units (APUs) in the state of Zacatecas were analyzed. Historical records were systematically processed, and simple linear regression analysis was applied. In addition, water temperature was evaluated at five APUs dedicated to tilapia production using HOBO Onset data loggers, which recorded hourly temperature values.
Results: Statistically significant increases ($p<0.05$) in maximum temperature were identified at tenmeteorological stations. In contrast, minimum temperature exhibited increases at three stations and decreases at two. With respect to water temperature, findings indicate that, overall, current thermal conditions are not optimal for sustainable production. This underscores the need to implement complementary technologies, such as greenhouse systems, to effectively mitigate the adverse effects of low temperatures.
Limitations: This study presents no major limitations.
Conclusions: The analysis of extreme ambient and water temperatures revealed a clear relationship between these variables. It was determined that Tabasco is the only Aquaculture Production Unit (APU) in which temperatures fall within the optimal range for productive development during the warm season (April -October), without requiring the implementation of additional technological support.

Keywords: Temperature, climate change, growth.

INTRODUCTION

Tilapia (*Oreochromis niloticus*) has become one of the most important species in global aquaculture due to its remarkable adaptive capacity, rapid growth rate, and strong market demand (FAO, 2020). However, as an ectothermic organism, its optimal development



largely depends on environmental temperature, which directly regulates its internal body temperature (Boyd, 2018). This physical factor exerts a decisive influence on several physiological processes, affecting growth, locomotion, and reproduction (Volkoff & Rønnestad, 2020). Various authors have described, with some variation, the optimal temperature range for tilapia farming; this concept should be understood as the thermal interval within which organisms achieve their highest physiological and productive performance, reflected in superior growth rates, feed conversion efficiency, and survival. According to Swann (2000), this range lies between 23.9 °C and 32.2 °C. To optimize both weight gain and total biomass, conditions are particularly favorable when temperatures approach 28 °C (Kalule *et al.*, 2021). Nevertheless, other studies have proposed slightly different ranges. Importantly, the temperature to which fish have been previously acclimated influences both their preferred thermal range and the temperatures they tend to avoid when exposed to changes in water temperature (Acosta *et al.*, 2018). The capacity to tolerate extreme temperatures is determined by genetic factors and the organism's nutritional status (Oselame *et al.*, 2020). Likewise, the optimal temperature for aquatic organisms varies according to age and developmental stage (Volkoff & Rønnestad, 2020); when temperatures fall below 20 °C, metabolic activity decreases, negatively affecting feeding behavior and prolonging grow-out cycles (Hamed *et al.*, 2024). Temperatures outside the optimal range induce thermal stress in tilapia, disrupting hormonal regulation and compromising immune response, thereby increasing susceptibility to disease (Abram *et al.*, 2017; Zhou *et al.*, 2022). When temperature declines to approximately 13 °C, organisms may enter a state of paralysis, whereas values exceeding 32 °C trigger heat stress, impairing physiological homeostasis (Hassan *et al.*, 2017). These conditions adversely affect productive performance, reducing growth and yield, particularly when thermal fluctuations are intense or abrupt; conversely, gradual variations may allow partial acclimation processes (Borja *et al.*, 2006; Kovacevic *et al.*, 2019; Santillán-Espinoza, 2024).

In the state of Zacatecas, environmental conditions constitute a thermally restrictive system for tilapia farming. The high average altitude, exceeding 2,000 meters above sea level across much of the territory, promotes lower ambient temperatures than those observed in tropical regions, thereby increasing the frequency of thermal declines in water bodies. Moreover, climate change has intensified both the magnitude and frequency of extreme temperature events (Luo *et al.*, 2017); as a result, global temperature patterns have undergone significant alterations and are expected to continue fluctuating (Md Jakiul *et al.*, 2021). Within this framework, short- and long-term temperature variability underscores the necessity of understanding trends in maximum and minimum temperature fluctuations (Islam *et al.*, 2022; Nagayi *et al.*, 2022). Such analysis facilitates the identification of optimal thermal windows and critical production periods, thereby enhancing survival, growth, and overall production efficiency in tilapia farming systems. Based on this background, the research hypothesis was as follows: Ambient and water thermal variations recorded in tilapia Aquaculture Production Units (APUs) in the state of Zacatecas negatively affect the productive viability of the culture system, understood as the capacity of an aquaculture system to sustain adequate biological performance, expressed as yield under specific environmental and management conditions, thus enabling the functional continuity of the production process. Accordingly, the aim was to analyze both ambient and water thermal variations in order to assess their effect on production viability. This approach may support informed decision-making regarding pond location, production-stage planning, and infrastructure investment for temperature management.

MATERIALS AND METHODS

Study site

The analysis of thermal profiles was conducted in Aquaculture Production Units (APUs) over the period from November 2022 to December 2024, located in the state of Zacatecas, Mexico, specifically within the municipalities of Morelos, Fresnillo, Jerez, Tabasco, and Villanueva (Figure 1). These units were selected based on their active operational status. Additionally, records from 14 official meteorological stations of the National Water Commission (Comisión Nacional del Agua, CONAGUA) (Table 1), situated in proximity to the APUs, were included in the analysis.

Acquisition and processing of meteorological data

For the analysis of ambient temperature, data were provided by the National Water Commission (Comisión Nacional del Agua, CONAGUA). The meteorological stations closest to the Aquaculture Production Units (APUs) were selected, prioritizing those with the most extensive datasets, covering historical periods ranging from 41 to 86 years. The number of observations per station varied due to differences in record length and data availability within the CONAGUA database.

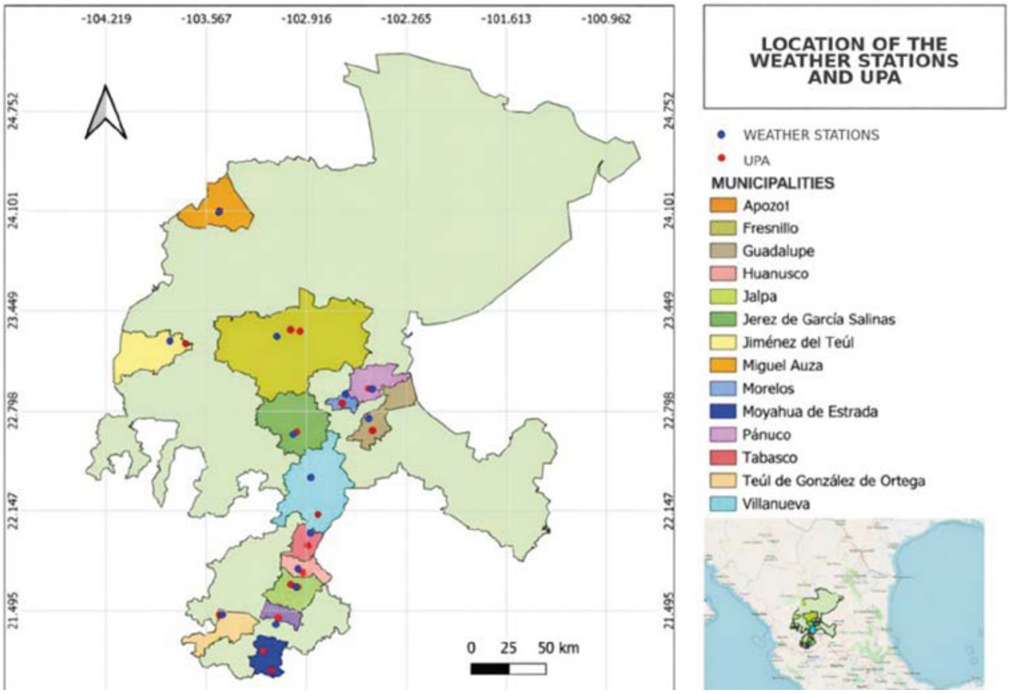


Figure 1. Location of the Aquaculture Production Units (APUs) and meteorological stations in the state of Zacatecas, Mexico.

Table 1. Spatial distribution of meteorological stations and Aquaculture Production Units (APUs) for thermal monitoring in Zacatecas, Mexico.

Station ID	Station	Latitude	Longitude	Elevation (masl)	UPA	Latitude	Longitude	Elevation (masl)
32191	Campo la Honda	24.0958	−103.4886	2191	Miguel Auza	24.1037	−103.4798	2193
32018	El Sauz	23.2817	−103.1089	2096	Fresnillo	23.3160	−102.9590	2042
32018	El Sauz	23.2817	−103.1089	2096	Fresnillo	23.3253	−103.0192	2062
32027	Jiménez del Teúl	23.2489	−103.8047	1924	Jiménez del Teúl	23.2334	−103.7003	2064
32047	San Antonio del Ciprés	22.9408	−102.4875	2173	Pánuco	22.9428	−102.5110	2259
32003	Calera	22.9086	−102.6597	2097	Morelos	22.8501	−102.6834	2203
32026	Jerez de García Salinas	22.6428	−103.0019	2000	Jerez	22.6610	−102.9780	2430
32121	Guadalupe	22.7469	−102.5067	2262	Guadalupe	22.6680	−102.4850	2292
32055	Tayahua	22.0978	−102.8719	1729	Villanueva	22.1214	−102.8414	1748
32013	El Chique	22.0003	−102.8892	1648	Tabasco	21.9170	−102.9050	1524
32025	Huanusco	21.7675	−102.9689	1490	Huanusco	21.7473	−102.9337	1439
32111	Jalpa	21.6522	−102.9814	1418	Jalpa	21.6501	−102.9668	1518
32111	Jalpa	21.6522	−102.9814	1418	Jalpa	21.6501	−102.9668	1532
32029	Juchipila	21.4047	−103.1142	1259	Apozol	21.4503	−103.1001	1302
32070	Teúl de González Ortega	21.4686	−103.4619	1909	Teúl de González Ortega	21.4667	−103.4833	1916
32125	Moyahua de Estrada	21.2589	−103.1569	1180	Moyahua de Estrada	21.6669	−103.0167	1560
32125	Moyahua de Estrada	21.2589	−103.1569	1180	Moyahua de Estrada	21.10722	−103.14295	1227

The APUs included in this study represent systems characteristic of the typical production management practices in the state of Zacatecas. No structural comparisons were conducted among units; therefore, variables such as pond type, operational volume, or depth were not considered analytical factors. The study focused exclusively on thermal variation. Some units operated under greenhouse infrastructure, whereas others functioned in open-air conditions; this distinction is described solely as part of the production context and was not incorporated as a comparative variable in the analysis. The duration of the record for each sensor was documented, along with any operational failures or data loss. The effect of water exchange on the thermal continuity of the time series was also considered. Instrument calibration checks were performed both before and after the monitoring period.

Subsequently, outliers and extreme values were removed, defined as those falling outside the range of the mean ± 1.96 times the standard deviation, approximating the 95% confidence interval. Once the dataset was refined, the intercept (β_0) and slope (β_1) were estimated using simple linear regression analysis in Excel (Microsoft). A significance level of $p<0.05$ was established for the slope coefficient β_1. The model applied was:

$$y = \beta_0 + \beta_1 X + \varepsilon$$

where: y corresponds to temperature (dependent variable); x to time in months (independent variable), β_0 to the intercept, β_1 to the slope reflecting the average change in temperature resulting from a unit variation in time and ε represents the error term.

The null hypothesis, evaluated at a significance level of $p<0.05$, postulated a slope equal to zero $(H_0 : \beta_1 = 0)$. Annual slopes, whether positive or negative, were transformed to a decadal scale $(\beta_1 \times 10)$ to enable comparison among time series of differing lengths; this procedure was described by Santillán-Espinoza (2011).

Water temperature was recorded using HOBO Onset devices (Pendant Temp/Light UA-002-64). The equipment was synchronized prior to installation and configured to record at hourly intervals.

Sensors were positioned at an approximate depth of 1 m within the pond. The recording duration was not uniform across all devices, as installation and operation were conducted in collaboration with the aquaculture producers. This resulted in variability in monitoring periods and partial data loss associated with routine system management practices, including pond water exchange.

Development of thermal profiles

Scatter plots were generated for the Aquaculture Production Units (APUs) using Excel (Microsoft), in which mean monthly water temperature, as well as mean monthly minimum and maximum ambient temperatures, were represented. A reference line corresponding to the optimal temperature interval for tilapia farming (23.9-32.2 °C) was incorporated.

Given that the monitoring period differed among units and that each site presented specific technical failures (periods without records), the total number of valid observations was not consistent across cases. Mean monthly water temperature was calculated as the arithmetic average of valid hourly records obtained during each month, whereas environmental variables were aggregated to the same temporal scale to ensure comparability. The optimal thermal interval was uniformly applied to all APUs as a physiological reference based on the species' thermal requirements, according to Swann (2000), regardless of variations in management practices or local environmental conditions. No statistical tests were performed to evaluate differences among months, as the analysis was descriptive and oriented toward the visualization of thermal patterns. Likewise, thermal profiles for all APUs are not presented in order to avoid redundancy.

Ambient-water thermal range in relation to the optimal interval for tilapia farming

A comparative assessment of the thermal variation range in the APUs was conducted, considering the annual amplitude of both ambient and water temperatures in relation to the optimal interval required by the species.

RESULTS AND DISCUSSION

Trend analysis of minimum temperature

Of the fourteen stations evaluated, Jerez de García Salinas, El Chique, and Jalpa exhibited statistically significant positive slopes ($p<0.05$) (Table 2). Conversely, San

Table 2. Results of the linear regression analysis of minimum temperature by station.

Minimum temperature trends					
ID	**Station**	β_0	β_1	**p**	**Trend (°C decade^{-1})**
32191	Campo la Honda	−203.7500	0.1018	0.0921	1.018
32018	El Sauz	−8.6349	0.0054	0.4477	0.054
32027	Jiménez del Teúl	24.7640	−0.0109	0.3663	−0.109
32047	San Antonio del Ciprés	232.3200	−0.1145	2.6747E-13	−1.145
32003	Calera	−19.4170	0.0110	0.3192	0.110
32121	Guadalupe	7.6521	−0.0012	0.9436	−0.012
32026	Jerez de García Salinas	−169.5100	0.0872	0.0002	0.872
32055	Tayahua	−37.8040	0.0220	0.0742	0.220
32013	El Chique	−48.8070	0.0290	0.0008	0.290
32025	Huanusco	102.9500	−0.0486	0.0017	−0.486
32111	Jalpa	−68.1560	0.0370	0.0349	0.370
32029	Juchipila	−0.5174	0.0040	0.7690	0.040
32070	Teúl de González Ortega	15.4820	−0.0051	0.6199	−0.051
32125	Moyahua de Estrada	79.9410	−0.0373	0.1513	−0.373

Antonio del Ciprés and Huanusco showed statistically significant negative slopes ($p<0.05$).

Análisis de la tendencia de la temperatura máxima

Las estaciones Campo la Honda, Jiménez del Teúl, Guadalupe, Jerez de García Salinas, Tayahua, El Chique, Huanusco, Jalpa, Teúl de González Ortega y Moyahua de Estrada registraron pendientes positivas con significancia estadística ($p<0.05$) (Cuadro 3). El Sauz presentó una pendiente negativa estadísticamente significativa ($p<0.05$).

Analysis of the thermal profile of the APUs

The thermal profiles of the Aquaculture Production Units (APUs) revealed the variation patterns of maximum and minimum water temperatures in conjunction with the corresponding mean maximum and minimum ambient temperatures. The temperature interval considered optimal for tilapia farming (23.9-32.2 °C) was also delineated.

Morelos production unit

As shown in Figure 2, the mean maximum water temperature reached 26.6 °C, whereas the mean minimum was 16.7 °C, the latter falling below the optimal interval for cultivation. It is important to note that this unit operates under greenhouse infrastructure. Regarding ambient maximum and minimum temperatures, the trend remained stable, as no statistically significant changes were detected.

Table 3. Results of the linear regression analysis of maximum temperature by season.

Maximum temperature trends					
ID	**Station**	β_0	β_1	**p**	**Trend (°C decade^{-1})**
32191	Campo la Honda	−191.3800	0.1088	0.0011	1.088
32018	El Sauz	47.7640	−0.0092	0.0244	−0.092
32027	Jiménez del Teúl	−49.2180	0.0398	4.5039E-09	0.398
32047	San Antonio del Ciprés	46.1920	−0.0087	0.2900	−0.087
32003	Calera	41.6500	−0.0069	0.1932	−0.069
32121	Guadalupe	−52.7120	0.0405	0.0002	0.405
32026	Jerez de García Salinas	−84.2540	0.0573	1.5781E-05	0.573
32055	Tayahua	−41.7320	0.0375	1.557E-06	0.375
32013	El Chique	−48.6840	0.0412	4.8739E-11	0.412
32025	Huanusco	−137.0100	0.0856	1.5343E-15	0.856
32111	Jalpa	−152.2200	0.0933	2.3796E-16	0.933
32029	Juchipila	12.2390	0.0113	0.1666	0.113
32070	Teúl de González Ortega	−71.6210	0.0513	2.3733E-14	0.513
32125	Moyahua de Estrada	−17.8680	0.0264	0.0422	0.264

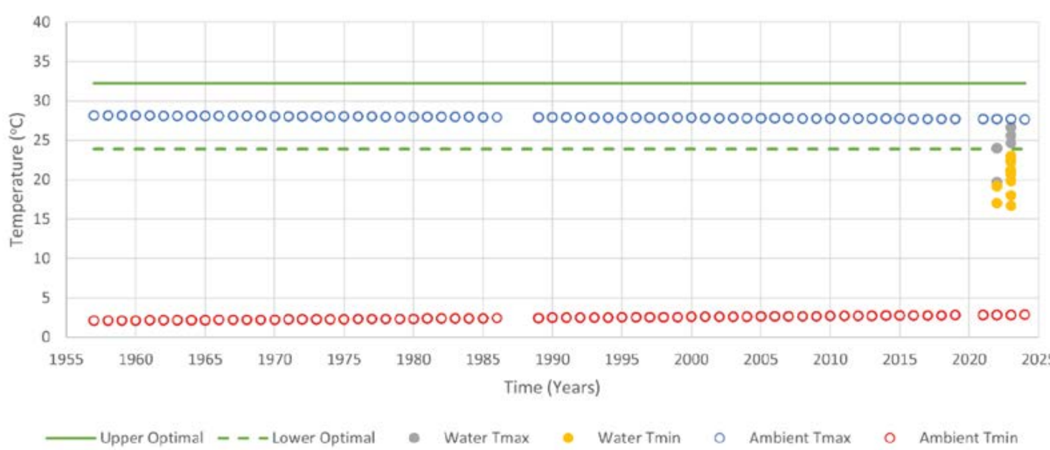


Figure 2. Historical ambient and water thermal profile in the Morelos Unit, with reference to the critical temperature range for tilapia farming.

Tabasco production unit

This unit exhibits relatively favorable conditions for cultivation, as mean maximum water temperatures reached 26.3 °C and mean minimum temperatures 19.9 °C. Furthermore, ambient temperatures showed an increasing trend, with a rise of 0.412 °C per decade in maximum temperature and 0.290 °C per decade in minimum temperature (Figure 3).

It is noteworthy that this unit operates under open-air conditions and benefits from access to a natural thermal water source characteristic of the region, which is strategically utilized to regulate pond temperature. This technological and environmental attribute

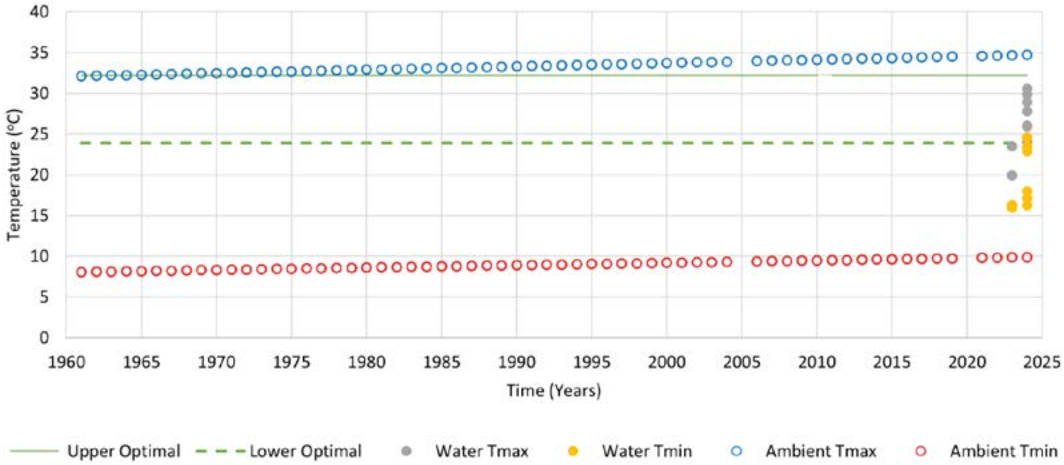


Figure 3. Historical ambient and water thermal profile in the Tabasco Unit, with reference to the critical temperature range for tilapia farming.

constitutes a competitive advantage over other production units located in areas with greater thermal risk.

Hourly temperature variation in the Morelos unit

As shown in Figure 4, water temperature remained within the optimal range for an average of 9.3 hours per day, with declines below this threshold occurring during the colder months.

Hourly temperature variation in the Tabasco Unit

The temperature record in the Tabasco Unit (Figure 5) indicated that, from November to March, water temperatures remained below the optimal range for cultivation. In

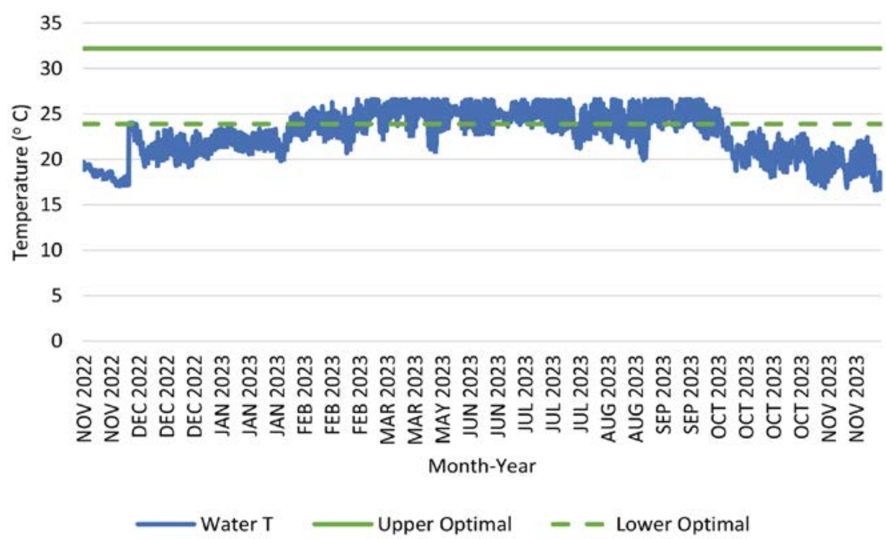


Figure 4. Water thermal profile in the Morelos Unit, with reference to the critical temperature range for tilapia farming.

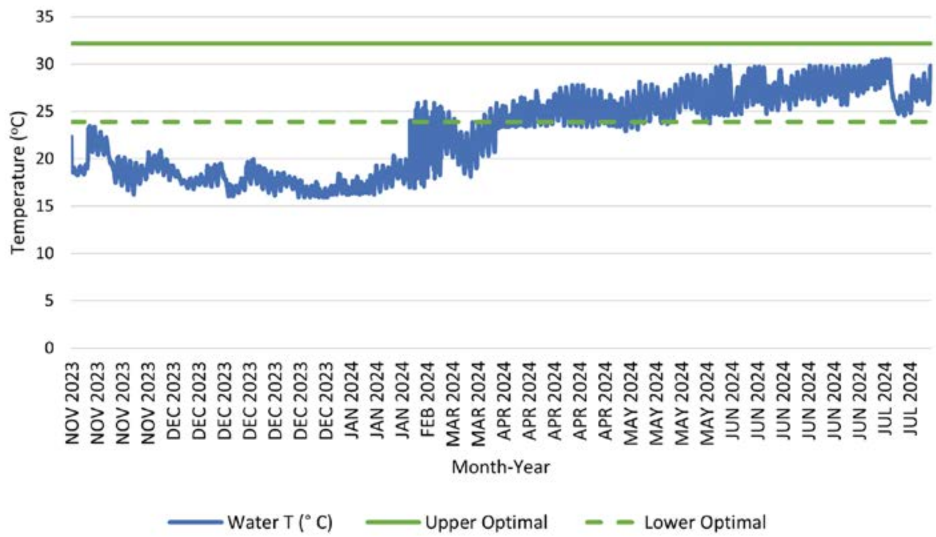


Figure 5. Water thermal profile in the Tabasco Unit, with reference to the critical temperature range for tilapia farming.

April, favorable thermal conditions were reached, with temperatures remaining within the optimal interval for an average of 22.3 hours per day, thereby enabling productive development without the need to implement supplementary technologies. Additionally, suitable conditions for cultivation were observed for approximately seven months of the year.

Ambient-water thermal range in relation to the optimal interval for tilapia

The assessment of thermal amplitude revealed marked variability among the APUs analyzed (Table 4). Ambient temperature amplitudes ranged from 23.2 °C to 29.5 °C, with the greatest amplitude recorded in Moyahua de Estrada. Regarding water temperature, amplitudes were comparatively lower, with values ranging from 4.2 °C to 9.9 °C. On average, water temperature across the APUs with available data was 21.8 °C.

The analysis of data obtained from meteorological stations located near the Aquaculture Production Units (APUs) enabled the identification of thermal variations within the study region. This information is essential for evaluating the viability of tilapia farming, as temperature constitutes a decisive factor in the sustainability and productivity of this activity. Of the 14 meteorological stations analyzed, 12 exhibited thermal trends, reflecting diverse scenarios. Maximum temperature increased at 10 stations and decreased at one, whereas minimum temperature increased at three stations and decreased at two.

This trend was observed in municipalities such as Miguel Auza, Jiménez del Teul, Guadalupe, Villanueva, Teul de González Ortega, and Moyahua de Estrada. With the exception of Moyahua de Estrada, this pattern resulted in an increase in thermal amplitude. According to Dos Santos *et al.* (2022), such conditions may constrain tilapia growth and weaken immune function. Despite the overall warming trend, water temperatures recorded in the Jerez Unit remain below the optimal values required for adequate tilapia growth,

Table 4. Variations in extreme temperatures.

APU	Ambient temperature (°C)			Water temperature (°C)				
	Tmax-Tmin	Mean	Amplitude	Tmin -Tmax (Optimal Range)	Optimal Mean	Tmax-Tmin	Mean	Amplitude
Miguel Auza	27.5-1.1	14.3	26.4	23.9-32.2	28.1			
Fresnillo	29.2-2.1	15.7	27.1	23.9-32.2	28.1	23.1-18.9	21.0	4.2
Jiménez del Teúl	30.1-3.1	16.6	27.0	23.9-32.2	28.1			
Pánuco	28.9-3.8	16.4	25.1	23.9-32.2	28.1			
Morelos	27.7-2.5	15.1	25.2	23.9-32.2	28.1	26.6-16.7	21.7	9.9
Guadalupe	28.4-5.2	16.8	23.2	23.9-32.2	28.1			
Jerez	30.6-5.4	18.0	25.2	23.9-32.2	28.1	24.7-18.7	21.7	6.0
Villanueva	33.2-6.2	19.7	23.7	23.9-32.2	28.1	23.7-19.2	21.5	4.5
Tabasco	33.2-9.1	21.2	24.2	23.9-32.2	28.1	26.3-19.9	23.1	6.4
Huanusco	33.8-6.0	19.9	27.8	23.9-32.2	28.1			
Jalpa	34.5-5.8	20.2	28.7	23.9-32.2	28.1			
Apozol	34.8-7.5	21.2	27.3	23.9-32.2	28.1			
Teúl de González Ortega	30.7-5.4	18.1	25.3	23.9-32.2	28.1			
Moyahua de Estrada	34.9-5.4	20.2	29.5	23.9-32.2	28.1			
Average	31.3-4.8	18.1	26.5	23.9-32.2	28.1	24.9-18.7	21.8	6.2

thereby limiting the potential benefits of this thermal increase. In contrast, the scenario in Tabasco is favorable during the warm season, as temperatures recorded during this period optimize productive development, as indicated by Abdou (2023). Stations with stable temperatures and no significant annual variation were also identified, as in the case of Calera.

Additionally, certain locations exhibited a decrease in minimum temperature while maximum temperature remained constant, such as San Antonio del Ciprés. In other cases, such as El Sauz, a decline in maximum temperature was recorded. According to Md Jakiul *et al.* (2021), Ahmed *et al.* (2023), and Khallaf *et al.* (2021), these scenarios pose a substantial risk to cultivation, as minimum temperatures below 0 °C are recorded during the coldest season of the year. After organizing temperature data according to geographic location from north to south, two distinct thermal trends were identified within the study area. The first group-Campo la Honda, El Sauz, Jiménez del Teul, San Antonio del Ciprés, Calera, Guadalupe, and Jerez de García Salinas-registered maximum temperatures below the upper optimal threshold.

This indicates that even during the warmest months, these regions present a high risk for tilapia production due to insufficient thermal conditions. It is noteworthy that the Calera station, although part of this group, did not exhibit a significant trend, indicating thermal stability; however, ambient conditions do not contribute to improving the situation in the Morelos Unit, as minimum temperatures remain below 0 °C.

In contrast, the second group Tayahua, El Chique, Huanusco, Jalpa, Juchipila, and Moyahua de Estrada showed average maximum temperatures of 33.7 °C and minimum temperatures of 6.4 °C. Notably, the Tabasco station recorded maximum temperatures of 34.7 °C and minimum temperatures of 9.8 °C. Although Juchipila did not present a significant trend, its maximum temperatures exceed the upper optimal threshold, and minimum temperatures remain near 7.5 °C; under specific conditions, this scenario may be favorable for cultivation during the warm season. In the southern region of the state, municipalities such as Villanueva, Tabasco, Huanusco, Jalpa, Apozol, Moyahua de Estrada, and Teúl de González Ortega except for the latter exhibit a thermal pattern distinct from the rest of the state, characterized by warmer climates. According to the present analysis, mean annual ambient temperatures range approximately between 20 and 22 °C, consistent with reports by the National Institute of Statistics and Geography (INEGI, 2021). A notable case within the region is the municipality of Teúl de González Ortega, which contrasts with the general thermal pattern. Owing to its higher altitude, this area exhibits a lower mean temperature (approximately 18 °C), resulting in comparatively colder environmental conditions. This atypical thermal behavior implies that, although the municipality is located within a predominantly warm subhumid region adjacent to municipalities such as Juchipila and Moyahua de Estrada, its actual thermal conditions may limit tilapia development, as water temperatures seldom reach the optimal growth range. This local variability underscores the importance of conducting site-specific thermal assessments prior to establishing aquaculture production units. Following the analysis of thermal profiles, results from two representative APUs were presented to illustrate the characteristic patterns identified: Morelos, belonging to the first group where ambient maximum temperatures remain below the upper optimal threshold, and Tabasco, representing the second group where maximum temperatures exceed this threshold.

Observed trends indicate a direct relationship between ambient and water temperatures, suggesting that meteorological records may serve as a valuable tool for predicting thermal behavior in culture ponds. These findings are consistent with Tamara *et al.* (2024), who also reported a strong correlation between air and water temperature. Overall, the average maximum water temperature across the APUs was 24.9 °C, and the average minimum was 18.7 °C, resulting in a general mean of 21.8 °C. Tabasco recorded the highest mean water temperature (23.1 °C) compared to Fresnillo, Morelos, Jerez, and Villanueva, demonstrating more favorable environmental characteristics for cultivation during the warm season. In contrast, temperatures in the remainder of the state fall below the optimal range, thereby limiting growth performance, as suggested by Ahmed *et al.* (2023). Regarding thermal amplitude, the Tabasco Unit exhibited lower amplitude, reflecting greater thermal stability and consequently more stable conditions for cultivation. Conversely, the Morelos Unit displayed greater amplitude, indicating more pronounced fluctuations between minimum and maximum temperatures-factors that directly influence metabolism and growth.

CONCLUSIONS

Differences were identified between ambient and water temperatures, with the latter exhibiting less pronounced oscillations. Although water temperature partially buffers thermal fluctuations, this mitigation is insufficient to ensure optimal tilapia performance. The identification of zones with temperatures closer to the optimal cultivation range facilitates the detection of areas requiring management adjustments under extreme thermal conditions. This approach supports the geographic prioritization of investments, the improvement of management practices, and the promotion of positive changes in production systems. The analysis of the production system's thermal profile revealed that, in general, temperatures are unsuitable for profitable tilapia development in most APUs. The exception is Tabasco, where optimal temperatures are reached during the warm season (April-October) without the need for technological intervention. These findings suggest substantial potential for the regionalization of Nile tilapia (*O. niloticus*) cultivation in the southern part of the state, particularly in the APUs located in Tabasco, Huanusco, Jalpa, Apozol, Juchipila, and Moyahua de Estrada.

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