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Beneficial properties of zeolite

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REVIEW ARTICLE

Abstract

Our focus was to obtain an overall picture of the different beneficial properties of zeolite, based on its chemical and physical characteristics, which depend on zeolite absorption and exchange of ions. These characteristics make them very useful for various applications, including agriculture (as an animal feed additive and in food technology production), veterinary and human medicine, ecology, certain manufacturing, and cosmetics. Zeolite has pleiotropic effects, and the most important of them are detoxifying, antioxidant, and anti-inflammatory roles. We wanted to underline, with the review of the scientific literature, the positive medical beneficial effects of zeolite on the general health status.

Keywords: different applications; physical-chemical properties; therapeutic benefits; zeolite

Introduction

Numerous *in vitro* and *in vivo* research has reported that zeolite has various positive medical effects due to its capacity for adsorption and exchange of ions, antioxidative and immunomodulatory effect, impact on the itestine status and microbiota (gut–brain axis), and antitumor and vaccine adjuvant properties (Kaljevic-Pavelić *et al*., 2018; Mastinu *et al*., 2019; Lacrimioara *et al*., 2022).

Origin and history of zeolites

In 1756, Swedish mineralist and chemist Alex Frederik Crönstedt was the first to identify the new mineral natural zeolite from a Swedish copper mine (Virta, 2015; Polat, 2014). For the majority of the countries, the pronounced expansion of production and use of zeolite started in 1960. Until now, about 50 natural (clinoptilolite, chabazite, erionite, phillipsite, mordenite, analcite), and 150 synthesized zeolites are known (Zimmermann and Haranczyk, 2016).

Structure and classification of zeolites

Zeolites represent an enormous family of the most important microporous materials, hydrated crystalline aluminosilicates of alkaline and alkali earth elements (cations) (Soledad and Font, 2022; Bruce *et al*., 2021). Among the most important chemo-physical properties of zeolite are: thermal expansion, morphology, the structure of external and internal tetrahedral linkages, dielectric property, color, density, particle size, uniformity of composition, hardness, optical properties, pore-volume, and thermochemistry (Xiao *et al*., 2021). Some biochemical transformations require zeolite, such as transportation, activation enzymes, and hormones action, which are necessary for the conversion of nutrients and maintenance of the balance of ions, nutrient conversion, and maintain

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ion balance (Chen *et al*., 2020). The alumino-silicates with $Si0_4$ and AlO_4 are the main constructive elements of zeolite (Qinming *et al*., 2022). Their ratio is an important characteristic that determines the ion-exchanging properties of zeolite. Based on the ratio, before 1977, zeolite minerals were described as clinoptilolite (Si/Al ≥ 4.0) or heulandite (Si/Al ≥ 4.0). In addition, there are zeolites A (Si/Al = 1.0–1.5), zeolites Y (Si/Al = 2–5), and erionite and mordenite (Si/Al > 10) (Laurino and Palmieri, 2015).

Three classification schemes are used for zeolite structures circumglobal (Ramesch *et al*., 2010).

(1) Zeolites erionite and mordenite-high Si/Al ratio (from 10 to several thousands);

(2) Zeolites Y-intermediate Si/Al ratio (2–5);

(3) Zeolites A-low Si/Al ratio (between 1.0 and 1.5)

Application of zeolites in agriculture

The natural zeolite, clinoptilolite, has widespread use in the field of agriculture (Lijuan *et al*., 2022.) because it is classified by the International Agency for Research on Cancer (IARC, 1997b) as "nontoxic," by the Food and Drug Administration (FDA), (FDA, Code of Federal Regulations, 2016), as safe for human consumption, and by The European Food Safety anda Authority as safe for animal use and environment. As a mycotoxin binder, it is also considered as an anti-caking agent and coagulant that has been recognized and suggested by the European Union for use in swine, rabbit, and, poultry breeding (EFSA FEEDAP Panel, 2017). Zeolite is present in large amounts in sediments and soils and is very often used for agricultural purposes (soil amendment and nitrogen retention) (Bočarov-Stančić *et al*., 2015; Ruobing *et al*., 2022) due to its properties such as ion exchange capacity (2.16 meq/g), specific gravity (2.15–2.25 g/cm^3), bulk density (1.15 g/cm^3), high heat stability and porosity (34%).

Due to their adsorbent capacity, zeolites can reduce the plant uptake of the metal contaminant (Cd, Pb, Ni, Cr, and Cu) and can remove it from sewage (Grądzki *et al*., 2020). Because of its properties regarding the exchange of cations, zeolite can promote hydraulic conductivity and increase yields (Eroglu *et al*., 2017).

Application as an animal feed additive

Zeolite can be added to feed poultry, pigs, calves, and sheep, which improves their characteristics such as shell thickness, feed conversion and utilization of nutrients, bone quality, and growth rate (Wang *et al*., 2018; Cataldo *et al*., 2021). Some of the important mechanisms of zeolite application properties are ammonia-binding, inhibition of mycotoxin, increase in toxic degradation products absorption, and reduced rate of passage of digestion products (Eroglu *et al*., 2017). For example, the addition of 5% zeolite clinoptilolite in food for swine and poultry resulted in the elevated weight of animals, with reduced cost of feed use. Also it schows favorable effect in improving of degradation of toxic products, amelioration of intestinal microbial degradation, and slower passage effect of digesta through the intestines (Lacrimioara *et al*., 2022).

Application in food production

Zeolite can be used as a food package ingredient, due to its content of SiO_2, water adsorption capacity, and pH levels (Ozdemir and Floros, 2004; Nešić *et al*., 2022). For example, a package with 1 and 5% zeolites retained the freshness of sardines longer and removed their odor (Papaioannou *et al*., 2005; Kuley *et al*., 2012).

Detoxification role of zeolite

Both *in vivo* and *in vitro* studies reported the protective effects of zeolite due to its capacity for absorption and exchange of ions, regarding mycotoxins, ammonia, heavy metals, and organic compounds (Pan *et al*., 2021). It enables the excretion of toxins from the intestine together with zeolite (EFSA Panel on Additives and Products or Substances Used in Animal Feed, 2017). Also, due to its hemostatic and antioxidant effects, zeolite could be added to standard human therapies, which warrants further research (Pavelic and Hadzija, 2003).

As for animals, zeolite could be used for humans regarding the removal of ammonia, the excessive production could result from an unbalanced diet or a diet rich in proteins (Schneider *et al*., 2017; Uddin, 2017). Also, excessive ammonia is reported in various pathogenesis such are colorectal cancer, irritable bowel syndrome, and ulcerative colitis (Adeyemo *et al*., 2017).

In addition, zeolite has a significant role in fighting mycotoxins, especially in reducing the toxic effects of aflatoxins. One of the mechanisms might be zeolite-induced increased activity of antioxidant enzymes as well as elevation of omega-3 fatty acids, which was reported for poultry eggs (Habib and Bockris, 1980). Very important is the adsorbing role of zeolite for mycotoxin and heavy elements (Yimnak *et al*., 2020) in the field of animal husbandry (Karnwal and Bhardway, 2014), and also the role of zeolite that can improve the quality of pelleted feedstuffs, repairing acidosis in ruminants rumen, especially

of dairy cows and beef cattle in intensive fattening. The positive results of testing zeolites in the ensiling process, regarding microbiological safety, are also underlined (Adamovic *et al*., 2020).

Antioxidative, anti-inflammatory effects of zeolites

Zeolite can activate antioxidant enzymes (peroxidase, catalase, and superoxide dismutase) (Huidong, 2022), which was reported in many animals. For example, dietary supplementation of rats with zeolite provided antioxidant protection after hepatectomy. Also, the reaction of rats to environmental stress is better after zeolite ingestion. Therefore, there might be indirect zeolite action on the central nervous system, *via* the gut-brain axis (Golokhvast *et al*., 2017; Katsoulos *et al*., 2005; Poulsen and Oksbjerg, 1995).

In addition, there was an improvement in the antioxidative potential of rats and broiler chicken due to zeolite treatment (Yapisklar *et al*., 2016). Antioxidant effects of zeolite, such as elevation of levels of antioxidant enzymes and reduction in lipid peroxidation, have been reported in smokers (Li *et al*., 2022).

It is also important to underline zeolite benefits in reducing hyperlipidemia in patients reported in various open-label prospective, uncontrolled, dose/granule size-ranging studies; zeolite improved the lipid profiles in the blood of dyslipidemic patients (La Rosa *et al*., 2018; Čutovic *et al*., 2017).

Epidemiological investigations point out the importance of the "Gut–Brain Axis," as an unhealthy lifestyle can cause intestinal permeability, which in turn can contribute to the development of Alzheimer's disease (Alkasier *et al*., 2016; Hu *et al*., 2016). The study by Montanaro *et al*. indicates that zeolite supplementation can be useful in maintaining gut electrolyte equilibrium and also in reducing oxidative stress (Spiridon 2022). Deposition of the amyloid-β peptides in the neuronal cells is one of the crucial mechanisms, which leads to an imbalance in cells hemostasis and disruption of their membrane (Giau *et al*., 2018 Moos *et al*., 2016 Wang *et al*., 2018; Montinaro *et al*., 2013). Therefore, a focus treatment strategy for Alzheimer's disease is targeting these amyloid structures (Griffiths, Mazmanian 2018; Kaelberer *et al*., 2018).Fibrinogen as a proinflammatory marker can be detected in the brain of patients with Alzheimer's disease (Castello and Soriano 2014; Mosesson, 2005). An important strategy for the prevention and treatment of Alzheimer's disease development is targeting the interaction of the Aβ–fibrinogen (Mahmoudi, 2013). Antioxidant, anti-inflammatory, and gut-protective properties of the Mediterranean diet rich in fibers, fruits, and vegetables, in comparison with the Western diet rich in high-fat, red meat has been reported as more favorable for gut homeostasis/integrity and reducing Alzheimer's disease development (Baldwin *et al*., 2011; Berti *et al*., 2018). We can also underline the immunomodulatory, anti-inflammatory role of acting superantigen, as a specific immunostimulant oligo-protein (Saribeyoglu *et al*., 2011; Wu *et al*., 2013, Levy *et al*., 2016).

Zeolite found its application in dentistry and is considered to be very efficient regarding the delivery of antimicrobiotics. Also, its addition to dental cement provided teeth more resistant to acid (Saghiri *et al*., 2014; Patel, 2016).

Zeolites as promising therapeutical delivery of anticancer drugs

Zeolite could be used as an addition to anticancer therapy (Hao *et al*., 2021). *In vivo* studies demonstrated that zeolite can block the growth of cancer cells by negative regulation of protein kinase (Ilgren *et al*., 2008; Pavelic *et al*., 2001; Pavelic *et al*., 2012). Animal studies on dogs and mice reported various tumor size reductions (Maleki *et al*., 2020; Ivković *et al*., 2004). A decrease in oxidative stress has been shown in cancer patients who ingested activated zeolite (Bagheri *et al*., 2021; Derakhshankhah *et al*., 2020; Ivkovic, Zabčić, 2002).

Application of zeolites in environment protection

Regarding ion-exchange activity and high sorption of zeolites, zeolite can decontaminate radioactive environments, and purify the soil, water, and air, from elements such as toxic Cr^{3+} and Cr^{6+} (Miramontes-Gutierrez E. 2021; Molla *et al*., 2017; Ryan *et al*., 2011).

Conclusions

According to the chemical and physical characteristics of zeolites, especially its absorbing capacity, in this review, our focus was to highlight some of its therapeutic potential effects. Based on the literature data, we tried to underline its multiple beneficial effects on animal and human well-being. As an oral food supplement, zeolite clinoptilolite can be used as an efficient adjuvant to traditional pharmacological treatment for the amelioration of gut–brain interconnection in animals and humans. Literature data point out that zeolite can remove toxic metabolites of various drugs. In addition, thanks to its binding properties, zeolite is applied in environmental decontamination. Nevertheless, further research

regarding the beneficial effects of zeolite on human health is necessary.

Conflict of Interests

The authors declare no conflict of interest.

Authors Contribution

G.O., B.P, and T.P. were involved in conceptualization, generation of the main idea, and writing of the manuscript M.T. participated in a literature search on physical-chemical properties of clinoptilolite, wrote parts of the manuscript related to clinoptilolite chemistry, and performed a critical review of data and literature. All authors have read and agreed to the published version of the manuscript.

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