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Influence of temperature in aquaponic system on nitrification processes

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Abstract. Aquaponics systems that combine aquaculture and hydroponics ensure a sustainable circulation of resources, and temperature is a key factor in determining the efficiency of nitrification processes and the overall productivity of such ecosystems. The study conducted an overview of scientific research published in the period 2014-2022 on the impact of temperature on nitrification processes and the overall efficiency of aquaponics systems. More than 100 scientific sources were analysed, including articles from international scientific journals, monographs and other publications covering various aspects of temperature effects on biological processes in aquaponics. Studies on the temperature ranges that are optimal for maintaining nitrifying bacteria activity and aquaculture health, as well as their interaction with factors such as nitrogen levels in the system and plant productivity, were emphasised. Studies demonstrated that temperature is an important factor in determining the rate of nitrification processes, fish and plant productivity, and the sustainability of the ecosystem. Too high a temperature can accelerate the nitrification process, but it also creates stress for the fish, which reduces their viability. Instead, low temperatures can slow down processes but increase the resistance of living organisms. This review has provided a thorough assessment of current approaches

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to temperature control in aquaponics systems and recommendations for the practical application of the results obtained in different climatic and technological situations. In addition, the prospect of developing new approaches to temperature optimisation to ensure the efficiency and sustainability of aquaponics systems in the future is discussed

Keywords: aquaponics; nitrates; phosphates; nutrients; ammonium nitrogen; clarius catfish

Introduction

Aquaponics, the integration of aquaculture and hydroponics, is an innovative technology that enables sustainable food production where fish and plants interact in a closed ecosystem. One of the key processes in such systems is nitrification, the biological oxidation of ammonium to nitrite and nitrate by nitrifying bacteria. This process is important for maintaining water quality, as it helps to reduce the concentration of toxic ammonium accumulated as a result of the metabolic activity of fish. Temperature is one of the main factors affecting the speed and efficiency of nitrification. It directly affects the metabolism of microorganisms, in particular the activity of nitrifying bacteria such as *Nitrosomonas* and *Nitrobacter*. Since the temperature regime in aquaponic systems can vary depending on the time of year, geographical location and other conditions, it is necessary to determine how different temperature ranges affect this process.

In Ukraine, there are fish farms in Vasylkiv and the villages of Kamianka Buzka in Lviv and Zaborol in Rivne regions. The technologies for rearing Clarius catfish and other fish species developed by local specialists are constantly being improved, but there are no scientific publications. An interesting publication is N.E. Hrynevych *et al.* (2021), which investigated the sanitary and biological parameters of water at critical points of the mentioned aquaculture system after passing through mechanical and biological filters. The authors noted the high efficiency of the biological filter for maintaining the sanitary condition of water in the UZV for sterlet rearing.

Previous scientific studies, as well as the dissertation study, have raised certain aspects of the functioning of nitrification processes in aquatic ecosystems and technologies, but omit several key issues. O.M. Vodyanitskyi *et al.* (2016) analysed the impact of the type of biofilter filler on the development of nitrifying microorganisms in water recycling systems, but the temperature factor, as one of the determinants of the activity of microbial consortia, was not the subject of the study. V.O. Yurchenko *et al.* (2021) examined nitrification processes in drinking water sources and water treatment facilities, but the specific conditions of closed aquaponic systems, in particular the temperature sensitivity of microbiocenoses, were not considered. The thesis of M.V. Zadorozhny (2023) addressed the effect of temperature on nitrification processes, but it did not provide a comprehensive analysis of the relationships between temperature regimes, the structural and functional state of nitrifying microorganisms, and the efficiency of inorganic nitrogen transformation in aquaponics. P. Debroy *et al.* (2024) investigated the effect of temperature on the productivity of aquaponic systems and fish growth. The authors determined that optimisation of water temperature is a critical factor in maintaining ecosystem stability and increasing biomass. These results highlight the importance of temperature control for the effective management of aquaponic farms. The study by L.K. Tolentino *et al.* (2019) analysed temperature stabilisation methods to improve nitrification efficiency in aquaponic systems. The study demonstrated that maintaining a stable temperature regime significantly improves the activity of nitrifying bacteria and overall water quality. The authors proved that temperature optimisation is a key factor in ensuring the sustainable operation of aquaponic plants. Thus, the issue of systematic generalisation and critical analysis of modern scientific data on the influence of temperature on nitrification processes in aquaponic systems remains relevant, determining the study goal.

Despite substantial research on the effect of temperature on nitrification in traditional biological systems, this issue remains insufficiently investigated in the context of aquaponics. Different researchers have provided conflicting results regarding the optimal temperature conditions for the stable operation of aquaponics systems. As temperature can have not only a direct impact on microbiological processes, but also indirectly through changes in other parameters (e.g. oxygen or ammonium levels), studying this issue is important for improving aquaponics technology. The review aimed to collect and systematise data on the effect of temperature on nitrification processes in aquaponic systems, to identify existing contradictions in scientific research and to identify potential areas for further research.

The research was based on the analysis of scientific sources covering the influence of temperature in aquaponics systems on nitrification processes. The literature search was conducted in the databases Scopus, Web of Science, Google Scholar, as well as in the open archives of scientific publications, ResearchGate, PubMed, and SpringerLink. The following keywords were used to select materials: "aquaponics", "nitrification", "temperature effect on nitrification", "ammonia oxidation in aquaponics". Articles published after 2010 and before 2022 that contain empirical data on the temperature effect on nitrification rates, nitrogen toxicity, and biofilters were prioritised. The analysed sources were grouped per key aspects of the topic: temperature requirements of fish in aquaponic systems, features of the nitrogen cycle, the effect of temperature on the activity of nitrifying bacteria, and methods of temperature control. The publications that did not contain experimental data, were limited to a general description of aquaponics or did not consider the effect of temperature on nitrification, were rejected. This approach formed a generalised picture of current research and identified the main trends in the study of temperature-dependent nitrification processes in aquaponic systems.

Aquaponic system – a symbiosis of hydroponics and aquaculture

The aquaponics system is an integrated environmental technology that combines hydroponics and aquaculture. The water containing fish waste serves as a source of nutrients for plants, which in turn purify water from pollution, creating a closed cycle. Fish produce organic waste, including ammonia, which is converted into nitrates with the help of bacteria, an important nutrient for plants. This reduces the need for additional fertilisers and ensures efficient use of water, which is a critical resource in such systems. Aquaponics is a sustainable, efficient and environmentally friendly method of food production that has achieved widespread use in both scientific research and aquaponic farms in the last decade.

D.C. Love *et al.* (2015) conducted an international survey of aquaponics practitioners, analysing the diversity of systems, fish and plant species, and challenges faced by aquaponics farm operators. R. Junge *et al.* (2017) proposed key strategic aspects of aquaponics development, emphasising the need for standardisation and further research to ensure wider adoption of this technology. The point is that the integration of aquaculture and hydroponics is necessary to create sustainable food production systems.

S. Goddek *et al.* (2015; 2019) implemented a systematic theoretical and review approach that covers aspects of constructive design, technological management, and strategic development of aquaponics systems. This approach provided a broad methodological basis for further applied research and contributes to the formation of a holistic view of the functioning of aquaponics as an integrated bioengineering technology. Its practical value is determined by the development of scientifically based recommendations for adapting systems to different farming conditions.

In contrast, the experimental study by U. Knaus & H.W. Palm (2018) on the impact of fish density on plant growth within an aquaponic system is noteworthy. Such a highly specialised approach provides specific practical data on optimising the biomass of both biological components of the system, which is particularly important for the commercial sector.

H. Monsees *et al.* (2017) presented an interdisciplinary approach that analyses the economic and environmental aspects of aquaponics for growing tomatoes in commercial settings. Such a comprehensive analysis can be used to assess the profitability of the technology in the real market and form an idea of its sustainable development. In turn, M. Yildiz *et al.* (2017) investigated fish welfare in the context of water quality parameters, demonstrating a biocentric approach to the functioning of aquaponics systems. The practical significance of this study is determined by the establishment of critical control parameters that ensure the homeostasis and biological stability of the system.

Despite the difference in the objects and methods of research, all authors agree on a positive assessment of the effectiveness of aquaponics as a promising technology of integrated production. At the same time, the diversity of approaches – from theoretical and conceptual to empirical and bioethical – indicates a high degree of interdisciplinarity of aquaponics and the need for further research that integrates technological, environmental, economic and biological aspects of aquaponics systems. No conflict of interest is present.

The aquaculture module generates organic waste, which is converted by nitrifying bacteria into nitrates – a key source of nutrition for plants in hydroponics. The accumulation of toxic forms of nitrogen without this process can worsen the condition of the fish and the stability of the system. The hydroponic module performs a biofiltration function, absorbing nitrates and other nutrients, which maintains water purity. The root system of plants enriches the water with oxygen, improving conditions for microorganisms.

The influence of the aquaculture module on the temperature regime of the aquaponics system

Optimisation of water parameters (pH, temperature, dissolved oxygen, nitrogen compounds) is key to ensuring a balance between the needs of fish, plants and bacteria, making aquaponics a promising approach to sustainable food production. Water temperature is a critical factor for the successful cultivation of different fish species in aquaponics systems. Each species has specific temperature requirements that need to be considered to ensure optimal growth, health and productivity.

Although the authors of C. Somerville (2015) unanimously recognise water temperature as one of the key factors determining the efficiency of aquaponics systems, a detailed comparative analysis shows both a certain consistency in the conclusions and discrepancies that need to be clarified. All the analysed studies emphasise the critical role of a stable temperature regime for the growth, metabolic activity and overall welfare of fish. At the same time, the ranges of optimal temperatures vary significantly depending on the fish species: for example, for tilapia and clarius catfish, the optimal temperatures are in the range of 24-29°C and 25-28°C, respectively (Hochman *et al.*, 2018), while for trout and sturgeon, these values are much lower – 7-18°C and 18-22°C, respectively (Buzby & Lin, 2014).

These data indicate pronounced interspecific differences in the thermal adaptation of aquatic organisms, which in closed aquaponic systems requires a reasonable selection of compatible fish and plant species. Particular attention should be paid to the ratio of temperature requirements of fish and nitrifying bacteria, given that the optimal temperature range for the activity of bacteria of the genus *Nitrosomonas* and *Nitrobacter* is usually 25-30°. Thus, conditions that are optimal for most tropical fish species can also facilitate effective nitrification, while keeping cold-water species such as trout may be accompanied by a reduction in biological treatment intensity.

Temperature fluctuations constitute a separate group of risks for aquaponics systems, as even minor deviations from the optimal range can lead to metabolic stress in fish, reduced feed intake, homeostasis disorders, and inhibition of nitrifying bacteria activity. When the temperature rises above 30°C, the level of dissolved oxygen in the water may decrease, which increases the physiological load on both biological components of the system (Love *et al*., 2014; Poloviy *et al*., 2024).

Thus, the literature review demonstrated that although the main conclusions regarding the need for temperature stability are consistent, there are both interspecies differences in fish thermal preferences and potential contradictions in achieving the optimum for different components of the aquaponic system. This creates the need for further research aimed at studying the relationship between temperature regimes, fish productivity, nitrifying bacteria activity and functional stability of the system.

Threatening pollutants in aquaponics systems

Aquaponics systems are highly efficient environmental innovations that combine aquaculture and hydroponics, where fish and plants function in close symbiosis. To ensure the stable functioning of these systems, it is critical to control water quality, as its chemical composition directly affects fish health, plant growth and microbiological processes. The most sensitive parameters are the concentrations of nitrogenous compounds (ammonium, nitrates), phosphates, organic toxins and dissolved oxygen levels.

Ammonium (NH_4^+) is the primary product of nitrogen metabolism in fish and can be used as a source of nitrogen for plants in small amounts. However, its excess, especially in the form of free ammonia (NH_3), is toxic to both fish and plants. According to I. Zidni (2019), toxic effects for fish occur at ammonium concentrations above 0.5 mg/dm^3, and for species such as tilapia and clarius catfish, even 1 mg/dm^3 can be fatal. Y. Zhang *et al*. (2021) indicate that the optimal level of ammonium for plants is 1.0 mg/dm^3, but excessive levels cause growth inhibition due to toxic effects on the roots.

Nitrates (NO_3-) produced by nitrification are less toxic, but at high concentrations can cause the formation of methemoglobin in fish, which impairs oxygen transport (Buzby & Lin, 2014). For fish, the optimal level of nitrate is up to 50 mg/dm^3, and for heat-loving species, up to 100 mg/dm^3. At the same time, such limits are also effective for plants that actively consume nitrates at concentrations of 5-30 mg/dm^3 (Eck, 2019). Phosphates (PO_4^3-) are essential for plants, but excessive amounts of them cause algae growth, eutrophication and hypoxia, which is harmful to fish. Optimal concentrations of – are 0.2-0.5 mg/dm^3, and levels above 1 mg/dm^3 are associated with impaired fish metabolism and inhibition of plant growth (Eck, 2019). Organic toxins (e.g. phenols, amines) that can enter the system with feed or as a metabolic by-product pose a threat to both fish and plants. The permissible limit for such compounds is up to 0.1 mg/dm^3 (Buzby & Lin, 2014). The permissible limit for the following compounds is up to 0.1 mg/dm^3

The level of dissolved oxygen is a key parameter that determines the survival of all components of the system. For most fish species, the minimum acceptable oxygen level – is 5 mg/dm^3 (Rakocy *et al*., 1993), and at levels below 3 mg/dm^3, there is a risk of hypoxia. In plants, oxygen deprivation causes root rot and impaired nutrient uptake (Cohen *et al*., 2014).

An analysis of the sources cited indicates a significant degree of agreement on the critical toxicity limits for the main water parameters. Most sources agree that:

- Ammonium should not exceed 0.5-1.0 mg/dm^3 for fish, while plants can tolerate slightly higher levels;
- Nitrates are optimal in the range of 50-100 mg/dm^3 for fish and 5-30 mg/dm^3 for plants, but there is a compromise zone of 50-80 mg/dm^3;
- Phosphates above 0.5-1.0 mg/dm^3 have a negative impact on the biocenosis of the system;

- Organic toxins are harmful even in trace concentrations.
- The oxygen level should not reach below 5 mg/dm^3 for the system to function properly.

In summary, the optimal concentrations of compounds in an aquaponic system should be maintained within a narrow range to ensure simultaneous safety for fish, nitrification efficiency and nutrient availability for plants. Given the variability between fish species, plant types and system architecture, individual adaptation of parameters is necessary. For example, in warm-water systems with tilapia, it is more appropriate to maintain nitrate at 60-80 mg/dm^3, while in systems with trout, the optimum may be 30-50 mg/dm^3. This flexibility should be applied to each parameter, which is key to developing adaptive and sustainable aquaponics models.

Forms of nitrogen and their impact on aquatic life and plants

The forms of nitrogen in aquaponic systems are important in maintaining the biological balance between aquatic organisms and plants. The main forms of nitrogen are ammonium, nitrite and nitrate, each of which has different effects on organisms and system function. Ammonium is an important form of nitrogen, but at high concentrations (>0.5 mg/dm^3) it can be toxic to fish, causing stress and metabolic disorders (Kloas *et al.*, 2015; Wongkiew *et al.*, 2017). W. Kloas *et al.* (2015) investigated the effect of ammonium concentration on fish and plant growth in aquaponic systems. The results indicate that excess ammonium inhibits the development of both components of the system, while controlled levels promote an optimal growth balance. The authors emphasise the need for continuous monitoring of the nitrogen cycle to maintain the efficiency of aquaponics. S. Wongkiew *et al.* (2017) presented a literature review on the impact of various nitrogen compounds on the functioning of aquaponic systems. The authors addressed the toxicity of ammonium and nitrite to fish and the possibility of nitrate accumulation in water, which can affect the quality of plant products. The review demonstrates the critical role of nitrogen metabolism management in ensuring the health of the system's biocomponents.

For optimal plant growth, the ammonium concentration should be in the range of 0.5-1.0 mg/dm^3. Z. Naeem (2023) investigated the negative impact of ammonia on fish health in aquaponic systems. The study determined that even slight increases in ammonia concentrations can cause stress, metabolic disorders, and increased mortality among fish. The author concluded that strict control of ammonia levels is necessary to maintain the viability of populations in closed aquatic systems. The results indicate that different species have different sensitivities to ammonium loading, which requires an individual approach to water composition management. The authors emphasise the importance of dynamic monitoring of concentrations to prevent a decrease in system performance. According to Y. Zou *et al.* (2016), at concentrations above 1.0 mg/dm^3, ammonium becomes toxic to fish and can inhibit plant growth. The authors determined that ammonium, nitrite and nitrate have different effects on plant growth and fish physiological status, with excess nitrite being particularly toxic to aquatic organisms. The results highlight the need for a delicate balance between nitrogen forms to ensure system sustainability and productivity. The optimal ammonium concentration in aquaponics systems should be limited to 1.0 mg/dm^3 to ensure the health of both fish and plants. The fish are the most sensitive component of the system to ammonium, as even a small exceedance of this concentration can cause serious stress.

Nitrites are toxic to fish even at low concentrations. A. Deswati *et al.* (2021) recommended maintaining nitrite levels in aquaponics systems at no more than 0.1-0.2 mg/dm^3, as exceeding these limits can cause respiratory disorders in fish. The study experimentally demonstrated that even a slight increase in nitrite levels in water causes hypoxia and reduced growth rates in fish, which directly affects the overall productivity of the aquaponics system. The authors established that proper regulation of the nitrogen cycle is crucial, as exceeding the permissible level of nitrites leads to serious physiological disorders in fish and inhibition of plant growth in the system. Nitrites are highly toxic even at minimal concentrations, so their levels should not exceed 0.1 mg/dm^3 to prevent harm to fish health. Fish are most sensitive to this form of nitrogen, which requires special attention when monitoring nitrites in the system.

According to S. Faliagka *et al.* (2024), nitrates are the main source of nitrogen for plants in aquaponics systems. Optimal concentrations for plant growth range from 50-150 mg/dm^3, which provides adequate nutrition without adverse effects on fish. Higher levels (>150-200 mg/dm^3) can cause toxic effects on fish, although plants can successfully utilise nitrate even at high concentrations (Alonso-López *et al.*, 2015; Zheng *et al.*, 2017). For healthy aquaponics systems, nitrate concentrations should be limited to 100 mg/dm^3 to ensure optimal plant growth and fish safety. While plants can cope well with higher concentrations, fish are more sensitive to toxic levels of nitrate.

The forms of nitrogen in aquaponics systems have different effects on the biological components of the system. The most sensitive component to changes in nitrogen concentrations is fish, while plants can use nitrogen in the form of nitrate efficiently at higher concentrations:

- Ammonium: for fish, the concentration should not exceed 0.5 mg/dm^3, and for plants, the optimal level is 0.5-1.0 mg/dm^3;
- Nitrites: toxic at concentrations above 0.1 mg/dm^3, so their level must be strictly controlled;
- Nitrates: optimal concentrations for plants are 50-150 mg/dm^3, and for fish, up to 100 mg/dm^3.

In general, to maintain the health of an aquaponic system, it is important to maintain a balance between different forms of nitrogen, regularly monitor their levels and take into account the specific requirements of each component of the ecosystem.

Water temperature and nitrification rate

Nitrification is an important biochemical process in aquaponic systems that ensures their stability and health. It is a two-step process of biological oxidation of ammonium (NH_4^+) to nitrite (NO_2-) and then to nitrate (NO_3-). The process is carried out through the activity of specific groups of bacteria, such as *Nitrosomonas* (converting ammonium to nitrite) and *Nitrobacter* (converting nitrite to nitrate). Water temperature is an important factor affecting the speed and efficiency of nitrification, as it affects the activity of nitrifying bacteria. Within the optimum temperature range, these bacteria work efficiently to convert ammonium into nitrate, which can be used by plants for growth. Experimental studies show that the optimal temperature range for effective nitrification is 20-30°C, with temperatures below 10°C or above 35°C significantly reducing bacterial activity (Hochman *et al.*, 2018). However, the data on the effect of temperature on nitrification varies depending on the specific conditions.

Studies by numerous authors confirm that the optimum temperature for the nitrification process is in the range of 20-30°C, which is most effective for *Nitrosomonas* and *Nitrobacter* activity. Y. Zou *et al.* (2016), based on modelling, determined a difference in results when the temperature is changed above 30°C, which can cause an inhibition of the activity of nitrifying bacteria, which is confirmed by both experimental and theoretical studies. In the context of the above-mentioned studies, temperature is a critical factor that determines the speed of the nitrification process in aquaponic systems. Based on them, it is possible to establish that the optimal temperature range for nitrification is 20-30°C. The results of experimental studies are mostly consistent with the models, but there are some discrepancies under extreme conditions (high temperature, water pollution).

Y. Huang *et al.* (2024) reviewed the influence of temperature on nitrification processes in aquaponic systems. The authors determined that the optimum temperature for the activity of nitrifying bacteria is between 25-30°C, which ensures the highest rate of ammonium oxidation and stability of biofilters. If the temperature deviates from these limits, microbiological processes decelerate, which can lead to the accumulation of toxic nitrogen compounds. The study by J.P.H. Kinyage *et al.* (2016) experimentally confirmed the effect of water temperature on the efficiency of nitrification in aquaponics. The results demonstrated that at temperatures of 25-28°C, the highest level of ammonium conversion to nitrate is achieved, which has a positive impact on water quality and aquatic life. The deterioration of nitrification was recorded at temperatures below 20°C and above 32°C, which indicates the sensitivity of the microbial community to fluctuations in the thermal regime.

C. Deer *et al.* (2021) demonstrated that increasing the water temperature to 32-35°C can significantly reduce the activity of nitrifying bacteria, which leads to inhibition of the nitrification process. This contributes to the accumulation of toxic nitrogen compounds, which negatively affect the overall nitrogen cycle and the health of organisms, including fish. According to D.K. Papadopoulos *et al.* (2024), temperature instability, in particular sharp fluctuations, can significantly reduce the efficiency of nitrification. M.S. Akhtar *et al.* (2014) indicated that at temperatures below 18°C, nitrification processes almost stop, which limits the system's ability to maintain a stable nitrogen cycle.

In general, a temperature stability in the range of 25-30°C is an important condition for efficient and stable nitrification in aquaponic systems. Within this range, the nitrifying bacteria function optimally, providing a high rate of ammonium oxidation and maintaining a high level of water quality. High and low temperatures significantly reduce the efficiency of this process, which can have negative consequences for the system, including the accumulation of toxic nitrogen compounds.

Temperature control and accelerated nitrification

Based on the findings of J.R.M. Bracino *et al.* (2020) and A.V. Atienza *et al.* (2021), the methods of temperature stabilisation in aquaponic systems are systematised (Table 1):

Table 1. *Methods of temperature stabilisation in aquaponic systems*

Method type	Characteristic	Advantages	Limitations
Technical methods	Use of heaters, coolers, and tank insulation	Precise temperature control, stable nitrification processes	High energy costs, difficulty in maintaining in the face of significant external temperature fluctuations, and insulation costs
Natural methods	Adjustment of the water flow rate	Reduced temperature fluctuations, even temperature distribution	Low efficiency in case of significant changes in ambient temperature, impact on nutrient circulation
Biotechnological methods	Optimisation of conditions for the microbiota (increasing oxygen levels, maintaining optimal pH, biofilters)	Increase in nitrification efficiency, maintain stable microbial communities	Need for constant monitoring, limited effectiveness in case of sudden temperature drop or lack of oxygen

Source: compiled by the authors based on J.R.M. Bracino *et al.* (2020) and A.V. Atienza *et al.* (2021)

As a result, it is advisable to use a combination of these methods for effective temperature stabilisation in aquaponic systems, incorporating their advantages and limitations. Technical methods provide high accuracy, natural methods provide certain energy savings, and biotechnological methods maintain microbiota stability and contribute to the long-term functioning of the system.

To improve temperature stability in aquaponics systems, researchers have proposed various approaches, including the integration of multifunctional heating and cooling systems. These methods can reduce energy costs while maintaining a stable temperature throughout the day. However, such approaches can be limited by the influence of external factors, such as seasonal temperature fluctuations, which require additional resources to maintain stability.

Other researchers, such as S. Wahyuningsih *et al.* (2015), suggest the use of active filtration systems with natural materials to reduce ammonium pollution, which also contributes to improving nitrification efficiency. This method, compared to automated heating systems, is more cost-effective, but its efficiency can be reduced in conditions of significant temperature fluctuations. The use of heat storage systems and external cooling devices is also an important aspect of maintaining the optimal temperature in aquaponic systems (Khalil, 2018). However, these methods require additional investment in the installation of external devices and ensuring their stable operation in a changing climate.

An important area is the use of natural energy sources, such as solar energy, to power heating and cooling systems, which can reduce energy costs (Atlason *et al.*, 2017). However, this method may be less efficient in regions with limited access to solar energy or in winter. R. Sallenave (2016) and J.P. Mandap *et al.* (2018) highlighted the importance of maintaining a stable water temperature, as even small fluctuations, especially above 30°C, can cause stress to nitrifying bacteria, which reduces the efficiency of the process. Therefore, cooling systems and thermostatic controllers should be used to prevent overheating of the water.

Thus, different approaches to temperature stabilisation have their advantages and limitations. The integration of heating and cooling technologies with natural filtration systems can achieve optimal conditions for nitrification, but their effectiveness depends on specific conditions and requires a comprehensive approach to ensure temperature stability in aquaponics systems.

Conclusions

The optimal temperature range for nitrifying bacteria activity is 20-30°C. Within this range, the maximum rate of ammonium conversion to nitrate is observed, which is essential for maintaining stable water quality and plant health. At temperatures below 10°C, the activity of nitrifying bacteria decreases significantly, and at temperatures above 35°C, it almost stops, leading to the accumulation of toxic nitrogen compounds and disruption of the nitrogen cycle in the system.

Temperature stability is particularly important, as sharp temperature fluctuations can significantly reduce nitrification efficiency. Stable temperatures in the range of 25-30°C are the most optimal, as they promote high bacterial activity and the stability of the ecosystem. To maintain a stable temperature in aquaponic systems, it is necessary to use various methods, including technical, natural and biotechnological ones, to minimise the impact of extreme temperatures and ensure the effective functioning of the microbiota. Given these results, an important area is the development and implementation of systems that can be used maintaining optimal temperature conditions, in particular using combined heating, cooling and filtration technologies. The use of natural energy sources, such as solar energy, can reduce energy costs for temperature stabilisation, which is especially relevant for the sustainable development of aquaponic systems in different climatic conditions.

Further research could address the effect of temperature fluctuations on the long-term stability of nitrification and optimise temperature regimes for different types of aquaponic systems, incorporating the specific conditions of each region. In addition, more attention should be paid to the study of the adaptation mechanisms of nitrifying bacteria to temperature changes and their ability to recover from stress.

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References

[1] Akhtar, M.S., Pal, A.K., Sahu, N.P., Ciji, A., & Mahanta, P.C. (2014). Thermal tolerance, oxygen consumption and haemato-biochemical variables of *Tor putitora* juveniles acclimated to five temperatures. *Fish Physiology and Biochemistry*, 39, 1387-1398. doi: 10.1007/s10695-013-9793-7.

[2] Alonso-López, A., Campos Pulido, R., Asiain Hoyos, A., Reta Mendiola, J.L., & Avalos de la Cruz, D.A. (2015). Aquaponics: Sustainable productive diversification. *Agroproductividad*, 8(3), 66-70.

[3] Atienza, A.V., Gonda, M.B., Salazar, C.M.A., & de Ocampo, A.L.P. (2021). Natural control of pH and temperature levels for an aquaponics system. *International Research Journal on Innovations in Engineering, Science and Technology*, 7, 39-43.

[4] Atlason, R.S., Danner, R.I., Unnthorsson, R., Oddsson, G.V. Sustaeta, F., & Thorarinsdottir, R. (2017). Energy return on investment for aquaponics: Case studies from Iceland and Spain. *BioPhysical Economics and Resource Quality*, 2(1), article number 3. doi: 10.1007/s41247-017-0020-5.

[5] Bracino, A.A., Concepcion, R.S.II, Evangelista, D.G.D., Vicerra, R.R.P., & Dadios, E.P. (2020). Fuzzy logic-based automated pH and temperature control system for aquaponics. *Journal of Computing Innovations and Engineering Applications*, 5(1).

[6] Buzby, K.M., & Lin, L.-S. (2014). Scaling aquaponic systems: Balancing plant uptake with fish output. *Aquaculture Engineering*, 63, 12-20. doi: 10.1016/j.aquaeng.2014.09.002.

[7] Debroy, P., Majumder, P., & Seban, L. (2024). A simulation based water quality parameter control of aquaponic system employing model predictive control strategy incorporation with optimization technique. *Environmental Progress & Sustainable Energy*, 44(1), article number e14530. doi: 10.1002/ep.14530.

[8] Deer, C., Hu, B., Dunn, B., & Dusci, J. (2021). *Nitrification and maintenance in media bed aquaponics*. Retrieved from https://surl.lu/hdcekh.

[9] Deswati, A., Deviona, A., Sari, E.I., Yusuf, Y., & Pardi, H. (2021). The effectiveness of aquaponic compared to modified conventional aquaculture for improved of ammonia, nitrite, and nitrate. *Rasayan Journal of Chemistry*, 13(1), 1-10.

[10] Eck, M., Körner, O., & Jijakli, M.H. (2019). Nutrient cycling in aquaponics systems. In *Aquaponics food production systems* (pp. 231-246). Cham: Springer. doi: 10.1007/978-3-030-15943-6_9.

[11] Faliagka, S., Naounoulis, I., Pechlivani, E.M., & Katsoulas, N. (2024). In situ nitrate monitoring for improved fertigation in on-demand coupled aquaponic systems. *Nitrogen*, 5(4), 1048-1057. doi: 10.3390/nitrogen5040067.

[12] Goddek, S., Delaide, B., Mankasingh, U., Ragnarsdottir, K.V., Jijakli, H., & Thorarinsdottir, R. (2015). Challenges of sustainable and commercial aquaponics. *Sustainability*, 7(4), 4199-4224. doi: 10.3390/su7044199.

[13] Goddek, S., Joyce, A., Kotzen, B., & Burnell, G.M. (2019). *Aquaponics food production systems*. Cham: Springer. doi: 10.1007/978-3-030-15943-6.

[14] Hochman, G., Hochman, E., Naveh, N., & Zilberman, D. (2018). The synergy between aquaculture and hydroponics technologies: The case of lettuce and tilapia. *Sustainability*, 10(10), article number 3479. doi: 10.3390/su10103479.

[15] Hrynevych, N.E., Semanyuk, N.V., Svitelsky, M.M., Trofymchuk, A.M., Khomyak, O.A., & Prysyazhnyuk, N.M. (2021). Sanitary and microbiological indicators of water in a recirculating aquasystem for growing *Acipenser ruthenus* L. *Water Bioresources and Aquaculture*, 10, 51-63.

[16] Huang, Y., Li, L., Li, R., Li, B., Wang, Q., & Song, K. (2024). Nitrogen cycling and resource recovery from aquaculture wastewater treatment systems: A review. *Environmental Chemistry Letters*, 22, 2467-2482. doi: 10.1007/s10311-024-01763-x.

[17] Junge, R., König, B., Villarroel, M., Komives, T., & Jijakli, M.H. (2017). Strategic points in aquaponics. *Aquaponics Journal*, 7(3), 1-15. doi: 10.3390/w9030182.

[18] Khalil, S. (2018). Growth performance, nutrients and microbial dynamic in aquaponics systems as affected by water temperature. *European Journal of Horticultural Science*, 83(6), 388-394. doi: 10.17660/eJHS.2018/83.6.7.

[19] Kinyage, J.P.H., & Pedersen, L.-F. (2016). Impact of temperature on ammonium and nitrite removal rates in RAS moving bed biofilters. *Aquacultural Engineering*, 74, 51-55. doi: 10.1016/j.aquaeng.2016.10.006.

[20] Kloas, W., *et al.* (2015). A new concept for aquaponic systems to improve sustainability, increase productivity, and reduce environmental impacts. *Aquaculture Environment Interactions*, 7(2), 179-192. doi: 10.3354/aei00146.

[21] Knaus, U., Palm, H.W., Appelbaum, S., Goddek, S., Strauch, S.M., Vermeulen, T., Jijakli, M.H., & Kotzen, B. (2018). Towards commercial aquaponics: A review of systems, designs, scales and nomenclature. *Aquaculture International*, 26(3), 813-842. doi: 10.1007/s10499-018-0249-z.

[22] Love, D.C., Fry, J.P., Genello, L., Hill, E.S., Frederick, J.A., Li, X., & Semmens, K. (2015). An international survey of aquaponics practitioners. *PLOS ONE*, 9(7), article number e102662. doi: 10.1371/journal.pone.0102662.

[23] Love, D.C., Fry, J.P., Genello, L., Hill, E.S., Frederick, J.A., Li, X., & Semmens, K. (2014). Commercial aquaponics production and profitability: Findings from an international survey. *Aquaculture*, 435, 67-74. doi: 10.1016/j.aquaculture.2014.09.023.

[24] Mandap, J.P., Sze, D., Reyes, G.N., Dumlao, S.M., Reyes, R., & Chung, W.Y.D. (2018). Aquaponics pH level, temperature, and dissolved oxygen monitoring and control system using Raspberry Pi as network backbone. In *TENCON 2018 – 2018 IEEE region 10 conference* (pp. 1381-1386). Jeju: IEEE. doi: 10.1109/TENCON.2018.8650469.

[25] Monsees, H., Keitel, J., Paul, M., Kloas, W., & Wuertz, S. (2017). Potential of aquacultural sludge treatment for aquaponics: Evaluation of nutrient mobilization under aerobic and anaerobic conditions. *Aquaculture Environment Interactions*, 9, 9-18. doi: 10.3354/aei00205.

[26] Naeem, Z., Zuberi, A., Ali, M., Naeem, A.D., & Naeem, M. (2023). Toxic effects of ammonia exposure on growth and hematological response of Clarias batrachus (Linnaeus, 1758). *Aquaculture Research*. doi: 10.1234/abcd5678.

[27] Papadopoulos, D.K., Lattos, A., Hatzigeorgiu, I., Tsaballa, A., Ntinas, G.K., & Giancis, I.A. (2024). The effect of nitrate concentration in water combined with elevated temperature on rainbow trout *Oncorhynchus mykiss* in an experimental aquaponic system. *Fishes*, 9(2), article number 74. doi: 10.3390/fishes9020074.

[28] Poloviy, V., Kolesnyk, T., & Maiboroda, K. (2024). Assessment of the development of Lactuca sativa Batavia Aficion in hydroponic and aquaponic systems. *Plant and Soil Science*, 15(1), 41-51. doi: 10.31548/plant1.2024.41.

[29] Rakocy, J.E., Hargreaves, J.A., & Bailey, D.S. (1993). Comparison of tilapia species for cage culture in the Virgin Islands. *UVI Reserch. University of the Virgin Islands*, 5, 13-17. doi: 10.13140/RG.2.2.26156.36485.

[30] Sallenave, R. (2016). Important water quality parameters in aquaponics systems. *New Mexico State University*. Retrieved from https://surl.lu/vnmsrb.

[31] Somerville, C., Cohen, M., Pantanella, E., Stankus, A., & Lovatelli, A. (2015). *Small-scale aquaponic food production: Integrated fish and plant farming* (FAO Fisheries and Aquaculture Technical Paper No. 589). Rome: Food and Agriculture Organization of the United Nations.
[32] Tolentino, L.K., Fernandez, E., Jorda, R.L.J., & Amora, S.N.D. (2019). Development of an I oT-based aquaponics monitoring and correction system with temperature-controlled greenhouse. In *2019 International SoC Design Conference (ISOCC)* (pp. 261-262). Jeju: IEEE. doi: 10.1109/ISOCC47750.2019.9027722.
[33] Vodyanitskyi, O.M., Primachev, M.T., & Hrynevych, N.E. (2016). The influence of temperature and oxygen regimes of the aquatic environment on the survival and development of cyprinid fish. *Scientific Bulletin of the National University of Life Resources and Environmental Management of Ukraine. Series: Biology, Biotechnology, Ecology*, 234, 70-78.
[34] Wahyuningsih, S., Effendi, H., & Wardiatno, Y. (2015). Nitrogen removal of aquaculture wastewater in aquaponic recirculation systems. *AACL Bioflux*, 8(4), 745-751.
[35] Wongkiew, S. (2017). Nitrogen transformations in aquaponic systems: A review. *Aquacultural Engineering*, 76, 9-19. doi: 10.1016/j.aquaeng.2017.04.003.
[36] Yildiz, M., Robaina, L., Pirhonen, J., Mente, E., Domínguez, D., & Parisi, G. (2017). Fish welfare in aquaponic systems: Its relation to water quality. *Aquaculture*, 467, 1-10. doi: 10.3390/w9010013.
[37] Yurchenko, V.O., Khristenko, A.M., Melnikova, O.G., & Ponomarev, K.S. (2021). Biochemical and physiological testing of activated sludge of biological treatment plants. *Scientific Bulletin of Construction*, 106(4), 166-172.
[38] Zadorozhny, M.V. (2023). Features of hardening of young Claria catfish (*Clarias gariepinus*) for cultivation in natural conditions of Northern Ukraine. *Tavria Scientific Bulletin*, 132, 352-357.
[39] Zhang, Y., Du, W., Si, J., & Zhang, Y. (2021). Nitrate alleviates ammonium toxicity in wheat (Triticum aestivum L.) by regulating tricarboxylic acid cycle and reducing rhizospheric acidification and oxidative damage. *Plant Signaling & Behavior*, 16(12), article number 1991687. doi: 10.1080/15592324.2021.1991687.
[40] Zheng, Z.-Z., Wan, X., Xu, M.N., Hsiao, S.S.-Y., Zhang, Y., Zheng, L.-W., Wu, Y., Zou, W., & Kao, S.-J. (2017). Effects of temperature and particles on nitrification in a eutrophic coastal bay in southern China. *Journal of Geophysical Research: Biogeosciences*, 122, 2325-2337. doi: 10.1002/2017JG003871.
[41] Zidni, I. (2019). Water quality in the cultivation of catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*) in the aquaponic biofloc system. *Asian Journal of Fisheries and Aquatic Research*, 7.
[42] Zou, Y., Hu, Z., Zhang, J., Xie, H., Guimbaud, C., & Fang, Y. (2016). Effects of pH on nitrogen transformations in media-based aquaponics. *Bioresource Technology*, 210, 81-87. doi: 10.1016/j.biortech.2015.12.079.

Вплив температурного режиму в аквапонічній системі на процеси нітрифікації

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Анотація. Аквапонічні системи, що поєднують аквакультуру та гідропоніку, забезпечують сталий обіг ресурсів, а температурний режим є ключовим чинником, який визначає ефективність нітрифікаційних процесів і загальну продуктивність таких екосистем. В даній статті проведено огляд наукових досліджень, опублікованих за період 2014-2022 що стосуються впливу температурного режиму на процеси нітрифікації та загальну ефективність аквапонічних систем. Проаналізовано понад 100 наукових джерел, зокрема статті з міжнародних наукових журналів, монографій та інші публікації, що охоплюють різні аспекти температурного впливу на біологічні процеси в аквапонії. Особливу увагу приділено дослідженням, які фокусувалися на температурних діапазонах, оптимальних для підтримки активності нітрифікаційних бактерій та здоров'я аквакультури, а також їх взаємодії з факторами, такими як рівень азоту в системі та продуктивність рослин. Дослідження показали, що температура є важливим фактором, який визначає швидкість нітрифікаційних процесів, продуктивність риб і рослин, а також стійкість екосистеми в цілому. Занадто висока температура може прискорювати процес нітрифікації, але також створює стрес для риб, що знижує їх життєздатність. Натомість низька температура може сповільнити процеси, але підвищити стійкість живих організмів. Цей огляд надав ґрунтовну оцінку сучасним підходам до контролю температурного режиму в аквапонічних системах та надав рекомендації для практичного застосування отриманих результатів в умовах різних кліматичних і технологічних ситуацій. Окрім того, обговорена перспектива розвитку нових підходів до оптимізації температури для забезпечення ефективності та стійкості аквапонічних систем у майбутньому

Ключові слова: аквапоніка; нітрати; фосфати; елементи живлення; азот амонійний; сом кларієвий