

Disinfection in Aquaponics: An Analysis of Plasma Technology Applications and Potential

Tanvi Sontakke

Dept. of Computer Science Symbiosis Institute of Technology Pune, India
aretanvi@gmail.com

Nilima Zade

Dept. of Computer Science Symbiosis Institute of Technology Pune, India
nilima.zade@sitpune.edu.in

R. Kamatchi Iyer

Universal AI University Karjat, India
rkamatchi.iyer@gmail.com

ABSTRACT

Aquaponics, an emerging innovation in sustainable agriculture that uses aquacultural discharge to grow plants and fish, deals with its own kind of challenges specifically optimizing water quality and maximising both fish and plant productivity. This analysis dives into the potential use of plasma technology in aquaponics by assessing current literature, exploring the efficiency of plasma treatments on water quality parameters, enhancing fish and plant growth by analysing the impact of plasma treatments on plant yield, nutrient uptake and overall health by with the possible effects of plasma on fish growth rates and survival. It also examines the long-term sustainability of an aquaponic system that is integrated with plasma technology by exploring the potential benefits and drawbacks of plasma technology in terms of energy consumption and cost-effectiveness. Although, while investigating the potential usage of plasma in aquaponics, several key questions remain unanswered. Future research should examine the impacts of plasma on fish growth in greater detail, assess the implications of plasma on the sustainability of aquaponic systems and different treatment protocols for specific aquaponic setups and conducting a thorough cost-benefit analysis to ensure the economic viability of this technology. By addressing these research gaps, we can explore the full potential of plasma technology and its adoption in sustainable agriculture.

Keywords—*aquaponics, plasma technology, sustainable agriculture, water quality, plant growth, fish growth*

INTRODUCTION

The agricultural sector faces ongoing pressure to keep up with changes in consumption trends, changes in production and climate change in this fast-paced world of increasing competition for food and resources [1]. The improper use of traditional agricultural practices, agrochemicals and technologies have led to detrimental impacts on the environment. Traditional farming in marginalized areas is plagued with drought-stricken lands, eroded soil, limited infrastructure and reduced market demand, the result being lower productivity and persistent poverty [2].

Drought-stricken lands, eroded soil, limited infrastructure, and reduced market demands, plague traditional farming in marginalized areas, the result being lower productivity and persistent poverty [2]. Thus, this calls for newer and more sustainable practices in a tech-driven world. Aquaponics is one such method, defined as the process of growing aquatic organisms and plants symbiotically. This involves the microbial modification of aquaculture effluent to serve as a supply of necessary nutrients required for plant growth, and the remediation of aquaculture water through the intake of nutrients from vegetations.

Aquaponic systems offer the ability to reduce the losses in productivity from land scarcity brought on by rapid urbanization while minimizing the significant supply inadequacies found in typical agricultural practices [3]. But like all systems, it faces issues such as poor water quality, high levels of stress amongst fish, lack of proper disinfection systems and introduction of contaminated materials into the system [4].

To ensure the complete removal of pathogens and improve the quality of water, many methods are available, namely mechanical filtration, biological filtration, UV sterilization [5], activated carbon [6], and an emerging innovation, plasma technology, the potential of integrating with an aquaponic system, which this paper explores. Plasma is an ionized gas that consists of a large number of different species such as electrons, positive and negative ions, free radicals and gas atoms, molecules in the ground or excited state and photons. Because of its distinct characteristics, plasma is sometimes mentioned as the fourth state of matter [7]. Of the different types of plasma available, cold plasma was frequently used for disinfection of water [8, 9] and removal of pathogens.

Table 1. Comparison of existing literature reviews on plasma in aquaponics

Reference No.	Mentioned issues of integrating plasma into aquaponics	Mentions long term impact of integration of plasma in aquaponics	Specified the type of plasma technologies used	Focus on disinfection using plasma
3	Ne	Ne	Ne	Ne
7	Ne	Ne	Aff	Aff
12	Ne	Ne	Aff	Aff
13	Ne	Ne	Aff	Aff
15	Aff	Ne	Aff	Ne
16	Ne	Ne	Aff	Aff
18	Ne	Ne	Aff	Ne
This study	Aff	Aff	Aff	Aff

Ne: Negative, Aff: Affirmative This study sheds light on the potential usage of plasma technology to revolutionize aquaponics

by exploring its effects on water purity, fish well-being and the flourishing of plant life, aiming to make the system cleaner and sustainable.

Table 2. Research objectives

Sr. No.	Research questions	Research objectives	Answered in Section
1.	What influence does plasma have on factors affecting water quality?	The objective is to investigate the effects of plasma treatment on the following water quality parameters: pH, temperature, dissolved oxygen, ammonia, nitrite, nitrate, phosphate, pathogens, using three kinds of treatments (PBAW, PAW, cold plasma)	I. A II. B
2.	How does plasma treatment affect the growth and yield of different types of plants and fish?	The goal is to examine how plasma affects the growth and yield of various fish and plants.	II. C
3.	What is the long-term impact of plasma treatment on the sustainability of aquaponic systems?	Another objective is to explore the possible long-term impact of plasma treatment on the sustainability of aquaponic systems.	II. D

LITERATURE REVIEW

A. *Cold plasma efficacy on water quality parameters*

Traditional water treatment methods, while effective often come with limitations and drawbacks. Seeking innovative solutions, researchers are turning to novel technologies like cold plasma to address water quality concerns. Cold plasma, a partially ionized gas generated by an electric field, harnesses the power of free electrons and reactive species to disinfect water without the need of harmful chemicals. A key finding mentions it is effective in destroying pathogens such as coliform and E. coli [9, 10], removing water odor with the help of the reactive species generated [10], thus contributing to safer water.

Research indicates that plasma treatment can elevate dissolved oxygen (DO) levels in surface water [9, 10] from 2.6 to 5.3 mg·L⁻¹ after cold plasma treatment [9], and reduce chemical oxygen demand (COD) [10], suggesting a decrease in organic matter content and improved overall water quality. Promising results have emerged regarding the ability of cold plasma to remove heavy metals like lead (Pb), cadmium (Cd), iron (Fe), manganese (Mn), chromium (Cr) and zinc (Zn) [9, 10]. Both ozone and cold plasma treatments greatly decreased the Mn concentration at 700 mV Oxidation reduction potential (ORP). There was also a slight decrease in the total soluble iron content with the increasing ORP over time [9]. Ozone or cold plasma treatment resulted in oxidation of soluble metals such as iron and manganese present in the solution [9].

Cold plasma effects on water temperature are minimal, since plasma generated is typically non-thermal, meaning it doesn't significantly raise the water temperature like other treatment methods (example, boiling). Although, some limited data suggests a slight increase in temperature (around 1-2°C) might occur depending on treatment parameters like power input and duration, however this variation is considered insignificant. Insufficient study has been done to precisely examine the effects of cold plasma on phosphate levels, but possible results observe a decrease in total phosphorus (TP) after cold plasma treatment. However, it's unclear if this reduction directly targets phosphate or includes other phosphorus forms. Further research is needed to clarify these results.

B. *Efficacy of Plasma Bubble Activated Water*

This section explores the potential efficacy of Plasma Bubble Activated Water, PBAW, its advantages and limitations in comparison to cold plasma and traditional methods, and key considerations for its successful implementation in aquaponics. PBAW utilizes electrical discharge within a submerged gas bubble, generating reactive nitrogen species (RONS) that diffuse into water. These highly reactive molecules effectively inactivate pathogens like bacteria and viruses. Unlike plasma discharge, PBAW presents a gentler approach with minimized harm to plants and fish, while providing a longer shelf life compared to standard plasma activated water (PAW) treatment.

Studies have demonstrated PBAW's effectiveness in eliminating foodborne pathogens, including E. coli, Salmonella Typhimurium, and Listeria monocytogenes [11]. A 20-minute PBAW treatment on tomatoes and their wash water successfully reduced pathogen levels below the detection limit (1 log CFU/g or 1 log CFU/mL, respectively) also ozonated micro-bubbles increased the oxidation efficiency more than conventionally generated ozonated water, enhancing the microbial collapse and resulting in the reduced viability of such pathogens [11], proving plasma's efficacy in pathogen removal.

Plasma treatment also shows to have an inhibitory effect on root rot and exhibits antifungal activity [18]. A decrease in pH and an increase in the oxidation-reduction potential of plasma bubble activated (PBAW) is observed [11]. Following are the advantages over traditional methods (conventional disinfectants like sodium hypochlorite or ethyl alcohol [14]):

- Environmentally friendly: PBAW avoids the use of harsh chemicals minimizing the environmental impact and safeguarding human health.
- Safer for fish and plants: PBAW presents a gentler alternative, potentially promoting a healthy balance within the system.
- Effective against resistant pathogens: PBAW has a multi-targeted mechanism of action, making it effective against pathogens that are resistant to traditional disinfectants.

Despite promising potential, PBAW's integration into aquaponics requires careful consideration of several factors:

- Stability: PBAW potency wanes over time, requiring frequent use of stabilizers, adding operational complexity.
- Selectivity: the broad-spectrum of action of PBAW can affect both beneficial and harmful bacteria.
- Dosage: finding the optimal PBAW dosage is critical; overdosing can harm fish and plants.
- Cost: PBAW generation equipment can be expensive, and the cost of electricity to operate the system needs to be considered

PBAW emerges as a compelling technology for pathogen control in aquaponics; its proven efficacy, environmental friendliness, and potential, for reduced chemical reliance require further investigation and optimization.

C. Impact of plasma activated water on plant and fish growth and yield

This section explores the differences between Plasma Activated Water (PAW) and cold plasma, mentioning their advantages and limitations for disinfection within aquaponic systems. It also examines the important considerations for their integration in these systems, and offers recommendations for the most suitable method and subsequently evaluates the potential effects of plasma on both fish and plant health in an aquaponic system. Plasma activated water (PAW), a promising and environmentally friendly approach to water treatment and disinfection, is a type of treated water infused with reactive chemical species generated by cold plasma technology using controllable parameters such as plasma-forming voltage, carrier gas, temperature, pulses, or frequency as required [12].

Cold plasma, on the other hand, is a nonthermal technology that uses energetic, reactive gases to inactivate contaminating microbes [13]. This flexible sanitizing method uses electricity and a carrier gas, such as air, oxygen, nitrogen, or helium; antimicrobial chemical agents are not required [13]. However, PAW would be more effective for usage in an aquaponic system rather than a cold plasma treatment because:

- Indirect application: Water is exposed to plasma, generating a reactive oxygen and nitrogen species (RONS) rich solution
- Longer shelf life: PAW can be stored for hours or even days and still retain some of its activity.
- Easier to handle: PAW can be easily applied through spraying, irrigation, or soaking.
- Lower initial cost: No specialized equipment needed to generate PAW, just a plasma source and a container for the water.

Table 3. Difference between PAW and Cold Plasma

Sr. No.	PAW	Cold Plasma
1.	Indirect approach	Direct application
2.	Broader action	Effective disinfection
3.	Minimal material impact	Limited penetration
4.	Shorter shelf life	Potential material damage

The choice between PAW and cold plasma treatment depends on the specific application and desired outcome, considering factors like:

- Target material: PAW offers a broader reach for liquids and surfaces within them.
- Material sensitivity: if the target is sensitive to direct plasma exposure (fishes and a few plant species come into the picture), PAW might be preferable.
- Disinfection needs: cold plasma might be sufficient for surface disinfection.
- Resource considerations: PAW generating equipment can be expensive, with ongoing electricity costs to operate the system.

Plasma, in general, affects the growth of plants, by helping promote faster seed germination [15, 18], improved disease resistance [18], enhance plant growth and productivity [15], and extend useful shelf-life of products post-harvest [15]. Cold atmospheric or low-pressure plasma has demonstrated to encourage plant growth and development in a number of environments, including indoor and greenhouse cultivation systems [1]. Despite the differences between PAW and cold plasma, studies suggest the latter too has potential uses in an aquaponic system:

- Pathogen control: Cold plasma effectively inactivates bacteria, viruses, fungi, and other pathogens in water, reducing disease outbreaks in both fish and plants [16].
- Water quality improvement: Plasma treatment oxidizes organic matter and removes harmful toxins from water, creating a healthier environment for both fish and plants [16].
- Fertilizer production: Cold plasma can fix atmospheric nitrogen into forms readily absorbed by plants, reducing reliance on traditional fertilizers [16] and is an effective way to reduce the harmful effects that chemicals and pesticides have on the environment [18].
- Ethylene removal: Cold plasma reduces ethylene levels in the air, delaying plant aging and extending shelf life [16].

Another study showed plasma nitrate as a sustainable alternative for hydroponic lettuce cultivation [17]. It investigated the potential of plasma-generated nitrate as a substitute for conventional chemical fertilizers in hydroponic lettuce production [17]. Below is a summary of key findings from the study:

- Growth and Yield of Lettuce: Plants grown with plasma nitrate showed comparable growth and yield performance in terms of plant height, leaf width, canopy width, number of leaves, higher leaf area (suggesting improved light

interception and potentially higher photosynthetic rate), larger chlorophyll content and better physiological function [17].

- Nitrate accumulation: Plasma nitrate treatment led to significantly lower accumulating in the portions that are above and below ground of the lettuce compared to the conventional nitrate treatment [17]. This suggests a safer option for both the environment and human health [17, 18], reducing the risk of nitrate leaching and excessive nitrate levels in plant tissues [17].

Beyond its established disinfectant properties, studies [17, 18] reveal the potential of plasma as a plant growth promoter and an environmentally friendly fertilizer. By achieving comparable yields with lower nitrate accumulation, plasma nitrate offers a promising alternative to conventional fertilizers in hydroponic systems, that can slowly be expanded to aquaponic systems. This dual functionality highlights the versatility of plasma technology and paves way for future research exploring its application in various agricultural contexts.

While research on plasma's effects on fish within aquaponics is still limited, current studies highlight its potential:

- Pathogen control: cold plasma effectively inactivates fish pathogens, reducing disease risk and promoting overall health.
- Improved water quality: plasma treatment can contribute to cleaner water, benefiting both fish and plant life.
- Reduced stress among fish

D. Impact of plasma on sustainability of an aquaponic system

Plasma technology, in general, has shown to be an effective tool for enhancing the sustainability of aquaponic systems. It greatly improves the quality of water by eliminating contaminants and pathogens, supporting the health of fish and plants alike. Hence, fewer conventional disinfectants are required, making such systems friendlier and more sustainable for the environment.

Although plasma technology has great potential, there are a few challenges that need to be carefully considered before implementing it:

- Efficacy: The effectiveness of plasma treatment can differ depending on system design, water composition, and specific aquaponic conditions.
- Energy consumption: Unless a sustainable solution can be found, producing plasma requires electricity leading to an increase in the system's carbon footprint.
- Cost of technology: Plasma generators can be expensive and have restricted accessibility and scalability for smaller aquaponic systems.
- Dosage optimization: It is essential to determine the ideal dosage and treatment intervals for various fish and plant species in order to reduce potential harm and optimize the benefits of plasma treatment.

SUMMARY AND RECOMMENDATIONS

E. Summary

The literature review explores the promising potential of cold plasma and PBAW for water treatment in aquaponics. While both showcase effectiveness in pathogen control and improving water quality, PBAW stands out for its gentler approach towards plants and fish, although with stability and selectivity challenges.

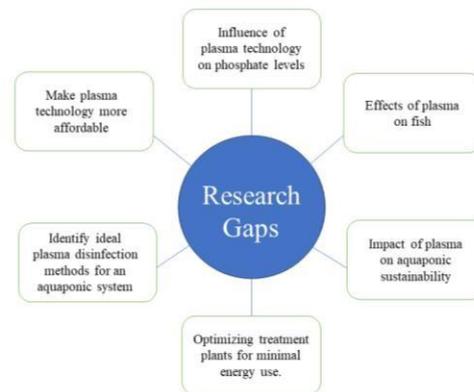
Further, the analysis also mentions another method of disinfection, namely PAW, and elaborates the advantages and disadvantages over cold plasma. Plasma's ability to promote plant growth and act as a sustainable fertilizer opens opportunities to reduce reliance on chemicals and boost aquaponic sustainability. However, key considerations including cost, energy consumption and finding the optimal dosage remain vital for successful implementation and optimization.

The review further mentions the benefits and drawbacks of another method of disinfection, namely PAW. Plasma's ability to promote plant growth and act as a sustainable fertilizer opens opportunities to reduce reliance on chemicals and boost aquaponic sustainability. For successful implementation and optimization, key considerations including cost, energy consumption, and determining the optimal dosage must be taken into account.

F. Research Gaps and Direction

This analysis focuses on the exciting potential of plasma technology for achieving sustainable disinfection in aquaponic systems. However, it also highlights a number of research gaps that demand further investigation. Addressing them is necessary and will pave way for a successful and widespread adoption of this innovative approach. Firstly, cost remains a hurdle, requiring a deeper examination of efficient integration and optimization of such treatment plants to minimize ongoing energy consumption, and determining the optimal plasma dosage required. Exploring the direct impact of plasma on fish

growth and yield, the influence of plasma on phosphate levels alongside continued research is vital to definitively identify the ideal disinfection method among PBAW, PAW, cold plasma and potentially unmentioned alternatives.



CONCLUSION

Plasma technology, presents a promising path for sustainable disinfection in an aquaponic system, offering numerous advantages like efficient pathogen control, improved water quality and reduced reliance on harsh chemicals.

While challenges regarding cost, energy consumption, integration, and plasma dosage optimization remain, addressing these through further research, particularly on plasma's effects on fish and optimizing treatment methods, can unlock the full potential of this technology and reform sustainable aquaponic disinfection practices.

REFERENCES

- [1] Syamlal Sasi, Karthika Prasad, Janith Weerasinghe, Olha Bazaka, Elena P. Ivanova, Igor Levchenko, Kateryna Bazaka, Plasma for aquaponics, Trends in Biotechnology, Volume 41, Issue 1, 2023, Pages 46-62, ISSN01677799
- [2] "What are the disadvantages of traditional farming?". SCISPACE. <https://typeset.io/questions/what-are-the-disadvantages-of-traditional-farming-5fi0fxax27> (accessed Dec 20, 2023).
- [3] Yep, B., & Zheng, Y. (2019). *Aquaponic trends and challenges – A review*. *Journal of Cleaner Production*. doi: 10.1016/j.jclepro.2019.04.290
- [4] "The Most Common Aquaponics Problems". Go Green Aquaponics. <https://gogreenaquaponics.com/blogs/news/the-most-common-aquaponics-problems-and-how-to-fix-them#:~:text=Common%20causes%20of%20pest%20and,contaminated%20materials%20into%20the%20system> (accessed Dec. 20, 2023).
- [5] N. Reed. "The History of Ultraviolet Germicidal Irradiation for Air Disinfection" [https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2789813/#:~:text=Low%2Dpressure%20mercury%20\(Hg\),their%20deoxyribonucleic%20acid%20\(DNA\)](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2789813/#:~:text=Low%2Dpressure%20mercury%20(Hg),their%20deoxyribonucleic%20acid%20(DNA)) (accessed Dec. 20, 2023).
- [6] H. Nowicki. "The basics of activated carbon adsorption". <https://www.watertechnonline.com/wastewater/article/15549902/the-basics-of-activated-carbon-adsorption> (accessed Dec. 20, 2023)
- [7] Mir, S. A., Shah, M. A., & Mir, M. M. (2016). *Understanding the Role of Plasma Technology in Food Industry*. *Food and Bioprocess Technology*, 9(5), 734–750. doi:10.1007/s11947-016-1699-9
- [8] DV Nguyen, PQ Ho, TV Pham, TV Nguyen, and L. Kim, "Treatment of surface water using cold plasma for domestic water supply," *Environmental Engineering Research*, vol. 24, no. 3. Korean Society of Environmental Engineering, pp. 412–417, 08-Oct-2018. <https://doi.org/10.4491/eer.2018.215>
- [9] Thakulla, D., & Fisher, P. R. (2023). Effects of cold plasma and ozone water treatment on micronutrient solubility. *Horticulturae*, 9(5), 568. <https://doi.org/10.3390/horticulturae9050568>
- [10] V, Dung & Kim, Lavane. (2018). A study on treatment of surface water using cold plasma for domestic water supply. *Environmental Engineering Research*. 24. 10.4491/eer.2018.215. <https://doi.org/10.4491/eer.2018.215>

- [11] Jin-Young Han, Sang-Hyun Park, Dong-Hyun Kang, Effects of plasma bubble-activated water on the inactivation against foodborne pathogens on tomatoes and its wash water, *Food Control*, Volume 144, 2023, 109381, ISSN 0956-7135, <https://doi.org/10.1016/j.foodcont.2022.109381>.
- [12] Soni A, Choi J, Brightwell G. Plasma-Activated Water (PAW) as a Disinfection Technology for Bacterial Inactivation with a Focus on Fruit and Vegetables. *Foods*. 2021 Jan 15;10(1):166. doi: 10.3390/foods10010166.
- [13] Niemira BA. Cold plasma decontamination of foods. *Annu Rev Food Sci Technol*. 2012; 3:125-42. doi: 10.1146/annurev-food-022811-101132.
- [14] Joo Hyun Kang, Jin-Young Han, Ho Seon Lee, Seungmin Ryu, Seong Bong Kim, Sangwoo Cho, Dong- Hyun Kang, Sea C. Min, Plasma-activated water effectively decontaminates steamed rice cake, *LWT*, Volume 157, 2022, 112838, ISSN 0023-6438, <https://doi.org/10.1016/j.lwt.2021.112838>.
- [15] Syamlal Sasi, Karthika Prasad, Janith Weerasinghe, Olha Bazaka, Elena P. Ivanova, Igor Levchenko, Kateryna Bazaka, Plasma for aquaponics, *Trends in Biotechnology*, Volume 41, Issue 1, 2023, Pages 46-62, ISSN 0167-7799,0 <https://doi.org/10.1016/j.tibtech.2022.08.001>
- [16] Pa' nka, D.; Jeske, M.; Łukanowski, A.; Baturo-Cieśniewska, A.; Prus, P.; Maitah, M.; Maitah, K.; Malec, K.; Rymarz, D.; Muhire, J.d.D.; et al. Can Cold Plasma Be Used for Boosting Plant Growth and Plant Protection in Sustainable Plant Production? *Agronomy* 2022, 12, 841. <https://doi.org/10.3390/agronomy12040841>
- [17] Ruamrungsri, S.; Sawangrat, C.; Panjama, K.; Sojithamporn, P.; Jaipinta, S.; Srisuwan,W.; Intanoo, M.; Inkham, C.; Thanapornpoonpong, S.-n. Effects of Using Plasma-ActivatedWater as a Nitrate Source on the Growth and Nutritional Quality of Hydroponically Grown Green Oak Lettuces. *Horticulturae* 2023, 9, 248. <https://doi.org/10.3390/horticulturae9020248>
- [18] Priatama RA, Pervitasari AN, Park S, Park SJ, Lee YK. Current Advancements in the Molecular Mechanism of Plasma Treatment for Seed Germination and Plant Growth. *Int J Mol Sci*. 2022 Apr 21;23(9):4609. doi: 10.3390/ijms23094609. PMID: 35562997; PMCID: PMC9105374.