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SAREPTA MUSTARD (*BRASSICA JUNCEA* (L.): EFFECTIVENESS OF PHYTOREMEDIATION AT THE FLOWERING STAGE

Abstract

The scientific paper investigates the effectiveness of phytoremediation of soil by Sarepta mustard (Brassica Juncea (L.)) at the flowering stage with an emphasis on heavy metals, in particular Barium, Zirconium and Zinc. Soil contamination with heavy metals in Ukraine has become an extremely urgent problem due to the hostilities taking place in the country. This pollution can have a significant impact on the yield and quality of agricultural crops, as well as pose a threat to the health of the population that consumes such products.

Sarepta mustard is used not only for food purposes but can also serve to restore soils contaminated with heavy metals. The study was conducted on a site near a busy road, where the soil potentially contains a higher content of heavy metals. For analysis, samples were taken from a meter layer of soil in increments of 10 cm before sowing and at the time of flowering of Sarepta mustard. Soil analysis at this stage is because in the case of a positive result, that is, a significant absorption of heavy metals, it will be possible to perform phytoremediation several times during the spring-summer season.

As a result of the study, it was found that Sarepta mustard can effectively absorb Barium from the soil, especially in layers of 20–30 cm, 40–50 cm, 50–60 cm and 60–70 cm. At the same time, the decrease in the concentration of Barium in the remaining layers was not statistically significant. For Zirconium, its content in the layers of 0-10 cm and 20–30 cm decreased slightly, although these changes were statistically significant, this does not allow to consider Sarepta mustard as an effective accumulator of this element in the flowering phase. Zinc absorption analysis showed that Sarepta mustard absorbs a small amount of this element in the flowering phase.

As a result, the study confirms the possibility of using Sarepta mustard for phytoremediation of Barium from the soil to the flowering phase, while for Zirconium and Zinc the absorption efficiency requires further research. Such studies are important for developing methods for monitoring and cleaning soils in regions affected by heavy metal pollution because of hostilities.

Key words: *mustard, phytoremediation, heavy metals, soil, XRF, soil restoration.*

Introduction. An essential component in producing agricultural commodities is soil [5]. One of the important aspects of soil management is the care of ecological and biological purity, and the presence of a minimum number of harmful substances that can be contained in it and get into agricultural products. Due to the active hostilities taking

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place in the north, east and south of Ukraine, soil pollution with heavy metals is currently an extremely urgent issue. Wars typically result in pollution from burning fuels and oils, combustion products, heavy metals from exploded weapons, and other substances [14]. In the post-war period, this can not only affect the yield and quality of crops, but also pose a threat to the health of the population consuming products grown in the contaminated area. Therefore, it is extremely important to implement measures for monitoring and cleaning of soils in the regions affected by hostilities.

In particular circumstances, mustard is a multipurpose crop in agriculture. It is grown not only for food purposes, but also used as a siderate culture for enriching the soil environment with organic substances, it is a good predecessor for grain crops, such as winter wheat, and it also has another special value – restoration of soils contaminated with heavy metals. This was confirmed by numerous studies of scientists from around the world. For instance, Du et al. (2020) established that Sarepta mustard is an extremely good accumulator of Cadmium and Zinc [6], Gurajala et al. (2019) confirmed the ability to effectively absorb Lead [8]. Moreover, certain genotypes of mustard are capable of absorbing Mercury [1].

Still in Ukraine, there are no effective mechanisms for assessing soil contamination with heavy metals and methods for their remediation. Studies in areas that have experienced direct military influence are not yet possible. Therefore, in this experiment, soil contaminated with heavy metals is modeled. In order to do this, a field segment that is close to a busy road and may have higher levels of heavy metals was selected. As the depth of their soil penetration is unknown, the study examined a meter layer of soil with a pitch of every 10 cm.

Research aim. The purpose of this work was to study the influence of Sarepta mustard on the extraction of heavy metals from every ten-centimeter layer of soil in the flowering phase and compare the results obtained with those that were obtained before sowing the culture.

The presentation of the main material of the research. Soil samples were taken on the field of the Training and Research and Production Plant of Sumy National Agrarian University. The test points are shown in Fig. 1. These sites were chosen to compare the content of heavy metals at points located near the road and at a distance of 500 m from it. The Sarepta mustard of the variety of Prima was grown according to the technology generally accepted for the Forest-Steppe zone. It is also worth to mention that the Prima variety is adapted to the growing conditions and is recommended for the Forest-Steppe zone of Ukraine.

Fig. 1. Soil sampling points, where sampling control points are indicated in red and sampling points before mustard sowing are indicated in yellow

The soil of the studied area is Chernozem. Soil fertility indicators are as follows: organic carbon content 1,65%, $pH_{(H2O)}$ – 6,3, amount of easily hydrolyzed nitrogen 19,8 mg/kg of soil, amount of mobile phosphorus 122,0 mg/kg of soil, the amount of exchangeable potassium – 133,1 mg/kg of soil.

The content of heavy metals was determined layer by layer to a depth of 1 m with a step of 10 cm during the flowering phase of mustard. After sampling, the soil was dried, ground according to generally accepted methods and analyzed using the X-ray fluorescence method with the device Thermo Scientific Niton XL2. Although the device used for analysis can detect 27 chemical elements in total, the article only mentions 3. These are Zinc, Barium, and Zirconium. This is because specific variations in the amount of these components were noted throughout the screening process of soil samples.

Statistical analysis of the obtained data was carried out in MS Excel and Statistica 10.0, ANOVA and Duncan's test was applied to establish a significant difference between the data.

Comparing the data on heavy metals of the control area and the place of soil extraction located near the road, a slightly higher number of heavy metals is clearly visible, especially in the layer of 0–30 cm.

According to the Decree of the Cabinet of Ministers of Ukraine, the maximum permissible concentration (MPC) of Barium in gross form should not exceed the norm of 200 mg/kg. However, Madejón (2013) states that on average its amount in the earth's crust ranges from 425–668m mg/kg of soil. This heavy metal is not used by plants in vital processes [9]. However, according to the data obtained, Sarepta mustard actively absorbed it during its vegetation in different soil layers (Table 1). Thus, in the soil layers of 0–10 and 10–20, 30–40 and 80–90 cm, the amount of Barium decreased, but did not have a statistically significant difference. However, in layers 20–30, 40–50 to 50–60, 60–70 cm there is a statistically significant difference in data compared to those values obtained before sowing the culture. At the same time, in layers 70–80 and 90–100 cm, the Barium content increased, but did not have a statistically significant difference.

It's worth mentioning that similar studies have already been conducted. For instance, Coscione & Berton (2009) investigated the absorption of Barium by Sarepta mustard and two other crops in a pot-experiment but could not come to a conclusion about the effectiveness of using mustard as an accumulator plant of this element [4]. However, in Bouslimi et al. (2021) it was confirmed that Sarepta mustard still has a high potential for absorption of Barium [2].

Table 1. Barium content in soil layers before and during vegetation of Sarepta mustard, mg/kg of soil

	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
Control	275±45	215±84	331±105	282±73	201±69	244±117	147±61	135±20	110±122	164±25
Before vegetation	279±139a	250±83a	263±103a	167±72a	230±53a	176±122a	235±128a	217±169a	207±87a	191±152a
Flowering period	183±72a	219±72a	90±45b	56±62a	45±71b	<LOD*b	87±96b	282±83a	133±150a	315±88a
p < 0,05 Duncan's criterion – 107,7										

*Note: according to the device manufacturer Thermo Scientific Niton XL2 < LOD for element Barium is 90 mg/kg of soil. In the table, the index "a" means that within each layer of the soil the content of the element does not have a significant difference compared to the data before vegetation, the index "b" means a significantly lower value.

Unlike Barium, the gross MPC for Zirconium is not regulated by the Decree. However, according to Shahid et al. (2013) its amount can vary between 32–850 mg/kg of soil and does not play an important role in plant life, however, it can still cause phytotoxicity [11].

As a result of this study, it was found that the amount of Zirconium decreased slightly in the layers of 0–10 and 20–30 cm (Table 2). However, even though these changes are statistically significant, it is difficult to say about the possibility of using Sarepta mustard as a Zirconium accumulator plant at the flowering phase. It is also worth mentioning that in the literary sources there was no information about plants that can effectively absorb this metal.

Table 2. Zirconium content in soil layers before and during vegetation of Sarepta mustard, mg/kg of soil

	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
Control	547±40	547±26	548±42	564±9	501±38	539±4	510±46	521±28	520±31	475±23
Before vegetation	565±32a	545±13a	559±21a	540±26a	559±54a	528±10a	531±24a	499±30a	507±24a	513±47a
Flowering period	519±23b	560±12a	525±12b	529±8a	539±12a	511±33a	501±8a	560±8c	538±15a	562±6c
p < 0,05 Duncan's criterion – 28,02										

*Note: In the table, the index “a” means that within each thickness of the soil, the content of the element does not have a significant difference compared to the data before vegetation, the index “b” means a significantly lower value, the index “c” means a significantly higher value.

Zinc is an element that is indispensable during the synthesis of proteins in plants [3]. Its amount in different soils can range from 10 to 300 mg/kg, although on average it ranges from 50-55 mg/kg [10]. It should be noted that its gross content is also not regulated by the Decree of the Cabinet of Ministers. Within the framework of this study, it was found that at the time of flowering, Sarepta mustard absorbs a small amount of zinc in the soil layers of at least 0–50 cm, however, the indicators obtained are not significantly lower (Table 3). At the same time, Ebbs & Kochian (1998) and Sridhar et al. (2005) found that Sareptan mustard absorbs Zinc quite well [7; 13]. Soleimannejad et al. (2020) emphasize that white mustard also has similar properties to zinc accumulation [12].

Table 3. Zinc content in soil layers before and during vegetation of Sarepta mustard, mg/kg of soil

	0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100
Control	35±6	36±4	34±5	33±3	34±5	32±4	26±2	30±7	28±2	31±2
Before vegetation	40±5a	40±6a	41±5a	37±5a	34±5a	34±5a	32±8a	31±4a	32±4a	29±7a
Flowering period	35±9a	38±3a	35±0,6a	31±5a	32±2a	30±5a	31±3a	34±7a	31±2a	29±3a
p < 0,05 Duncan's criterion – 5,77										

*Note: In the table, the index “a” means that within each layer of the soil, the content of the element does not have a significant difference compared to the data before vegetation.

Conclusions. During the study, it was found that Sarepta mustard in the flowering phase can effectively absorb barium from the soil, especially in layers of 20–30, 40–50, 50–60, 60–70 cm, which confirms its effectiveness in removing this element, while the decrease in the concentration of barium in other layers was not statistically significant. As for Zirconium, its content in the 0–10 and 20–30 cm layers decreased slightly, but the changes were insignificant, which does not allow to consider Sarepta mustard as an effective battery of this element in the flowering phase. Analysis of zinc absorption showed that Sarepta mustard absorbs a small amount of this element, confirming its potential for Zinc accumulation. Further studies on the accumulation of heavy metals by Sarepta mustard in the phase of complete ripeness are necessary for a more complete understanding of the picture.

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ГІРЧИЦЯ САРЕПТСЬКА (*BRASSICA JUNCEA* (L.): ЕФЕКТИВНІСТЬ ФІТОРЕМЕДІАЦІЇ НА ЕТАПІ ЦВІТІННЯ

Анотація

У статті досліджується ефективність фіторемедіації ґрунту гірчицею сарептською Brassica Juncea (L.) на етапі цвітіння з акцентом на важкі метали, зокрема Барій, Цирконій та Цинк. Забруднення ґрунту важкими металами в Україні стало надзвичайно актуальною проблемою через бойові дії, що відбуваються на території країни. Це забруднення може мати значний вплив на врожайність та якість сільськогосподарської продукції, а також становити загрозу для здоров'я населення, яке споживає таку продукцію.

Гірчиця сарептська використовується не лише для продовольчих цілей, але також може слугувати для відновлення ґрунтів, забруднених важкими металами. Дослідження проводилося на ділянці поблизу жвавої дороги, де ґрунт потенційно містить вищий вмісту важких металів. Для аналізу було взято зразки із метрового шару ґрунту з кроком у 10 см до сівби гірчиці сарептської та на час її цвітіння. Аналіз ґрунту саме на цьому етапі обумовлений тим, що у випадку позитивного результату, тобто значного поглинання важких металів, можна буде виконувати фіторемедіацію кілька разів протягом весняно-літнього сезону.

В результаті дослідження встановлено, що гірчиця сарептська здатна ефективно поглинати Барій з ґрунту, особливо в шарах 20–30 см, 40–50 см, 50–60 см та 60–70 см. Водночас зниження концентрації Барію в інших шарах не було статистично істотним. Щодо Цирконію, його вміст у шарах 0–10 см та 20–30 см дещо зменшився, хоча ці зміни були статистично істотними, це не дозволяє розглядати гірчицю сарептську як ефективного акумулятора цього елементу у фазу цвітіння. Аналіз на поглинання Цинку показав, що гірчиця сарептська поглинає незначну кількість цього елементу у фазу цвітіння.

У підсумку, результати дослідження підтверджують можливість використання гірчиці сарептської для фіторемедіації Барію з ґрунту до фази цвітіння, тоді як для Цирконію та Цинку ефективність поглинання потребує подальших досліджень. Такі дослідження є важливими для розробки методів моніторингу та очищення ґрунтів у регіонах, що постраждали від забруднення важкими металами внаслідок воєнних дій.

Ключові слова: *гірчиця, фіторемедіація, важкі метали, ґрунт, XRF, відновлення ґрунту.*

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