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# THE EFFECT OF HEAVY METAL IONS ON THE AMOUNT OF PROLINE IN THE ROOTS OF CORN VARIETIES

*A.Digarbayeva[1], Zh.Rakhimberdiyeva[2], R.Zhumakhanova[2], A.Syzdykova[3]

1. Kazakh national women's teacher training university, Almaty, Kazakhstan
2. M. Auezov south Kazakhstan university, Shymkent, Kazakhstan
3. Abai Kazakh national pedagogical university, Almaty, Kazakhstan

(*Corresponding author: asema1985d@mail.ru )

Understanding plant responses to adverse environmental conditions remains a key challenge in modern plant physiology, particularly in the context of increasing heavy metal contamination. The development of resistant crop varieties requires detailed investigation of biochemical adaptation mechanisms under stress. This study examines the effect of heavy metal exposure on maize plants through structural and metabolic changes, with a focus on proline accumulation as a stress-associated indicator. Comparative analysis of proline content in maize varieties differing in resistance demonstrates the functional role of this amino acid in protecting root tissues and maintaining physiological stability under toxic ion influence. The findings contribute to a deeper understanding of plant adaptive strategies and highlight the practical importance of biochemical markers for evaluating tolerance in breeding research.

***Keywords:*** stress, heavy metal, plant, proline, $CuSO_4$, $CdSO_4$.

*Introduction*

Abiotic factors remain among the most significant limiting influences in modern agriculture, shaping both the productivity and stability of crop systems. Environmental stressors such as drought, salinity, temperature fluctuations, light imbalance, nutrient deficiency and the presence of heavy metals disrupt physiological processes in plants and ultimately reduce yield potential. Under these conditions, the development and identification of stress-resistant varieties acquire not only agronomic but also economic importance. Although drought and salinity are traditionally considered the dominant abiotic stresses affecting agricultural crops [2–3], increasing anthropogenic pressure has intensified the role of heavy metals as an additional destabilising factor in agroecosystems.

Plant stress is understood as a complex physiological response to unfavourable environmental influences, typically accompanied by a slowdown in metabolic activity and redistribution of energy resources aimed at maintaining survival. Anti-stress regulation involves activation of biochemical pathways and protective metabolites that support cellular stability, enhance nutrient uptake and promote recovery of growth processes [1]. Consequently, the search for resistant genotypes and the evaluation of their adaptive potential under different environmental conditions remain a central focus of plant physiology and breeding research [4]. At the biochemical level, one of the most frequently discussed indicators of stress response is the accumulation of free proline. Numerous studies suggest that lower tolerance to adverse factors is often associated with increased proline concentration in plant tissues; however, this relationship is not always linear and may depend on experimental design, stress intensity or interactions with other protective compounds. Comparative analyses of proline accumulation across plant organs and varieties with different resistance levels therefore remain essential for clarifying its functional role in stress adaptation.

The relevance of such research is particularly evident in the context of Kazakhstan, where agriculture occupies a strategically important position in the national economy. In 2022, the total cultivated area reached 22.9 million hectares, including 15.8 million hectares of grain and leguminous crops, 2.9 million hectares of oilseeds and 3.7 million hectares of fodder crops. At the same time, agricultural intensification has been accompanied by a growing use of agrochemicals. According to official data, 1,021 pesticide brands were registered for use in Kazakhstan, including 386 containing active substances classified as particularly hazardous by the International Pesticide Action Network [2,3]. During the same period, 626.5 thousand tons of mineral fertilizers and 16.6 million liters of pesticides were applied to agricultural lands. While such measures contribute to crop productivity, they may also disturb ecological balance, promote soil and groundwater contamination and increase environmental risks [2,6,7]. These factors highlight the importance of investigating plant responses to chemical stressors and identifying reliable biochemical markers of tolerance.

Different theoretical approaches distinguish between limiting stress, associated with resource deficiency, and destructive stress, which involves redistribution of internal resources to prevent structural damage [8]. Insufficient water supply, for example, can lead to the development of xeromorphic traits similar to those observed during drought conditions [10]. Among the biochemical indicators used to assess plant stress responses, proline occupies a prominent position due to its multifunctional role in osmotic adjustment and protection against oxidative damage [9]. This heterocyclic amino acid accumulates in plant tissues under adverse conditions and contributes to the stabilisation of proteins, DNA and cellular membranes [11]. One of its key biochemical properties is the ability to neutralise reactive oxygen species, including singlet oxygen and hydroxyl radicals, thereby maintaining cellular redox balance. The significant increase in proline levels observed in various plant species under stress has attracted considerable attention from researchers, including studies conducted at V.N. Karazin Kharkiv National University, which demonstrated the potential of proline as a biochemical marker of adaptive responses. Observations of halophytic plants, capable of accumulating high concentrations of proline, further emphasise the importance of investigating its antioxidant function and role in maintaining cellular homeostasis under conditions of increased ROS formation.

Previous investigations devoted to maize resistance to heavy metals have already addressed several physiological aspects, including growth dynamics and pigment system responses. In particular, the results of experimental studies were published in the journals of the National Academy of Sciences of the Republic of Kazakhstan (“Effect of heavy metals on the growth of corn varieties”, Reports of NAS RK, 2021, No. 2, pp. 39–45) and in the Biology Bulletin of Al-Farabi Kazakh National University (“Study of the heavy metals effect on the corn varieties pigment system”, Biology Bulletin, No. 2 (87), 2021). These works demonstrated the sensitivity of maize physiological parameters to metal exposure; however, the biochemical dimension of stress adaptation specifically the role of proline accumulation in root tissues remains insufficiently characterised. In this context, the comparative analysis of proline content at early stages of plant development represents an important step toward clarifying varietal differences in tolerance mechanisms and identifying reliable biochemical indicators of heavy metal resistance.

The purpose of the present study was therefore to compare the resistance of selected maize varieties to heavy metal stress factors based on the content of the heterocyclic amino acid proline (pyrrolidine-α-carboxylic acid) in the roots of maize seedlings.

*Experimental*

Research method: determination of free proline content was carried out according to the classical spectrophotometric method of Bates (1973), which is widely used in plant physiology for assessing biochemical responses of plants to abiotic stress. The choice of this method was обусловлен its sensitivity to changes in amino acid metabolism under heavy metal exposure and its suitability for comparative evaluation of stress tolerance among plant varieties.

As experimental material, four maize varieties were selected: Independence-20, Kazakhstan-435, Turan-170 and Turan-480. The selection of several genotypes allowed a comparative analysis of physiological responses under identical experimental conditions and made it possible to assess varietal differences in adaptation mechanisms. The study examined the influence of heavy metal ions on the accumulation of free proline in the root tissues of maize seedlings at an early developmental stage. Seedlings aged 10 days were used, since young root systems demonstrate the most pronounced metabolic sensitivity to toxic ions and reflect early stress-induced changes in osmotic regulation.

Root tissues were chosen as the main object of analysis because underground organs represent the primary zone of heavy metal uptake and the initial site of biochemical response formation. For proline determination, equal fresh weight samples (100–200 mg) were taken from each experimental variant in order to maintain analytical comparability. Plant material was placed into clean test tubes, followed by the addition of 10 ml of distilled water, and heated in a boiling water bath for 10 minutes to extract soluble compounds. The obtained extract was filtered to remove tissue residues and ensure optical clarity of the reaction mixture.

From each filtrate, 2 ml were transferred into new test tubes; then 2 ml of acetic acid and 2 ml of ninhydrin reagent were added. The mixtures were heated in a water bath for 20 minutes, allowing the formation of a chromophore complex characteristic of free proline. After rapid cooling to room temperature, optical density was measured using a spectrophotometer at a wavelength of 520 nm, which corresponds to the absorption maximum of the coloured reaction product. Uniform sample mass, reagent volumes and incubation режим were strictly maintained for all variants, ensuring comparability of biochemical indicators between maize varieties exposed to heavy metal stress. During the experimental cultivation, the growth conditions of maize seedlings and their development under exposure to heavy metal ions were visually monitored in order to ensure uniformity of environmental parameters and to document the phenotypic state of the plants throughout the experimental period. The general scheme of cultivation conditions and treatment variants is presented in Figure 1.

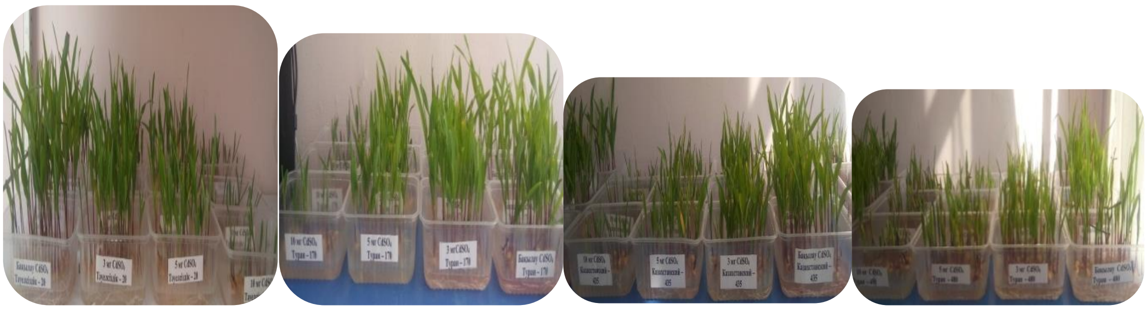

**Figure1.** Conditions for growing varieties of corn under the influence of heavy metals

In addition to biochemical assessment, morphophysiological observations were conducted to characterise the vegetative development of maize seedlings under stress conditions. Changes in the growth of above-ground and underground organs were recorded as supporting bioparametric indicators, allowing a more comprehensive interpretation of stress responses. The main vegetative growth parameters of 14-day-old seedlings are illustrated in Figure 2.

**Figure 2.** Influence of heavy metals on the growth of vegetative organs of corn varieties (bioparametric indicators of 14-day seedlings)

*Results and Discussion*

The adaptive responses of maize plants to heavy metal exposure are closely associated with metabolic shifts aimed at maintaining cellular homeostasis. Among the biochemical components involved in stress tolerance, free proline occupies a central position due to its multifunctional protective role. Numerous studies indicate that the accumulation of this heterocyclic amino acid reflects the intensity of stress perception and the ability of plant tissues to reorganise osmotic balance under unfavourable environmental conditions. In vegetative organs, increased proline levels are often interpreted not simply as a symptom of damage, but as an active component of protective regulation that contributes to cellular stability.

Under conditions of heavy metal exposure, disturbances in ionic equilibrium and water relations initiate a cascade of anti-stress reactions. One of the earliest responses involves the synthesis and redistribution of compatible osmolytes, which help to preserve membrane integrity and enzymatic activity. Proline participates in this process by stabilising macromolecular structures, supporting redox balance, and maintaining osmotic potential within the cytoplasm. As noted by a number of authors [9,10,21], variations in proline accumulation among genotypes may serve as an indirect indicator of their physiological resistance, especially when comparing varieties grown under identical experimental conditions.

The osmoprotective role of proline becomes particularly evident under exposure to copper and cadmium ions. These metals disrupt water uptake and induce oxidative stress, which leads to a decline in cellular turgor and metabolic imbalance. The presence of proline partially compensates for these effects by lowering osmotic potential and limiting the damaging action of toxic ions. Earlier hypotheses proposed by N.I. Shevyakova [14] emphasised the function of proline as an osmoregulator; however, subsequent research has demonstrated that its role extends beyond osmotic adjustment. In addition to maintaining cytoplasmic stability, proline contributes to the protection of enzymes and intracellular structures, participates in free-radical scavenging, and provides an additional source of carbon and nitrogen during post-stress recovery [15,16,25]. Therefore, differences in proline concentration among maize varieties may reflect not only the degree of stress exposure but also the efficiency of their adaptive mechanisms.

During the present experiment, the content of free proline in the underground organs of maize seedlings was determined using the acid ninhydrin reaction. The obtained values allowed a comparative evaluation of varietal responses under cadmium stress conditions, the results of which are presented below.

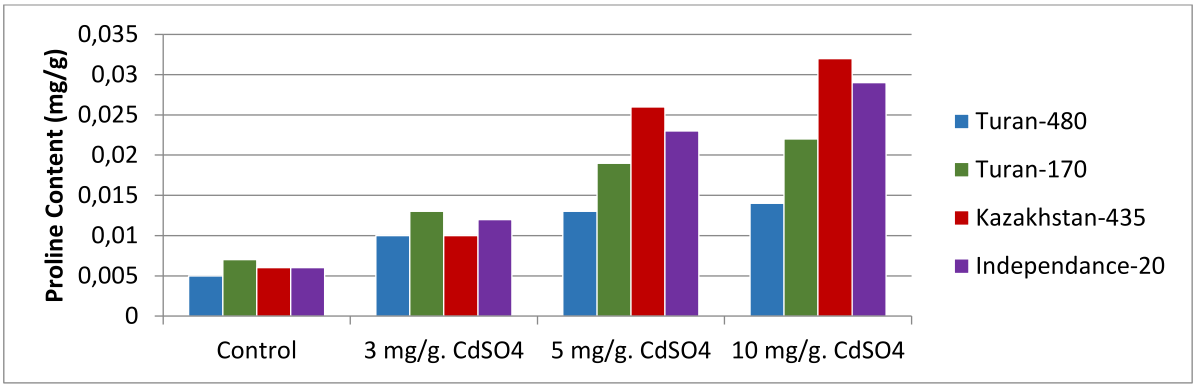


**Figure 3.** The amount of free proline in the corn varieties roots are grown at different concentrations of cadmium sulfate, %

The comparative analysis of proline accumulation under cadmium exposure revealed distinct varietal differences in biochemical response patterns. The obtained data demonstrate that changes in proline content were not uniform across maize genotypes, which indicates variability in adaptive strategies under heavy metal stress. Rather than reflecting a simple linear reaction to toxic exposure, proline dynamics appear to be associated with the intrinsic physiological characteristics of each variety.

In the variants treated with cadmium sulfate at concentrations of 10 mg/g, 5 mg/g and 3 mg/g, the Independence-20 variety showed a decrease in proline content by approximately 20–35 % relative to the control, suggesting a more restrained metabolic response at the early stages of stress perception. A similar tendency was observed in the Kazakhstan-435 variety, where proline accumulation declined by about 41 %, which may indicate either a lower activation threshold of osmoprotective mechanisms or the involvement of alternative protective pathways. In contrast, the Turan-170 variety demonstrated an increase in proline levels by approximately 21 %, reflecting a more pronounced activation of osmotic adjustment processes. Such a pattern suggests that this genotype may rely more strongly on biochemical regulation of cellular water balance as part of its adaptive response.

The Turan-480 variety exhibited comparatively lower proline accumulation, with values decreasing by around 9 % relative to the control. This tendency may indicate a reduced capacity to activate proline-mediated protective mechanisms under cadmium stress. Importantly, the observed differences should be interpreted not only as quantitative fluctuations but also as indicators of distinct physiological strategies among maize varieties. While higher proline levels are frequently associated with increased tolerance, the absence of accumulation does not necessarily imply complete sensitivity; rather, it may reflect alternative regulatory pathways that were not assessed within the scope of the present biochemical analysis.

Taken together, the comparative evaluation of cadmium-treated variants suggests that Independence-20, Kazakhstan-435 and Turan-170 exhibit more stable biochemical responses under heavy metal exposure, whereas Turan-480 demonstrates comparatively lower adaptive activation within the parameters measured in this study. These observations provide a basis for further investigation into genotype-specific mechanisms of heavy metal tolerance..

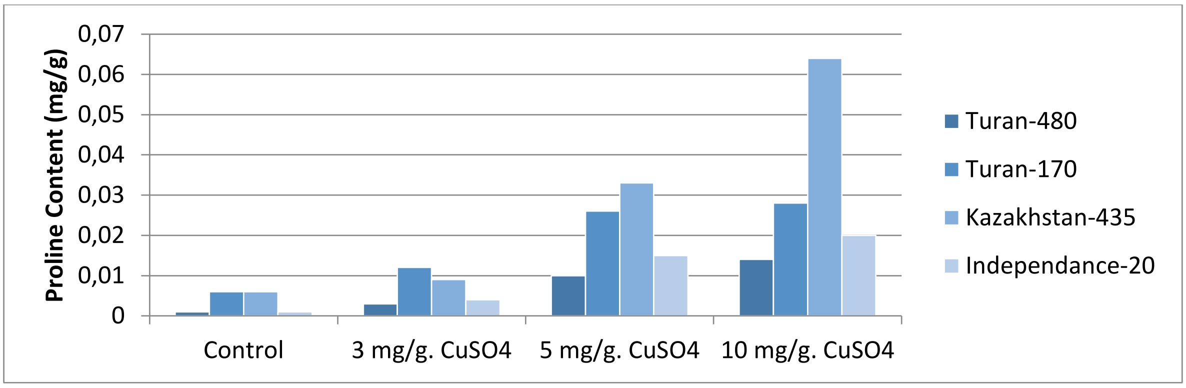


**Figure 4.** The amount of free proline in the roots of corn varieties grown in different concentrations of copper sulfate, %

The analysis of proline accumulation under copper sulfate exposure revealed trends that were generally consistent with the patterns observed under cadmium stress, yet demonstrated several varietal distinctions. Copper ions, similar to cadmium, induced metabolic adjustments associated with osmotic regulation and protection against oxidative damage; however, the intensity of proline synthesis differed depending on genotype-specific responses.

In the presence of copper sulfate, the varieties Independence-20, Kazakhstan-435, and Turan-170 maintained relatively higher levels of free proline compared with the control variants. This tendency suggests that these genotypes are capable of activating biochemical defence mechanisms aimed at stabilising intracellular structures and preserving water balance under toxic ion exposure. The observed increase in proline concentration may reflect a compensatory reaction that mitigates the disruptive effects of copper ions on membrane permeability and enzyme activity.

In contrast, the Turan-480 variety demonstrated a comparatively weaker accumulation of proline under identical experimental conditions. Such a response may indicate a lower intensity of osmotic adjustment processes or a delayed activation of protective metabolism. It should be noted, however, that differences in proline levels should not be interpreted as the sole indicator of stress tolerance; rather, they reflect one aspect of a complex adaptive system that includes multiple physiological pathways.

Overall, the comparative evaluation of maize varieties under copper-induced stress supports the assumption that increased proline accumulation is associated with enhanced capacity for biochemical regulation during exposure to heavy metals. The consistency of this pattern across both cadmium and copper treatments suggests that proline may serve as a stable biochemical marker of adaptive responses in the studied genotypes.

The obtained results confirm that proline accumulation remains one of the most sensitive biochemical indicators reflecting the response of plants to abiotic stress factors. In maize seedlings exposed to heavy metal ions, variations in free proline content appear to be associated with the capacity of plant tissues to maintain metabolic stability under unfavourable conditions. Elevated levels of this amino acid are commonly interpreted as a manifestation of protective regulation, since proline contributes to the stabilisation of membrane structures, preservation of enzymatic activity and reduction of oxidative damage caused by toxic ions [17,19,22].

The protective role of proline is not limited to osmotic adjustment alone. Its accumulation is often linked with the maintenance of protein synthesis processes and the activation of stressresponsive metabolic pathways. Under heavy metal exposure, the synthesis of compatible osmolytes such as proline may reduce the negative impact of metal-induced dehydration and help sustain cellular homeostasis. From this perspective, the higher proline levels observed in certain maize varieties can be considered an indicator of enhanced biochemical flexibility and adaptive potential.

At the same time, the interpretation of proline accumulation in stress physiology remains complex and sometimes controversial. While many studies associate increased proline levels with higher tolerance, other authors suggest that excessive accumulation may also reflect heightened stress sensitivity rather than resistance [18,26]. Therefore, the patterns observed in the present study should be regarded as part of a broader adaptive framework rather than as an isolated determinant of tolerance. The variability detected among maize varieties highlights the importance of considering genotype-specific responses when evaluating biochemical markers under heavy metal exposure.

Taken together, the analysis of proline dynamics under cadmium and copper treatments suggests that biochemical responses in maize seedlings are closely linked to varietal characteristics and to the intensity of environmental stress. The data obtained in this study support the view that proline accumulation represents an important component of plant adaptive regulation, while also emphasising the need for further integrative investigations combining biochemical and morphophysiological parame

*Conclusion*

In conclusion, environmental heavy metals impact the early stages of plant growth and development, inhibiting seed germination, seedling formation, and biomass accumulation in certain plants. In some cases, low concentrations of $CuSO_4$ and $CdSO_4$ have been found to positively affect seed germination, the growth of above-ground organs, biomass production, and the development of some corn varieties. It was observed that cadmium and copper ions together hinder the formation of photosynthetic pigments in the leaves and either increase or decrease proline synthesis in the above-ground organs and stems of corn seedlings, depending on the specific characteristics of the variety. These indicators reflect the varietal specificity of corn and highlight the need to further study the resistance of different varieties to heavy metals in relation to other mechanisms of resistance.

It has been observed that a high concentration of proline in the root tissue of corn plants is an indicator of tolerance, while a low proline level indicates intolerance. The greater the amount of proline, the better the plant's ability to adapt to adverse environmental conditions.

**Список литературы**

1 Вонг М.Х. Загрязнение окружающей среды: риски для здоровья и экологическое восстановление / М.Х. Вонг. – Великобритания : Taylor & Francis Group, 2012. – 345 с.

2 Мосина Л.В., Довлетярова Э.А., Ефремова С.Ю., Норвосурен Ж. Экологическая опасность загрязнения почвы тяжелыми металлами (на примере свинца) // Известия Пензенского государственного педагогического университета им. В.Г. Белинского. Сер. Естественные науки. – 2012. – № 29. – С. 383–386.

3 The results of the development of the agricultural sector in 2021 and the plans for the coming period [Electronic resource]. – Access mode: https://primeminister.kz/ru/news/reviews/itogi-razvitiya-sfery-selskogo-hozyaystva-za-2021-god-i-plany-na-predstoyashchiy-period-22422 (дата обращения: 21.05.2025).

4 Maksimov I.V., Veselova S.V., Nuzhnaya T.V., Sarvarova E.R., Khairullin R.M. Plant growth-stimulating bacteria in the regulation of plant resistance to stress factors // Plant Physiology. – 2015. – Vol. 62, No. 6. – P. 763–775.

5 List of pesticides (poison chemicals), authorized for use on the territory of the Republic of Kazakhstan 2022–2031 : approved. – 31 May 2025. – Order No. 87.

6 Mustafina V.V., Dushkina Yu.N., Argynbayeva E.M., Gor N.V. Especially dangerous pesticides in Kazakhstan: the current situation and recommendations for minimizing negative effects // Chemical Safety. – 2020. – № 4(1). – P. 236–247. – DOI: https://doi.org/10.25514/CHS.2020.1.17017.

7 Гринин А.Л. Устойчивость растений горчицы к засолению и возможная роль пролина : автореф. дис. … канд. биол. наук. – М., 2010. – 3 с.

8 Колупаев Ю.Е., Вайнер А.А. Механизмы стресс-протекторного влияния брассиностероидов на растения // Агрохимия. – 2014. – № 7. – С. 69–84.

9 Саубенова М.Г., Олейникова Е.А., Ермекбай Ж.Н., Абдиева Г.Ж., Елубаева М.Е. Роль эндофитных микроорганизмов в повышении устойчивости растений в условиях солевого стресса // Микробиология және вирусология. – 2023. – № 1(40). – URL: https://imv-journal.kz

10 Kolupaev Y.E., Firsova E.N., Yastreb T.O., Kirichenko V.V., Ryabchun N.I. Effect of hydrogen sulfide donor on antioxidant state of wheat plants and their resistance to soil drought // Russian Journal of Plant Physiology. – 2019. – Vol. 66, No. 1. – P. 59–66.

11 Колупаев Ю.Е., Вайнер А.А., Ястреб Т.О. Пролин: физиологические функции и регуляция содержания в растениях в стрессовых условиях // Вісник ХНАУ. Сер. Біологія. – 2014. – № 2(32). – С. 6–22.

12 Симеониди Д.Д., Бигаева И.М., Агаева Ф.А., Данильянц А.А., Джерапова А.К. Влияние ионов тяжелых металлов (на примере меди и свинца) на состояние и рост растений // International Research Journal. – 2022. – № 12(126). – DOI: https://doi.org/10.23670/IRJ.2022.126.68

13 Абилова Г.А. Влияние ионов кадмия и свинца на рост и содержание пролина в растениях тритикале (Triticosecale Wittm.) // Труды Карельского научного центра РАН. – 2016. – № 11. – С. 27–32. – DOI: https://doi.org/10.17076/eb424

14 Shamsul Hayat, Qaiser Hayat, Mohammed Nasser Alyemeni, Arif Shafi Wani, John Pichtel, Aqil Ahmad. Role of proline under changing environments: A review // Plant Signaling & Behavior. – 2012. – Vol. 7, No. 11. – P. 1456–1466. – DOI: https://doi.org/10.4161/psb.21949

15 Айтлесов К.К., Аубакирова К.М., Аликулов З.А. Снижение ингибирования ферментов тяжелыми металлами in vitro с помощью пролина // Вестник КазНУ. Сер. Биология. – 2022. – № 4(93). – С. 74. – DOI: https://doi.org/10.26577/eb.2022.v93.i4.07

16 Hoang H.G. et al. Human health risk simulation and assessment of heavy metal contamination in a river affected by industrial activities // Environmental Pollution. – 2021. – Vol. 285.

17 Oziegbe O. et al. Assessment of heavy metal bioremediation potential of bacterial isolates from landfill soils // Saudi Journal of Biological Sciences. – 2021. – Vol. 28, No. 7. – P. 3948–3956.

18 Ding Q. et al. Effects of natural factors on the spatial distribution of heavy metals in soils surrounding mining regions // Science of the Total Environment. – 2017. – P. 605–606.

19 Sayyadian K. et al. Effect of biochar on cadmium, nickel and lead uptake and translocation in maize irrigated with heavy metal contaminated water // Applied Ecology and Environmental Research. – 2019. – Vol. 17, No. 1. – P. 969–982.

20 Duruibe J.O., Ogwuegbu M.O.C., Egwurugwu J.N. Heavy metal pollution and human biotoxic effects // International Journal of Physical Sciences. – 2007. – Vol. 2, No. 5. – P. 112–118.

21 Rah Z., Singh V.P. The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr) (VI), mercury (Hg), and lead (Pb)) on the total environment: An overview // Environmental Monitoring and Assessment. – 2019. – Vol. 191, No. 7.

22 Sodhi K.K. et al. Perspective on the heavy metal pollution and recent remediation strategies // Current Research in Microbial Sciences. – 2022. – Vol. 3, September. – P. 100166.

23 Rizvi A., Ahmed B., Zaidi A., Khan M.S. Heavy metal mediated phytotoxic impact on winter wheat: Oxidative stress and microbial management of toxicity by Bacillus subtilis // RSC Advances. – 2019. – Vol. 9. – P. 6125–6142.

24 Mohammad J.K., Muhammad T., Khalid K. Effect of organic and inorganic amendments on the heavy metal content of soil and wheat crop irrigated with wastewater // Sarhad Journal of Agriculture. – 2013. – Vol. 29. – P. 145–152.

25 Mammadova S.A., Ibragimova Z.Sh., Aliyev R.T. Assessment of the resistance of various wheat samples to aging, drought and salinization // International Journal of Applied and Fundamental Research. – 2018. – No. 12-1. – P. 84–87.

26 Sharma N. et al. Heavy metal pollution: Insights into chromium eco-toxicity and recent advancement in its remediation // Environmental Nanotechnology, Monitoring & Management. – 2021. – Vol. 15.

**References**

1 Vong, M. Kh. (2012). Zagryaznenie okruzhayushchey sredy: riski dlya zdorov'ya i ekologicheskoe vosstanovlenie [Pollution of the environment: Health risks and environmental restoration]. Velikobritaniya: Taylor & Francis Group.

2 Mosina, L. V., Dovletyarova, E. A., Efremova, S. Yu., & Norvosuren, Zh. (2012). Ekologicheskaya opasnost' zagryazneniya pochvy tyazhelymi metallami (na primere svintsa) [Environmental danger of soil contamination with heavy metals (on the example of lead)]. Izvestiya Penzenskogo gosudarstvennogo pedagogicheskogo universiteta im. V. G. Belinskogo. Seriya: Estestvennye nauki, (29), 383–386.

3 The results of the development of the agricultural sector in 2021 and the plans for the coming period. (2022). [Electronic resource]. Retrieved from https://primeminister.kz/ru/news/reviews/itogi-razvitiya-sfery-selskogo-hozyaystva-za-2021-god-i-plany-na-predstoyashchiy-period-22422

4 Maksimov, I. V., Veselova, S. V., Nuzhnaya, T. V., Sarvarova, E. R., & Khairullin, R. M. (2015). Plant growth-stimulating bacteria in the regulation of plant resistance to stress factors. Plant Physiology, 62(6), 763–775.

5 Ministry of Agriculture of Kazakhstan. (2022). List of pesticides (poison chemicals), authorized for use on the territory of the Republic of Kazakhstan 2022–2031: Approved May 31, 2025, Order No. 87.

6 Mustafina, V. V., Dushkina, Yu. N., Argynbayeva, E. M., & Gor, N. V. (2020). Especially dangerous pesticides in Kazakhstan: The current situation and recommendations for minimizing negative effects. Chemical Safety, 4(1), 236–247. https://doi.org/10.25514/CHS.2020.1.17017

7 Grinin, A. L. (2010). Ustoichivost' rasteniy gorchitsy k zasoleniyu i vozmozhnaya rol' prolina [Resistance of mustard plants to salinization and the possible role of proline] (Author's abstract of candidate dissertation). Moscow.

8 Kolupaev, Yu. E., & Vayner, A. A. (2014). Mekhanizmy stress-protektornogo vliyaniya brassinosteroidov na rasteniy [Mechanisms of stress-protective influence of brassinosteroids on plants]. Agrokhimiya, (7), 69–84.

9 Saubenova, M. G., Oleynikova, E. A., Ermekbay, Zh. N., Abdieva, G. Zh., & Elubaeva, M. E. (2023). Rol' endofitnykh mikroorganizmov v povyshenii ustoichivosti rasteniy v usloviyakh solevogo stressa [The role of endophytic microorganisms in increasing plant resistance under salt stress]. Mikrobiologiya zhane virusologiya, 1(40). Retrieved from https://imv-journal.kz

10 Kolupaev, Y. E., Firsova, E. N., Yastreb, T. O., Kirichenko, V. V., & Ryabchun, N. I. (2019). Effect of hydrogen sulfide donor on antioxidant state of wheat plants and their resistance to soil drought. Russian Journal of Plant Physiology, 66(1), 59–66.

11 Kolupaev, Yu. E., Vayner, A. A., & Yastreb, T. O. (2014). Prolin: fiziologicheskie funktsii i regulyatsiya soderzhaniya v rasteniyakh v stressovykh usloviyakh [Proline: physiological functions and regulation in stress conditions]. Visnyk KhNAU. Seriya: Biologiya, 2(32), 6–22.

12 Simeonidi, D. D., Bigaeva, I. M., Agaeva, F. A., Danilyants, A. A., & Dzherapova, A. K. (2022). Vliyanie ionov tyazhelykh metallov (na primere medi i svintsa) na sostoyanie i rost rasteniy [Effect of heavy metal ions on plant condition and growth]. International Research Journal, 12(126). https://doi.org/10.23670/IRJ.2022.126.68

13 Abilova, G. A. (2016). Vliyanie ionov kadmiya i svintsa na rost i soderzhanie prolina v rasteniyakh tritikale (Triticosecale Wittm.) [Influence of cadmium and lead ions on growth and proline content in triticale plants]. Trudy Karel'skogo nauchnogo tsentra RAN, (11), 27–32. https://doi.org/10.17076/eb424

14 Hayat, S., Hayat, Q., Alyemeni, M. N., Wani, A. S., Pichtel, J., & Ahmad, A. (2012). Role of proline under changing environments: A review. Plant Signaling & Behavior, 7(11), 1456–1466. https://doi.org/10.4161/psb.21949

15 Aytlesov, K. K., Aubakirova, K. M., & Alikulov, Z. A. (2022). Snizhenie ingibirovaniya fermentov tyazhelymi metallami in vitro s pomoshch'yu prolina [Reduction of enzyme inhibition by heavy metals in vitro using proline]. Vestnik KazNU. Seriya: Biologiya, 4(93), 74. https://doi.org/10.26577/eb.2022.v93.i4.07

16 Hoang, H. G., et al. (2021). Human health risk simulation and assessment of heavy metal contamination in a river affected by industrial activities. Environmental Pollution, 285.

17 Oziegbe, O., et al. (2021). Assessment of heavy metal bioremediation potential of bacterial isolates from landfill soils. Saudi Journal of Biological Sciences, 28(7), 3948–3956.

18 Ding, Q., et al. (2017). Effects of natural factors on the spatial distribution of heavy metals in soils surrounding mining regions. Science of the Total Environment, 605–606.

19 Sayyadian, K., et al. (2019). Effect of biochar on cadmium, nickel and lead uptake and translocation in maize irrigated with heavy metal contaminated water. Applied Ecology and Environmental Research, 17(1), 969–982.

20 Duruibe, J. O., Ogwuegbu, M. O. C., & Egwurugwu, J. N. (2007). Heavy metal pollution and human biotoxic effects. International Journal of Physical Sciences, 2(5), 112–118.

21 Rah, Z., & Singh, V. P. (2019). The relative impact of toxic heavy metals (THMs) (arsenic, cadmium, chromium, mercury, and lead) on the total environment: An overview. Environmental Monitoring and Assessment, 191(7).

22 Sodhi, K. K., et al. (2022). Perspective on the heavy metal pollution and recent remediation strategies. Current Research in Microbial Sciences, 3(September), 100166.

23 Rizvi, A., Ahmed, B., Zaidi, A., & Khan, M. S. (2019). Heavy metal mediated phytotoxic impact on winter wheat: Oxidative stress and microbial management of toxicity by Bacillus subtilis. RSC Advances, 9, 6125–6142.

24 Mohammad, J. K., Muhammad, T., & Khalid, K. (2013). Effect of organic and inorganic amendments on the heavy metal content of soil and wheat crop irrigated with wastewater. Sarhad Journal of Agriculture, 29, 145–152.

25 Mammadova, S. A., Ibragimova, Z. Sh., & Aliyev, R. T. (2018). Assessment of the resistance of various wheat samples to aging, drought and salinization. International Journal of Applied and Fundamental Research, (12-1), 84–87.

26 Sharma, N., et al. (2021). Heavy metal pollution: Insights into chromium eco-toxicity and recent advancement in its remediation. Environmental Nanotechnology, Monitoring & Management, 15.

Түйіндеме

## АУЫР МЕТАЛЛ ИОНДАРЫНЫҢ ЖҮГЕРІ СОРТТАРЫНЫҢ ТАМЫРЫНДҒЫ ПРОЛИН МӨЛШЕРІНЕ ӘСЕРІ

А.М. Дигарбаева[1], Ж.Ш. Рахимбердиева[3], Р.Жумаханова[3], А.Сыздыкова[4]

Өсімдіктердің қолайсыз экологиялық жағдайларға жауап беру механизмдерін түсіну қазіргі өсімдіктер физиологиясының негізгі міндеттерінің бірі болып табылады, әсіресе ауыр металдармен ластану деңгейі артқан жағдайда. Төзімді ауыл шаруашылығы дақылдарын қалыптастыру стресс жағдайына бейімделудің биохимиялық тетіктерін терең зерттеуді талап етеді. Осы зерттеуде ауыр металл иондарының жүгері өсімдіктеріне әсері құрылымдық және метаболикалық өзгерістер арқылы қарастырылып, стресс жауаптың индикаторы ретінде пролиннің жиналуына ерекше назар аударылады. Төзімділігі әртүрлі жүгері сорттарындағы пролин мөлшеріне жүргізілген салыстырмалы талдау бұл аминқышқылының тамыр тіндерін қорғаудағы және улы иондардың әсері кезінде физиологиялық тұрақтылықты сақтаудағы функционалдық рөлін көрсетеді. Алынған нәтижелер өсімдіктердің бейімделу стратегиялары туралы түсінікті кеңейтіп, селекциялық зерттеулерде тұрақтылықты бағалауда биохимиялық маркерлердің практикалық маңызын айқындайды.

**Түйінді сөздер*:*** стресс,ауыр метал, өсімдік,пролин, $CuSO_4$ ,$CdSO_4$

**Резюме**

## ВЛИЯНИЕ ИОНОВ ТЯЖЕЛЫХ МЕТАЛЛОВ НА КОЛИЧЕСТВО ПРОЛИНА В КОРНЯХ СОРТОВ КУКУРУЗЫ

А.М. Дигарбаева[1], Ж.Ш. Рахимбердиева[2], Р.Жумаханова[2], А.Сыздыкова[3]
1. Казахстанский национальный женский педагогический университет, Алматы, Казахстан
2. Южно-Казахстанский университет им. М. Ауэзова, Шымкент, Казахстан
3. Казахстанский национальный педагогический университет им. Абая, Алматы, Казахстан

Понимание механизмов реакции растений на неблагоприятные экологические условия остаётся одной из ключевых задач современной физиологии растений, особенно в условиях усиления загрязнения тяжёлыми металлами. Создание устойчивых сельскохозяйственных культур требует углублённого изучения биохимических механизмов адаптации к стрессу. В настоящем исследовании рассматривается влияние ионов тяжёлых металлов на растения кукурузы через структурные и метаболические изменения с акцентом на накопление пролина как индикатора стрессового ответа. Сравнительный анализ содержания пролина у

сортов кукурузы с различной степенью устойчивости демонстрирует функциональную роль этой аминокислоты в защите корневых тканей и поддержании физиологической стабильности при воздействии токсичных ионов. Полученные результаты расширяют представления об адаптивных стратегиях растений и подчёркивают практическую значимость биохимических маркеров при оценке устойчивости в селекционных исследованиях.
**Ключевые слова:** стресс, тяжелый металл, растение, пролин, CuSO4, CdSO4

Authors:

Assem Digarbayeva – Corresponding author, PhD student, Kazakh national women's teacher training university, Almaty, Republic of Kazakhstan.
E-mail: asema1985d@mail.ru
ORCID: https://orcid.org/0000-0003-3785-984X

Zhanar Rakhimberdiyeva – Director of the research Institute "Pedagogy and Psychology", PhD, Acting Associate professor, Lecturer at M. Auezov South Kazakhstan University, Shymkent, Republic of Kazakhstan.
E-mail: rakhymberdieva80@mail.ru
ORCID: https://orcid.org/0000-0001-9752-5986

Roza Zhumakhanova – Candidate of technical sciences, Senior Lecturer, M. Auezov South Kazakhstan university, Shymkent, Republic of Kazakhstan.
E-mail: roza_aru76@mail.ru
ORCID: https://orcid.org/0000-0002-4446-4718

Ainur Syzdykova – PhD student, Abai Kazakh national pedagogical university, Almaty, Republic of Kazakhstan.
E-mail: syzdykova.ajnur@mail.ru
ORCID: https://orcid.org/0000-0003-1617-4892