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ORIGINAL ARTICLE

Effectiveness of conditioned natural adsorbents for ammonia removal from aquaculture

Eda Sertaşı[1] · Meryem Öz[2] · Dilek Şahin[3] · Ünal Öz[2]

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Abstract

This study aims to evaluate the potential use of clinoptilolite-type zeolite, leonardite, and diatomite, which have abundant reserves in Türkiye and can be mined more easily and economically compared to other mines, as water parameters regulators. The trial was conducted in seven groups in triplicate. The groups were assigned as the control (C), natural zeolite (NZ), natural leonardite (NL), natural diatomite (ND), conditioned zeolite (CZ), conditioned leonardite (CL), and conditioned diatomite (CD). The trial was initiated by adding 2 g of natural and conditioned zeolite, leonardite, and diatomite to their respective groups, excluding the control inside 500 ml tap water. Water parameters (temperature, dissolved oxygen, pH, and NH_4^+) were measured daily for 14 days. In this study, as of the 4th day of the experiment, a decrease was observed in ammonia values originating from the feed in the groups treated with adsorbent compared to the control group. When all adsorbent groups were evaluated together, the ammonia values in the groups containing natural leonardite and conditioned leonardite remained at the recommended values for aquaculture throughout the experiment period (14 days). As a result of the study, it was concluded that leonardite (1.66 ± 0.001) and zeolite (0.71 ± 0.03) (4 g/l) could be used effectively in ammonia removal for aquaculture practices. The current study is one of the first studies to investigate the effect of natural adsorbents on ammonia removal and pH. Furthermore, it is the first study to demonstrate a reduction in fish feed-derived ammonia values compared to the unconditioned (natural) forms of conditioned diatomite and leonardite, based on a literature review.

Keywords Leonardite · Zeolite · Diatomite · Aquaculture · Water parameters

Introduction

Aquaculture is one of the most rapidly growing food production industries worldwide. Feed additives and raw materials, which have crucial effects on fish growth, reproduction, and coloration, are of great importance in aquaculture (Şahin et al. 2022). The raw materials that constitute the fish feed originate from plant and animal sources. Feed additives are products used in feeds in addition to raw materials to improve feed quality, accelerate fish growth, and increase overall performance (Ebeneezar et al. 2021). Balanced feeding and optimum water conditions are essential for sustainable aquaculture practices. Removing ammonium (NH_4^+) from the environment is necessary since its excessive amount is toxic to aquatic life. For example, the ammonium nitrogen concentration should not exceed 1.5 mg of NH_4^+ ions for most fish species (Alshameri et al. 2014). Therefore, preventing nitrogen pollution by removing NH_4^+ from wastewater is very important (Jorgensen And Weatherley 2003). Various methods, such as aeration, biological processes, and adsorption, have been used for NH_4^+ removal (Gupta et al. 2011).

Research on the use of natural additives for environmental applications is expanding due to various beneficial properties of these additives, such as non-toxicity, low cost, wide application area, etc. (Karadağ et al. 2006; Şahin 2022). Zeolite, leonardite, and diatomite, which are among the natural raw materials of our country, are minerals that

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✉ Dilek Şahin
dsahin@sinop.edu.tr

[1] Sinop University Vocational School of Health Sevices, 57000 Sinop, Turkey

[2] Sinop University Fisheries Faculty, 57000 Sinop, Turkey

[3] Sinop University Vocational School, 57000 Sinop, Turkey

can be used in many sectors (i.e., agriculture, aquaculture, wastewater treatment, etc.) and are called the mines of the century. Zeolites are mineral substances that have been the subject of several previous research, especially on water treatment and feed additives (Alshameri et al. 2014); however, investigations on the use of leonardite and diatomite for water treatment and as feed additives are scarce (Öz et al. 2022; Şahin 2022; Zengin 2013).

Zeolites are hydrated alumina silicates with a crystalline structure of alkali and alkaline earth metals and belong to the framework silicates group. Natural zeolites are low-cost materials commonly found in nature, have high cation exchange capability, display molecular sieve properties, and exhibit a unique design for adsorption and catalysis (Cataldo et al. 2021).

Diatomite is a sedimentary rock composed primarily of the fossilized remains of unicellular freshwater plants known as Diatoms. There are abundant natural diatomite sources in Türkiye. This organic, natural product contains the fossilized skeletons of trillions of microscopic, unicellular aquatic plants of freshwater origin. Diatomite is pH stable and has gained the feature of use in various environments due to this property (Öz, 2024a,b); Przybek et al. 2024). It is a low-density porous material composed mainly of silicon dioxide. Although diatomite has a unique combination of physical and chemical properties, its use as an adsorbent in wastewater treatment has remained largely unexplored (Ahmad et al. 2019; Bakr 2010).

Leonardite is a special low-grade coal obtained from lignite that has undergone oxidation during surface exposure or represents rich sediments in terms of a humic substance (Ausavasukhi 2016). Leonardite contains large amounts of humic substances that form complexes in their properties from the carboxylic and hydroxylic regions of functional groups in humic substances and various inorganic minerals (Chammui et al.2014).

In adsorption processes using natural adsorbents, pretreatment methods (such as conditioning) can be applied to enhance the removal efficiency of the adsorbent (Muscarella et al. 2021). The wide diversity of mineral in nature, in terms of the chemical structure and atomic composition, determines the need for accurate characterization for the choice of specific applications for maximum effectiveness. In addition to the choice of the type of zeolite suitable for the specific application, physical or chemical treatment processes are often required to increase their efficiency.In these terms, the role of the conditioning process is fundamental, as it determines the presence, in the pores and on the surface of the mineral, of species that, once desorbed, are not harmful to the system in which they are released and are highly selective in adsorption of ions in aqueous solution (Biblioteca et al. 2023). The use of natural and environmentally friendly adsorbents for the removal of organic wastes, such as ammonia, in aquaculture environments is considered an eco-friendly approach that promotes the health of aquatic organisms (Öz, 2024a, b); Şahin et al. 2025). Ammonia, which is studied as a pollution source, is toxic to fish in aquaculture and also has toxic effects on the environment at high concentrations (Edwards et al. 2024). While the application properties of zeolite in aquaculture have been extensively investigated in numerous studies, the potential use of diatomite and leonardite in aquaculture has not been fully determined (Öz et al. 2022; Şahin 2022; Öz, 2024a, b; Şahin et al. 2025). In this study, it is planned to evaluate the properties of leonardite and diatomite and obtain original data, using zeolite as a reference.

It has been reported that modifying the adsorbent surface using NaOH, NaCl etc., increases adsorption capacity, and that preconditioning using such substances can alter surface properties and be beneficial in increasing the adsorption capacity for ammonium ions in aqueous solution (Lin et al. 2013; Yuliani et al. 2022).

In this study, it was aimed to evaluate the potential of leonardite and diatomite, which have abundant reserves in Turkey and can be extracted more easily and economically than other minerals, as water parameter regulators by comparing them with clinoptilolite type zeolite.

Materials and methods

Experimental design

In the study, powder-sized (100 microns) natural and NaCl-conditioned zeolite, leonardite, and diatomite were used. Zeolite, leonardite and diatomite used in the study were provided by Rota Madencilik (Manisa, Türkiye), Kütahya Kimya (Kütahya, Türkiye) and Nanotech İnşaat Kimya Mining and Logistics, respectively.

Raw zeolite, leonardite, and diatomite materials were used as supplied without any processing. The conditioned raw materials were shaken separately with 250 mL of distilled water and 1 M NaCl in an orbital shaker at 80 rpm for 24 h at room temperature. Then the samples were filtered through Whatman #42 filter paper. They were rinsed with 250 mL of distilled water three times to remove excess NaCl and dried in an oven at 103–105 °C for 2 h. The adsorbents were set up for use after cooling down to room temperature (Alshameri et al. 2014; Muscarella et al. 2021). Natural zeolite, leonardite, diatomite and conditioned zeolite, leonardite and diatomite's Specific Surface Area (BET) (m^2/g) showed in Table 1.

The trial was conducted in seven groups in triplicate. The groups were assigned as the control (C), natural zeolite

Table 1 XRF values of natural and conditioned clinoptilolite, diatomite, and Leonardite at the end of the experiment

Compositions	Natural Clinoptilolite (NZ)	Conditioned Clinoptilolite (CZ)	Natural Diatomite (ND)	Conditioned Diatomite (CD)	Natural Leonardite (NL)	Conditioned Leonardite (CL)
SiO_2 (%)	67.83	69.46	78.36	79.09	8.98	13.44
Al_2O_3 (%)	11.54	11.86	11.63	12.08	4.47	6.43
MgO (%)	1.24	1.192	3.81	4.20	0.19	0.32
K_2O (%)	2.11	2.101	1.15	0.90	0.34	0.48
CaO (%)	3.23	2.89	2.63	2.01	3.05	2.87
Na_2O (%)	0.57	0.86	1.46	1.75	0.01	0.07
Fe_2O_3 (%)	1.40	1.41	2.75	1.97	0.88	1.04
P_2O_5 (%)	0.22	0.23	0.37	0.33	0.31	0.23
SiO_2/Al_2O_3	5.88	5.86	6.73	6.55	2.00	2.10
Specific Surface Area (BET) (m^2/g)	32.289	14.1971	186.589	94.3162	7.872	0.9880

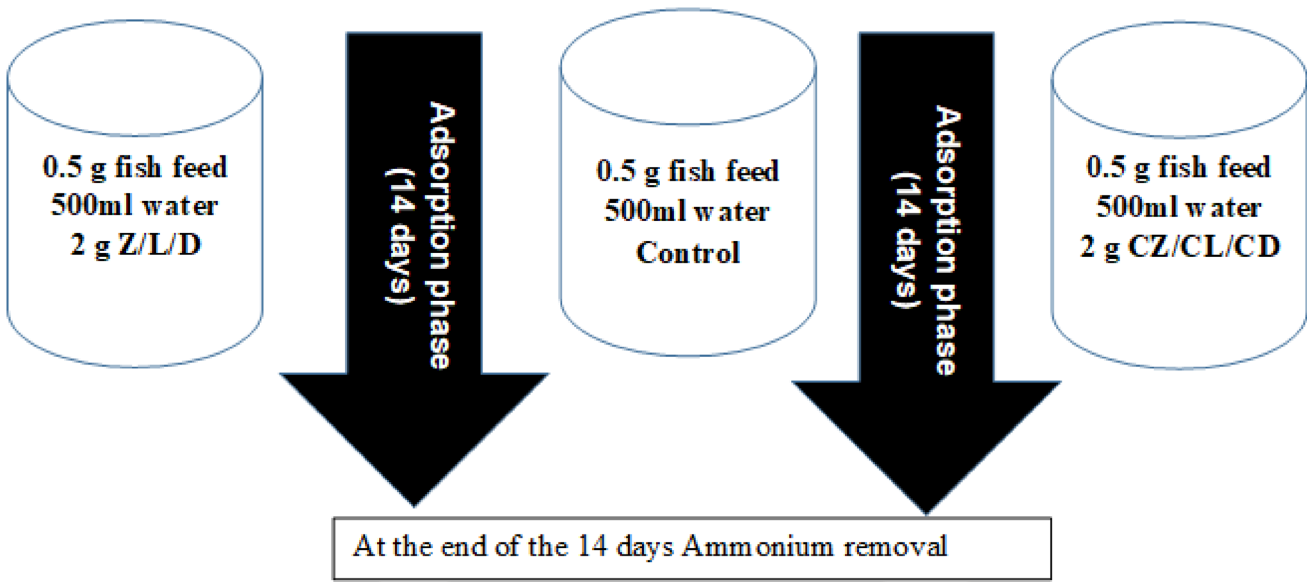

Fig. 1 Flowchart of the experiment

(NZ), natural leonardite (NL), natural diatomite (ND), conditioned zeolite (CZ), conditioned leonardite (CL), and conditioned diatomite (CD). The crude protein ratio in aquarium fish feed varies between 28 and 30% and 45–50%, depending on the nutritional requirements of the reared fish species (Ahmed And Maqbool 2017). In this study, feed containing 42.5% crude protein was used to represent this protein value range. Each trial setup consisted of 500 ml of tap water and 0.5 g of feed (Öz et al. 2022). The trial was initiated by adding 2 g of natural and conditioned zeolite, leonardite, and diatomite to their respective groups, excluding the control (Fig. 1).

The experiment was conducted at room temperature, and no aeration or agitation was applied. Water parameters (temperature, pH, and NH_4^+) were measured daily for 14 days with the YSI Professional Plus Series instrument. Zeolite, leonardite, and diatomite samples were obtained from Rota Mining Corporation (Türkiye), Kütahya Chemistry (Türkiye), and Nanotech Corporation (Türkiye), respectively.

Data evaluation

Measured NH_4^+, water temperature, and pH values were used to calculate NH_3 and TAN (Total Ammonia Nitrogen) values (EPA, 2013, Emerson et al. 1975; Chow et al. 1997). It has been reported that the data obtained using the Nessler method were similar and reliable to those obtained with the conventional electrode method (Prajapati 2014). The ammonia and TAN values were computed using the following formulae (Purwono et al. 2017):

$$pK\,(NH_3) = \frac{2726.3}{273 +^{\circ} C} + 0.0963 \quad (1)$$

$$NH_3 - N \ = 10^{(pH - pK(NH_3))} \times NH_4^+ - N \quad (2)$$

$$TAN = \ NH_3 - N + \ NH_4^+ - N \quad (3)$$

The adsorption capacity of amomnia at the equilibrium q (mg/g) was calculated by mass balance as follows (Abed et al. 2024):

$$q = \frac{(C_0 - C_e)\,V}{M}$$

where, C_o and C_e is the initial and final concentration of ammonia in solution (mg/l), V is the volume(l) of ammonia solution for adsorption experiments and M is the adsorbent mass (g) respectively.

The BET (Brunauer-Emmett-Teller) analysis and XRF (X-ray Fluorescence) analyzes of clinoptilolite, leonardite and diatomite used in the study were carried out at Kastamonu University Central Research Laboratory using Quantachrome brand Nova Touch LX4 and Spectro brand Xepos II model devices, respectively. SEM-EDS (Scanning Electron Microscope) analyses for the natural adsorbents were performed using the FEI brand Quanta FEG 250 model instrument at the Kastamonu University Central Research Laboratory and JEOL brand JSM 7001 F model device at the Ondokuz Mayıs University Karadeniz Advanced Technology Research and Application Center was used for the conditioned adsorbents.

Statistical analyses

All statistical analyses were conducted using Minitab Software (Release 17 for Windows) with a 5% margin of error. All data presented in the study are expressed as mean ± standard error (SE). The normality of the data was confirmed by the Anderson–Darling, Ryan–Joiner (similar to Shapiro–Wilk) and Kolmogorov–Smirnov tests. When the variance analysis prerequisites were met, the data were subjected to parametric tests (ANOVA). The analysis of non-normal groups was examined by the Kruskal-Wallis method. When the difference was significant, the Mann-Whitney test was used to determine which groups were different (Öz, 2024a, b); Şahin et al. 2025).

Results

Morphology and crystalline structure of used minerals

The BET (Brunauer-Emmett-Teller) analysis and XRF (X-ray Fluorescence) results of clinoptilolite, leonardite, and diatomite used in the study are presented in Table 1.

The natural and conditioned zeolite (Fig. 2a and b), diatomite (Fig. 2c and d), and leonardite (Fig. 2e and f) used in the study were characterized by SEM imaging and EDS analysis.

Considering the EDS spectra presented in Fig. 2a, b and c, and 2d, it was determined that natural zeolite and diatomite, as well as conditioned zeolite and diatomite, contain high levels of aluminum and silicon. When the EDS spectra given in Fig. 2e and f were investigated, high carbon and oxygen contents were observed for natural and conditioned leonardite.

Effects of zeolite, diatomite and leonardite on water parameters

At the beginning of the study, all groups displayed similar ($P > 0.0.5$) water parameters. The initial water temperature, pH, and ammonium were 20.1 ± 0.02 °C, 8.84 ± 0.01, and 0.10 ± 0.01 mg/l, respectively. Table 2 displays the water parameters determined at the end of the 14-day trial period. The temperature values were indifferent among groups at the end of the study ($P > 0.05$). However, the differences between groups regarding NH_4^+, TAN and pH values were statistically significant ($P \leq 0.05$).

Ammonia adsorption capacity was evaluated on the 13th day, when the maximum amount of ammonia was observed. As a result, it was determined that natural leonardite and conditioned leonardite groups had higher adsorption capacity than other groups (Table 1). When the adsorption capacities are examined, it is seen that the conditional leonardite values are higher than other groups.

The NH_3 values determined daily for 14 days are presented in Fig. 3. In this study, as of the 4th day of the experiment, a decrease was observed in ammonia values originating from the feed in the groups treated with adsorbent compared to the control group. When all adsorbent groups were evaluated together, the ammonia values in the groups containing natural leonardite and conditioned leonardite remained at the recommended values for aquaculture throughout the experiment period (14 days).

TAN values obtained from natural and conditioned adsorbents throughout the experiment were compared for each adsorbent individually and presented in Table 1.

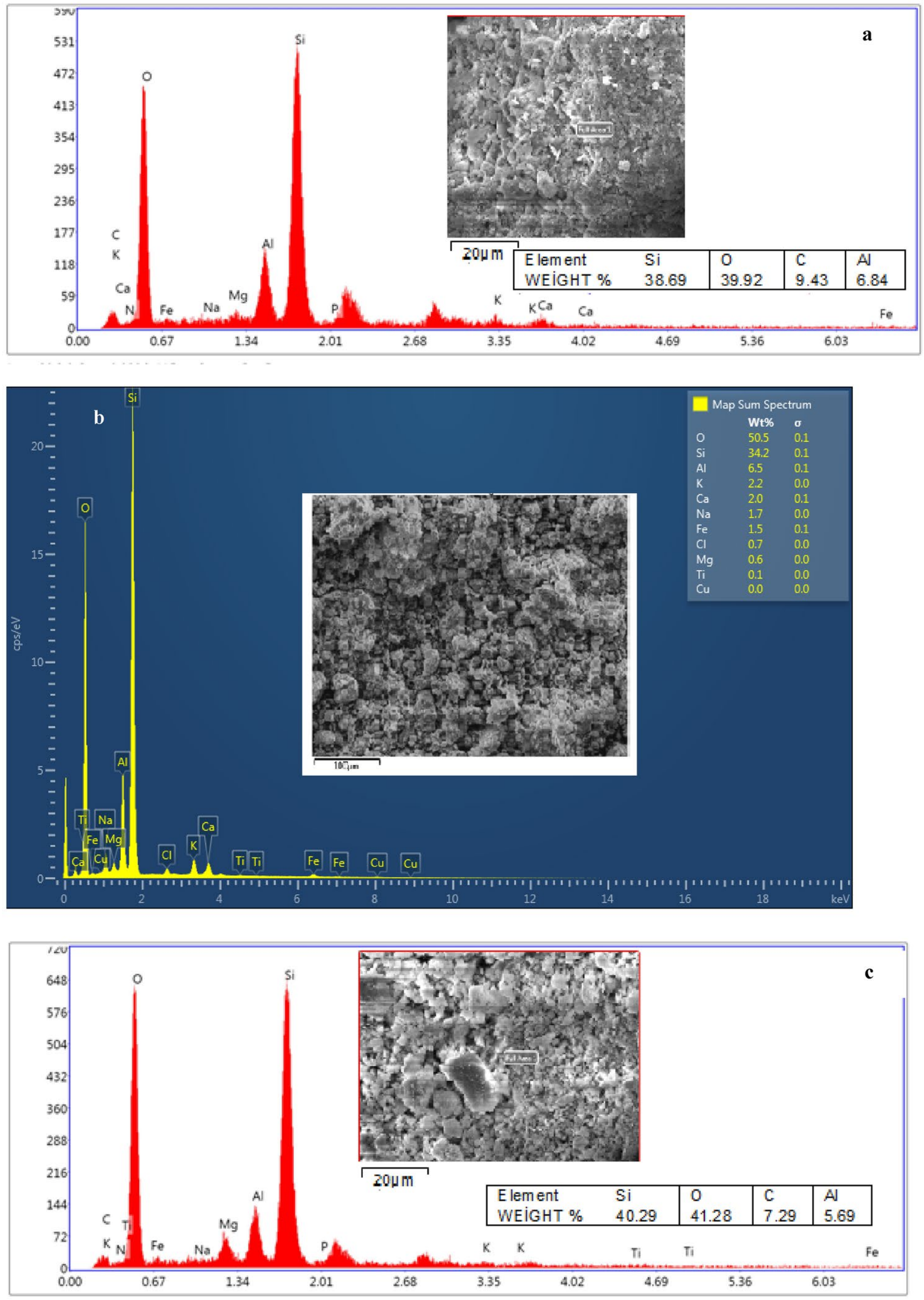

Fig. 2 SEM images and EDS analyses of natural zeolite (NZ, **a**), conditioned zeolite (CZ, **b**), natural diatomite (ND, **c**), conditioned diatomite (CD, **d**), natural leonardite (NL, **e**) and conditioned leonardite (CL, **f**)

When Table 1 is examined, it was found that the conditioned groups for zeolite and leonardite were more effective in TAN removal than the natural groups. However, when the natural and conditioned diatomite groups were examined, it was determined that the TAN values were similar.

Discussion

One of the known causes of water pollution is ammonia. Since it has distinctive properties and may have contributed to the reduction of dissolved oxygen needed by aquatic life, the excessive nitrogen component in wastewater is known to contribute to a considerable pollution burden. In addition, too much nitrogen may have contributed to fish toxicity. The purification of wastewater is one of the most well-known ways for dealing with this problem. This has a direct impact

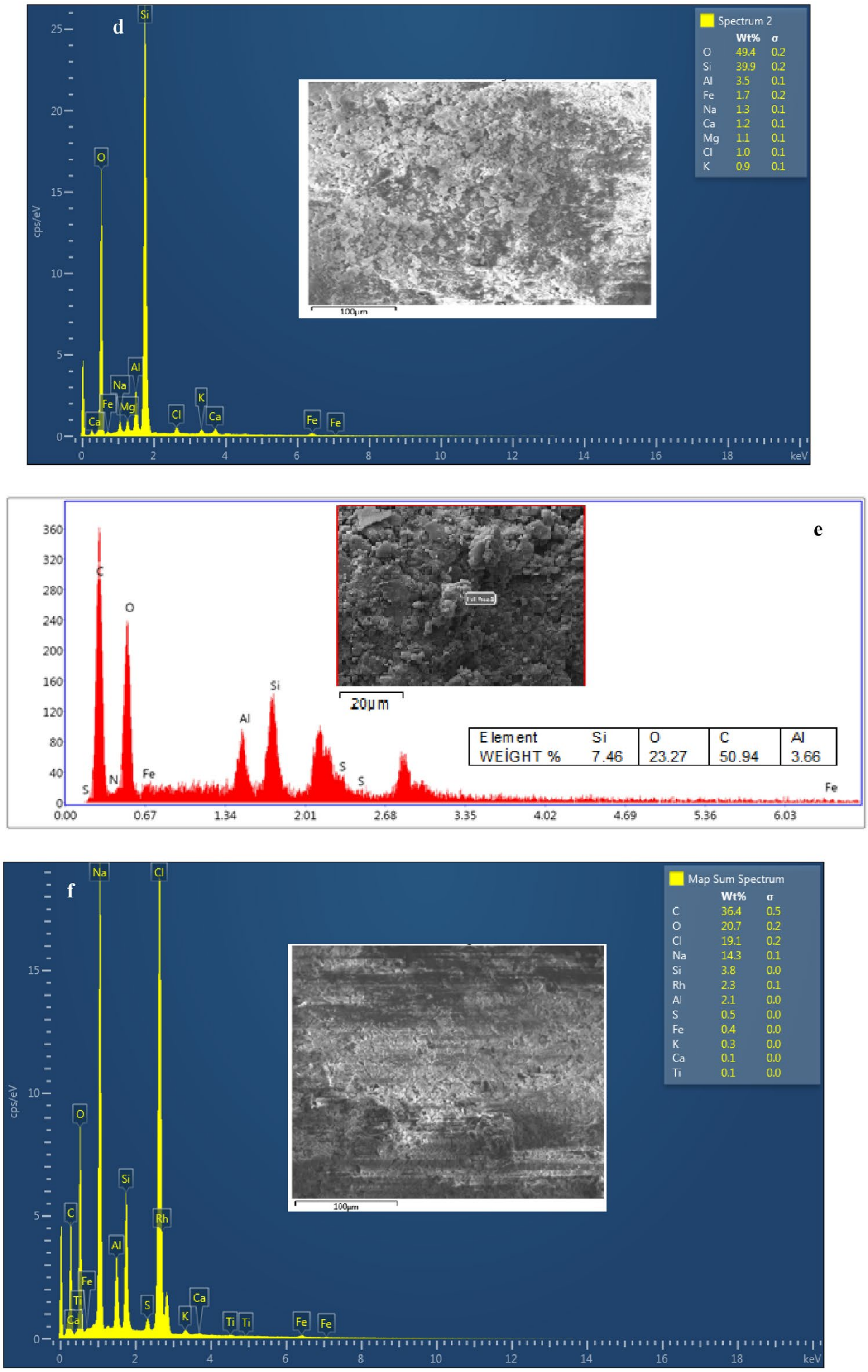

Fig. 2 (continued)

on the high cost of operation because it necessitates the use of innovative technology. To date, a wide variety of applications have used the adsorption technique to remove contaminated parts from liquid or gas mixtures. Additionally, natural materials have been widely used for the removal of contaminants attributable to the porous and high surface area that offers vast active sites for the adsorption process (Adam et al., 2023).

Table 2 Temperature, pH, NH_4^+, and TAN values in natural and conditioned diatomite, leonardite, zeolite and control groups at the end of the experiment (mean ± SE)

	Water Parameters				
Experimental Groups*	Temperature (°C)	pH	NH_4^+ (mg/l)	TAN (mg/l)	Adsorption capacity (mg/g)
Natural diatomite	20.96 ± 0.17	8.34 ± 0.07^{a}	$9.97 \pm 1.27^{a, b}$	$11.07 \pm 1.64^{a, b}$	0.07 ± 0.01^{e}
Natural leonardite	20.97 ± 0.17	7.79 ± 0.05^{b}	$8.82 \pm 1.27^{b, c}$	$9.26 \pm 1.34^{b, c}$	1.49 ± 0.01^{b}
Natural zeolite	20.97 ± 0.17	8.4 ± 0.07^{a}	$6.67 \pm 0.82^{b, c,d}$	$8.23 \pm 1.06^{b, c}$	0.68 ± 0.02^{c}
Conditioned diatomite	20.97 ± 0.17	8.39 ± 0.07^{a}	$9.59 \pm 1.2^{a, b}$	$11.79 \pm 1.54^{a, b}$	0.24 ± 0.01^{d}
Conditioned leonardite	20.95 ± 0.17	7.63 ± 0.05^{c}	$6.00 \pm 1.03^{c, d}$	6.18 ± 1.08^{c}	1.66 ± 0.001^{a}
Conditioned zeolite	20.96 ± 0.17	8.42 ± 0.08^{a}	5.67 ± 0.73^{d}	7.16 ± 0.98^{c}	0.71 ± 0.03^{c}
Control	20.97 ± 0.17	8.41 ± 0.07^{a}	11.78 ± 1.38^{a}	14.27 ± 1.73^{a}	0.00 ± 0.00^{a}

*Superscript letters in the same column denote statistically significant differences between groups ($P \leq 0.05$). Means were compared with Non-parametrics and classified by Mann-Whitney range test

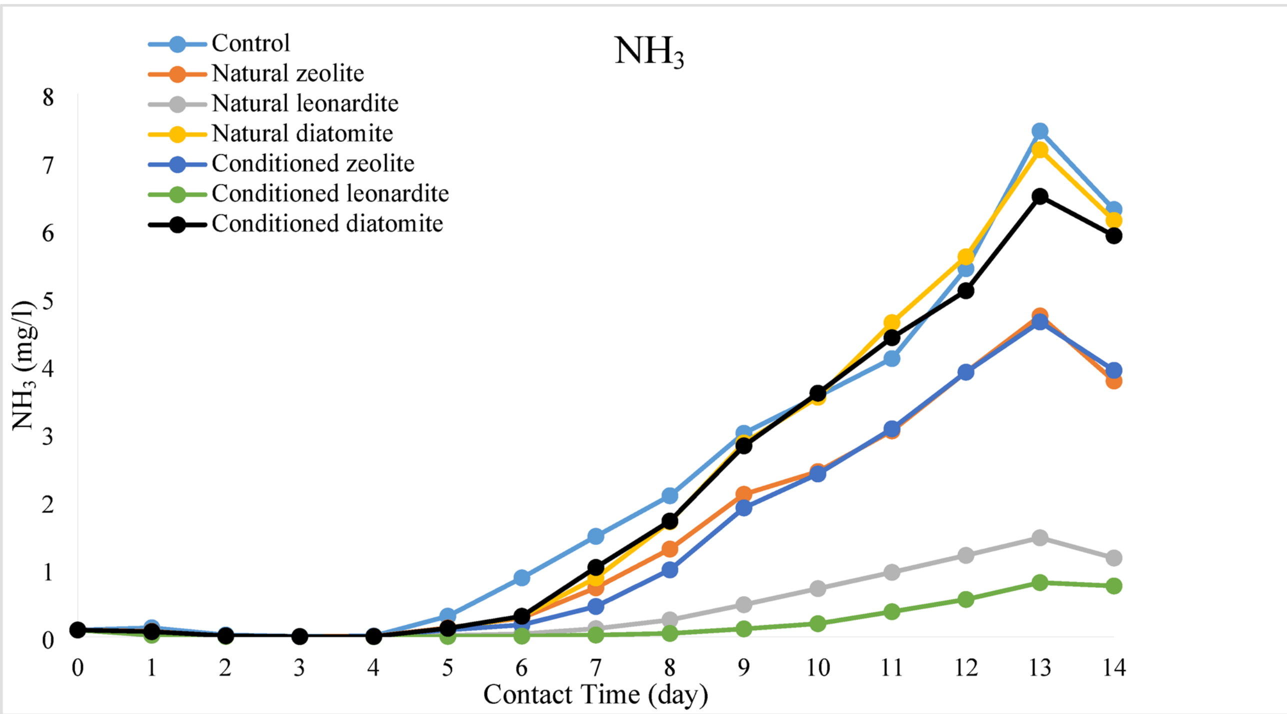

Fig. 3 Temporal changes in ammonia (NH_3) concentration (mg/l) throughout the experiment

Natural adsorbents have been reported to be used for ammonia removal in aquaculture. The use of natural adsorbents to regulate ammonia levels has the potential to increase the efficiency of aquaculture practices. It can also help reduce pollution problems from mixing nutrient substances such as ammonia from fish facility waters to natural water resources (Skleničková et al. 2020; Öz et al. 2021).

Ammonia and pH values are among the most critical parameters for fish farming, and these parameters affect each other. This study investigated the effects of natural and conditioned zeolite, leonardite, and diatomite on water parameters. When the ammonia values obtained at the end of the 14-day experiment were examined, the ammonia concentrations for natural zeolite, natural diatomite, conditioned zeolite, and conditioned diatomite were 3.77 mg/l, 6.15 mg/l, 3.92 mg/l, and 5.91 mg/l, respectively. Although a decrease in ammonia concentrations was detected in all these adsorbent groups compared to the control group (6.29 mg/l), the value known to cause death, i.e., 2 mg/l (Randall And Tsui 2002; Floyd et al. 2015), for many fish species could not be reached. The lowest ammonia values were found in the groups containing conditioned leonardite (0.74 mg/l) and natural leonardite (1.16 mg/l), and these ammonia concentrations were lower than the lethal concentration (2 mg/l). According to the results obtained in the study, it was determined that leonardite, whether natural or conditioned, can be used effectively to reduce ammonia values in aquaculture. The use of leonardite as an adsorbent in combination with zeolite was examined in the studies by Zengin (2013) and Şahin (2022); and it was reported that it exhibited a positive

Table 3 Adsorption capability of ammonium removal with other reported adsorbents

Adsorbent	Removal Rate	References
Gravel, zeolite	Ammonium removal due to adsorption reached 96.49% for zeolite, and 16.84% for gravel.	Gikas et al. (2025)
Biochar obtained from rice straw	The removal efficiency of NH_4^+ recorded 69.5%, with maximum adsorption value of 4.5 mg/g at 45 ± 5 °C, at pH 7.5.	Khalil et al. (2018)
Clay mineral halloysite	The ammonium adsorption of halloysite was saturated with 1.66 mg/g at 303 K, pH of 5.6 and initial ammonium NH_4^+ concentration of 600 mg/L.	Jing et al. (2017)
Bentonite	Under optimal operating conditions, the removal efficiency attained 53.36%.	Angar et al. (2017)
Activated carbon	The highest efficiency, between 85.4% and 87.0%, was obtained with a large mass bed (200 g) and lower temperature (40 °C).	Rodrigues et al. (2007)
Salt activated Chinese natural zeolite	Zeolite is activated under the condition of 1 M NaCl, stirring time of 30 min, an excellent removal of NH_4^+ was obtained.	Alshameri et al. (2014)
Bentonite/Chitosan	Under optimal operating conditions, the removal efficiency attained 100%.	Yadi et al. (2016)
Peanut shell based modified biochar	The maximum capacity of unmodified biochar (BC) and modified biochar (MBC) to ammonium absorption could reach 3.83 mg/g and 6.92 mg/g, respectively,	An et al. (2021)
NaCl-modifed zeolite	The results showed that the highest removal efficiency of NH_4^+-N (92.13%) was achieved at pH 8.	Cheng et al. (2017)
Calcium alginate (Ca-Alg) beads	The alginate beads showed relatively high removal efficiency for ammonia ions (94.94%)	Isik et al. (2021)

effect on zinc and ammonia removal, respectively. However, no other study was found that tested the leonardite's individual effect on ammonia removal and pH values. In this sense, the current study is one of the first studies to investigate the effect of natural adsorbents on ammonia removal and pH. However, it is the first study to reduce ammonia originating from fish feed compared to unconditioned (natural form) forms of conditioned diatomite and leonardite. In addition to its positive effect on ammonia removal, leonardite did not alter pH values, enabling it to be within the suitable limits for the culture of aquatic organisms. The groups containing natural leonardite and conditioned leonardite showed the lowest pH values, while all other experimental groups displayed statistical similarity within themselves ($P > 0.05$). At the end of the study, when ammonia removal and pH values were evaluated, it was determined that conditioned zeolite, leonardite and diatomite were more effective than their respective natural forms. These findings agree with the results of Muscarella et al. 2021; Alshameri et al. 2014; Sarıoğlu 2005.

When the TAN values obtained in the study were examined, it was determined that the conditioned zeolite and leonardite groups showed more efficient removal efficiency than their respective natural forms. On the other hand, the TAN removal values of conditioned diatomite and natural diatomite were similar. It was inferred that conditioning with NaCl is not very effective in diatomite groups, and it may be helpful to implement different modifications in future studies. Similar to this study, Biblioteca et al. (2023) reported that Na values increased in zeolite conditioned with NaCl, and that the conditioned adsorbent's efficiency was higher than that of natural adsorbents. Similarly, Na values increased in leonardite and diatomite conditioned forms, and these results are preliminary findings. Furthermore, ammonium removal studies obtained from various previous conditioning processes are presented in Table 3.

The EDS spectra of the adsorbents showed that natural and conditioned zeolite and diatomite (Fig. 2a, b and c, and 2d) were structurally similar. Moreover, natural and conditioned leonardite (Fig. 2e and f) contained a high carbon rate similar to the structure of activated carbon (Deshmukh et al. 2018; Jitjamnong et al. 2020). The decrease in ammonia concentrations in natural and conditioned leonardite is thought to be due to the carbon content with a structure similar to that of activated carbon.

Natural zeolite's ion-exchange ability makes it an attractive choice for adsorption in its suspended powder (adsorbent) form, which is used to remove numerous pollutants from water, including ammonia (Adam et al. 2020). Each moment an aluminium (Al_3^+) atom replaces a silicon (Si_4^+) atom in the zeolite framework, a negative charge is produced. As a result, the negative charge of the zeolite increases with increased aluminium atom exchange (Nguyen and Tanner 1998). The cations (positively charged) present on the surface of the zeolite, such as K^+, Na^+, Mg_2^+, and Ca_2^+, then balance these negative charges within the pores (Rasidi et al. 2023). A weaker electrostatic contact that results in the ability of exchange with specific cations present in the solution (NH_4^+), binds these cations to the aluminosilicate. Consequently, this will eventually aid in the adsorption of ammonia in wastewater (Adam et al. 2023). In this study, when the analysis results of conditioned and unconditioned adsorbents were examined, an increase was observed in the values of SiO_2, Al_2O_3, and Na_2O, which could potentially influence adsorption.

In the use of adsorbents such as zeolite, diatomite, leonardite, and activated carbon in aquaculture, it should be taken into consideration that water parameters should be within the ideal limits required for aquatic organisms (pH 6-5−8.5; water temperature 15–27° C, dissolved oxygen < 5 mg/l, etc.) (Rasidi et al. 2023; Sharma 2020). Some other physical and chemical properties of water, especially water temperature and pH, also affect the ammonium removal efficiency of natural adsorbents. Therefore, in the use of natural adsorbents in aquaculture environments, both the ideal removal efficiency and other water parameters must be kept within ideal limits. In this study, it was determined that zeolite, which has been the subject of many studies on its use in aquaculture, as well as diatomite, which has been the subject of few studies, and especially leonardite had a significant effect on the reduction of NH_3-N values from fish feed compared to the control group. As a usage rate, especially considering the pH values, the use of 2 g leonardite (natural and conditional) per 0.5 l freshwater can be recommended. It was determined that pH values should be considered when using higher doses of leonardite. Especially in the use of high doses of leonardite, aquatic species should be suitable for pH tolerance. Research on this subject can be carried out. Zeolite and diatomite groups were less effective on pH values and provided an effective removal of NH_3-N values compared to the control group. In these groups, the use of 2 g zeolite and diatomite (natural and conditional) per 0.5 l freshwater can be recommended. In addition, since it was determined that the use of zeolite and diatomite did not affect the pH values, studies on the use of higher ratios can be carried out.

Conclusion

Natural water conditioning materials with the potential to be used in aquaculture are very important for sustainable aquaculture. Leonardite and diatomite, which are the subjects of this research, are potential raw materials that can be used in regulating water parameters and there are few studies on this subject in the last few years. However, scientific studies similar to this study are needed to fully reveal their usability features in aquaculture conditions.

In the study, it was determined that ammonia values in the adsorbent applied groups were lower proportionally to the study period compared to the control group. When the groups with adsorbent added were evaluated among themselves, the ammonia values in the groups containing natural leonardite and conditioned leonardite remained at the recommended values for aquaculture throughout the experimental period (14 days). As a result of the study, it was concluded that leonardite and zeolite (2 g/0.5 l) could be used effectively in ammonia removal for aquaculture practices.

When evaluating the findings of this study, it was found that the removal efficiency of the three adsorbents increased with the conditioning process. The highest removal efficiency was observed in conditioned leonardite. Over the 14 days, TAN (Total Ammonia Nitrogen) values increased to an average of 14.27 mg/l in the control group, while the lowest value was observed in the conditioned leonardite group, remaining at 6.18 mg/l. Proportionally, a reduction of 56.69% was noted. Using leonardite and zeolite together at different rates, applying different conditioning processes, and their effects on an environment where fish is present can be recommended for future studies. Compared to expensive adsorbents like activated carbon, zeolite, leonardite and diatomite have the potential to be economically used in aquaculture. Furthermore, unlike activated carbon, they can be reconditioned, allowing for repeated use in aquaculture. They can also be used as feed additives, filtration materials and substrates.

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Author contributions ES: Conceptualization, Investigation, Formal analysis, Writing—review and editing; MÖ: designing, performing the experiment and data analysis, data collection and writing; DŞ: Supervision, Investigation, Formal analysis, Writing—review and editing; ÜÖ: Investigation and data analysis. All authors read and approved the final manuscript.

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Data availability All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of interest The author declare no competing interests.

Ethical approval and consent to participate Not applicable.

Consent for publication Not applicable.

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