https://doi.org/10.15407/scine19.06.077

KOVAL, M. G.[1] (https://orcid.org/0000-0001-9680-8052),
KONOHRAI, V. A.[2] (https://orcid.org/0000-0003-3183-7375),
FESHCHENKO, N. V.[1] (https://orcid.org/0000-0002-4331-8196),
ROMANENKO, N. G.[1] (https://orcid.org/0000-0003-2161-5736),
and YAKYMENKO, I. K.[2] (https://orcid.org/0000-0001-9469-8240)

[1] Cherkasy State Technological University,
460, Shevchenko Blvd., Cherkasy, 18006, Ukraine,
+380 472 51 3672, chdtu@chdtu.edu.ua
[2] VSP Society "UKRAVIT SCIENCE PARK" "Institute of Plant Health",
10, Energostroitel passage, Cherkasy, 18000, Ukraine,
+380 634 78 8300, institut-roslyn@ukravit.ua

ASSESSMENT OF PHYTOTOXICITY OF USED ZEOLITE AS A SORBENT OF THE DYEING AND FINISHING PRODUCTION WASTEWATER BY THE PHYTOINDICATION METHOD

Introduction. *The optimization of the technological processes for dyeing textile materials using wastewater adsorption purification via natural zeolite is relevant. The purified water can be used as recycled water for reuse in fabric dyeing technology.*

Problem Statement. *The used zeolite sorbent belongs to the by-products of the dyeing and finishing industry's wastewater treatment process. However, there is possibility to reuse it as a secondary material resource after determining the level of toxicity.*

Purpose. *The purpose of this research is to assess the phytotoxicity of spent zeolite as a natural adsorbent for the purification of wastewater from dyeing and finishing production of textile dyes and auxiliary substances by the methods of phytoindication to determine possible directions of its use without additional costs for its disposal.*

Material and Methods. *Wastewater from dyeing and finishing production and spent zeolite are research materials and winter barley seeds are the phytotest object. The method of scientific information generalization has been used; chemical analysis of wastewater has been carried out by the method of optical emission spectrometry with inductively coupled plasma; the intensity of winter barley stalks growth has been studied by the method of laboratory phytotesting; phytotoxicity has been evaluated with the use of analytical expression.*

Results. *The phytotoxicity of used zeolite on water, soil, and concentrated substrates does not exceed 20%, which indicates the absence or low level of its toxicity and the possibility of reuse. The phytotoxicity of the aqueous substrate (water extract) of the spent zeolite has a negative value (–6.67%), which indicates that the studied aqueous substrate is not toxic.*

Conclusions. *The experimental assessment of the toxicity of the used sorbent has allowed reusing it in the field of road construction and in the production of building materials.*

Keywords: dyeing and finishing production, wastewater, adsorption, zeolite, phytotoxicity, phytotesting, barley.

Citation: Koval, M. G., Konohrai, V. A., Feshchenko, N. V., Romanenko, N. G., and Yakymenko, I. K. (2023). Assessment of Phytotoxicity of Used Zeolite as a Sorbent of the Dyeing and Finishing Production Wastewater by the Phytoindication Method. *Sci. innov.*, 19(6), 77—86. https://doi.org/10.15407/scine19.06.077

The technologies for dyeing textile materials are associated with the consumption of material and energy resources, as well as with the generation of waste. The wastewater that contains a mixture of residual synthetic dyes and auxiliary substances is a waste of dyeing and finishing industries. It causes significant damage to the ecological system of the water region. That is why, the problem of optimizing the technological processes of the dyeing and finishing production in order to rationally use resources, protect the environment, and reduce the impact on the ecosystem is rather current. All this is done through the deep cleaning of wastewater from this production to such a degree of purity that in the future the purified water can be used as recycled water is urgent for reuse in textile dyeing technology [1, 2].

Since the specifics of the water supply of a textile dyeing enterprise are determined by high requirements for the quality of the consumed process water, the most effective method of wastewater treatment is adsorption. The advantages of the method are high efficiency, the possibility of cleaning wastewater containing several substances, as well as the recovery of these substances. Adsorption treatment of wastewater is most rational when it contains mainly aromatic compounds, non-electrolytes, or weak electrolytes, dyes, and aliphatic compounds. The possibility of substances of multicomponent mixtures adsorption and high efficiency of cleaning (80—95%), especially weakly concentrated wastewater, are the basic advantages of this method [3]. Effluent treated by sorption methods can be reused in the textile industry during the technological processes of dyeing and finishing production [4].

Spent zeolite is one of the solid wastes of industrial wastewater adsorption treatment from the dyeing and finishing industry [1]. The significant volumes of waste accumulated in Ukraine and the lack of effective measures aimed at their disposal or reuse are inhibiting factors in the development of the national economy. Significant volumes of solid waste are accumulated every year in the Ukrainian industry and utility sector, of which only a small part is used as secondary material resources while the rest end up in landfills [5].

Therefore, there is a problem of disposal or possible reuse of spent zeolite sorbent as a secondary material resource.

The spent mineral zeolite can be utilized to ensure the stable operation of the highway structure as part of the road pavement basics [6, 7]. Zeolite is a natural mineral that can be used in the production of building materials (manufacturing of cement, concrete solutions, foam, and aerated concrete). Zakarpattia zeolites, being aluminosilicates of the alkaline and alkaline soil metals, are active mineral additives in the production of concrete grades with the strength class 100—400. At the same time, the introduction of zeolite in the composition of concrete in optimal quantities allows reducing the consumption of cement by an average of 50 kg per 1 m^3 of concrete while maintaining the strength of the concrete brand. A mixture of cement and additives containing 60% clinoptilolite and mordenite (in a ratio of 19 : 1 to 6 : 1) is used for the production of high-strength concrete. This makes it possible to obtain concrete with greater compressive strength than Portland cement. Studies have shown that natural zeolites can be used in nuclear power as they are resistant to nuclear degradation and are cheaper than organic ion exchange resins. Zeolites react quickly with cement and glass, which makes it possible to create more reliable concrete storage for radioactive materials. Considerable research in this field has been conducted in the last 15—20 years in such countries as the United States, Canada, Bulgaria, France, Germany, Great Britain, and Japan [8].

After the adsorptive treatment of wastewater from the dyeing and finishing industry, zeolite contains molecules of textile dyes and auxiliary substances in the pores of the molecular mesh structure. Textile dyes are mainly organic azo or diazonium salts that constitute a serious hazard. They are classified as local poisons that have a toxic and inhibitory effect on the human body [9].

Studies were conducted to determine its toxicity, in particular phytotoxicity, to enable its reuse in construction and other industries, as well as its possible disposal. Phytotoxicity is the ability of pesticides or other chemicals to have a toxic (poisonous) effect on plants. Signs of the poisonous substance's phytotoxic effect on cultivated plants can be manifested in a decrease in germination and seed vigor. They can suppress the growth and development of plants and lead to distortion of stems and metabolic disorders [10]. It's important to establish the difference between the intensity of plant growth in the studied samples and compare them with the reference sample to determine the toxicity of the studied object on higher plants.

The purpose of the work is to evaluate the phytotoxicity of spent zeolite, used as a natural adsorbent for the purification of wastewater from dyeing and finishing production from textile dyes and auxiliary substances, by means of phytotesting in order to determine possible directions of its use without additional costs for its disposal. The following tasks were formulated to achieve the goal:

1. Evaluation of the spent zeolite's toxicity level by the laboratory phytotesting with the selection of winter barley seeds as the test object.

2. Analysis and processing of the obtained results to state conclusions about the toxicity presence in the studied samples of substrates.

3. Determination of potential directions and opportunities for the use of spent zeolite as an auxiliary material depending on the field of application and observing the hypothesis of its non-toxicity.

The native zeolite (sokyrnite) of the Sokyrnytskyi deposit of the Zakarpattia Oblast (Ukraine) was the subject of research. Zeolite is a natural aqueous aluminosilicate containing oxides of alkali or alkaline soil metals. This adsorbent is characterized by a regular structure of pores, the sizes of which are similar to the sizes of the absorbed molecules. The peculiarity of zeolites is that the adsorption surfaces are interconnected by cells of a certain diameter, through which only molecules of a smaller size can penetrate. The sorbent has an increased porosity that gives the material high hydrodynamic characteristics. The porous structure of zeolite contains active exchange centers and causes unique adsorption, cation exchange, and catalytic properties. Sokyrnite has a mineral composition: clinoptilolite (65—80%), montmorillonite (2—4%), quartz (up to 10%), plagioclase (5—10%), carbonate (3%), and hydromica (1—3%). The general molecular formula is $Mx/n\ [Al_2O_3)_x (SiO_2)_y] WH_2O$ [11]. The chemical composition of zeolite is as follows: 65.0—71.3% of SiO_2; 11.5—13.1% of Al_2O_3; 2.7—5.2% of CaO; 2.2—3.4% of K_2O; 0.7—1.9% of Fe_2O_3; 0.6—1.2% of MgO; 0.2—1.3% of Na_2O; 0.1—0.3% ofTiO_2; 0.04 % of MnO; 0.02% of P_2O_5. The frame type is layered, the diameter of the channels is 0.38—0.62 nm, and the total exchange capacity is 2.64 mg-eq/l. The native zeolite was subjected to thermal activation (baked in a muffle furnace for 4.5 hours at a temperature of 450 °C) to improve the adsorption properties and subjected to acid modification (treated with a solution of sulfuric acid H_2SO_4 with a concentration of 10 mol/l). The prepared zeolite was used as an adsorbent for wastewater treatment painting and finishing production [1] (Fig. 1).

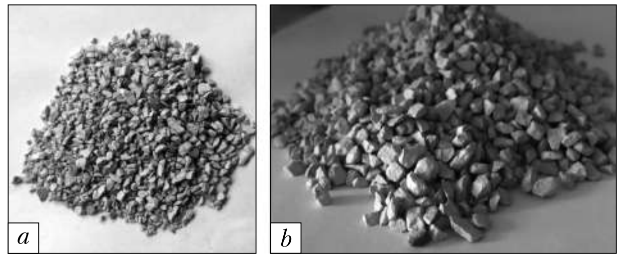

Fig. 1. Natural sorbent with a fraction of 2—5 mm: *a* — native zeolite; *b* — spent zeolite

Many studies on the thermal desorption of spent zeolite demonstrated that there is a chemical bond between the dye molecules (which are fixed in the pores of the zeolite) and their molecular structure. We can conclude about the presence of chemical adsorption (chemisorption) of dye molecules in zeolite as a sorbent, which makes it possible to formulate a problem for research — determining the level of spent zeolite toxicity in order to identify the ways of its reuse or, in case of toxicity, its disposal.

It is advisable to use biological test objects to determine the toxicity of spent zeolite. There is a

Fig. 2. Seeds of winter barley Ninth Val variety

wide variety of phytotests among biotesting methods. These include growing plants on substrates whose toxicity needs to be determined (soils, water, etc.), as well as watering plant seedlings with investigated solutions (aqueous soil extracts and wastewater) [12—14].

Seeds of winter barley (*Hordeum vulgare* L.) the Ninth Val variety (medium ripe) of Ukrainian selection were used as a test object in the study (Fig. 2).

A high-intensity variety has a potential yielding ability of 9.0—10.5 t/ha. The weight of 1000 seeds is 40.5—49.4 g. The variety has high frost and drought resistance. It is characterized by high plasticity. It grows poorly on sandy soils and is greatly inhibited on acidic soils (at pH < 6). Seedlings do not appear at pH $= 3.5$. The optimal soil pH for barley is 6.0—7.5 [15]. It's not picky about the heat. Seeds begin to germinate at a temperature of 1—3 °C, seedlings can appear in the field conditions at 4—50 °C. Seedlings withstand frosts up to –3—(–4) °C [16]. Barley is the most demanding crop in terms of soil fertility in comparison with other grain crops. This is due to the intensive accumulation of organic matter in a relatively short time and the comparably underdeveloped root system that is highly sensitive to the concentration of salts in the soil solution, especially in the initial period of growth. The speed of development and the nature of barley growth are largely determined by the type and soil fertility [17].

The phytotoxicity of spent zeolite was determined by a series of experiments with different initial conditions and on different research substrates:

Experiment 1. Water extracts of native and spent zeolites were studied.

Experiment 2. Soil mixtures with native and spent zeolites were studied.

Experiment 3. Substrates (concentrates) of native and spent zeolites were studied.

Experiment 4. Wastewater from the dyeing and finishing industry was studied.

Description of experimental research.

Experiment 1. The methods of physical and chemical analysis of water extracts are effective for both qualitative and quantitative determination of the toxicants content in the studied environment. Three samples were tested as substrates: 1 — distilled water (reference), 2 — water extract of native zeolite, and 3 — water extract of spent zeolite. Water extracts were prepared according to DSTU 7534:2014 "Greenhouse grounds. Method for preparation of water extract" and their pH were determined. It was found that the pH of distilled water is 7.6; The pH of the aqueous extract of native zeolite is 7.04; The pH of the aqueous extract of spent zeolite is 7.02. Barley seeds have been previously soaked in distilled water for 12 hours. Then, they were planted on filter paper moistened with the studied water extracts (20 seeds per each). A mandatory condition for experimenting was constant humidity maintenance of the studied samples. Plants have been growing at a temperature of 18 °C for 12 days. Each version of the experiment was carried out in triplicate. The following parameters were recorded during the study: seed germination time, the total number of seeds that emerged, the height of stems, and the length of the root system. Changes in the state of plants at various stages of their development were observed throughout the experiment. The number of sprouted winter barley seeds is shown in Fig. 3. The germinating capacity of winter barley grains for the reference is 90%, for the water extraction from native zeolite is 95%, and for the spent zeolite is 85%. Photos of germinated seeds are presented in Fig. 4.

The phytotoxic effect is determined as a percentage by any bioparameter: by the length of the root or stem system, the number of suppressed plants, the number of seeds that have sprouted, the weight of plants, etc. The height of the barley stalks that germinated during the entire experiment was chosen as the bioparameter for calculation in the conducted experiment. The phytotoxicity index is calculated according to the formula [18]:

$$P = \frac{(B_c - B_i)}{B_c} \cdot 100\%, \qquad (1)$$

where P is the phytotoxicity, %; B_c is the average stem height as bioparameter for the reference sample, cm; B_i is the average stem height as bioparameter for the studied sample, cm.

The studied samples show phytotoxicity in a case when $P > 20\%$ [19]. The average height of the winter barley stems as bioparameter and the phytotoxicity calculated by formula (1) on different substrates are shown in Table 1.

Negative phytotoxicity on the investigated substrates signifies the absence of studied water extracts toxicity and its potential stimulation to the grain crops' germination.

Experiment 2. Soil mixtures with native and spent zeolites were tested. Three samples were subjected to research as substrates: 1 — chernozem soil (reference), 2 — a mixture of soil with native zeolite (the ratio of soil and zeolite by mass is 4 : 1, respectively [20]), 3 — a mixture of soil with spent zeolite (4 : 1 by mass, respectively). The soil is a typical chernozem (Chervona Sloboda village, Cherkasy district, Cherkasy region, Ukraine). The content of the humus is 2.4%. The weighted phosphorus content is 158 mg/kg, the nitrogen content is 90 mg/kg, and the potassium content is 62 mg/kg [21]. Since barley germinates at a 6—7.5 pH, this value was determined in the studied soil samples by preparing water extracts that were tackled according to DSTU 7534:2014 "Greenhouse grounds. Method for preparation of water extract". It was found that the pH of the soil water extract is 7.5; the pH of the soil mixture with native zeolite aqueous extract is 7.7; The pH of the soil mixture with spent zeolite aqueous extract is 7.6. Presoaked barley seeds (for 12 hours) were planted in accordance with the international standards ISO 11269-1 and ISO 11269-2 and were grown directly in the soil and the studied mixtures

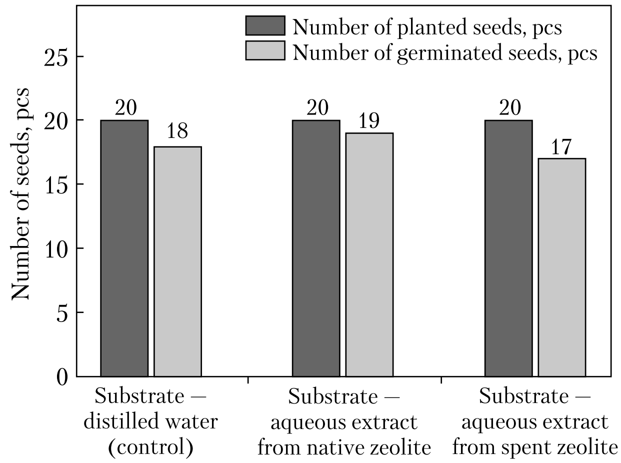

Fig. 3. Number of planted and germinated winter barley seeds on different substrates

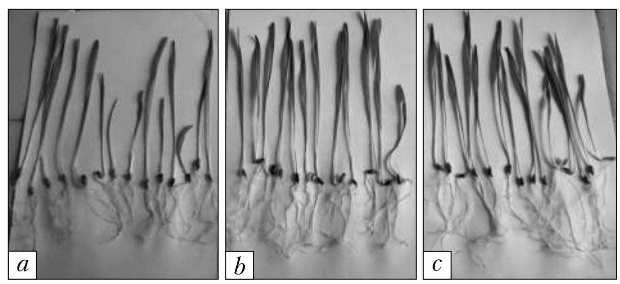

Fig. 4. Photos of germinated winter barley seeds on different substrates: *a* — distilled water (reference); *b* — aqueous extract from native zeolite; *c* — aqueous extract from spent zeolite

Table 1. **Average Height of the Winter Barley Stems as Bioparameter and Phytotoxicity on Different Substrates**

Investigated substrate	The average height of the winter barley stems, cm	Phytotoxicity, %
Distilled water (reference)	13.5	–
Aqueous extract from native zeolite	15.4	–14.07
Aqueous extract from spent zeolite	14.4	–6.67

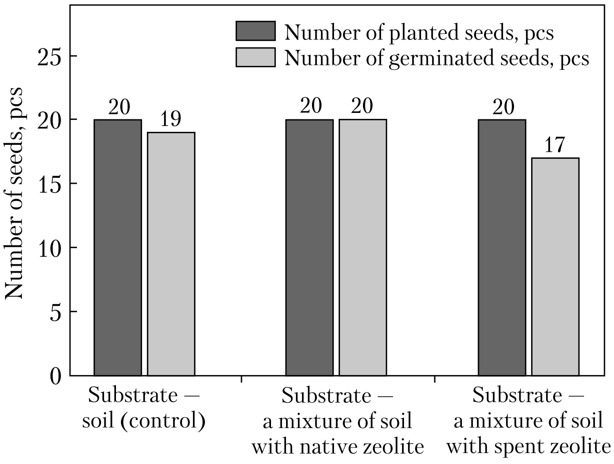

Fig. 5. Number of planted and germinated winter barley seeds on soil substrates

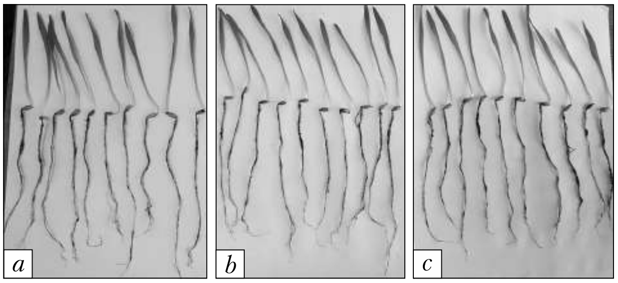

Fig. 6. Photos of germinated winter barley seeds on soil substrates: *a* — soil (reference); *b* — mixture of soil with native zeolite; *c* — mixture of soil with spent zeolite

(20 seeds in each sample). Maintaining constant humidity of the studied samples was a mandatory condition for the experiment. Plants have been growing at a temperature of 16 °C for 12 days. Each version of the experiment was carried out in triplicate. The seed germination time was recorded in the course of the study, the same as the total number of seeds that emerged and the height of the stems. The number of sprouted winter barley seeds is shown in Fig. 5. Similarity of winter barley grains for the reference is 95%, for the native zeolite is 100%, and for the spent zeolite is 85%. Photos of germinated seeds are presented in Fig. 6.

Table 2. **Average Height of the Winter Barley Stems as Bioparameter and Phytotoxicity on Soil Substrates**

Investigated substrate	The average height of the winter barley stems, cm	Phytotoxicity, %
Soil (reference)	11.1	—
Mixture of soil with native zeolite	10.6	4.5
Mixture of soil with spent zeolite	10.4	6.3

The height of barley stalks was selected as bioparameter for calculation in the conducted experiment. The average height and the calculated phytotoxicity are shown in Table 2. Phytotoxicity was calculated mathematically according to formula (1).

The phytotoxicity does not exceed 20%, which indicates the absence of spent zeolite toxicity.

Experiment 3. The investigation was focused on concentrates of native and spent zeolite. Three samples were used as substrates for winter barley seeds germination: 1 — sand (reference); 2 — crushed native zeolite; 3 — crushed spent zeolite. We used previously sterilized laboratory sand (at a temperature of 150 °C) with a fraction of 1 mm. Barley seeds have been pre-soaking in distilled water for 12 hours. Then they were planted in the investigated substrates-concentrates (10 seeds in each sample). A mandatory condition for experimenting was constant humidity maintenance of the studied samples. Plants have been growing at a temperature of 18 °C for 12 days. Each version of the experiment was carried out in triplicate. The seed germination time was recorded in the course of the study, the same as the total number of seeds that emerged and the height of stems. The number of sprouted winter barley seeds is shown in Fig. 7. The similarity of winter barley grains for the reference is 80%, for the native zeolite is 80%, and for the spent zeolite is 90%. Photos of germinated seeds are presented in Fig. 8.

The height of barley stalks was selected as a bioparameter for calculation. The average height and the calculated phytotoxicity are given in Table 3. The phytotoxicity was calculated mathematically according to formula (1).

There is inhibition of the root system growth and yellowing of winter barley stalks in the studied samples (as compared with the reference ones) along with the negative phytotoxicity that indicates the absence of spent zeolite toxicity. This may indicate a negative effect of concentrates of native and spent zeolites on the formation of chlorophyll. The point is that the chemical elements of plant nutrition must be in an easily accessible water-soluble form. Microelements contained in the investigated substrates are in an insoluble form that is inaccessible to plants, in the absence of which the growth and metabolism processes are disturbed.

Experiment 4. The wastewater from the dyeing and finishing production of the Private Joint Stock Company Cherkasy Silk Plant (Cherkasy, Ukraine) was the subject of investigation. There were three samples as substrates for the winter barley seeds germination: 1 — distilled water (reference); 2 — averaged wastewater (formed at a ratio of 1 : 100 with distilled water, respectively. Wastewater of this composition and concentration was subjected to adsorption purification with zeolite); 3 — concentrated wastewater, formed directly after textile dyeing processes.

Wastewater was analyzed according to DSTU EN ISO 11885:2019 "Water quality. Determination of selected elements by inductively coupled plasma optical emission spectrometry" (ICP-OES) (EN ISO 11885:2007; ISO 11885:2009, IDT) with a parallel emission spectrometer and inductively coupled plasma Shimadzu ICPE-9800. The results of the studies are listed in Table 4.

Barley seeds have been previously soaked in distilled water for 12 hours. Then they were planted on filter paper moistened with the investigated solutions (40 seeds per each). A mandatory condition for experimenting was constant humidity maintenance of the studied samples. Plants have been growing at a temperature of 11 °C for 12 days. Each version of the experiment was carried out in triplicate. The following parameters were recorded during the study: seed germination time, the total number of seeds that emerged, and the height of stems. Changes in the state of plants at various stages of their development were observed throughout the experiment. The number

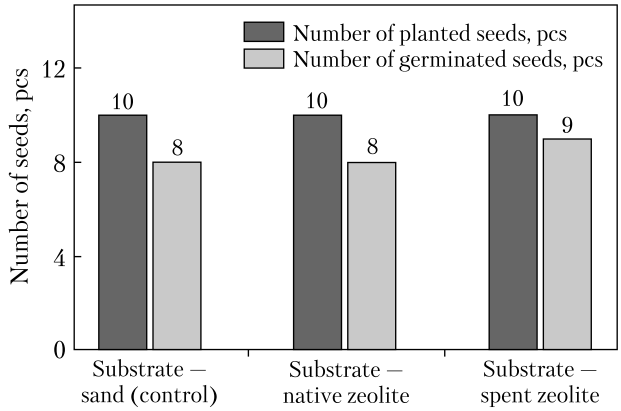

Fig. 7. Number of planted and germinated winter barley seeds in substrate concentrates

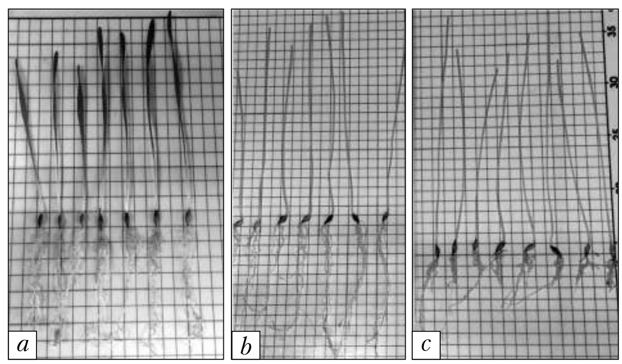

Fig. 8. Photos of germinated winter barley seeds in substrate concentrates: *a* — sand (control); *b* — native zeolite; *c* — spent zeolite

of sprouted winter barley seeds is shown in Fig. 9. The similarity of winter barley grains for the reference is 90%, for the averaged wastewater is 75%, and for the concentrated wastewater is 0%. Photos of germinated seeds are presented in Fig. 10.

Table 3. **Average Height of the Winter Barley Stems as Bioparameter and Phytotoxicity on Concentrate Substrates**

Investigated substrate	The average height of winter barley stems, cm	Phytotoxicity, %
Sand (control)	14.2	—
Native zeolite	21.3	–50
Spent zeolite	20.2	–42.3

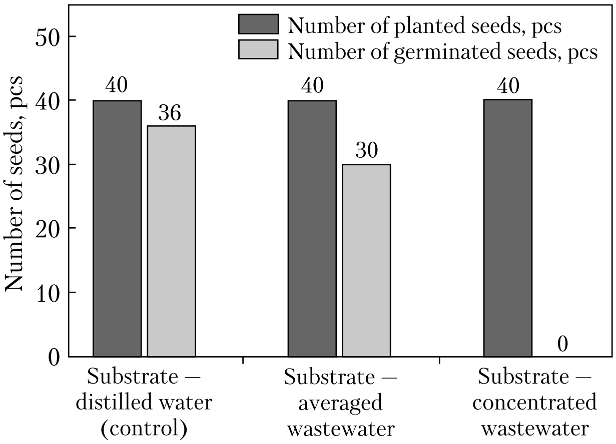

Fig. 9. Number of planted and germinated winter barley seeds on water substrates

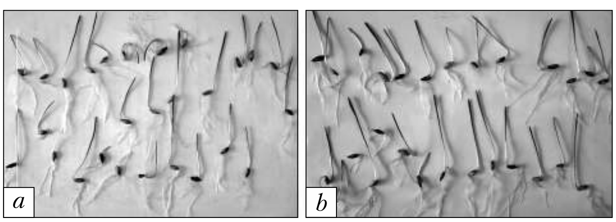

Fig. 10. Photo of germinated winter barley seeds on water substrates: *a* — distilled water (reference); *b* — averaged (diluted) wastewater

Table 4. **Chemical Element Composition of Dyeing and Finishing Production Wastewater**

Chemical element, mg/l	Averaged wastewater (1 : 100), pH 9.8	Concentrated wastewater, pH 10.26
Aluminum (Al)	0.251	0.178
Borum (B)	0.149	0.398
Calcium (Ca)	2.24	34.9
Chromium (Cr)	0.036	0.038
Cuprum (Cu)	0.027	1.74
Ferrum (Fe)	0.341	0.7
Kalium (K)	7.17	105
Magnesium (Mg)	0.317	5.5
Manganum (Mn)	—*	0.118
Natrium (Na)	80.4	.... (≥ 5540)
Zincum (Zn)	0.147	0.183
Phosphorus (P)	5.02	4.89
Sulfur (S)	.... (≥ 253)	.... (≥ 249)

* Values outside the calibration limits or below the detection limits.

The height of barley stalks was selected as the bioparameter for calculation. The average height and the calculated phytotoxicity are given in Table 5. The phytotoxicity was calculated mathematically according to formula (1).

The phytotoxicity does not exceed 20%, which indicates the absence or weak level of toxicity. The growth and development of the studied barley can be explained by the presence in wastewater of macro- and microelements of a certain concentration, which are necessary for its growth and development. Plants need N, P, and K macronutrients in the largest amount. They participate in the metabolic processes that take place in plant organisms, including respiration and photosynthesis. Microelements (Fe, Cu, S, Mn, Zn, and B) activate enzymes and increase the efficiency of photosynthesis. They belong to enzymatic systems involved in the respiration and synthesis of proteins and auxins. Moreover, such microelements increase the heat, drought, and cold resistance of plants. They help to regulate growth processes, manage protein and carbohydrate metabolism, and increase resistance to diseases [22].

A series of experimental studies was conducted to determine the level of spent zeolite toxicity as a natural sorbent of wastewater from the dyeing and finishing industry, containing synthetic textile dyes and auxiliary substances.

The laboratory phytotesting method demonstrated that the phytotoxicity of spent zeolite does not exceed 20%, which, according to existing criteria, indicates the absence or weak level of its toxicity.

Table 5. **Average Height of Winter Barley Stems as Bioparameter and Phytotoxicity on Water Substrates**

Investigated water substrate	The average height of the winter barley stems, cm	Phytotoxicity, %
Distilled water (reference)	5.37	—
Averaged wastewater (1 : 100)	4.37	18.62
Concentrated wastewater	—	—

The aqueous substrate phytotoxicity (water extract) of spent zeolite has a negative value (–6.67%). This indicates the absence of the investigated aqueous substrate toxicity, its nutrition, and its potential stimulation to the grain crops germination.

Analysis of the spent zeolite phytotoxicity indicators reveals the possibility to predict its use as a secondary material resource: to ensure the stable operation of the highway structure as part of the road pavement basics; in the production of building materials (manufacturing of cement, concrete solutions, foam, and aerated concrete). The use of spent zeolite as bioadditive for plant growth and development is possible due to additional more detailed agrochemical and biological research.

Reusing spent zeolite can solve the problem of its disposal as a solid by-product of adsorption wastewater treatment that will significantly reduce the ecological burden on the environment. The reuse of spent zeolite will decrease the economic costs of its disposal.

REFERENCES

1. *Patent of Ukraine No. 151829*. Koval M. G., Kuzmenko V. G., Romanenko N. G. Method of treatment of multicomponent wastewater of dyeing and finishing production [in Ukrainian].
2. *Patent of Ukraine 151832*. Koval M. G., Kuzmenko V. G. Technological system of wastewater treatment complex for dyeing and finishing production with natural zeolite [in Ukrainian].
3. Wastewater treatment by adsorption. Theoretical foundations of environmental protection. URL: https://stud.com.ua/458/ekologiya/ochischennya_stichnih_adsorbtsiyeyu (Last accessed: 02.02.2023).
4. Koval, M. G. (2022). Planning and organization of experimental studies of the cyclic use of resources in the technology of dyeing textile materials (on the example of dispersed dark blue Z dye). *Scientific Notes of the V.I. Vernadsky Taurida National University. Series: Technical sciences,* 33(72), 5, 203—209. https://doi.org/10.32782/2663-5941/2022.6/32 [in Ukrainian].
5. The Law of Ukraine on Waste. URL: https://zakon.rada.gov.ua /laws/show/187/98-vr#Text (Last accessed: 20.01.2023) [in Ukrainian].
6. *Terminological Dictionary of Construction and Architecture* (2010). Lviv [in Ukrainian].
7. DBN B.2.3-4: 2015 (2015) Highways. Part I. Design. Part II. Construction. Kyiv [in Ukrainian].
8. Zeolite in building materials. URL: https://lugova16.ibud.ua/ ru/company-prais/tseolit-fr-0-1mm-lugova16-10964915 (Last accessed: 20.12.2022).
9. Krasnoborodko, I. G. (1988). *Destructive treatment of wastewater from dyes.* Leningrad [in Russian].
10. Spodin, S. O., Timofeev, M. O., Korbut, M. B. Phytotoxicity and chemical pollution of soils. URL: https://conf.ztu.edu.ua/wp-content/uploads/2021/05/107-1.pdf (Last accessed: 10.11.2022).
11. Small Mining Encyclopedia in 3 vols. (2013). Vol. 3 (Ed. V.S. Biletskyi). Donetsk [in Ukrainian].
12. Dzhura, N. M. (2011). Possibilities of using plant test systems for biomonitoring of oil-contaminated soils. *Biological studies*, 5(3), 105—123 [in Ukrainian].
13. Nadgorska-Socha, A. (2017). Air pollution tolerance index and heavy metal bioaccumulation in selected plant species from urban biotopes. *Chemosphere,* 183, 471—482.
14. Laffray, X. (2010). Biomonitoring of traffic-related nitrogen oxides in the Maurienne valley (Savoie, France), using purple moor grass growth parameters and leaf 15N/14N ratio. *Environmental Pollution,* 158(5), 1652—1660.
15. *Special selection and seed production of field crops*: a textbook. (2010). Kharkiv [in Ukrainian].
16. Seeds of winter barley. Ninth shaft. URL: https://svg-group.com.ua/posevnoj-material/jachmen /devyatyy-val-semena-yachmen#:~:text (Last accessed:15.09.2022).
17. Biological features of sowing barley. URL: http://agro-business.com.ua/ ahrarni-kultury/item/8902-bioekolohichni-osoblyvosti-iachmeniu-posivnoho.html (Last accessed: 09.02.2023).
18. Rabosh, I. O., Kofanova, O. V. (2019). Evaluation of phytotoxicity of urban soils contaminated by road transport infrastructure. *Scientific reports of NULES of Ukraine,* 1(77), 121—132. https://doi.org/10.31548/dopovidi2019.01.003 [in Ukrainian].
19. *Patent of Ukraine No. 113560*. Krainiukov O. M., Kryvytska I. A. Method for determining the degree of soil contamination [in Ukrainian].

20. Zeolite soil additive. URL: https://sokirnitskij-tseoltovij-zavod.prom.ua//ua/p66439053-dobavka-grunt-tseolitu.html (Last accessed: 15.09.2022).
21. Kachanovska, L. O., Pavliuk, S. D. Agroecological assessment of soils in Cherkasy region. URL: http://journals.nubip.edu.ua/index.php/Dopovidi/article/viewFile/9476/8491 (Last accessed: 22.01.2023).
22. Plant nutrition. What micro and macro elements are needed? URL: https://www.agroglass.com.ua/home/information/novosti-i-issledovaniya/zhyvlennya-roslyn-yaki-mikro-ta-makroelementy-neobkhidni/ (Last accessed: 10.01.2023).

Received 22.02.2023
Revised 02.05.2023
Accepted 10.05.2023

М.Г. Коваль[1] (https://orcid.org/0000-0001-9680-8052),
В.А. Коноград[2] (https://orcid.org/0000-0003-3183-7375),
Н.В. Фещенко[1] (https://orcid.org/0000-0002-4331-8196),
Н.Г. Романенко[1] (https://orcid.org/0000-0003-2161-5736),
І.К. Якименко[2] (https://orcid.org/0000-0001-9469-8240)

[1] Черкаський державний технологічний університет,
бульвар Шевченка, 460, Черкаси, 18006, Україна,
+380 472 51 3672, chdtu@chdtu.edu.ua
[2] ВСП ТОВ «UKRAVIT SCIENCE PARK» «Інститут здоров'я рослин»,
проїзд Енергобудівельників, 10, Черкаси, 18000, Україна,
+380 63 478 8300, institut-roslyn@ukravit.ua

ОЦІНКА ФІТОТОКСИЧНОСТІ ВІДПРАЦЬОВАНОГО ЦЕОЛІТУ ЯК СОРБЕНТУ СТІЧНОЇ ВОДИ ФАРБУВАЛЬНО-ОПОРЯДЖУВАЛЬНОГО ВИРОБНИЦТВА МЕТОДОМ ФІТОІНДИКАЦІЇ

Вступ. Актуальним питанням є оптимізація технологічних процесів фарбування текстильних матеріалів шляхом адсорбційного очищення стічних вод природним цеолітом для подальшого використання очищеної води як оборотної для повторного використання при фарбуванні тканин.

Проблематика. Відпрацьований сорбент цеоліт належить до побічних твердих відходів процесу очищення стічної води фарбувально-опоряджувального виробництва. Проте існує можливість повторного його використання як вторинного матеріального ресурсу після визначення рівня токсичності.

Мета. Оцінювання фітотоксичності відпрацьованого цеоліту, використаного як природного адсорбента для очищення стічних вод фарбувально-опоряджувального виробництва від текстильних барвників та допоміжних речовин, методами фітоіндикації для визначення можливих напрямків його використання без додаткових витрат на його утилізацію.

Матеріали і методи. Використано стічну воду фарбувально-опоряджувального виробництва, відпрацьований цеоліт, фітотест-об'єкт — насіння озимого ячменю; метод узагальнення наукової інформації; хімічний аналіз стічної води виконано методом оптичної емісійної спектрометрії з індуктивнозв'язаною плазмою; інтенсивність росту стебел озимого ячменю досліджено методом лабораторного фітотестування; фітотоксичність обраховано аналітичним виразом.

Результати. Фітотоксичність відпрацьованого цеоліту на водних, ґрунтових та концентрованих субстратах не перевищує 20%, що вказує на відсутність чи слабкий рівень його шкідливості та можливість повторного використання. Значення фітотоксичності відпрацьованого цеоліту має негативний показник (–6,67%), що свідчить про відсутність токсичності досліджуваного водного субстрату.

Висновки. Отримана оцінка токсичності використаного сорбенту можливість його вторинного використання в галузі дорожнього будівництва та у виробництві будівельних матеріалів. Це може вирішити проблему його утилізації, що значно зменшить екологічне навантаження на довкілля та знизить економічні витрати.

Ключові слова: фарбувально-опоряджувальне виробництво, стічна вода, адсорбція, цеоліт, фітотоксичність, фітотестування, ячмінь.