

FEASIBILITY OF SOY WASTE BIO-COAGULANT FOR POLLUTANT REMOVAL IN AQUACULTURE WASTEWATER TREATMENT

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(Received 19th November 2025; revised 11th February 2026; accepted 27th February 2026)

Abstract. Aquaculture wastewater typically contains high levels of turbidity and total suspended solids (TSS), which may adversely affect receiving water bodies if discharged without adequate treatment. This study evaluated the feasibility of using soy waste as a bio-coagulant for turbidity and TSS removal from aquaculture wastewater through a coagulation–flocculation process. Aquaculture wastewater was collected from a local fishery facility, while soy waste was obtained from a soy-based food processing company. Jar test experiments were conducted under fixed mixing and settling conditions using different bio-coagulant dosages, and the removal efficiencies of turbidity and TSS were evaluated. The results showed that the best soy waste-based bio-coagulant dosage was 0.1 mg/L, achieving turbidity and TSS removals of approximately 9.1% and 5.6%, respectively. Increasing the bio-coagulant dosage beyond this level did not improve removal performance and led to higher turbidity and TSS due to the presence of fine, whitish soy waste particles remaining in suspension. Overall, raw soy waste exhibited limited effectiveness as a standalone bio-coagulant for aquaculture wastewater treatment; however, the findings provide useful insight into its behaviour and highlight the potential for further improvement through pre-treatment or modification.

Keywords: *bio-coagulant, aquaculture wastewater, soy waste, wastewater treatment*

Introduction

The aquaculture sector has experienced accelerated growth in recent decades to satisfy the rising global demand for fish and seafood products. Intensive aquaculture practices, including high stocking densities and formulated feed usage, have significantly improved production efficiency. However, these practices also generate large volumes of wastewater during routine operations such as pond drainage, tank cleaning, and water exchange. As aquaculture continues to grow, the management of wastewater generated from these activities has become an important environmental and operational concern (Arshad et al., 2024). Aquaculture wastewater is typically characterised by elevated levels of turbidity and total suspended solids (TSS), arising from uneaten feed, fish faeces, plankton, and disturbed bottom sediments. The discharge of untreated aquaculture effluent into natural water bodies can degrade water quality by reducing light penetration, increasing oxygen demand, and promoting eutrophication. These impacts may adversely affect aquatic ecosystems and downstream water users highlighting the need for effective and sustainable treatment strategies prior to discharge or reuse (Bergheim and Brinker, 2004). Various physical, chemical, and biological treatment methods have been applied for the treatment of aquaculture wastewater. Common approaches include sedimentation, filtration, constructed wetlands, biofiltration, and coagulation–flocculation processes. Among these methods, coagulation–flocculation is widely employed as a primary treatment step due to its simplicity, relatively low operational requirements, and effectiveness in removing

turbidity and suspended solids. The process destabilises colloidal particles and promotes floc formation, allowing suspended matter to be removed through settling or filtration (Kashem et al., 2023).

Conventional coagulation processes typically rely on chemical coagulants such as aluminium sulphate and polyaluminium chloride. Although these coagulants are effective, their use is associated with several limitations, including high chemical consumption, sludge disposal issues, and concerns related to residual metal content in treated water (Thom et al., 2024). In response to these challenges, increasing attention has been directed toward the use of bio-coagulants derived from biological and agricultural waste materials. Bio-coagulants present a promising alternative to traditional chemical coagulants in wastewater treatment, offering biodegradable and environmentally friendly solutions. While their performance in turbidity and TSS removal is generally moderate compared to chemical options, they are particularly effective in pre-treatment scenarios or for low-strength wastewater applications. Bio-coagulants like *Moringa oleifera* and *Opuntia ficus-indica* have shown up to 100% turbidity removal in synthetic water tests, outperforming traditional coagulants like alum and ferric chloride in specific conditions (Hadadi et al., 2022). Studies also indicated that biowaste materials, such as banana peels and watermelon rinds, can achieve over 80% removal efficiency for turbidity and chemical oxygen demand (COD) (Ngomane, 2025; Kouniba et al., 2024). Soy waste, a by-product generated from soy-based food processing industries, represents a potential bio-coagulant due to its organic and polymeric constituents. Despite its abundance, soy waste is commonly underutilised and disposed of as solid waste (Davy and Vuong, 2022). Limited studies have investigated its application in aquaculture wastewater treatment. Therefore, the aim of this study is to evaluate the effectiveness of soy waste-based bio-coagulant for turbidity and TSS removal from aquaculture wastewater with the objective of promoting a low-cost and sustainable treatment alternative while supporting waste valorisation.

Literature review

Coagulation and flocculation are critical processes in water treatment, effectively reducing turbidity and total suspended solids. Coagulation destabilizes colloidal particles by neutralizing their electrostatic charges, allowing them to aggregate. Flocculation further enhances this aggregation through mechanisms like polymer bridging, resulting in larger flocs that can be easily removed via sedimentation or filtration. This combination is widely employed in both potable water treatment and wastewater management. As a result, suspended matter can be effectively removed through sedimentation or filtration, making coagulation–flocculation a common primary treatment method for turbidity and total suspended solids reduction (Gaid., 2023). Conventional coagulation processes predominantly employ chemical coagulants which are effective in destabilising negatively charged colloidal particles and achieving high removal efficiencies. Their widespread use is attributed to predictable performance and ease of operational control (Teguh et al., 2022). However, chemical coagulation is associated with several drawbacks, including high chemical consumption, generation of non-biodegradable sludge, and concerns related to residual metal content in treated water. These limitations have raised environmental and health considerations, particularly for applications involving water reuse or discharge into sensitive ecosystems (Bahrodin et al., 2021). In response to these challenges, increasing attention has been directed toward the development of bio-coagulants derived from biological

and agricultural sources. Bio-coagulants present a sustainable alternative to chemical coagulants in wastewater treatment, leveraging their biodegradable and renewable properties. Their coagulation mechanisms, primarily involving adsorption, charge neutralization, and polymer bridging, are facilitated by functional groups such as hydroxyl, carboxyl, and amino groups found in various bio-based materials. While bio-coagulants may exhibit lower removal efficiencies compared to their chemical counterparts, they are often sufficient for pre-treatment processes and low-strength wastewater applications (Alazaiza et al., 2022; Hadadi et al., 2022).

Plant-based bio-coagulants have emerged as effective alternatives for wastewater treatment, leveraging their natural properties to reduce turbidity and other pollutants. These coagulants, derived from seeds, mucilage, leaves, and agricultural waste, utilize mechanisms such as cationic protein interactions and polymer bridging to facilitate particle destabilization and removal. The efficiency of these bio-coagulants is significantly influenced by factors including dosage, preparation methods, and the characteristics of the wastewater being treated. High protein content in seeds like *Moringa oleifera* and *Cucurbita pepo* enhances turbidity removal, achieving reductions of up to 92% under optimal conditions. The study highlights that *Moringa Oleifera* seeds effectively reduce water turbidity, with removal efficiency influenced by dosage, mixing time, and pH. Optimal turbidity removal of 92% was achieved using 8 g/l of *Moringa Oleifera* for 80 minutes (Shabaa et al., 2021). Paul et al. (2024) highlights that *Cucurbita pepo* and *Cicer arietinum* seeds effectively reduce turbidity, biochemical oxygen demand (BOD), and coliform counts in water. Their bio-coagulant properties are influenced by factors like seed dose, pH, and water quality parameters, demonstrating their potential as sustainable alternatives. Agricultural waste-derived bio-coagulants are increasingly recognized for their potential as sustainable alternatives in wastewater treatment. These materials, while generally less effective than chemical coagulants, demonstrate significant capabilities in reducing turbidity and total suspended solids, making them suitable for preliminary treatment stages in decentralized systems. Their use aligns with circular economy principles by valorising waste and minimizing environmental impact. Studies show that bio-coagulants like *Arachis hypogaea* shells and walnut husks can achieve turbidity removal efficiencies of up to 93.37% and 96.59%, respectively (Varsani et al., 2024; Zourif et al., 2024).

Soy waste, particularly from tofu and soy milk production, has garnered attention for its potential in environmental remediation and wastewater treatment. The unique composition of soy waste, rich in proteins and polysaccharides, enhances its ability to adsorb pollutants through various mechanisms. The presence of these components allows for adsorption and bridging mechanisms, effectively capturing suspended solids and organic matter (Frezzini et al., 2018). Although studies specifically applying soy waste as a bio-coagulant for aquaculture wastewater are limited, existing findings suggest that soy waste exhibits potential for turbidity and solids reduction when applied in raw or minimally processed form. These characteristics indicate that soy waste may serve as a low-cost bio-coagulant, particularly for pre-treatment applications. Despite the growing body of research on plant-based and agricultural waste bio-coagulants, limited studies have focused on the application of soy waste-based bio-coagulants for aquaculture wastewater treatment. In particular, information on its effectiveness in removing turbidity and total suspended solids from aquaculture effluent remains scarce. This gap highlights the need for further investigation into the feasibility of soy waste–

based bio-coagulants as a sustainable and low-cost treatment option for aquaculture wastewater.

Materials and Methods

Aquaculture wastewater collection

Aquaculture wastewater used in this Aquaculture wastewater was collected from a local fishery company located in Labu, Negeri Sembilan, Malaysia. Samples were collected using clean polyethylene containers that had been pre-rinsed with distilled water and the sampled wastewater. The collected samples were transported to the laboratory on the same day of sampling and stored at 4 °C in a chiller to minimise biological activity and physicochemical changes prior to analysis. Before use in the coagulation–flocculation experiments, the wastewater samples were allowed to reach room temperature and gently mixed to ensure homogeneity. Initial turbidity and TSS were measured to establish baseline conditions for subsequent treatment experiments

Preparation of soy waste as natural coagulant

Soy waste used for the preparation of the bio-coagulant was collected from a local soy company located in Klang, Selangor. The collected soy waste was first washed several times with distilled water to remove adhering impurities and residual soluble components. The cleaned material was then air-dried at room temperature until a relatively constant weight was achieved. After drying, the soy waste was manually ground using a laboratory mortar and pestle to obtain a fine powder. The powdered material was sieved to remove coarse particles and to ensure uniformity. The prepared soy waste powder was stored in a clean, airtight container at room temperature and used directly as a bio-coagulant without any chemical or thermal modification. During the coagulation–flocculation experiments, the required amount of soy waste–based bio-coagulant was accurately weighed and added directly to the aquaculture wastewater samples according to the designated dosage levels

Experiment of jar test

Jar test experiments were conducted using five 1 L beakers to evaluate the performance of the soy waste–based bio-coagulant for aquaculture wastewater treatment. For each experimental run, 500 mL of aquaculture wastewater was transferred into each beaker. The required amount of soy waste–based bio-coagulant was then added directly to each beaker according to the calculated dosage levels. The coagulation–flocculation process was performed under fixed mixing conditions. Rapid mixing was carried out at a speed of 180 rpm for 3 min to ensure uniform dispersion of the bio-coagulant and effective destabilisation of suspended particles. This was followed by a slow mixing stage at 10 rpm for 20 min, which facilitated floc formation and growth through particle collision and bridging mechanisms. After completion of the flocculation stage, the samples were allowed to settle under quiescent conditions for 30 min to allow separation of the formed flocs from the treated water. Upon completion of the settling period, supernatant samples were carefully withdrawn from the upper portion of each beaker without disturbing the settled flocs. The collected samples were subsequently analysed for turbidity and total suspended solids (TSS) to evaluate the treatment efficiency of the soy waste–based bio-coagulant (Ahmad et al., 2021).

Analysis on the removal efficiency

The removal efficiency of turbidity and total suspended solids (TSS) was calculated to evaluate the performance of the soy waste-based bio-coagulant. The removal efficiency was determined using the following Eq. (1):

$$\text{Efficiency (\%)} = \left(\frac{\text{Initial} - \text{Final}}{\text{Initial}} \right) * 100\% \quad \text{Eq. (1)}$$

Where, is the initial of turbidity (NTU) or TSS (mg/L) before treatment, and is the final after the coagulation–flocculation process and settling period. The calculated removal efficiencies were used to assess the effectiveness of the bio-coagulant at different dosage levels under fixed operating conditions.

Results and Discussion

Turbidity removal efficiency

Figure 1 shows the effect of soy waste bio-coagulant dosage on turbidity removal from aquaculture wastewater. The initial turbidity of the wastewater was approximately 507 NTU for all experimental conditions. As illustrated in the figure, turbidity removal did not improve with increasing bio-coagulant dosage, instead a decreasing trend in removal efficiency was observed as the dosage increased. In the absence of bio-coagulant (0 mg/L), a turbidity reduction of approximately 12.62% was achieved. This reduction can be attributed to natural sedimentation during the settling period, where heavier suspended particles settled without chemical assistance. When soy waste-based bio-coagulant was applied at a low dosage of 0.1 mg/L, turbidity removal decreased to approximately 9.06%. Further increases in dosage to 0.5 mg/L and 1 mg/L resulted in lower removal efficiencies of about 4.99% and 3.01%, respectively. At higher dosages (5 mg/L and 0.01 mg/L), no effective turbidity removal was observed, and the final turbidity exceeded the initial value, indicating deterioration in water clarity. Based on the graphical trend, the highest turbidity removal was achieved without bio-coagulant addition, while 0.1 mg/L represents the optimum dosage when the soy waste-based bio-coagulant was applied as it produced the greatest turbidity reduction among the tested dosages. However, at this optimum dosage, the bio-coagulant did not outperform natural sedimentation.

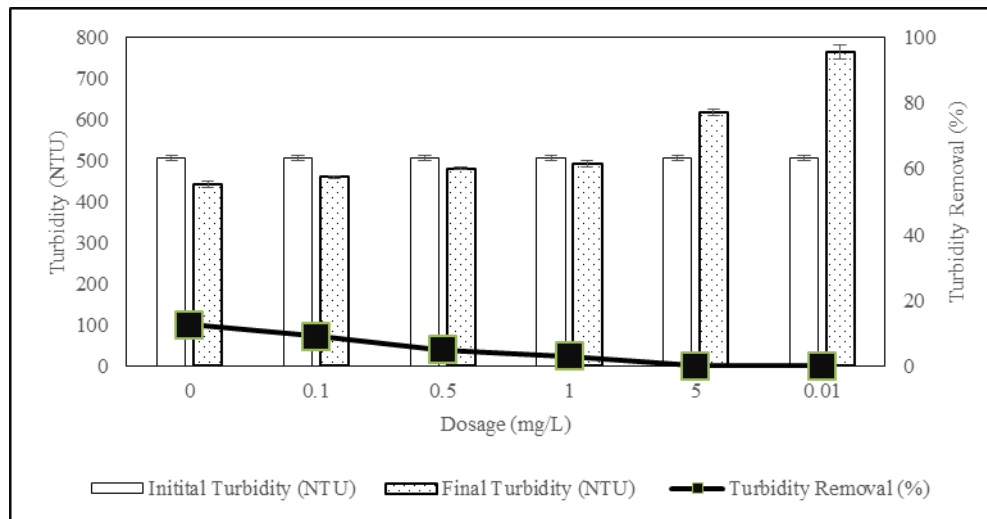


Figure 1. Turbidity removal efficiency of aquaculture wastewater at different soy waste bio-coagulant dosages.

The reduction in turbidity removal efficiency at higher dosages is likely related to the physical characteristics of the soy waste-based bio-coagulant. The soy waste used in this study exhibited a light or whitish appearance, and increasing the dosage introduced a greater quantity of fine, pale particles into the wastewater. These particles may remain suspended after mixing and settling, increasing light scattering and leading to higher turbidity readings (Aina Nadhillah Muhamad et al., 2020). Consequently, excessive addition of soy waste may have contributed to an apparent increase in turbidity due to colour and fine particulate interference rather than effective coagulation. Similar observations have been reported in studies involving raw or minimally processed bio-coagulants, where the introduction of fine organic matter negatively affected turbidity removal performance (Putra et al., 2020). Comparable trends have been reported in previous studies using untreated bio-coagulants. For example, studies on banana peel powder achieved up to 90% turbidity removal at 0.4 g/L, contrasting with studies on raw banana peel and corn cob powders, which reported efficiencies below 20% and declining performance at higher dosages (Dharsana and Prakash, 2023). Higher dosages of coagulants can lead to decreased performance due to the release of fine particles, which can reintroduce turbidity into the water (Azamzam et al., 2022). Similarly, investigations using unextracted *Moringa oleifera* seed powder showed limited turbidity removal at low dosages and increased turbidity at higher dosages, attributed to excess organic matter and colour interference (Camacho et al., 2017). In aquaculture wastewater applications, untreated plant-based bio-coagulants have also been reported to perform modestly, with turbidity removal largely influenced by sedimentation rather than coagulation when applied without chemical extraction or modification (Kurniawan et al., 2023a). Overall, the turbidity removal behaviour observed in this study is consistent with previous findings on raw agricultural waste-based bio-coagulants. While soy waste demonstrates potential as a sustainable and low-cost bio-coagulant, its effectiveness for turbidity removal in aquaculture wastewater is limited when applied in its raw form. Further enhancement through pre-treatment, such as removal of fine particles or extraction of active coagulating components, may be required to improve performance.

Based on turbidity removal results, natural sedimentation provided the highest reduction in turbidity, while the optimum soy waste-based bio-coagulant dosage was identified as 0.1 mg/L. The decline in performance at higher dosages is attributed to the whitish colour and fine particles of soy waste, which increased light scattering and apparent turbidity. These findings are consistent with previous studies on untreated bio-coagulants and indicate that raw soy waste is more suitable for exploratory or pre-treatment applications rather than as an effective standalone turbidity removal agent.

TSS removal efficiency

Figure 2 illustrates the effect of soy waste-based bio-coagulant dosage on total suspended solids (TSS) removal from aquaculture wastewater. The initial TSS concentration remained relatively constant at approximately 515.67 mg/L for all experimental conditions. As shown in the figure, a decreasing trend in TSS removal efficiency was observed with increasing bio-coagulant dosage. In the absence of bio-coagulant (0 mg/L), a TSS removal efficiency of approximately 10.85% was achieved, indicating that natural sedimentation played a significant role in the removal of suspended solids during the settling period. When a low dosage of soy waste-based bio-coagulant was applied (0.1 mg/L), TSS removal decreased to approximately 5.57%. Further increases in dosage to 0.5 mg/L and 1 mg/L resulted in lower removal efficiencies of approximately 3.63% and 2.46%, respectively. At higher dosages (5 mg/L and 10 mg/L), no effective TSS removal was observed, and the final TSS concentration exceeded the initial value, indicating an increase in suspended solids. Based on the graphical trend, the highest TSS removal was achieved without bio-coagulant addition, while 0.1 mg/L represents the optimum dosage among the tested bio-coagulant concentrations, as it provided the greatest TSS reduction when soy waste was applied. However, similar to turbidity removal, the soy waste-based bio-coagulant did not outperform natural sedimentation under the tested conditions. The reduction in TSS removal efficiency at higher dosages can be attributed to the introduction of fine particulate matter from the soy waste itself. The soy waste used in this study consisted of light-coloured, finely divided particles, which may have remained suspended after mixing and settling. As the dosage increased, the contribution of these fine particles likely outweighed the coagulation effect, resulting in an apparent increase in TSS concentration. This behaviour suggests that excess bio-coagulant addition may lead to re-stabilisation of particles or direct contribution of suspended solids, particularly when raw or minimally processed materials are used (Mohd Aripin et al., 2023).

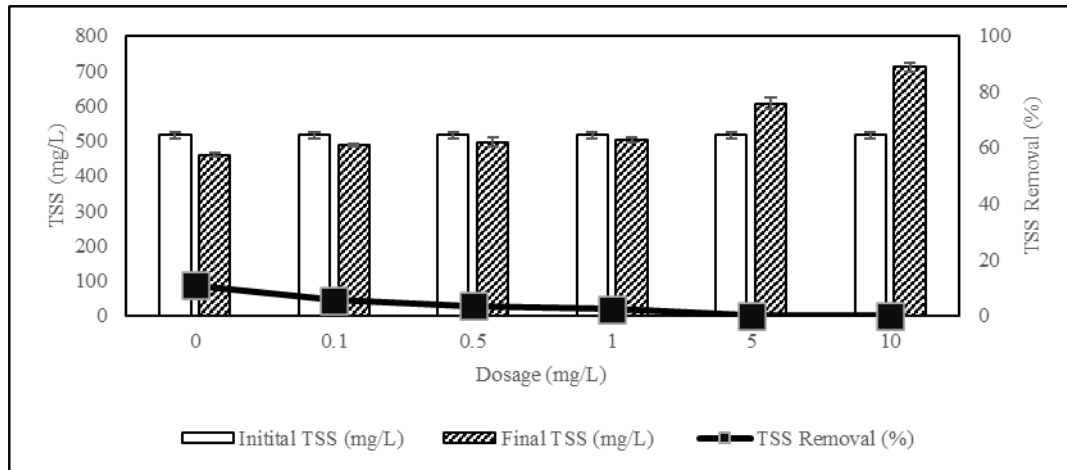


Figure 2. Total suspended solids (TSS) removal efficiency of aquaculture wastewater at different soy waste bio-coagulant dosages.

Similar trends have been reported in previous studies involving untreated bio-coagulants. For example, study indicate that banana peel powder can achieve TSS removal efficiencies of up to 66.81% at optimal dosages, but performance declines significantly at higher concentrations (Yolanda Putri et al., 2024). The maximum TSS removal observed was 66.66% with other natural coagulants, suggesting that banana peel powder alone may not be the most effective option (Maurya and Daverey, 2018). Research on corn cob-based bio-coagulants also demonstrated limited TSS removal when applied without chemical extraction, with increased suspended solids observed at excessive dosages. Corn extracts have shown varying efficiencies in TSS removal, with corn extract achieving a 35% removal rate under specific conditions (Prihatinningtyas and Effendi, 2022). The method of preparation significantly influences the performance of bio-coagulants. For instance, mechanical preparation methods like drying and grinding enhance the extraction of active compounds, leading to better coagulation outcomes (Kurniawan et al., 2023b).

Overall, the TSS removal behaviour observed in this study is consistent with findings reported for other agricultural waste-based bio-coagulants applied in raw form. While soy waste demonstrates potential as a sustainable and low-cost bio-coagulant, its effectiveness for TSS removal in aquaculture wastewater is limited under the tested conditions. Improved performance may be achieved through pre-treatment or modification of the soy waste to reduce fine particle release and enhance coagulation activity. Based on TSS removal results, natural sedimentation achieved the highest reduction in suspended solids, while the optimum soy waste-based bio-coagulant dosage was identified as 0.1 mg/L. The decline in TSS removal at higher dosages is attributed to the contribution of fine soy waste particles to the treated water. These findings are consistent with previous studies on untreated bio-coagulants and indicate that raw soy waste is more suitable for exploratory or pre-treatment applications rather than as an effective standalone TSS removal agent.

Conclusion

This study evaluated the performance of a soy waste-based bio-coagulant for the treatment of aquaculture wastewater, with a focus on turbidity and total suspended

solids (TSS) removal using a coagulation–flocculation process. The results demonstrated that the application of raw soy waste as a bio-coagulant did not significantly enhance turbidity or TSS removal compared to natural sedimentation under the tested conditions. For turbidity removal, the highest reduction was achieved in the absence of bio-coagulant, indicating that sedimentation played a dominant role in particle removal. Among the tested dosages, 0.1 mg/L was identified as the optimum soy waste–based bio-coagulant dosage; however, its performance remained lower than that of sedimentation alone. At higher dosages, turbidity increased due to the introduction of fine, whitish soy waste particles, which enhanced light scattering and reduced water clarity. A similar trend was observed for TSS removal. Natural settling resulted in the highest reduction of suspended solids, while the addition of soy waste–based bio-coagulant led to progressively lower removal efficiencies with increasing dosage. Excess bio-coagulant contributed additional fine particulate matter, resulting in increased TSS concentrations at higher dosages. These findings are consistent with previous studies on untreated agricultural waste bio-coagulants, which reported limited solids removal when applied without pre-treatment or modification. Overall, the results indicate that raw soy waste–based bio-coagulant exhibits limited effectiveness for turbidity and TSS removal in aquaculture wastewater. Nevertheless, the study provides valuable insight into the behaviour of soy waste as a bio-based treatment material and highlights its potential for further development. Future work should focus on pre-treatment or modification of soy waste, such as removal of fine particles, extraction of active coagulating components, or optimisation of operating conditions, to enhance its coagulation performance. The utilisation of soy waste as a bio-coagulant remains attractive from a sustainability perspective, particularly for waste valorisation and low-cost wastewater treatment research.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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