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ВЕСТНИК

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НАН РК сообщает, что научный журнал «Вестник НАН РК» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Вестника НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному мультидисциплинарному контенту для нашего сообщества.

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HYPERACCUMULATOR PLANTS FOR PHYTOREMEDIATION OF SOIL CONTAMINATED WITH HEAVY METALS

Abstract. Environmental pollution, including pollution of urban soils by heavy metals causes serious environmental concern around the world. Heavy metals accumulate relatively quickly in soil but their removal rate is very slow. Hyperaccumulator plants help cleanse the environment from heavy metals. Phytoremediation is cleansing of soils contaminated with heavy metals, using plants that accumulate significant amounts of metals. An important environmental problem in large industrial cities is pollution by toxic compounds, including heavy metals. Due to the potential toxicity and high resistance of metals, soils contaminated with these elements are an environmental problem that requires effective and affordable solution. In soils heavy metals are in varying degrees of accessibility to plants. Water-soluble forms of heavy metals, as a rule, are presented in the form of various salts and organic complex compounds. Phytoremediation of urban soils from heavy metals is an important environmental challenge. Among the wild species, a special group of heavy metal hyperaccumulator plants is highlighted. Some of the land plants that can accumulate abnormally high levels of potentially toxic trace elements are known as “hyperaccumulators” and their number includes about 500 taxa. Phytoremediation is much more environmentally friendly and cheaper than other techniques, so recently it has received widespread use in various countries.

Key words: Phytoremediation, heavy metals, hyperaccumulators, phytoextraction, urban soils.

Introduction. Recently, there has been an increased interest in study of ecological state of environmental object located in urban areas. Study of soil and soil cover takes an important place in such research. Urban soils are poorly studied biological systems that differ in some properties from natural ones. They are characterized by high mosaic and irregularity of profile, significant compaction, alkaline reaction, pollution with various toxic substances. Thus, an important environmental problem in large industrial cities is pollution by toxic compounds, including heavy metals [1-3]. In soils, heavy metals are in varying degrees of accessibility to plants. Water-soluble forms of heavy metals, as a rule, are represented by chlorides, nitrates, sulfates and organic complex compounds. Heavy metals accumulate relatively quickly in soil and are very slowly removed from it: the half-removal period of zinc is up to 500 years, cadmium - up to 1100 years, copper - up to 1500 years, lead - up to several thousand years [4]. Heavy metals are highly toxic substances due to their high lethality; they are not biodegradable and have low mobilization ability in the environment. Therefore, they cause soil and water pollution, as well as toxic, genotoxic, teratogenic and mutagenic effects in living organisms, causing endocrine and neurological disorders even at low concentrations [5-7].

Regarding phytoremediation technology. Restoring the environment with plants is of great interest around the world due to the possibilities that phytoremediation technology opens up for cleansing upper layers of contaminated soils [4,15]. Phytoremediation is the most suitable alternative to traditional technologies of physical and chemical rehabilitation, which are very expensive and technically more suitable for small areas, create secondary pollution and impair soil fertility. Phytoremediation method does not require large expenditures, it is simple in practical implementation, and is applicable in any environmentally unfavorable zones [10-13].

The effect of nickel hyperaccumulation by plants was first noted in the seventies of the twentieth century [8,9]. Since then, study of hyperaccumulators has attracted attention of plant physiologists, molecular biologists and biotechnologists. Advances in study of hyperaccumulators have led to identification of about

500 taxa capable to hyperaccumulate various elements [14]. Some of the land plants that can accumulate abnormally high levels of potentially toxic trace elements are known as “hyperaccumulators” [15]. These plants have been the subject of intensive research in recent decades, which has led to their widespread use in biotechnologies for soil cleaning [16], phytoproduction [17] and nanotechnology [18,19].

Studies show that plants can cleanse the environment from metals, and phytoremediation allows use of green plants for removing pollutants from surface layer of soils or turn the latter into harmless compounds, making it a promising method. Among wild-growing species, a special group of heavy metal hyperaccumulator plants is distinguished. Their shoots are able to accumulate from 1,000 to 30,000 mg of metal per kilogram of dry mass of plant without visible signs of damage [20,14]. Cultivation of heavy metal hyperaccumulator plants in contaminated areas allows to cleanse soil of excess metals [21-23].

Hyperaccumulation of heavy metals in soil. The first threshold values for hyperaccumulation of trace elements were determined as follows: 1000 mg / kg for Ni, Co, Cu, Cr, Pb and > 10000 mg / kg for Zn and Mn [20, 24]. According to Yang et al. [25], the threshold value for Zn should be reduced to 3000 mg / kg. Sun et al. [26] suggested that the threshold for Cd should be 100 mg / kg. A new updated and revised proposal for thresholds considers a plant a candidate for hyperaccumulator if its dry matter of aboveground tissue contains more than 100 mg / kg Se, Cd and Tl, 300 mg / kg Cu, Co, Cr, 1000 mg / kg Ni and Pb, 3000 mg / kg Zn and 10000 mg / kg Mn [14]. In addition, Pratas et al. [27] suggested a threshold level of 1 mg / kg for Ag.

Critical evaluations of hyperaccumulation reports mentioned that hyperaccumulative plants are now broadly divided into eight groups: (i) plants from ultrabasic soils showing hyperaccumulation of Ni (and rarely Co); (ii) plants from soils enriched with chalcophilic elements, such as Zn, Pb, Cd and Tl, which may exhibit hyperaccumulation of any of these elements; (iii) plants from soils rich in Cu and Co, exhibiting hyperaccumulation of one or both of these elements; (iv) plants exhibiting hyperaccumulation of Mn, which may arise from some ultrabasic soils and from some other substrates; (v) plants with unusually high concentration of Se from soils with increased concentrations of this element; (vi) plants that have been identified as hyperaccumulators based on the absorption of elements from industrially contaminated soils, which include many of the elements listed above, as well as reports of hyperaccumulation of Cr and As; (vii) plants reported to accumulate light rare earth elements such as Ce and La; and (viii) plants reported to be hyperaccumulating basic soil elements (that is, those that are higher than concentration of microelements), such as Fe or Al, a category that we will not discuss further [14,28,29,12,30].

Since the decorative flower crops used to create flower beds are practically not considered as means of soil remediation, but rather for decorative purposes and so far haven't been taken much into account, studying their accumulating abilities is also very important [31].

Due to the potential toxicity and high durability of metals, soils contaminated with these elements are an environmental problem that requires an effective and affordable solution. Phytoextraction has been developed as part of intensive research for more efficient, cheaper and less hazardous methods to remove contaminated soils. It is based on removal of metals by plants through absorption and accumulation in biomass [32].

Hyperaccumulative plants. Hyperaccumulators have found their widest application in phytoextraction, which is one of the phytoremediation strategies [33,24,35]. The ideal plant kinds to be used in this process should have: (i) high biomass production, rapid growth and easy assembly (the short time needed to effectively reduce the concentration of elements in phytoremedic soils, [36-38] (ii) the ability to exist outside its native region [33,39,40]. The second feature is often problematic because hyperaccumulators are often endemic and their appearance is limited to contaminated sites. It is estimated that almost 90% of known hyperaccumulators are endemic for metal-containing soils, such as serpentine soil [41].

Along with hyperaccumulative herbaceous plants, several species of tree species are considered promising for further study. Since many woody plants grow quickly, have deep roots, produce abundant biomass, and several species show some ability to tolerate and accumulate heavy metals. In recent years, significant progress has been made in identifying native plants and developing genetically modified woody plants to restore the environment contaminated with heavy metals. On a large scale, metal uptake by trees can be more efficient, mainly because of a deeper root system and higher biomass yields [42,43].

Phytoremediation is based on removal of contaminants from soil by using mechanisms such as phytoextraction, phytodegradation, rhizofiltration, phytostabilization and phytovolysis [44,45,6,12], but the mechanisms involved in heavy metals regeneration are limited by absorption, adsorption, transport and translocation, sequestration in vacuoles, supersaturation and, in some cases, volatilization [46].

Two main areas of interest for the study of new hyperaccumulators include: (i) identification of new indigenous plant species that demonstrate tremendous ability to bind elements [47,48] and (ii) search for multi-element hyperaccumulators called coaccumulators [49] that can be used during phytoremediation of contaminated soils.

Use of synthetic chelators and mineral fertilizers effectively stimulates accumulation of heavy metals in plant organs by increasing bioavailability and productivity [50-55,45]. The addition of certain PGPR - bacterial strains and mycorrhizal fungi to plants rhizosphere also stimulates accumulation of heavy metals in plant organs [56-59].

One of the promising areas of phytoremediation of soils contaminated with heavy metals is usage of transgenic plants specially designed as hyperaccumulators [51,55,11,6].

Phytoremediation methods are developed and implemented in Bulgaria, the USA, Great Britain, Spain, Canada, China, Mexico, New Zealand and other countries [15,16]. However, implementation of this environmental protection technology in the CIS countries is largely hindered by the need to search for heavy metal accumulator plants adaptable to our environmental conditions or use of introducers. Nevertheless, the work of researchers from Kazakhstan and the CIS on accumulation of heavy metals by wild-growing and cultivated plants provides sufficient grounds for finding plants suitable for introducing phytoremediation technology in Kazakhstan and the CIS [55,60-66]. In Kazakhstan, scientists from the Institute of Biology and Biotechnology of the MES RK and other organizations are actively involved in improving phytoremediation methods [55,63,64].

Conclusion. Heavy metals are highly toxic substances, they are not biodegradable and have low mobilization ability in the environment. Therefore, restoration of the environment through plants is of great interest throughout the world, which opens possibilities for phytoremediation technology for cleaning the upper layers of contaminated soils. The phytoremediation method does not require large expenditures, is simple in practical implementation, and is applicable in any environmentally unfavorable zones. Advances in study of hyperaccumulators have led to the identification of about 500 taxa capable of hyperaccumulation of various elements. The phytoremediation method does not require large expenditures, is simple in practical implementation and is applicable in any environmentally unfavorable zones. Almost 90% of known hyperaccumulators are endemic. The use of synthetic chelators and mineral fertilizers effectively stimulates accumulation of heavy metals in plant organs by increasing bioavailability and productivity. Among promising areas of phytoremediation of soils contaminated with heavy metals is use of transgenic plants specially designed as hyperaccumulators. Phytoremediation methods are developed and implemented in different countries of the world, including Kazakhstan.

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АУЫР МЕТАЛДАРМЕН ЛАСТАНҒАН ТОПЫРАҚ ФИТОРЕМЕДИАЦИЯСЫНА АРНАЛҒАН ӨСІМДІК-ГИПЕРАКУМУЛЯТОРЛАР

Аннотация. Соңғы уақытта қала аумағындағы қоршаған орта объектілерінің экологиялық жай-күйін зерттеуге қызығушылық артып келеді. Қала топырағы – аз зерттелген биологиялық жүйе. Олар улы қосылыстар, оның ішінде ауыр металдармен ластанады деп сипатталады. Ауыр металдар топырақта тез жиналады және өте баяу, яғни бірнеше мың жылға дейін шығарылады.

Фиторемедиация физикалық-химиялық оналтудың дәстүрлі технологияларына ең қолайлы балама және үлкен шығынды талап етпейді, іс жүзінде жүзеге асыру жеңіл және кез келген экологиялық қолайсыз аймақтарда қолдануға болады. Зерттеулер көрсеткендей, кейбір өсімдіктер қоршаған ортаны металдан тазарта алады. Ластанған жерлерде ауыр металл гипераккумуляторларын өсіру топырақты ауыр металдардан тазартуға мүмкіндік береді.

Өсімдік гипераккумуляторлар қазіргі уақытта ауыр металдардың шоғырлану қабілетіне байланысты сегіз топқа бөлінеді. Осы процесте қолданылатын өсімдік түрлері биомассаның жоғары өнімі, жылдам өсуі және жеңіл жиналуы, сондай-ақ өзінің жергілікті аймағынан тыс жерлерде өсетін қабілеті болуы тиіс. Өйткені ашылған гипераккумуляторлардың 90% құрамында металл бар топырақ үшін эндемикалық түрлер болып саналады.

Фиторемедиация фитоэкстракция, фитодеградация, ризофльтрация, фитостабилизация және фитоволи-заттау сияқты тетік көмегімен топырақтан ластаушы заттарды шығаруға негізделген, бірақ ауыр металдарды регенерациялауға қатысатын механизмдер сіңіру, адсорбция, көлік және

транслокация, вакуольдардағы секвестрация, аса қанығу және кейбір жағдайда ұшып кету арқылы шектелген. Сондықтан жаңа гиперакку-муляторларды табу өте маңызды.

Синтетикалық хелаторлар мен минералдық тыңайтқыштарды қолдану биожегімділігі мен өнімділігін арттыру есебінен өсімдік органдарында ауыр металдың шоғырлануын тиімді ынталандырады. Кейбір рpрг - бактериялық штаммдар мен микоризді саңырауқұлақтардың өсімдік ризосферасына қосылуы, сондай-ақ өсімдік органдарында ауыр металдардың шоғырлану жағдайын ынталандырады.

Ауыр металдармен ластанған топырақты фиторемедиациялаудың перспективалық бағыттарының біріне гипераккумулятор ретінде арнайы жобаланған трансгендік өсімдіктерді пайдалану жатады.

Гипераккумуляторларды зерттеудегі жетістіктер әртүрлі элементтерді гипераккумуляциялауға қабілетті 500-ге жуық таксон анықталған. Фиторемедиация әдістері әлемнің түрлі елінде, соның ішінде Қазақстанда әзірленіп, енгізілуде.

Түйін сөздер: фиторемедиация, ауыр металдар, гипераккумуляторлар, фитоэкстракция, қала топырағы.

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РАСТЕНИЯ-ГИПЕРАККУМУЛЯТОРЫ ДЛЯ ФИТОРЕМЕДИАЦИИ ЗАГРЯЗНЕННЫХ ТЯЖЕЛЫМИ МЕТАЛЛАМИ ПОЧВ

Аннотация. В последнее время отмечается повышенный интерес к исследованию экологического состояния объектов окружающей среды городских территорий. Городские почвы – это малоизученные биологические системы, отличные по ряду свойств от природных. Они характеризуются загрязненными токсичными соединениями, в том числе тяжелыми металлами. Тяжелые металлы сравнительно быстро накапливаются в почве и крайне медленно из нее выводятся до периода в несколько тысяч лет.

Фиторемедиация – наиболее подходящая альтернатива традиционным технологиям физико-химической реабилитации и не требует больших затрат, проста в практическом осуществлении и применима в любых экологически неблагоприятных зонах. Исследования показывают, что некоторые растения позволяют очистить окружающую среду от металлов. Культивирование растений-гипераккумуляторов тяжелых металлов на загрязненных территориях позволяет очистить почву от избытка металлов.

Растения гипераккумуляторы в настоящее время подразделяются на восемь групп в зависимости от способности аккумуляции тяжелых металлов. Идеальные виды растений, которые будут использоваться в этом процессе должны иметь высокое производство биомассы, быстрый рост и легкую сборку, а также способность расти вне своей аборигенной области, так как почти 90% известных гипераккумуляторов являются эндемичными для металлосодержащих почв.

Фиторемедиация основана на удалении загрязнений из почвы с помощью таких механизмов, как фитоэкстракция, фитодеградация, ризофилтрация, фитостабилизация и фитоволизирование, но механизмы, участвующие в регенерации тяжелых металлов, ограничены поглощением, адсорбцией, транспортом и транслокацией, секвестрацией в вакуолях, сверхнасыщением и, в некоторых случаях, улетучиванием. Поэтому поиск новых гипераккумуляторов очень важен.

Применение синтетических хелаторов и минеральных удобрений эффективно стимулирует аккумуляцию тяжелых металлов в органах растений за счет увеличения биодоступности и урожайности. Добавления некоторых PGPR – бактериальных штаммов и микоризных грибов в ризосферу растений также стимулирует аккумуляцию тяжелых металлов в органах растений.

Одним из перспективных направлений фиторемедиации загрязненных тяжелыми металлами почв является использования трансгенных растений, специально спроектированных в качестве гипераккумуляторов.

Успехи в изучении гипераккумуляторов привели к идентификации около 500 таксонов, способных к гипераккумуляции различных элементов. Методы фиторемедиации разрабатывают и внедряют в разных странах мира, в том числе и в Казахстане.

Ключевые слова: фиторемедиация, тяжелые металлы, гипераккумуляторы, фитоэкстракция, городские почвы.

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