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Manganese- and Zinc-Containing Metalloproteins Have a Value in the Species Composition of Semi-Artificial Arid Phytocenoses in the Contact Zone with the Agrocenoses

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Abstract

This article aims to show certain features in the frequency of individual dominant and subdominants of arid phytocenoses in the composition of technogenic intrusions, directly adjacent and negatively affecting the cultural agrocenoses. To substantiate the consort relationships of these plants with other ecosystem participants, we analyzed the fragments of their proteomes with respect to key manganese- and zinc-containing proteins. As a result, the concentration of mobile forms of manganese and zinc in the soil of arid territories was shown to be a significant forming factor for the structure of dominant and subdominant technogenic intrusions in the contact zone to agrocenoses. The presence in the composition of the proteome dominants and subdominants of these vital proteins confirms the argument about the possibility of control the population size and consort activity of such plants within the phytocenosis of technogenic intrusion. The obtained data can be used to form biotechnology for optimization of agrocenoses in the conditions of the arid zone.

Keywords: arid plant communities, plant phenology, plant traits, metalloproteins, manganese, zinc, database, plant biotechnology.

1. Introduction

The arid plant communities are characterized by a constant impact of a complex of stress factors affecting significantly the metabolic re-structure of plants and microorganisms living in these areas (El-Sayed et al., 2014; He et al., 2014). Natural and anthropogenic systems directly adjacent to agrocenoses occupy a special place in this complex system of competitive relations. They create unique consort connections between soil microbiota, plants and entomofauna (Hudson et al., 2016; Liu et al., 2014). The dependence of the dynamics of metabolism and energy in such semi-artificial biocenoses on the influence of soil and climatic conditions is considered in a number of fairly extensive studies (El-Sayed et al., 2014; Mushaeva, 2015). As a result, adjacent biocenoses (intrusions) usually have an active, and more often, negative impact on the human–created ecosystem of the treated field (Ivantsova et al., 2018; Ndiribe et al., 2013).

On the other hand, interspecific connections in technogenic intrusions are not so stable. In connection with this, the attempts to change the general properties of such systems by point control actions can be effective (Drenovsky et al., 2012; Kertész et al., 2017). In particular, such effects can be found in the control of metal-containing plant proteins, the influence on which was possible both by direct molecular genetic methods, and through the regulation of metal concentration in the soil or the impact on the consort bonds in the system of metal transportation to plants (Gall et al., 2015; Ma et al., 2016).

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Previously, we have shown almost complete absence of dependence between the force of technogenic intrusions influence on adjacent agricultural crops and the content of mobile forms of Nickel and copper in the soil (Ivantsova et al., 2017; Ivantsova et al., 2018). In this regard, in this study we made an attempt to consider in more detail the relationship between the presence of mobile forms of trace soil elements such as manganese and zinc, and the prevalence of individual representatives of plant communities, including in connection with the influence of intrusion on the adjacent cultivated fields.

2. Material and methods

The analysis of the concentration of mobile forms of trace elements in the soil was carried out by the precision method of atomic absorption spectrometry using the spectrometer 'Quantum.Z', LLC KORTEK, Russia (Tikhonova, 2017).

Manganese concentration in all investigated samples ranged from shaft to 510.3 of 129.5 mg/kg. In this regard, the content of trace element in the areas was assessed as low in the case, when it was less than 225 mg/kg (25 % of observations). We considered the value high in the case of Mn concentration more than 355 mg/kg (25 % of observations), the remaining cases were regarded as the average content of the mobile form of manganese in the soil. The concentration of zinc was ranked in intervals 13,3 – 23,0 – 42,6 – 52,5 mg/kg, respectively.

To study the proteome and metal-containing proteins, we selected the dominant plant species and subdominants in the studied technogenic intrusions. Bioinformatic analysis consisted in virtual screening of the database using open access resources UniProt (www.uniprot. org) and GeneOntology (http://geneontology.org). Pre-select metals were manganese or zinc. For the search we used synonymic constructs of the following type – zinc and organism: "Artemisia absinthium (Absinth wormwood) [72332]". The search included metals within the co-factor, and also atoms in metal-bond sites. Thus, we complete the selection of all metal-dependent proteins that contain metal in their structure or bind to metal for the manifestation of their activity.

The structure of the knowledge base on metal-containing proteins we built using MicrosoftExel (USA). It included the following lines: the name of the species, the names of metals, the vertical function of proteins in the body, the names of proteins, protein id in UniProt. Vertically we included data from the GeneOntology, which allow more detail to reflect the functioning of the protein. These data were found for proteins with non-annotated function is in UniProt. More significant functions of metal-containing proteins, as photosynthesis, salt tolerance, respiratory chain, etc., we selected in special column.

3. Results and discussion

Table 1 demonstrates the different types the most dominated (or were subdominants) in the plant communities of technogenic intrusions at different concentrations of the soil mobile forms of manganese and zinc.

Table 1. The dependence between the content of soil mobile forms of manganese and the frequency of domination/sub-domination of individual plants in technogenic intrusions (%)

Plant species	Concentration of soil mobile form of manganese, mg/kg		
	Low (less than 225)	Moderate (from 225 to 355)	High (more than 355)
The positive dependence on the concentration			
Artemisia lercheana *	14%	57%	57%
Atriplex tatarica *	-	36%	57%
The negative dependence on the concentration			
Cichórium íntybus	71%	21%	14%
Descurainia sophia	43%	36%	-
Lactuca tatarica *	57%	36%	14%
Tripleuros pérmuminodórum	43%	43%	-
Xanthium albinum	28%	28%	-
No dependence on the concentration			
Artemísia absínthium	57%	43%	57%

Convolvulus arvensis	28%	36%	28%
Elytrigia repens	43%	36%	43%
Euphorbia helioscopia *	28%	36%	28%
Euphorbia seguieriána *	43%	36%	43%
Crépis tectórum *	28%	50%	28%

Note: here and in the following table asterisks (*) marked the plants, other things being equal, being dominates or subdominants in intrusions with a significant negative impact on the surrounding agrocenoses.

Table 2 demonstrates the similar differences between frequency of plant dominants/subdominants according to the different concentrations of the soil mobile forms of manganese and zinc.

As you can see, there is a certain dependence for dominant plants. Some of them are more likely to dominate at relatively low concentrations of manganese or zinc, others ones prefer relatively high concentrations of trace elements in the soil. More than half of the dominants and subdominants we have no any dependence within the studied intrusions. This was partly explained by their non-permanent presence in ecosystems.

Nevertheless, it is necessary to take into account the positive dependence on the concentrations of manganese or zinc in the dominants, negatively affecting the adjacent agrocenosis. Such a finding suggests the possibility to reduce such a negative effect, selectively changing the concentration of these metals or their bioavailability with the help of agrotechnical and biotechnical measures. On the contrary, the presence of Lactuca tatarica's 'preference' for manganese allows, by increasing the concentration of ions of this metal in the soil, to reduce the impact of intrusion on agrocenosis due to the violation of the consort bonds in the community intrusion.

Table 2. The dependence between the content of soil mobile forms of zinc and the frequency of domination/sub-domination of individual plants in technogenic intrusions (%)

Plant species	Concentration of soil mobile form of zinc, mg/kg		
	Low (less than 23,0)	Moderate (from 23.0 to 42.6)	High (more than 42.6)
The positive dependence on the concentration			
Artemisia lercheana *	-	64%	57%
Atriplex tatarica *	-	43%	43%
Lactuca tatarica *	14%	43%	57%
The negative dependence on the concentration			
Artemísia absínthium	57%	57%	28%
Cichórium íntybus	57%	36%	-
Tripleuros pérmuminodórum	28%	50%	-
No dependence on the concentration			
Convolvulus arvensis	28%	36%	28%
Crépis tectórum *	43%	29%	28%
Descurainia sophia	28%	25%	28%
Elytrigia repens	28%	50%	28%
Euphorbia helioscopia *	28%	36%	28%
Euphorbia seguieriána *	43%	36%	43%
Xanthium albinum	14%	21%	28%

In the process of studying the proteomes of plants, we found, that only 6 plant species among all representatives in phytocenoses had sufficient annotations of metal-containing proteins: *Amaranthus retroflexus L., Medica gosativa L., Melilotus officinalis L. Pall., Polygonum aviculare L., Convolvulus arvensis L.,* и *Hordeum vulgare L.* (Table 3).

Table 3. Comparison of Mn- and Zn-containing proteins in proteomes of dominant/subdominant plant species in arid phytocenoses

Plant species	Metal-containing proteins			
	Annotated functions		Non-annotated functions	
	Mn	Zn	Mn	Zn
Amaranthus retroflexus	2	-	-	2
Medicago sativa	9	10	2	2
Melilotus officinalis	4	-	-	-
Polygonum aviculare	-	-	-	-
Convolvulus arvensis	2	-	-	-
Hordeum vulgare	22	90	11	107

At the same time, the proteome for the majority plants in arid zone, not included in human economic activity, has not yet been studied in detail, and the amount of annotated proteins was insignificant.

The UniProt-annotated metal-containing proteins in representatives of phytocenoses are responsible to perform functions such as photosynthesis, regulation of cell cycle and metabolism, biosynthesis of pigments, participation in the respiratory chain.

Amaranthus retroflexus L. and *Convolvulus arvensis L.* give as two manganese-containing protein each, responsible for photosynthesis, *Amaranthus retroflexus L.*, also allocated 2 protein of zinc with unknown function. We found nine annotated proteins that are associated with the manganese and is responsible for the function of photosynthesis in *Medicago sativa L.* It also had ten proteins associated with zinc, being responsible for the destruction of radicals in the cells, salt resistance, proteolytic activity, lignification, metabolism of carbon dioxide. Four manganese-containing proteins responsible for photosynthesis and separate links of the general metabolism are the annotated metalloprotein pool for the *Melilotus officinalis L. Pall.*

As a cultivated plant, *Hordeum vulgare* has 282 studied metal-dependent proteins, of which 112 were annotated with manganese (22) and zinc (90). The manganese-containing proteins are responsible for the formation of s-adenosylmethionine from methionine and ATP and participate in protective mechanisms. Zinc-containing proteins perform metabolic functions, as well as participate in ubiquitin detoxification and subsequent proteasomal degradation of target proteins (Table 4).

Table 4. The most important metal-containing proteins in the dominant plant species of arid technogenic intrusions

Protein name	Function	Representatives
Manganese-containing proteins		
Photosystem II protein (EC 1.10.3.9)	Photosynthesis	*Hordeum vulgare L.* *Amaranthus retroflexus L.* *Medicago sativa L.* *Convolvulus arvensis L.* *Melilotus officinalis L.*
Isocitrate dehydrogenase [NADP], chloroplastic (EC 1.1.1.42)	Basic metabolism	*Medicago sativa L.*
S-adenosylmethionine synthase (EC 2.5.1.6)		*Medicago sativa L.*
S-adenosylmethionine synthase (EC 2.5.1.6)		*Hordeum vulgare L.*
Serine/threonine-protein phosphatase PP2A catalytic subunit (EC 3.1.3.16)	Cell cycle regulation	*Medicago sativa L.*
Oxalateoxidase 1 (EC 1.2.3.4)	Defense mechanism	*Hordeum vulgare L.*

Zinc-containing proteins		
Carbonic anhydrase (EC 4.2.1.1)	Carbon dioxide metabolism	*Medicago sativa L.*
Acetyl-CoA carboxylase carboxyl transferase subunit beta, chloroplastic (EC 6.4.1.2)	Regulation of the basic metabolism	*Medicago sativa L.*
Glutamate--tRNA ligase, chloroplastic/mitochondrial (EC 6.1.1.17)		*Hordeum vulgare L.*
Protein arginine methyltransferase (EC 2.1.1.320)	Basic metabolism	*HordeumvulgareL.*
ATP-dependent zinc metalloprotease FTSH, chloroplastic (EC 3.4.24.-)		*Medicago sativa L.*
Methionine synthase (Fragment)		*Medicago sativa L.*
Methylthioribulose-1-phosphate dehydratase (EC 4.2.1.109)		*Hordeum vulgare L.*
E3 ubiquitin-protein ligase (EC 2.3.2.27)		*Hordeum vulgare L.*
Histidinol dehydrogenase, chloroplastic (EC 1.1.1.23)		*Hordeum vulgare L.*
Cinnamylalcoholdehydrogenase (EC 1.1.1.195)	The formation of cell wall, the scent	*Medicago sativa L.*
Pollen allergen MetE (EC 2.1.1.14)	Non-annotated	*Amaranthus retroflexus L.*

Starting the discussion, we emphasize that we have identified not absolute, but only relative preferences of dominant and subdomains of intrusive phytocenoses in the arid zone to one or another concentration of mobile forms of soil manganese. This dependence is fuzzy, because it could not be decisive in the ability of a plant to grow in the natural environment of its habitat (He et al., 2016; He et al., 2016).

Both of these elements are essential metals, but the peculiarities of their metabolism in plants of different species lead to differences in their needs and, accordingly, in different reactions to changes in their concentration in the soil (Leszczyszyn et al., 2013; Sorty et al., 2016).

As shown by the research, a lot of metal-dependent proteins, especially-containing manganese, involved in photosynthesis and energy exchange in plants. The zinc-containing proteins are involved in the performance of specific functions such as lignification, synthesis of aromatic substances of the plant, as well as maintenance of salt stability, regulation of fatty acid synthesis. Other important functions provided by the presence of metal-dependent proteins are metabolic and transport.

Naturally, only the evolutionary processes may explain all specific generic and species mechanisms of adaptation to environmental conditions, based on the processes of biochemical transformation of manganese and zinc. The basic mechanism of this process is the regulated flow of these microelements from the soil, which is largely determined by the composition and activity of the soil microbiota (Bargaz et al., 2018; Gibbons et al., 2017; Vardharajula et al., 2011).

The revealed dependences may form the basis of such biotechnological strategies, which were able to limit the number and consort influence of a number of "undesirable" plant dominants on the adjacent agricultural plant communities (Dudchenko, 2012; Gibbons et al., 2017). We believe it is possible to develop on this basis, to stimulate the number and activity of subdominants, which, according to our previous studies (Ivantsova et al., 2017; Ivantsova et al., 2018), was accompanied by increased intraspecific competition within phytocenosis and weakening its influence on contact plant communities.

4. Conclusion

The concentration of mobile forms of manganese and zinc in the soil of arid territories was shown to be a significant forming factor for the structure of dominant and subdominant

technogenic intrusions in the contact zone to agrocenoses. The presence in the composition of the proteome dominants and subdominants of these vital proteins confirms the argument about the possibility of control the population size and consort activity of such plants within the phytocenosis of technogenic intrusion. The program of impacts adapted to regional conditions in the long term is able to provide its economic accessibility for individual land users, the needs of which are focused on the technology of point regulation of the state of agrocenoses.

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