Nano zeolite-silica composite: a potential innovative technology for enhancing pond soil quality in aquaculture

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Abstract. Nanotechnology offers promising benefits for aquaculture efficiency and sustainability, yet research on nano zeolite-silica composites for pond soil conditioning, especially in tropical and brackish environments, remains limited. Thus, this study was conducted to compare the effect of nano zeolite-silica composite in the total nitrogen, available phosphorus, available potassium, pH, and organic matter in pond soil placed in polyvinyl chloride (PVC) pipes used as soil containers. Briefly, biochar from rice hull (bottom ash) was synthesized into pure nano char (nano-silica), followed by intercalation of commercial zeolite, and nano zeolite-silica composite was characterized to comfirm its properties. Treatment groups involved control (T1), 30 g of biochar with 30 g of commercial zeolite (T2), 30 g of nano zeolite with 300 mg of nano-silica (T3), and 60 g of nano zeolite with 600 mg of nano silica (T4) applied on the surface pond soil placed in 1 m long and 4 inches in diameter PVC pipes. The application of biochar with zeolite (T2) proved most effective in enhancing nutrient retention (N, P, K), organic matter, and maintaining favorable pH, while high concentrations of nano-zeolite and nano-silica (T4) reduced soil quality, suggesting that moderate nanomaterial application (T3) yields better outcomes and underscores the dosage sensitivity of engineered nanomaterials in aquaculture soils. Although no statistically significant effects were observed among treatments ($p > 0.05$), T3 demonstrated the most balanced nutrient profile, supporting its potential as a suitable amendment for sustainable pond soil management. Moreover, these findings provide the aquaculture industry with alternative methods for managing soil quality in a low-cost and locally sourced manner.

Key Words: biochar modification, engineered nanomaterials, pond sediment management, soil nutrients, sustainable aquaculture.

Introduction. Aquaculture plays an important role in fulfilling the increasing demand for fish globally, accounting for over half of all human food consumption. As the global population expands, there is a pressing need for advanced technologies to enhance fish production rates while minimizing the industry's negative impact on the ecosystem (Golbad et al 2017; Ghasemi et al 2018). Furthermore, aquaculture has attracted considerable attention across various disciplines due to its potential to provide nutritious diets in developing nations and secure food availability as the global population continues to grow rapidly (Igwegbe et al 2021). For many years, maintaining water quality has long been considered a top priority in pond aquaculture. However, despite mounting evidence that the condition of pond bottoms and the way soil interacts with water are critical to preserving water quality and have a major influence on the general health of the aquatic environment, pond soil quality management is occasionally overlooked (Boyd 1995).

The use of the word biochar here has come by extension from charcoal production and has, thus, been annexed to soil management and carbon sequestration problems (Demirbas 2004; Lehmann 2007; Jung et al 2013). However, there has been limited studies on the use of nanotechnology in biochar research. According to Wang et al (2023) and Bare et al (2023), biochar cleans the water in aquaculture by eliminating cadmium and polycyclic aromatic hydrocarbons (PAHs) (with an efficiency of up to 91%) and also captures nitrogen and phosphorus to reduce nutrient pollution. This approach of biochar increases soil fertility through increased retention of nutrients and water while reducing greenhouse gas emissions that benefit aquatic ecosystem health and climate change mitigation (Mary et al 2020; Kusman et al 2024).

Nanotechnology is theoretically suited for usage in practically all sectors and technologies, including environmental technology which is being promoted as a technology that can help address various global issues through environmentally friendly means and reducing pollutants (Algellai et al 2016). Nanoparticle (NP)-based technologies for remediating polluted sites have rapidly advanced, particularly in North America and Europe, although most experiments are conducted on a bench scale with few field studies (Karn et al 2011; Mueller et al 2012; NANOREM 2013). Nanotechnology is quickly establishing itself as the new scientific and technology platform for the next generation of agri-food system development and transformation (Kuzma & Verhage 2006), as well as improving the living conditions of the poor (Rather et al 2011). Numerous technologies are available for remediating contaminated soils and groundwater, categorized into off-site and on-site methods wherein the former method include eliminating contaminated materials for treatment elsewhere, while the latter method treat pollutants directly within the subsurface (Sharma & Reddy 2004; Karn et al 2011). The technology can help reduce water treatment costs in aquariums and commercial fish ponds. Likewise, it has been claimed that nanotechnology can assist in keeping fishponds free of disease and pollution (Can et al 2011). Presently, nanoparticles (NPs) are increasingly recognized for their effectiveness in eliminating microbes, organic and inorganic chemicals, halogenated compounds (such as pesticides), and heavy metals from the aquatic environment, particularly in inland aquaculture settings (Selvaraj et al 2014; Iwuozor 2018). Their small size, high stability, and processability are critical characteristics that enable these applications. These nanoparticles includes zinc oxide (ZnO), iron oxide (Fe_3O_4), tin oxide (TiO_2), silver (Ag), and carbon nanotubes (CNTs) are some of the most widely researched nanomaterials for aquaculture to enhance water quality (Eletta et al 2019; Ighalo et al 2021).

Although, nanotechnology holds promise for transforming the aquaculture industry by addressing water quality issues in fish farms (Ogunfowora et al 2021), there is a gap in specific studies focusing on using nanoparticles to enhance soil quality for aquaculture operations. Therefore, this study aims to apply nanotechnology to improve soil quality for aquaculture purposes.

Material and Method

Synthesis of biochar from rice hull (bottom ash) to pure nanochar (nano silica). The biochar from rice hull (bottom ash) was collected from Green Innovations For Tomorrow Corporation (GIFTCOR) in Bakal 2, Muňoz, Nueva Ecija. The synthesis, intercalation of commercial zeolite, and characterization of the nano zeolite-silica composite were conducted in October 2020, following the method developed by Suyom et al (2020), as shown in Figure 1. First, 100 grams of bottom ashes (biochar) was prepared and weighed prior to thorough washing to remove large impurities like soils and dirt. Then, it was placed in a 1000 mL beaker with one liter of water and boiled for about 30 minutes. After boiling, the bottom ashes were washed with distilled water and boiled again in a 3.6% hydrochloric acid (HCl) solution (36 mL of HCl: 964 mL of water) and boiled again for another 30 minutes. When the boiling process was done, the bottom ash (biochar) samples were washed thoroughly again with water or distilled water for the second time to treat the acid in the bottom ash sample and were dried under the sun for 5-6 hours or airdried at room temperature up to 48 hours in order to attain the desired bottom ash. The dried bottom ash was heated in a muffle furnace at 800°C for six hours to obtain a high degree of purity silica which is usually white-gray colored biochar ash. In the second process, 10 grams of white-gray ash (biochar) was prepared and refluxed with 80 mL solution of sodium hydroxide (NaOH) (2.5 N) for four hours. Twenty (20) mL of NaOH was added when the solution subsided lower than the required solution (80 mL) of refluxed white-gray ash. After four hours, the viscous solution was filtered in the Erlenmeyer flask and was rinsed with 40 mL hot distilled water. The clear, colorless, and viscous solution was left to cool to room temperature. The viscous solution of sodium silicate was stirred, followed by adding with 5 N (normal) sulfuric acid (H_2SO_4) solutions by gradually dropping of the solution in the viscous sodium silicate solution until it turned to gel like sodium silicate or at pH of 9. Then, the mixture remained untouched for 24 hours for the gel-like sodium silicate to solidify and the excess water to evaporate. The gel-like sodium silicate was thoroughly washed with distilled water through filtration process until the OH had dissipated. In the third process, the gel-like sodium silicate or the precipitated silica in the Erlenmeyer flask was placed in the filtration paper. Then, the precipitated silica was thoroughly rinsed several times with warm distilled water or deionized water until the filtrate became completely alkali-free. Once alkali-free, the silica was dried at 60°C for 48 hours, transforming it into pure nanochar or nanosilica.

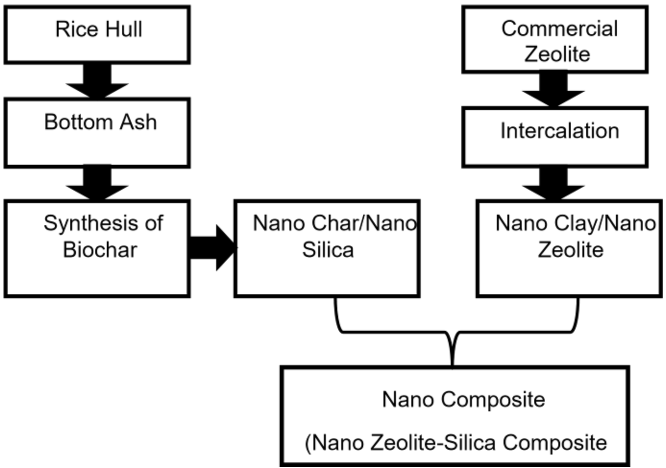

Figure 1. Process of synthesis, intercalation, and characterization of nano zeolite-silica composite.

Intercalation of commercial zeolite to nanoclay (nano zeolite). The commercial zeolite was purchased in sales industries in Valenzuela City, Metro Manila. Intercalation is one of the methods to determine its nano form by converting the micro scale to nanoscale through organo-modification. The preparation involved creating two separate solutions. The first solution consisted of 50 g of zeolite mixed with 1000 mL of hot distilled water. The second solution contained 1.0 g of 12-aminolauric acid ($C_{12}H_{25}NO_2$), 40 mL of HCl, and 200 mL of hot distilled water. To achieve intercalation, the second solution was gradually added to the first while continuously stirring the mixture for 24 hours. After stirring, the mixture was filtered using filter paper, and the filtered commercial zeolite was dried in an oven at 100°C for 2 hours. Once dried, the zeolite was ground into a fine powder to produce nanoclay or nanozeolite (Suyom et al 2020).

Characterization of nano zeolite-silica composite. The synthesized nano zeolite-silica composite were characterized based on chemical, crystal or porosity, and morphological characteristics using different instrumentation methods. Fourier Transform Infrared Spectroscopy (FTIR) analysis (Horizon MB300) was conducted to investigate the chemical structure and functional groups present in the porous nanoparticles of nano silica. The dried samples were placed in a sample holder, and spectra were recorded within the range of 4000 cm^{-1} to 450 cm^{-1}. The Hitachi Flex SEM 1000 Oxford EDX system was used to evaluate surface morphology using Scanning Electron Microscopy (SEM) in conjunction with Energy Dispersive X-Ray Spectroscopy (EDX).

The samples were mounted on a small holder using copper tape and analyzed under a voltage of 2.0 kV, a current of 86 Pa, and magnifications of 6,000x, 8,000x, 150,000x, and 3,000x. Image analysis was performed using ImageJ software. To determine the crystallinity or amorphous nature of the synthesized nanoparticles, an X-

Ray Diffractometer (Model XRD 6000, Shimadzu) was utilized. The samples were finely ground into a powder, then subjected to an acceleration voltage of 40.0 kV and a current of 30 mA. The diffraction angles were scanned from 2 to 60° 2ϴ (theta) at a scanning rate of 1°C per 1.2 seconds.

Experimental soil. Dark soil with very thick accumulated organic matter and wastes was collected at CLSU College of Fisheries freshwater fishpond. Upon collection of the slurry or soil sample (2 sacks), these were transferred to a large container (pail) and mixed with chicken manure (1 sack) for the simulation process to make the soil polluted.

Experimental set-up and treatment groups. Experimental polyvinyl chloride (PVC) pipes with a 4-inch nominal diameter were used as soil containers. Each pipe was cut to a length of one meter, with one end sealed using plastic to prevent leakage, and positioned vertically. Each container held approximately 0.008211 m^3 of soil. The experimental set-up used completely randomized design (CRD). This study consisted of four treatment groups replicated thrice. The four treatment groups are as follows: T1 as control (without any treatment), T2 (a mixture of 30 g of biochar and 30 g of commercial zeolite), T3 (a mixture of 30 g of nano zeolite-silica composites and 300 mg of nanochar), and T4 (a mixture of 60 g of nano zeolite-silica composites and 600 mg of nanochar).

Application of experimental treatments in the soil. Depending on the treatment groups, the needed biochar, commercial zeolite, nano zeolite-silica composite in each respective treatment was applied on the top of the wet soil and mixed only up to one-inch depth from the surface of the soil for five seconds using glass rod. This study was conducted for a month to determine its absorption effectiveness in improving soil quality for aquaculture.

Data gathering. After a month of applying the respective treatments, the soil samples were collected and placed in the zip lock plastic bags for analysis to determine the effectiveness of biochar, commercial zeolite, and nano zeolite-silica composite in improving soil quality. The different data gathered were total nitrogen, available phosphorus, available potassium, pH, and organic matter.

Data analysis. To find significant variations between the treatment group means, the data were arranged and statistically examined using Analysis of Variance (ANOVA) in R statistical software. The treatment means were then compared using Tukey's post-hoc analysis.

Results

Synthesized biochar from rice hull (bottom ash) and intercalated commercial zeolite. The synthesized bottom ash (biochar) from rice hulls became alkali-free and transformed into pure nano-silica. The nano-silica and nano zeolite products were fine (crystalline), odorless, and porous in nature.

Characterized nano silica and nano zeolite composite. FTIR analysis results confirmed characteristic functional groups that were found in both the nano-silica and nano-zeolite, with some notable bands regarding the vibrations from Si-OH, Si-O-Si, and Si-H functional groups. On the contrary, according to the XRD results, the synthesized nano-silica was amorphous as it produced a broad peak at 2θ, while the nano-zeolite also displayed low-intensity peaks, indicating its partially amorphous characteristics. The SEM analysis further supported the observations, when showing irregular and porous surface morphologies in both materials. Average particle size results were determined from ImageJ software: 24.64±29.37 nm for nano-silica and 8.26±7.24 nm for nano-zeolite. The findings were in line with that of Suyom et al (2020), who reported the successful synthesis and characterization of amorphous nano-silica and nano-zeolite with sustained differences in nanoscale particle sizes, suggesting the versatility and reproducibility of this method in developing efficient soil conditioners.

The EDS analysis of nano silica is shown in Table 1, which shows that it is composed of silica (Si) and oxygen (O), with 35.37% silica and 64.63% oxygen. While, EDS analysis of the nano zeolite was made up of 2.27% aluminum (Al), 19.72% silicon (Si), 17.47% carbon (C), and 60.54% oxygen (O) (Table 2).

Table 1

EDS analysis of nano silica

Element	*Atomic (%)*
Si	35.37
O	64.63
Total	100 %

Table 2

EDS analysis of nano zeolite

Element	*Atomic (%)*
Oxygen	60.54
Silicon	19.72
Carbon	17.47
Aluminium	2.27
Total	100%

Effect of biochar with zeolite and nano zeolite-silica composite in soil quality. In terms of percent total nitrogen, the highest concentration was observed in T2 (0.35%), followed by T3 (0.33%), T1 (0.29%), and T4 (0.25%) (Figure 2). T2 consistently stands out, suggesting improved nitrogen retention or enhanced microbial activity contributing to nitrogen accumulation. Biochar is known to facilitate this effect, particularly when used in combination with zeolite. Similarly, the highest mean phosphorus concentration was recorded in T2 (280.10 ppm), followed by T3 (245.97 ppm), T1 (238.32 ppm), and T4 (194.20 ppm) (Figure 3). All treatments exhibited very high phosphorus levels, with T2 demonstrating the most favorable results. These findings imply efficient phosphorus retention or solubilization, potentially due to the synergistic effect between biochar and nano-zeolites, which possess high surface area and ion exchange capacity. In terms of available potassium, the highest percentage was also found in T2 (0.22%), followed by T3 (0.19%), T1 (0.16%), and T4 (0.13%) (Figure 4). Once again, all treatments fall within the very high fertility range. The data suggest that the biochar–zeolite combinations, especially T2 and T3, enhanced potassium retention - likely attributable to their high cation exchange capacity. Regarding soil pH, T1 (control) had a pH value of 7.55. The addition of biochar with zeolite and nano-zeolite-silica composite slightly reduced the soil pH in T2 (7.50), followed by T3 (7.48), and T4 (7.23) (Figure 5). All treatments remained within the > 6.8 pH range, indicating near-neutral to slightly alkaline conditions, which are generally favorable for nutrient availability. The slight decreases in pH observed in T2 to T4 may suggest mild acidifying effects of the amendments, though not sufficient to shift the soil out of the optimal range. Finally, the highest percentage of organic matter (OM) was recorded in T2 (4.91%), followed by T3 (4.65%), T1 (3.93%), and T4 (3.86%) (Figure 6). Treatments T2 and T3 demonstrated significantly improved OM levels, reaching the very high category (> 4.5%), which indicates effective organic matter retention or enhancement due to biochar-based amendments. Although statistical analysis showed no significant differences ($p > 0.05$) across the measured parameters, the observed trends suggest potential benefits from the inclusion of biochar and zeolite, particularly in T2 and T3.

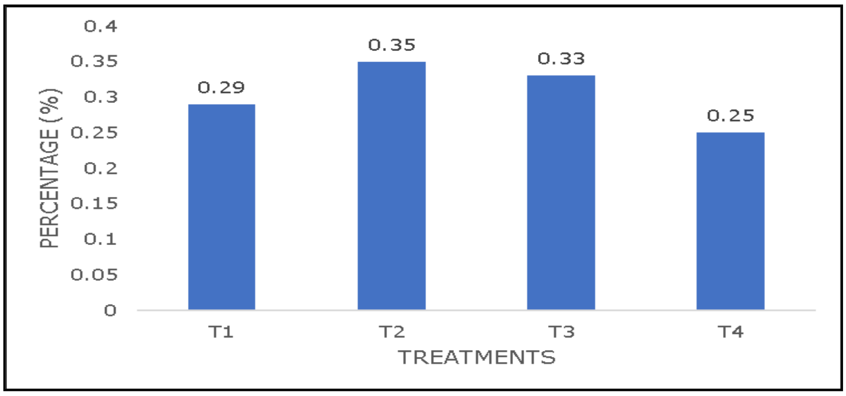

Figure 2. Mean percentage of total nitrogen in every treatment group.

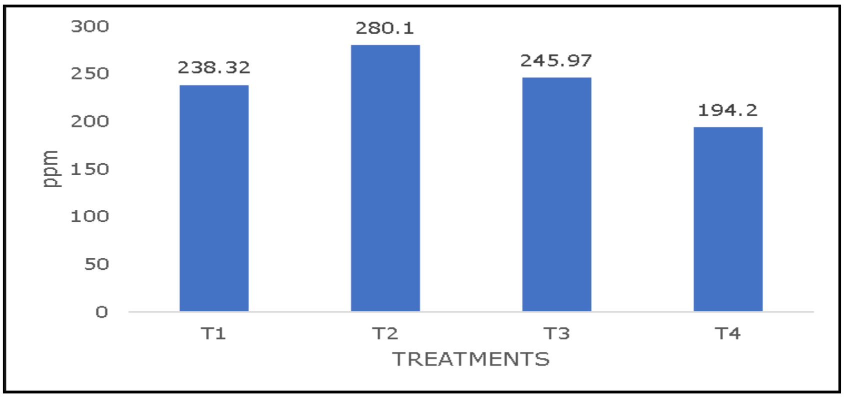

Figure 3. Mean concentration of available phosphorous in every treatment group.

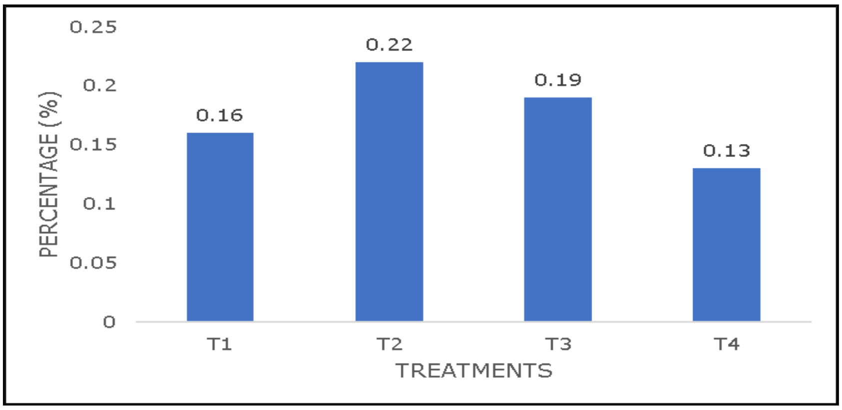

Figure 4. Mean percentage of available potassium in every treatment group.

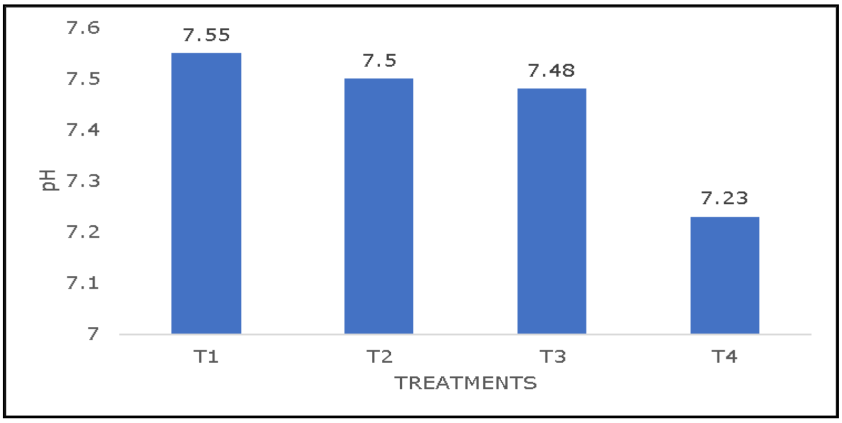

Figure 5. Mean pH level in every treatment group.

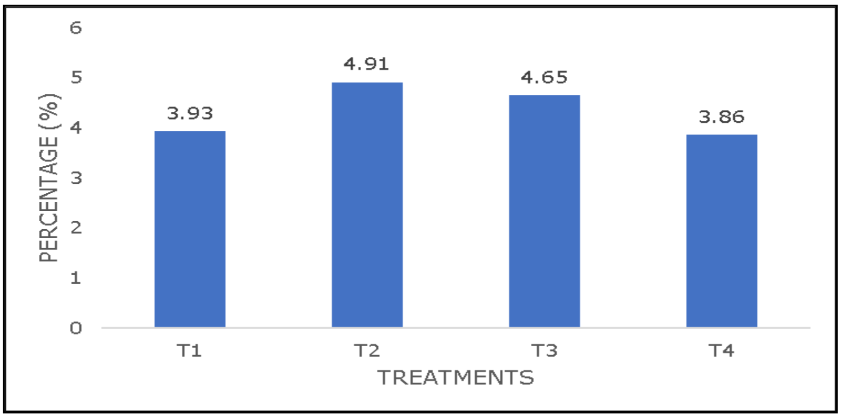

Figure 6. Mean concentration of organic matter in every treatment group.

Discussion. Nitrogen is a vital nutrient for pond productivity, supporting phytoplankton growth and fish development. However, excessive nitrogen can deteriorate water quality by promoting ammonia and nitrite buildup, which are toxic to aquatic organisms (Paul et al 2020). Therefore, maintaining moderate nitrogen levels in pond soils is essential to sustain productivity while avoiding environmental harm. Optimal nitrogen content in aquaculture soils typically ranges between 0.02 and 0.5% (Hickling 1971; Datta 2009). Lower concentrations within this range are considered more suitable, as they reduce risks of nutrient leaching and eutrophication (Paul et al 2020). In the present study, T2 (biochar + zeolite) had the highest total nitrogen at 0.35%, followed by T3 (0.33%), T1 (0.29%), and T4 (0.25%) (Figure 2). All values fall within the acceptable range for aquaculture soils. While differences were not statistically significant ($p > 0.05$), the trend shows that T4, which used nano-zeolite-silica composites, maintained the lowest nitrogen level, indicating better alignment with optimal pond soil conditions. Zeolites are known to enhance nitrogen retention through their affinity for ammonium (NH_4^+), reduce leaching, and improve nitrogen use efficiency (He et al 2002; Zaman et al 2012). However, excessive use of nanomaterials, as in T4, may reduce effectiveness due to concentration-related limitations (Josko et al 2014; Raja & Barron 2020). Overall, the study supports that lower nitrogen concentrations, such as those observed in T4, may be more beneficial for pond soil quality, provided that essential nutrient thresholds are still met.

Phosphorus is a vital nutrient for aquaculture ponds, as it promotes phytoplankton growth - the base of the aquatic food chain. However, it is often the most limiting nutrient and thus requires regular supplementation (Jana 2007). Higher phosphorus levels in pond soil are generally beneficial for aquaculture, as they enhance productivity and create a more favorable environment for fish. This is primarily because phosphorus supports the growth of phytoplankton and zooplankton, which are essential for maintaining a healthy and balanced aquatic ecosystem (Chattopadhyay et al 2003). According to Hickling (1971), soil phosphorus above 60 ppm is considered productive. In the present study, all treatments exceeded this threshold, with concentrations ranging from 194.20 ppm (0.01942%) to 280.10 ppm (0.02801%), indicating good fertility and potential for high fish yield. However, T2 recorded the highest phosphorus content (280.10 ppm), outperforming other treatments. This suggests that the combination of biochar and commercial zeolite significantly enhances phosphorus retention and availability. Antoniadis et al (2012) reported a 4.02% increase in P recovery efficiency using zeolite, while the current study showed a 7.65% increase with 30 g of nano zeolite and 300 mg of nano silica (T3), further validating the effectiveness of this treatment. Although higher concentrations of nanomaterials like nano-zeolite-silica may reduce efficacy due to aggregation and limited surface reactivity (Lowry et al 2012; Raja & Barron 2020), lower doses in this study were more efficient in improving phosphorus levels. These findings support earlier reports that zeolite can regulate and retain phosphorus in a sustainable manner (Kavvadias et al 2018; Nayak & Mohanty 2019).

Potassium is an essential macronutrient in aquaculture, supporting the growth of phytoplankton and zooplankton - key components of the aquatic food web (Ajide-Akinola

& Akinwole 2023). Over time, potassium can accumulate in pond soils through sedimentation, influencing both soil properties and water chemistry (Ritvo et al 2002). Zeolite is effective in managing potassium due to its high cation exchange capacity and persistent negative surface charge, allowing it to adsorb nutrients like K^+, NH_4^+, Ca^{2+}, Na^+, and Mg^{2+} (Sprynskyy et al 2005; Zabochnicka-Swiatek & Malinska 2010). However, zeolite already contains potassium, and mixing it with compost may further elevate potassium to excessive levels (Moraetis et al 2016). In the current study, the application of 60 g nano zeolite with 600 mg nano silica (T4) was found to reduce available potassium content in the soil compared to other treatments, likely due to high adsorption capacity of the nanoparticles (Raja & Barron 2020). This outcome supports Khati et al (2018), who observed that nano zeolite modestly improved potassium management, making it more effective in regulating potassium status than bulk materials. Overall, while potassium is essential in small quantities (Rana et al 2017), T4 proved most beneficial in moderating excessive potassium levels, helping maintain a balanced nutrient profile in pond soils.

Soil pH plays a vital role in aquaculture pond productivity, as it influences nutrient availability, microbial activity, and organic matter decomposition. Ponds with pH below 6 generally exhibit low alkalinity and hardness, leading to poor fish or shrimp production (Wurts & Masser 2013). In contrast, neutral to slightly alkaline pH (7.0-8.6) supports higher microbial activity, better organic carbon levels, and nitrogen transformation, which are beneficial for shrimp and fish health (Vinatea et al 2006; Vinothkumar et al 2018). According to Rana et al (2017), a pH of around 7.65 promotes optimal fish growth and nutrient availability, including phosphorus. However, extremely high or low pH values can affect nutrient cycling, turbidity, and even phytoplankton communities (Holopainen 1992; Mandal 2014). For instance, ammonium adsorption drops beyond pH 7 due to reduced ion-exchange potential (Wang & Zhu 2006), and low pH can hinder organic matter decomposition, leading to oxygen buildup in the surface soil layer (Rana et al 2017). Zeolites, especially when modified, can enhance soil pH by improving pore structure and ammonium ion retention (Liang & Ni 2009; Shaikh & Chendake 2016). Similarly, Si-based nanomaterials such as nano zeolite-silica composites can modify pH through surface interactions (Ji et al 2017). This was also observed in the present study, where Treatment 1 to treatment 4 exhibited a gradual decrease in soil pH, although the readings remained nearly neutral across all groups (Figure 5). This is advantageous in neutralizing acidic pond soils, thus enhancing the overall productivity and suitability of the pond environment for aquaculture species.

Soil OM plays a critical role in aquaculture systems by enhancing microbial activity, nutrient cycling, and overall soil structure. Saha & Manda (2023) reported that organic carbon levels between 1.02 and 3.85% are ideal for aquaculture productivity, while Boyd (2003) recommends maintaining 3-4% to ensure optimal microbial function. Integrated pond systems typically fall within this range, indicating a healthy environment for aquaculture (Ajide-Akinola & Akinwole 2023). OM improves soil structure, moisture retention, nutrient availability, and supports diverse microbial life (Bot & Benites 2005), which is essential for maintaining productive pond bottoms. Accumulation of organic debris also increases with pond age and depth, averaging 1.76-2.51% (Rana et al 2017). According to BARC (2005), at least 2.5% OM is desirable in pond soils. However, the impact of engineered nanomaterials on soil OM dynamics varies. Low doses typically show no substantial negative effects (Rahmatpour et al 2017), and some materials like TiO_2 nanoparticles can even stabilize soil OM by forming bonds with humic substances (Nuzzo et al 2016). On the other hand, ZnO and CuO nanoparticles at high concentrations have been linked to reduced microbial activity and decreased OM decomposition (Rashid et al 2017; Shi et al 2018). In the present study, high concentrations of nano zeolite-silica composite (T4: 60 g nano zeolite + 600 mg nano silica) were observed to decrease soil OM, likely due to reduced microbial activity and nanoparticle aggregation, which limits reactivity (Lowry et al 2012). In contrast, lower concentrations (T3: 30 g nano zeolite + 300 mg nano silica) enhanced soil OM content, indicating that moderate applications of NMs can boost soil quality without suppressing microbial function (Figure 6). Moreover, zeolite’s ability to retain nutrients and water improves soil infiltration and reduces runoff, enhancing carbon sequestration and promoting long-term soil health (Girijaveni et al 2018). Thus, proper management of nano-based soil amendments is crucial for maintaining favorable OM levels in aquaculture systems.

Conclusions. The synthesized biochar, intercalated commercial zeolite, and characterized nano zeolite-silica can be utilized and developed as new technology in improving soil quality through nanotechnology. Among the treatments, T2 (biochar + zeolite) consistently enhanced nutrient retention (N, P, K) and organic matter while maintaining favorable pH, making it the most beneficial treatment. T4 (high nano-zeolite + nano-silica) showed reduced nutrient levels and organic matter due to possible nanoparticle aggregation and limited microbial activity. Moderate nanoparticle application (T3) performed better than T4, implying dosage sensitivity of engineered nanomaterials in aquaculture soils. Furthermore, it is highly recommended that biochar from the rice hull (bottom ash) should be utilized as a newly developed product of nanotechnology. Likewise, for the improvement of the said technology, additional studies about soil quality with integration of nano zeolite-silica composite in a lesser concentration should be conducted in order to determine its significant effects in N, P, K, pH, and OM. Moreover, the results of the study serve as a basis for developing biochar from rice hull to pure nano silica composite as a potential soil conditioner in aquaculture operations.

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Conflict of interest. The authors declare that there is no conflict of interest.

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