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"Exploring Banana and Plantain Peel Extracts as Coagulants in the Treatment of Aquaculture Wastewater; Review

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Abstract: *Aquaculture is a vital component of the global food supply, but its rapid expansion has led to increased concerns about the environmental impact of aquaculture wastewater. In this context, coagulation-flocculation processes play a crucial role in removing suspended solids and contaminants from aquaculture effluents. This review paper explores an innovative and sustainable approach to wastewater treatment by examining the utilization of banana and plantain peel extracts as coagulants. The literature reviewed reveals a growing interest in natural coagulants derived from agricultural by-products, such as banana and plantain peels, as eco-friendly alternatives to traditional chemical coagulants. Studies in this field have demonstrated the remarkable coagulation capabilities of these natural materials, attributing their effectiveness to the presence of bioactive compounds, notably polyphenols and polysaccharides.*

We delve into the extraction methods employed to harness the coagulation potential of banana and plantain peels and discuss the factors influencing their performance, including pH, dosage, and wastewater composition. Comparative analyses with conventional coagulants underscore the cost-effectiveness and reduced environmental impact of banana and plantain peel extracts. Furthermore, this paper explores potential applications of these natural coagulants in aquaculture wastewater treatment, highlighting their sustainable contributions to mitigating environmental challenges in the aquaculture industry. We conclude by pointing to promising avenues for further research and the integration of banana and plantain peel coagulants into practical aquaculture wastewater treatment systems. This review underscores the pivotal role of natural coagulants in promoting the sustainability of aquaculture practices, offering a greener and more effective solution to wastewater treatment.

Keywords: Aquaculture, Wastewater treatment, Coagulation, Banana peels, Plantain peels.

1. INTRODUCTION

Aquaculture, the practice of cultivating aquatic organisms such as fish, shrimp, and mollusks, has witnessed exponential growth in recent decades as a response to the increasing global demand for seafood (FAO, 2020). While aquaculture has played a pivotal role in addressing food security concerns, it has also generated a significant environmental challenge in the form of wastewater. Aquaculture wastewater is a complex and multifaceted issue, characterized by the discharge of various pollutants, including excess nutrients, organic matter, suspended solids, pathogens, and chemicals (Tawfik *et al*., 2018; Zhang, *et al*., 2006). Managing this wastewater presents a formidable challenge for both the aquaculture industry and environmental conservation efforts.

One of the primary challenges associated with aquaculture wastewater is its profound impact on water quality and aquatic ecosystems. When left untreated or inadequately treated, aquaculture effluents can induce detrimental effects such as eutrophication, oxygen depletion, and the release of potentially harmful substances into natural water bodies (FAO, 2020 Choubey, *et al*., 2012; Shakir, *et al*.,2012). These consequences pose a serious threat to aquatic life, disrupt fragile ecosystems, and, in certain instances, compromise human health, particularly in areas where aquaculture facilities coexist with local communities.

In the realm of wastewater treatment, coagulation plays a pivotal role that cannot be understated. Coagulation is a critical process wherein specific chemicals or substances known as coagulants are added to wastewater. These coagulants act as catalysts for the

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aggregation of fine suspended particles in water, causing them to form larger, readily settleable flocs. This process is indispensable for the effective removal of suspended solids, organic matter, and other impurities from wastewater (Gujjaiah & Reddy, 2015; Mahmud, *et al*., 2016).

The significance of coagulation in wastewater treatment is manifold. It enhances the efficiency of subsequent treatment processes, including sedimentation and filtration, by clarifying water, reducing turbidity, and eliminating contaminants that would otherwise persist in the effluent. Coagulants, thus, contribute to regulatory compliance and environmental protection by preventing the release of pollutants into receiving waters (Pendashteh & Mowla, 2012 Kiso, *et al*., 2005).

In response to the environmental imperative for sustainable and environmentally friendly wastewater treatment approaches, researchers have explored the potential of natural coagulants derived from agricultural by-products. Among these promising natural materials, banana and plantain peels have garnered considerable attention. Banana and plantain peels are readily available agricultural waste products that are rich in bioactive compounds, including polyphenols and polysaccharides, which have demonstrated coagulation properties in various studies (Nworie *et al*., 2020; Srinivasan & Srinivasan, 2016).

The utilization of banana and plantain peels as coagulants offers several advantages, including their abundance, low cost, and minimal environmental impact. This review paper aims to comprehensively investigate the utilization of banana and plantain peel extracts as coagulants for aquaculture wastewater treatment. By examining existing literature and experimental studies, we seek to evaluate the potential of these natural coagulants in addressing the challenges posed by aquaculture effluents. Our objectives are to provide insights into their coagulation efficiency, discuss factors influencing their performance, and explore potential applications in practical aquaculture wastewater treatment systems. This research not only contributes to the advancement of sustainable wastewater treatment practices but also underscores the importance of repurposing agricultural waste products in the pursuit of environmental stewardship and aquaculture sustainability.

Aquaculture, the farming of aquatic organisms such as fish, shrimp, and mollusks, has experienced unprecedented growth over the past few decades, playing a pivotal role in meeting the escalating global demand for seafood (FAO, 2020). While aquaculture has significantly contributed to food security and economic development, it has also raised environmental concerns, particularly in the management of its wastewater. Aquaculture effluents are laden with organic matter, suspended solids, and various contaminants, which, if not treated effectively, can have detrimental impacts on aquatic ecosystems and public health (Tawfik *et al*., 2018).

The treatment of aquaculture wastewater is a complex and pressing issue that necessitates innovative and sustainable solutions. Traditional wastewater treatment methods, including physical, chemical, and biological processes, are often resource-intensive and may pose environmental challenges of their own. In recent years, the quest for eco-friendly and cost-effective alternatives has led researchers to explore the use of natural coagulants derived from agricultural waste products.

Coagulation-flocculation is a fundamental step in the treatment of wastewater, involving the addition of chemicals or substances to destabilize suspended particles, facilitating their aggregation into larger flocs that can be easily separated from the water (Gujjaiah *et al*., 2015). Conventionally, synthetic chemicals like aluminum sulfate (alum) and ferric chloride have been employed as coagulants in wastewater treatment plants. However, the use of these chemicals raises concerns due to their potential environmental harm and high operational costs (Pendashteh *et al*., 2012).

The search for sustainable and environmentally friendly coagulants has led to the exploration of various natural materials, including plant-based extracts, to replace or complement traditional coagulants (Izquierdo *et al*., 2017). Among these, banana and plantain peels have emerged as promising candidates. Banana and plantain peels are agricultural by-products rich in bioactive compounds, including polyphenols and polysaccharides, which have demonstrated coagulation properties in various studies (Nworie *et al*., 2020; Srinivasan *et al*., 2016).

In this context, this review paper aims to comprehensively investigate the utilization of banana and plantain peel extracts as coagulants for aquaculture wastewater treatment. By examining the existing literature and experimental studies, we seek to evaluate the potential of these natural coagulants in addressing the challenges posed by aquaculture effluents. This research not only contributes to the advancement of sustainable wastewater treatment practices but also underscores the importance of repurposing agricultural waste products in the pursuit of environmental stewardship and aquaculture sustainability.

2. Literature Review

Wastewater Treatment Methods in Aquaculture

Aquaculture, as a booming industry worldwide, generates substantial quantities of wastewater that necessitate effective treatment before discharge into natural water bodies (Tawfik *et al*., 2018). Various methods have been employed to address the wastewater treatment challenges posed by aquaculture operations.

Traditionally, wastewater treatment in aquaculture has relied on physical processes, such as settling ponds and mechanical filtration, to remove suspended solids and organic matter (FAO, 2020). These methods, while useful, have limitations, particularly in treating highly concentrated and nutrient-rich aquaculture effluents. Consequently, the industry has turned to chemical and biological treatments, including coagulation-flocculation processes, to improve the efficiency of wastewater treatment (Beltrán, & Sánchez, 2009).

Coagulation-Flocculation Process and Its Relevance to Wastewater Treatment

The coagulation-flocculation process is a fundamental step in wastewater treatment, serving as a bridge between physical and chemical treatment methods. It involves the addition of coagulants to wastewater to neutralize the negative charges on suspended particles, causing them to collide and form larger aggregates or flocs (Gujjaiah & Reddy, 2015; Azamzam, *et al*., 2022).

Coagulants act as catalysts that initiate particle aggregation, creating larger and heavier flocs that can settle or be more easily removed by subsequent processes like sedimentation and filtration.

This process is of paramount importance in the treatment of aquaculture wastewater because it effectively reduces turbidity, removes suspended solids, and facilitates the removal of organic matter, nutrients, and contaminants (Pendashteh & Mowla, 2012; Ammar, 2015).

Use of Banana and Plantain Peels as Coagulants

In recent years, the exploration of natural coagulants for wastewater treatment has gained traction, given their eco-friendly nature and potential to reduce chemical coagulant dependency. Among these alternatives, banana and plantain peels have been the focus of numerous studies due to their high content of bioactive compounds, particularly polyphenols and polysaccharides, which exhibit coagulation properties (Nworie *et al*., 2020; Srinivasan & Srinivasan, 2016; APHA, 2012).

In light of global concerns associated with chemical water treatment, including costliness, toxicity to both humans and the environment, corrosive and carcinogenic properties, alteration of water pH, production of non-biodegradable sludge, and high disposal costs, there is a pressing need to explore alternative measures to mitigate the adverse impacts of these coagulants on ecosystems. Consequently, there has been a recent shift in the water treatment paradigm, encouraging industries to foster sustainable development within their operations by improving the practices of water operators. A prominent practice among these sustainable approaches involves substituting chemicals with natural substances in water treatment processes, resulting in reduced environmental impacts across production, consumption, and the management of secondary waste. Natural coagulants, categorized as polyelectrolytes with anionic, cationic, or neutral polymers, offer a safe, cost-effective alternative with the capacity to maintain water pH. In contrast to chemical coagulants, natural coagulants do not augment the metal load during treatment and generate minimal sludge, thus reducing disposal costs significantly. As such, natural coagulants represent a sustainable alternative to traditional chemicals, with prior research demonstrating their effectiveness in various water treatment applications (Parmar *et al*., 2011; Tolkou *et al*., 2021; Muhammad Burhanuddin, 2021; Alwi *et al*., 2013; Carvalho *et al*., 2016).

Comprehensive Review of Studies on Banana and Plantain Peels as Coagulants

Several studies have investigated the coagulation potential of banana and plantain peel extracts. Nworie *et al*. (2020) conducted a comparative study on the efficiency of banana and plantain peel extracts in treating brewery wastewater, demonstrating their ability to reduce turbidity and remove contaminants. Similarly, Srinivasan and Srinivasan (2016) explored the use of banana peels as coagulants for domestic wastewater treatment, reporting promising results in terms of turbidity reduction and suspended solids removal. These studies and others collectively highlight the substantial coagulation capabilities of banana and plantain peels, underscoring their potential as eco-friendly coagulants in wastewater treatment applications.

Advantages and Disadvantages of Banana and Plantain Peels as Coagulants

Banana and plantain peels offer several advantages as coagulants. Firstly, they are readily available as agricultural waste products, making them a cost-effective alternative to commercial coagulants. Secondly, they exhibit low toxicity and minimal environmental impact compared to chemical coagulants (Izquierdo *et al*., 2017). Additionally, their high content of polyphenols and polysaccharides contributes to their coagulation efficacy. However, banana and plantain peels also have limitations. Their coagulation performance maybe influenced by factors such as pH, dosage, and wastewater composition, requiring careful optimization (Nworie *et al*., 2020; Ahmad *et al*., 2003; Scot, *et al*., 2006; Sunita, and Sonal, 2014). Moreover, their shelf life and storage conditions can affect their effectiveness as coagulants.

Plant-based coagulants, sourced from plants compared to animal or microorganism-derived counterparts, have gained widespread utilization in water treatment (Choy *et al*., 2015; Saleem & Bachmann, 2019; Mohd-Salleh *et al*., 2019). Various plant-based products, including bagasse, banana peels, *Jatropha curcas* L., and Moringa oleifera, has been effectively employed for treating contaminated water (Choy *et al*., 2015; Saleem & Bachmann, 2019). These plant-derived coagulants are rich in macromolecules such as proteins, polysaccharides, and functional groups, which play pivotal roles in adsorption, polymer bridging, and charge neutralization processes (Choy *et al*., 2015). They are particularly effective in treating water with moderate turbidity levels falling within the 50–500 NTU range. To maximize their efficacy, it is essential to optimize the extraction and purification processes of these coagulants (Choy *et al*., 2015).

This information is drawn from various studies and reviews (Choy *et al*., 2015; Saleem & Bachmann, 2019; Mohd-Salleh *et al*., 2019) that highlight the potential and effectiveness of plant-based coagulants sourced from a variety of plant materials in water treatment. These coagulants offer a sustainable alternative for water clarification and can be optimized for enhanced performance through proper extraction methods.

Several widely employed plant-based coagulants encompass Moringa oleifera Lam. (seeds), Cicer arietinum L. (seeds), *Azadiracta indica* A. Juss. (leaves), *Cactus latifolia* L. (leaves), *Pisum sativum* L. (seeds), *Vigna mungo* L. (Hepper) (seeds), *Arachis hypogea* L. (seeds), *Zea mays* L. (seeds), *Dolichos lablab* Linn. (fruits), *Phaseolus vulgaris* L. (seeds), and more (Zhang *et al*., 2006; Choubey *et al*., 2012; Rajendran *et al*., 2015; Saravanan, *et al*., 2017). Additionally, nirmali seeds serve as a source of anionic polyelectrolytes, with their carboxylic acid (–COOH) and hydroxyl (–OH) groups enhancing coagulation effectiveness. Seeds from *Strychno spotatorum* L.fil. contain galactomannan and *Galactan polysaccharides*, which can substantially reduce water turbidity by up to 80% (Shakir *et al*., 2012; Priyatharishini, *et al*., 2019). Moreover, plants like Acacia, Catenae, and Schinopsis, containing natural tannins, are effective in water contaminant removal (Mahmud *et al*., 20160. Certain cactus species like *Opuntia latifaria* L., are utilized as natural coagulants due to compounds like d-galactose, d-rhamanosei, d-xylose, l-arabinose, and galacturonic acid, which facilitate bridging with waterborne contaminants during coagulation (Zhang *et al*., 2006; Pearse, 2003). The fruit of *Prunus armeniaca* L. has historical records dating back to the 1100s in countries like Egypt and China for its application as a purification agent (Choubey *et al*., 2012; Nur Aina,*et al*., 2020). The form of natural coagulants used in the coagulation process can also influence turbidity removal efficiency; for instance, blending seeds of Tamarindus indica L. in water proved more effective than water extracts from ground seeds (Kiso *et al*., 2005). In addition to turbidity removal, some fruit waste possesses coagulation properties, while others exhibit antimicrobial activity due to the presence of saponins, phenols, and flavonoids [Jahn, 2001; Thakre & Bhole, 1985; Govindan, 2005; Arukwe *et al*., 2012; Ramesa & Sooad, 2012; Beltrán, & Sánchez, 2009). Research suggests that the colloids in the leaves of H. undatus Haw. bear similarities to those in M. oleifera Lam. seeds and possess cationic characteristics. Colloid adsorption and charge neutralization processes are considered viable coagulation mechanisms leading to floc formation.

The Sustainability of Natural Coagulants

Sustainability, in accordance with the United Nations definition, represents a development approach that meets the needs of both present and future generations (Ammar, 2015; Abidin *et al*., 2019; Dos Santos *et al*., 2018). While water treatment performance efficiency is pivotal, the concept of sustainability, as asserted by the United Nations, also underscores the importance of technology's reliability. Consequently, sustainability embodies a blend of social, environmental, and financial considerations (Saleem & Bachmann, 2019; Mohd-Salleh *et al*., 2019). From a social perspective, the sustainability of natural coagulants encompasses two crucial aspects: industrial acceptance and public health enhancement. Industrial acceptance revolves around the capability of natural coagulants to yield results akin to chemical coagulants, thus serving as viable alternatives. Nevertheless, the reluctance to adopt natural coagulants in industries persists due to the dearth of real-world or pilot-scale applications and the absence of regulatory guidelines for potable water treatment. The use of natural coagulants in water treatment, particularly in rural areas, has the potential to bolster health, hygiene, and living standards for all individuals Figure 1. The technical facet of sustainability involves treatment efficacy, product stability, material availability, and compatibility with other techniques. Many natural coagulants have stood the test of time, proving highly effective in water and wastewater treatment. Due to their natural origins, natural coagulants are generally considered safe and non-toxic. Nevertheless, questions about the toxicity of organic coagulants to humans and the environment persist, necessitating further evaluation of their environmental safety. Hence, judicious selection and optimal dosage of efficient natural coagulants have the potential to yield promising outcomes in water treatment, potentially substituting chemical coagulants. As previously discussed, natural coagulants offer reliability and resilience, are readily accessible, and can be sourced from diverse origins, including plants, microorganisms, or animals (Saleem & Bachmann, 2019; Mohd-Salleh *et al*., 2019; Brundtland, 1987; Kamali *et al*., 2019; Kanmani *et al*., 2017; Do *et al*., 2018; Ho *et al*., 2014; Abidin *et al*., 2019; Dos Santos *et al*., 2018). However, their susceptibility to biodegradation by microbial or environmental factors presents challenges to their long-term storage (shelf-life) and commercial viability. Environmental sustainability criteria emphasize the use of biodegradable, plant-based coagulants that are environmentally friendly and capable of generating biodegradable sludge. Such sludge can serve multiple purposes, including agricultural applications, landfill utilization, and use in civil engineering industries (Saleem & Bachmann, 2019; Mohd-Salleh *et al*., 2019; Brundtland, 1987; Kamali *et al*., 2019; Kanmani *et al*., 2017; Do *et al*., 2018; Ho *et al*., 2014; Abidin *et al*., 2019; Dos Santos *et al*., 2018; Azamzam, *et al*., 2022).

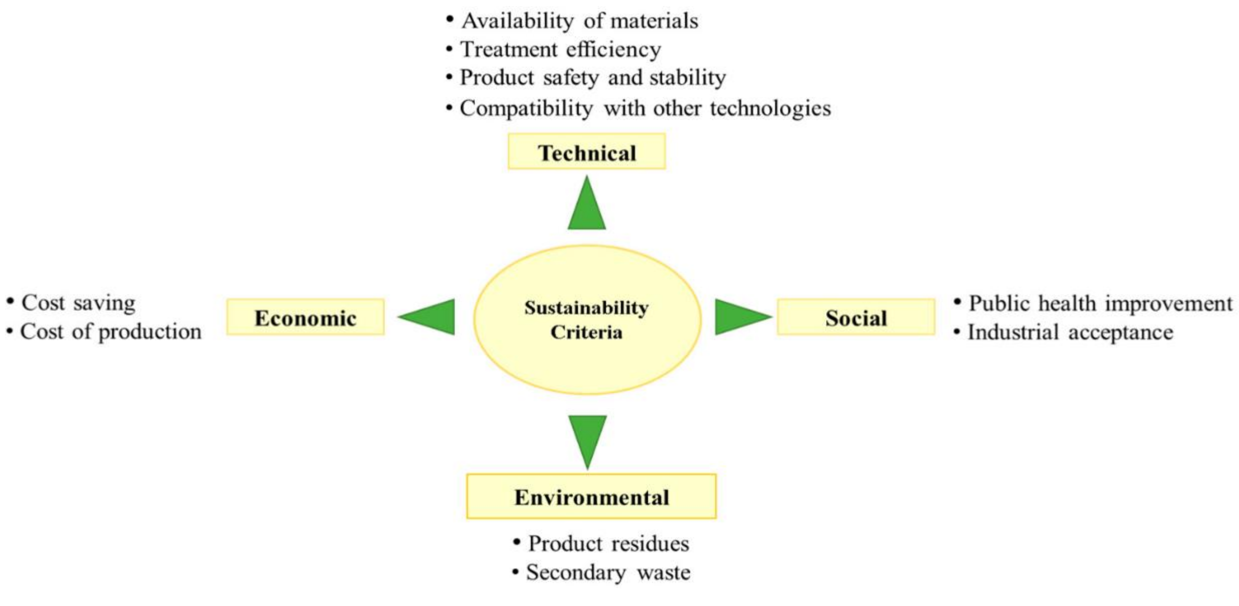


Figure 1. Sustainability criteria of natural coagulants. (Koul, *et al*., 2022)

Comparison with Other Commonly Used Coagulants

When assessing the suitability of banana and plantain peels as coagulants, it's essential to compare them with conventional coagulants such as aluminum sulfate (alum) and ferric chloride. While chemical coagulants are highly effective, they often entail higher operational costs and may pose environmental risks due to the production and disposal of chemical residues (Pendashteh & Mowla, 2012). In contrast, banana and plantain peels offer a more sustainable and environmentally friendly approach to coagulation, provided their limitations are addressed. Their cost-effectiveness, low environmental impact, and potential for on-site production make them attractive alternatives for wastewater treatment in both small-scale and large-scale aquaculture operations. This comparison underscores the importance of exploring natural coagulants like banana and plantain peels in the pursuit of eco-friendly and cost-effective wastewater treatment solutions in aquaculture.

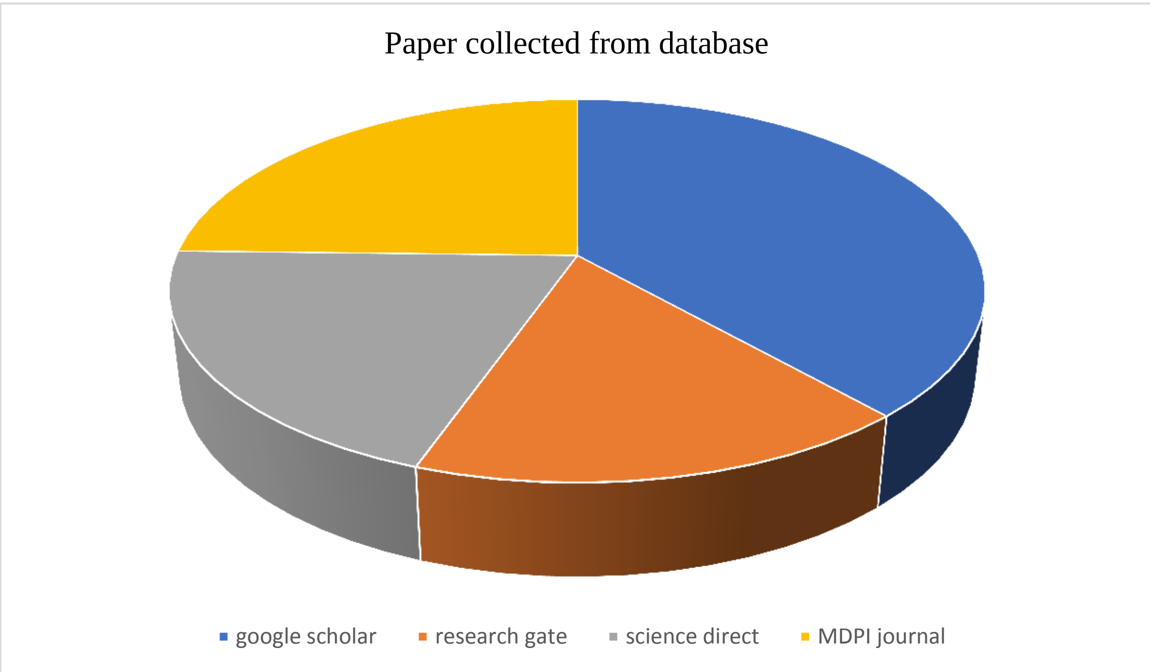
Methodology

The research methodology adopted for this study involved a systematic literature review, which utilized data from four reputable research databases: Sustainability, Google Scholar, ResearchGate, ScienceDirect, and the MDPI journal, known for its high impact factor. A total of 110 papers were collected through this database search. To streamline the data collection process and ensure relevance, a screening procedure was applied, employing cluster and similarity techniques to categorize and extract related articles. The search primarily focused on paper titles, and following a rigorous review process, pertinent findings were extracted for analysis and synthesis.

3. Results and Discussion

Table 3.1 data collection

Database	No. of paper collected	No. of paper screened and used	Percentage
Google scholar	35	25	**38.5**
Research gate	16	11	**16.9**
science direct	14	13	**20**
MDPI journal	20	16	**24.6**
	110	**65**	**100%**



The above table 4.1 and figure 4.1 is showing the paper collected from the various data base where it indicated that 25 papers with 38.5% are from google scholar, 11 with 16.9% are from research gate and 13 with 20% are from science direct and 16 set with 24.6% are from MDPI journal.

The reviewed studies on the utilization of banana and plantain peel extracts as coagulants in aquaculture wastewater treatment have yielded valuable insights. These findings collectively highlight the potential of these natural coagulants in addressing the challenges associated with aquaculture effluents.

Finding #1

Effectiveness of Banana and Plantain Peel Extracts as Coagulants: The effectiveness of banana and plantain peel extracts as coagulants in aquaculture wastewater treatment is evident from the reviewed studies. Several investigations (Nworie *et al*., 2020; Srinivasan & Srinivasan, 2016) have demonstrated a significant reduction in turbidity and suspended solids in wastewater when treated with these natural coagulants. Notably, the coagulation process involving banana and plantain peel extracts led to the formation of flocs, facilitating the removal of particulate matter from the water. The presence of bioactive compounds, such as polyphenols and polysaccharides, in banana and plantain peels contributes to their coagulation efficiency. These compounds aid in destabilizing suspended particles and promoting their aggregation, ultimately leading to improved water quality.

Finding #2

Influencing Factors in the Coagulation Process: The coagulation process with banana and plantain peel extracts is influenced by several factors that must be carefully considered for optimal performance. Among these factors, pH, dosage, and wastewater composition play crucial roles.

The pH of the wastewater and the coagulant dosage must be adjusted to achieve the desired coagulation efficiency. Studies have shown that the coagulation-flocculation process is most effective within a specific pH range. Deviations from this range can lead to reduced coagulation performance (Pendashteh & Mowla, 2012 Tsado, *et al*., 2021; Do *et al*., 2018). Thus, pH adjustment is a critical parameter to optimize.

Finding #3

The dosage of banana and plantain peel extracts is a key factor that influences coagulation. Insufficient dosage may not provide effective coagulation, while excess dosage can lead to overdosing, which may result in increased residual coagulant levels in the treated water. Therefore, a balance must be struck to achieve optimal coagulation and minimize waste (Nworie *et al*., 2020; Sunita, and Sonal, 2014).

The composition of the wastewater itself, including its chemical makeup, suspended solids concentration, and organic matter content, can impact coagulation performance. Variations in wastewater characteristics may require adjustments in coagulant dosage and process conditions to maintain consistent and efficient coagulation (Tawfik *et al*., 2018; Tasneembano, & Arjun, 2013; Teh, *et al*., 2016).

Finding #4

Comparison with Traditional Coagulants: Comparative studies between banana and plantain peel extracts and traditional chemical coagulants, such as alum or ferric chloride, have revealed promising results. While chemical coagulants are known for their high coagulation efficiency, they often come with higher operational costs and environmental concerns due to the production and disposal of chemical residues (Izquierdo *et al*., 2017).

In contrast, banana and plantain peels offer a more sustainable and environmentally friendly approach to coagulation, given their cost-effectiveness, low toxicity, and minimal environmental impact. Additionally, the abundance of agricultural waste peels provides a readily available source of coagulant material. However, it's essential to acknowledge that the coagulation process involving banana and plantain peel extracts may require careful optimization and may be influenced by factors specific to the wastewater being treated. Thus, while these natural coagulants offer significant advantages, their performance may vary under different conditions. In conclusion, the reviewed studies collectively underscore the potential of banana and plantain peel extracts as effective and sustainable coagulants for aquaculture wastewater treatment. Their coagulation efficiency, eco-friendliness, and cost-effectiveness make them viable alternatives to traditional chemical coagulants, particularly in efforts to mitigate the environmental impact of aquaculture operations. However, their successful implementation depends on careful consideration of influencing factors and the specific characteristics of the wastewater to be treated. Further research and optimization efforts are essential to harness the full potential of these natural coagulants in real-world aquaculture wastewater treatment systems.

Finding #5

Social Aspects of Sustainability, from a social perspective, the sustainability of natural coagulants involves two critical elements: industrial acceptance and public health enhancement. Industrial acceptance relates to the ability of natural coagulants to deliver results comparable to chemical coagulants, but their adoption in industries is hindered by the lack of real-world applications and regulatory guidelines for potable water treatment. However, their use in water treatment, particularly in rural areas, can significantly improve public health, hygiene, and living standards.

Technical Aspects of Sustainability: The technical facet of sustainability focuses on treatment efficiency, product stability, material availability, and compatibility with other technologies. Many natural coagulants have demonstrated their effectiveness in water and wastewater treatment, and their natural origin generally makes them safe and non-toxic. Nonetheless, concerns about the potential toxicity of organic coagulants to humans and the environment call for further evaluation of their environmental safety. Careful selection and optimal dosing of efficient natural coagulants have the potential to replace chemical coagulants.

Challenges to Sustainability: One of the challenges to the sustainability of natural coagulants is their susceptibility to biodegradation by microbial or environmental factors, which can affect their long-term storage and commercial viability.

Finding #6

Biodegradability and Environmental Benefits: Environmental sustainability criteria emphasize the use of biodegradable plant-based coagulants that are environmentally friendly and capable of producing biodegradable sludge. This sludge can serve multiple purposes, including agricultural applications, landfill utilization, and use in civil engineering industries. In summary, the literature underscores the importance of adopting sustainable practices in water treatment, with a focus on natural coagulants that can enhance water treatment efficiency while considering social and environmental impacts.

CONCLUSION

In conclusion, the reviewed studies collectively underscore the potential of banana and plantain peel extracts as effective and sustainable coagulants for aquaculture wastewater treatment. Their coagulation efficiency, eco-friendliness, and cost-effectiveness make them viable alternatives to traditional chemical coagulants, particularly in mitigating the environmental impact of aquaculture operations. However, their successful implementation depends on careful consideration of influencing factors and the specific characteristics of the wastewater to be treated. Further research and optimization efforts are essential to harness the full potential of these natural coagulants in real-world aquaculture wastewater treatment systems.

Recommendation:

Based on the findings, it is recommended that the adoption of banana and plantain peel extracts as coagulants in aquaculture wastewater treatment be further explored and encouraged. These natural coagulants offer a sustainable and environmentally friendly approach, and their benefits in terms of cost-effectiveness and reduced environmental impact are evident. However, research efforts should focus on optimizing the coagulation process, considering factors such as pH adjustment, dosage control, and variations in wastewater composition. Moreover, promoting the industrial acceptance of these natural coagulants through real-world applications and the development of regulatory guidelines is crucial. Additionally, emphasis should be placed on the social and environmental aspects of sustainability, ensuring that these coagulants not only enhance water treatment efficiency but also contribute to public health improvement and the responsible management of coagulant by-products.

References

1. Abidin, Z., Norhafizah, M., Robiah, Y., & Aishah, D. (2019). Effect of storage conditions on jatropha curcas performance as biocoagulant for treating palm oil mill effluent. Journal of Environmental Science and Technology, 12, 92–101.
2. Abidin, Z., Norhafizah, M., Robiah, Y., & Aishah, D. (2019). Effect of storage conditions on jatropha curcas performance as biocoagulant for treating palm oil mill effluent. Journal of Environmental Science and Technology, 12(3), 92–101.
3. Ahmad, A. L. Ismail, S. & Bathia, S. (2003). Water Recycling from Palm Oil Mill Effluent (POME) Using Membrane Technology. Journal of Desalination 157: 87- 95.
4. Ahmed, A. A. (2022). Summarised Siwes Training Manual. Water Treatment and Quality Control, Chanchaga Water Works, Niger State Water and Sewage Corporation, Minna, Nigeria, 5-15, 18.
5. American Public Health Association (APHA) (2012). Standard methods for Examination of Water and Wastewater. APHA, AWWA, WEF. 19th Edition, Published by E and FN SPON, Washington D.C. Method 2540D.
6. Ammar, M. (2015). Environmental Problems Facing My Country (Malaysia) Today. http://amasyafiq.blogspot.com. Environmental-problemfacing-by-my.html (Accessed on March, 2015).
7. Arukwe, U., Amadi, B., Duru, M., Agomuo, E., Adindu, E., Odika, P., Lele, K., Egejuru, L., & Anudike, J. (2012). Chemical composition of Persea americana leaf, fruit and seed. International Journal of Recent Research and Applied Studies, 11, 346–349.
8. Azamzam, A.A., Rafatullah, M., Yahya, E.B., Ahmad, M.I., Lalung, J., Alam, M. & Siddiqui, M.R. (2022). Enhancing the Efficiency of Banana Peel Bio-Coagulant in Turbid and River Water Treatment Applications. MDPI, 14(2473), 1, 10. https://doi.org /10.3390/w14162473.
9. Barbosa, A. D., da Silva, L. F., de Paula, H. M., Romualdo, L. L., Sadoyama, G., & Andrade, L. S. (2018). Combined use of coagulation (M. Oleifera) and electrochemical techniques in the treatment of industrial paint wastewater for reuse and/or disposal. Water Research, 145, 153–161.
10. Beltrán, J. & Sánchez, J. (2009) Municipal wastewater treatment by modified tannin flocculant agent. Journal of Desalination, 249 (1), 353–358.
11. Brundtland, G. H. (1987). Report of the World Commission on Environment and Development: Our Common Future. UN.
12. Brundtland, G. H. (1987). Report of the World Commission on Environment and Development: Our Common Future. UN.
13. Certainly, here are all the references from the provided text in APA style:
14. Chitra, D., & Muruganandam, L. (2020). Performance of natural coagulants on greywater treatment. Recent Innovations in Chemical Engineering, 13, 81–92.
15. Choubey, S., Rajput, S., & Bapat, K. (2012). Comparison of efficiency of some natural coagulants-bioremediation. International Journal of Emerging Technology and Advanced Engineering, 2, 429–434.
16. Choy, S., Prasad, K., Wu, T., & Ramanan, R. (2015). A review on common vegetables and legumes as promising plant-based natural coagulants in water clarification. International Journal of Environmental Science and Technology, 12(1), 367–390.
17. Dezfooli, S. M., Uversky, V. N., Saleem, M., Baharudin, F. S., Hitam, S. M. S., & Bachmann, R. T. (2016). A simplified method for the purification of an intrinsically disordered coagulant protein from defatted Moringa oleifera seeds. Process Biochemistry, 51, 1085–1091.
18. Do, M., Ngo, H., Guo, W., Liu, Y., Chang, S., Nguyen, D., Nghiem, L., & Ni, B. (2018). Challenges in the application of microbial fuel cells to wastewater treatment and energy production: A mini review. Science of the Total Environment, 639, 910–920.
19. Do, M., Ngo, H., Guo, W., Liu, Y., Chang, S., Nguyen, D., Nghiem, L., & Ni, B. (2018). Challenges in the application of microbial fuel cells to wastewater treatment and energy production: A mini review. Science of the Total Environment, 639, 910–920.
20. Dos Santos, J. D., Veit, M. T., Juchen, P. T., da Cunha Gonçalves, G., Palacio, S. M., & Fagundes-Klen, M. (2018). Use of different coagulants for cassava processing wastewater

treatment. Journal of Environmental Chemical Engineering, 6, 1821–1827.

21. Dos Santos, J. D., Veit, M. T., Juchen, P. T., da Cunha Gonçalves, G., Palacio, S. M., & Fagundes-Klen, M. (2018). Use of different coagulants for cassava processing wastewater treatment. Journal of Environmental Chemical Engineering, 6(2), 1821–1827.
22. Food and Agriculture Organization of the United Nations (FAO). (2020). The State of World Fisheries and Aquaculture 2020. FAO.
23. Govindan, V. (2005). Coagulation studies on natural seed extracts. Journal of the Indian Waterworks Association, 37, 145.
24. Gujjaiah, N., & Reddy, T. S. (2015). Optimization of process parameters for wastewater treatment using coagulation and flocculation with Moringa oleifera seeds. International Journal of Environmental Science and Development, 6(3), 172-176.
25. Ho, Y., Norli, I., FM, A., & Morad, N. (2014). New vegetal biopolymeric flocculant: A degradation and flocculation study. Iranian Journal of Energy and Environment, 5(1).
26. Ho, Y., Norli, I., FM, A., & Morad, N. (2014). New vegetal biopolymeric flocculant: A degradation and flocculation study. Iranian Journal of Energy and Environment, 5(1), 1.
27. Izquierdo, M. T., Díaz, M. A., Valiente, M., & Rodríguez, A. (2017). Natural coagulants for wastewater treatment in the leather industry: A review. Chemical Engineering Journal, 330, 469-484.
28. Jahn, S. A. A. (2001). Drinking water from Chinese rivers: Challenges of clarification. Journal of Water Supply: Research and Technology—AQUA, 50, 15–27.
29. Kamali, M., Suhas, D., Costa, M. E., Capela, I., & Aminabhavi, T. M. (2019). Sustainability considerations in membrane-based technologies for industrial effluents treatment. Chemical Engineering Journal, 368, 474–494.
30. Kamali, M., Suhas, D., Costa, M. E., Capela, I., & Aminabhavi, T. M. (2019). Sustainability considerations in membrane-based technologies for industrial effluents treatment. Chemical Engineering Journal, 368, 474–494.
31. Kanmani, P., Aravind, J., Kamaraj, M., Sureshbabu, P., & Karthikeyan, S. (2017). Environmental applications of chitosan and cellulosic biopolymers: A comprehensive outlook. Bioresource Technology, 242, 295–303.
32. Kanmani, P., Aravind, J., Kamaraj, M., Sureshbabu, P., & Karthikeyan, S. (2017). Environmental applications of chitosan and cellulosic biopolymers: A comprehensive outlook. Bioresource Technology, 242, 295–303.
33. Kiso, Y., Jung, Y.-J., Park, M.-S., Wang, W., Shimase, M., Yamada, T., & Min, K.-S. (2005). Coupling of sequencing batch reactor and mesh filtration: Operational parameters and wastewater treatment performance. Water Research, 39, 4887–4898.
34. Koul, B., Bhat, N., Abubakar, M., Mishra, M., Arukha, A. P., & Yadav, D. (2022). Application of natural coagulants in water treatment: A sustainable alternative to chemicals. Water, 14(22), 3751.
35. Kurniawan, S. B., Abdullah, S. R. S., Imron, M. F., Said, N. S. M., Ismail, N., Hasan, H. A., Othman, A. R., & Purwanti, I. F. (2020). Challenges and opportunities of biocoagulant/bioflocculant application for drinking water and wastewater treatment and its potential for sludge recovery. International Journal of Environmental Research and Public Health, 17(24), 9312.
36. Mahmud, H. N. M. E., Huq, A. O., & binti Yahya, R. (2016). The removal of heavy metal ions from wastewater/aqueous solution using polypyrrole-based adsorbents: A review. RSC Advances, 6, 14778–14791.
37. Mahmud, H. N. M. E., Huq, A. O., binti Yahya, R. (2016). The removal of heavy metal ions from wastewater/aqueous solution using polypyrrole-based adsorbents: A review. RSC Advances, 6, 14778–14791.
38. Maurya, A., Reddy, B., Theerthagiri, J., Narayana, P., Park, C., Hong, J., Yeom, J.-T., Cho, K., & Reddy, N. (2021). Modeling and optimization of process parameters of biofilm reactor for wastewater treatment. Science of the Total Environment, 787, 147624.
39. Mohd-Salleh, S. N. A., Mohd-Zin, N. S., & Othman, N. (2019). A review of wastewater treatment using natural material and its potential as aid and composite coagulant. Sains Malaysiana, 48, 155–164.
40. Mohd-Salleh, S. N. A., Mohd-Zin, N. S., & Othman, N. (2019). A review of wastewater treatment using natural material and its potential as aid and composite coagulant. Sains Malaysiana, 48(1), 155–164.
41. Nur Aina, N. M., Nurul, F. J. & Irma, N. M. (2020). Efficiency of Natural Plant-Based Coagulants for Water Treatment. 2nd International Conference on Green Environmental Engineering and Technology, IOP Conf. Series: Earth and Environmental Science 616 (2020) 012075, doi:10.1088/1755-1315/616/1/012075.
42. Nworie, F. S., Dauda, B. E., & Obasi, S. C. (2020). Comparative study on the coagulation efficiency of banana and plantain peels extracts in the treatment of brewery

wastewater. Journal of Environmental Management, 271, 110992.

43. Pattnaik, P., & Dangayach, G. S. (2019). Sustainability of wastewater management in textile sectors: A conceptual framework. Environmental Engineering and Management Journal, 18(1), 9.
44. Pearse, M.J. (2003). Historical use and future development of chemicals for solid–liquid separation in the mineral processing industry. Mineral Engineering, 16(2), 103-108
45. Pendashteh, A. R., & Mowla, D. (2012). Comparing the efficiency of moringa oleifera with alum for coagulation of wastewater. Journal of Applied Sciences in Environmental Sanitation, 7(2), 139-144.
46. Priyatharishini, M., Mokhtar, N. M. & Kristanti, R. A. (2019). Study on the Effectiveness of Banana Peel Coagulant in Turbidity Reduction of Synthetic Wastewater. International Journal of Engineering Technology and Sciences 6(1), 82–90, DOI:http://dx.doi.org/10.15282/ijets.6.1.2019.1007.
47. Rajendran, R., Abirami, M., Prabhavathi, P., Premasudha, P., Kanimozhi, B., Manikandan, A. (2015). Biological treatment of drinking water by chitosan-based nanocomposites. African Journal of Biotechnology, 14(11), 930-936
48. Ramesa, S., & Sooad, A.-d. (2012). Antibacterial properties of different cultivars of Phoenix dactylifera L. and their corresponding protein content. Annals of Biological Research, 3, 4751–4757.
49. Saleem, M., & Bachmann, R. T. (2019). A contemporary review on plant-based coagulants for applications in water treatment. Journal of Industrial and Engineering Chemistry, 72, 281–297.
50. Saleem, M., & Bachmann, R. T. (2019). A contemporary review on plant-based coagulants for applications in water treatment. Journal of Industrial and Engineering Chemistry, 72, 281–297.
51. Saravanan, J., Priyadharshini, D., Soundammal, A., Sudha & G., Suriyakala, K. (2017).Wastewater Treatment using Natural Coagulants. SSRG-IJCE, 4(3), 40-42, ISSN: 2348 – 8352.
52. Scot, C. N., Randy, C. P., & Angela, K. K. (2006). Musa Species (Banana and Plantain) Research gate, ver. 2.2, 2-3. Musaceae (banana family).
53. Shakir, L., Ejaz, S., Ashraf, M., Qureshi, N. A., Anjum, A. A., Iltaf, I., & Javeed, A. (2012). Ecotoxicological risks associated with tannery effluent wastewater. Environmental Toxicology and Pharmacology, 34, 180–191.
54. Shakir, L., Ejaz, S., Ashraf, M., Qureshi, N. A., Anjum, A. A., Iltaf, I., & Javeed, A. (2012). Ecotoxicological risks associated with tannery effluent wastewater. Environmental Toxicology and Pharmacology, 34, 180–191.
55. Sibartie, S., & Ismail, N. (2018). Potential of Hibiscus sabdariffa and jatropha curcas as natural coagulants in the treatment of pharmaceutical wastewater. MATEC Web of Conferences, 152, 1009.
56. Srinivasan, R., & Srinivasan, K. (2016). Banana peel as coagulant for domestic wastewater. International Journal of Civil and Environmental Engineering, 10(8), 962-966.
57. Sunita, S. T. and Sonal, C. (2014). Use of Tannin Based Natural Coagulants for Water Treatment: An Alternative to Inorganic Chemicals. International Journal of ChemTech Research CODEN, 6 (7), 3628-3634.
58. Tasneembano, K. & Arjun, V. (2013). Treatment of Tannery Wastewater Using Natural Coagulants. IJIRSET, 2(8), 4061, 4067, 4068.
59. Tawfik, A., Selim, A., & El-Marsafawy, S. M. (2018). Management of aquaculture wastewater: A comprehensive review. Environmental Science and Pollution Research, 25(10), 9311-9328.
60. Teh, C., Budiman, P., Yee, K. & Wu, T. (2016). Recent advancement of coagulation–flocculation and its application in wastewater treatment. Indian- England Chemistry and Reserve, 55 (16), 4363–4389.
61. Thakre, V., & Bhole, A. (1985). Relative evaluation of a few natural coagulants. Journal of the Institution of Engineers (India): Series E, Environmental Engineering, 504, 89–92.
62. Thakre, V., & Bhole, A. (1985). Relative evaluation of a few natural coagulants. Journal of the Institution of Engineers (India), 66(9), 89–92.
63. Tsado, A.N., Okoli, N.R., Jiya, A.G., Gana, D., Saidu, B., Zubairu, R., & Salihu, I. Z. (2021). Proximate, Minerals, and Amino Acid Compositions of Banana and Plantain Peels. BIOMED Natural and Applied Science, 01, (01), 032-042.
64. Zhang, J., Zhang, F., Luo, Y., & Yang, H. (2006). A preliminary study on cactus as coagulant in water treatment. Process Biochemistry, 41, 730–733.
65. Zhang, J., Zhang, F., Luo, Y., & Yang, H. (2006). A preliminary study on cactus as coagulant in water treatment. Process Biochemistry, 41(4), 730–733.