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THE PROBLEMS SUSTAINABLE REMEDIATION OF THE CHERNOBYL ALIENATION AREAS

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***Abstract*:** A lot of radioactive isotopes were released by the Chernobyl accident in environment. Big territory still is contaminated by long-term half-life radionuclides such as ^{137}Cs, ^{90}Sr, several trans-uranium isotopes that will affect biota for many years. The chronic irradiation total dose includes external and internal doses. Evaluation, determination and calculation of the third part of dose (radioactive fallout) is very difficult because it depends on plenty of hard defines the environmental parameters. To implement this investigation two wild plants and several cultural plants of some generation were harvested from fields with high-level radioactive contamination (Yaniv, Chistogalovka) and control plots (Chernobyl). Epigenetic changes of genome function closely depend on the net signal system pathways. Proteomic research will provide information about changes in protein abundances that may be used for technical purposes. Low-level concentration of radionuclide accumulation in seeds and oil enables us to use agricultural plants for sustainable remediation of the Chernobyl alienation areas.

Keywords: Chernobyl, radionuclide ^{137}Cs and ^{90}Sr, plant, remediation, «hot particles», contaminated site, α-track, proteomics**.**

1. Introduction

Since the accident in 4th block of the Chernobyl Nuclear Power Plant at 1986 until nowadays in contaminated with radionuclide sites performances some main below mentioned remediation processes [1,2]:

1. The amount of radioactivity isotopes ^{141}Ce, ^{144}Ce, ^{103}Ru, ^{140}Ba, ^{131}I, ^{95}Zr, ^{95}Nb, ^{140}La, ^{134}Cs with short time half-period decay rapidly were declined,
2. The soil in the close vicinity of Chernobyl Nuclear Power Plant is still heavily contaminated with long-living radioisotopes. Therefore the chronic irradiation dose on biota was forming due to isotopes ^{137}Cs, ^{90}Sr and other trans-uranium radionuclide and uranium fission products with long time half-life decay,
3. Part of some amount radionuclide was diffused vertically from contaminated surface layer of the soil areas and moved to deep underground layers of soil [3, 4].

The initial composite of the biota contamination total dose was create from the several pathways up took doses of nuclides. Basically of which as to their various contribution into the exposure rate of biosphere were formed radionuclide with short half-life and radioactivity isotopes with long-term half- life as well as several production of uranium and trans-uranium fission products. However, hereinafter ^{137}Cs, ^{90}Sr and a lot of trans-uranium radioactive isotopes have made a major contribution into the dose in accounting of their migration from surface of the soil sites. On bases above mentioned processes the chronic radioactive irradiation background in Chernobyl town and around closely sites were decreasing during time and nowadays it is variety in interval 2.5 – 5.0 nSv/hour in compare of immediately after accident the background was changed into interval 0.1 – 0.4 mSv/hour. As result the chronic radioactive irradiation background in Chernobyl town and around was decreased 40 – 80 folds, respectively.

Decontamination of the Chernobyl town and around it immediately after catastrophe there was washing of buildings and road, was cleaning surface same areas by help of polymeric film which after adsorbing with radioactivity dust had been withdraw and the some areas were asphalting and/or was falling clean soil layer over contaminated ones were included. It is known that the land around Chernobyl town is sod-podzolic soil with pH 5.5 and content 12 percent clay, 2.0% organic compounds it has been as typical soil in Ukrainian region of Polessia.

These traditional investigations based on coarse methods that do not give us verified significant data. Under chronic irradiation in plant appear no only genetic changes but we observed internal processes elucidation as called epigenetic changes on growth and development vegetative material and seeds. For estimate these barely perceptible externally epigenetic changes the proteomics analysis of seeds is experimental attempt as fine methods of research. Proteomics analysis for this aim is very important approach for evaluation amount and profile of express key proteins, especially for growth and development seed after flowering until forming matured seeds [6].

Necessary mentioned that in any case under stress factors harvesting yield of seeds of plant sufficiently decreased [5]. In despite assessment of parameter gross plant phenotype seed germination, growth, development not slightly differ from control plant but the evaluation of the mutations and blooming, these ones are significantly differ from control plants sometimes.

To produce above-mentioned countermeasures over all Chernobyl alienated zone are very hard and expensive because a lot area remain high contamination sites with radionuclide and often were happened "hot particles" radioactive substance with high specific activity. In this connection of situation the aim our study is an agricultural using contaminated fields for sustainable remediation and possibility of get up less contaminated harvest at Chernobyl alienated zone was main reason of our investigations.

2. Methods and materials

In our experiments we use wild and cultivated plants for analysis effect chronic irradiation by help of coarse - gross plant phenotype, structure yield of seeds, chromosome aberrations, flowering terms, seed germination and fine: measurement of the radioactivity isotopes ^{137}Cs and ^{90}Sr of plant and soil samples from Chernobyl zone. The transfer coefficient (TC) is ratio specific activities (kBq/kg) of plant to specific activity of soil (kBq/kg) where it's grown that characterize go over a radionuclide from soil to vegetative plant on experimental plot. The sample of plants and soil were collected around village Yaniv, Chistogalovka and Chernobyl district. All gathered biological samples from above mentioned contaminated sites dried and grinded for investigation to content isotopes ^{137}Cs and ^{90}Sr [3,4].

The study autoradiography investigation leaves of wild plants and soil were settled down on the microscopic glass slides and dried a few days. During this process they were gluing to the slides themselves. The slides with parts of plants were coated with photo emulsion LM-1 in gel (Amersham – Biosciences UK) and exposure during time 20 days at temperature +4 C. After development the samples of slides were observed of the track of particles decayed nuclides by help of light microscope JENEVAL (Karl Zeiss, Jena, Germany) [7,8].

A total protein fraction was isolated from mature and developing seeds, and analyzed using two-dimensional gel electrophoresis combined with tandem mass spectrometry. Proteomics analyses of proteins isolated from plants soybean and flax was performed in Slovakia

(Nitra) using Q-TOF Premier mass spectrometer that use state-of-the-art MSE technology along with classical MS2 experiment. The ProteinLynx 2.4 software that is capable to provide absolute and relative quantitative analysis of proteins on based on MSE data performed proteomics-related bioinformatics [9].

3. Results and Discussions

To evaluate content of radionuclide on part of plants and transfer coefficient revealed that in seed contamination rate with radionuclide very low level was revealed (Table 1).

Table 1. Quantities distribution radionuclide ^{137}Cs and ^{90}Sr in parts of soybean and flax plants grown in Chistogalovka and Chernobyl experimental areas and transfer coefficients (TC)

Parts of plants	Content of radionuclide, Bq/kg		TC for ^{137}Cs	TC for ^{90}Sr
	^{137}Cs	^{90}Sr		
Soybean, Chernobyl				
Soil activity at Chernobyl	1414±71	550±55	-	-
Leaves	30± 3	-	0.021	-
Shoots	28± 3	-	0.020	-
Valve	27± 2	-	0.019	-
Seeds	11± 4	90± 18	0.008	0.164
Flax, Chernobyl				
Vegetative top	10± 2	-	0.007	-
Seeds	8± 5	80± 16	0.006	0.146
Soybean, Chistogalovka				
Soil activity at Chistogalovka	20650± 1050	5180± 550	-	-
Leaves	3600± 144	-	0.174	-
Shoots	3220± 80	-	0.16	-
Valve	2600± 200	-	0.13	-
Seeds	2130± 207	11840± 1800	0.102	2.286
Flax, Chistogalovka				
Vegetative top	850± 60	-	0.041	
Seeds	780± 39	3550± 360	0.038	0.685

Herein we showed a different accumulation of radionuclides in soybean and flax seeds, which belong to distant taxonomic categories. The soil activity of ^{137}Cs in the test field inside of the Chernobyl exclusion zone was almost 15 times higher comparing to control; ^{90}Sr activity differed about 9 times. For both studied species and dose-forming radionuclides, accumulation rates were much higher in contaminated area and mature soybean seeds in all cases had higher radionuclide activity then flax.

Morphometric analysis showed that soybean seeds from contaminated area are smaller and their imbibitions' is delayed comparing to control. There were no significant fresh weight differences of flax seeds grown in the radionuclide-contaminated field, but germination percentage was lower due to the chronic low-dose irradiation.

Necessary mentioned that measurements the amount of radionuclide and the TC are variable and its differ on depend of parts of plant were determinate that distribution amount of radioactivity isotopes by part of plants were decreasing due to similar consequentially chain - Leaves ≥ Roots > Shoots > Seeds [10]. For example, for matured seed the value of the TC and content of radionuclide observed less than for other vegetative parts of the plant [3, 4, 11]. These important fact will be using for agriculture countermeasures for receive seeds harvest with low-level radioactivity from cultured plants on contaminated areas of the Chernobyl zone.

Our study is focused on the investigation of soybean and flax response toward permanently increased level of radiation, using a quantitative high-throughput proteomics approach. During the ontogenesis, investigated plants received the following equivalent doses: a) at the contaminated field – 11.4 cSv for flax, 13.2 cSv for soybean; b) at the control field – less than 0.4 cSv for both species of the plants. The total capture dose formed as sum external and internal doses where internal dose approximately consist no more than 10% of total dose. As result for wild and cultural plants grow under chronic irradiation the total dose summering included two parts of external and internal doses. But in field experimental condition in Chernobyl alienation zone we observed third additional part of dose forming due to fallout radionuclide contaminated dust and especially with micro- and nano-sized "hot particles" on leaves and top of plants and on surface of soil sites (Figure 1).

Fallout radioactivity isotopes also go into vegetative plant by help of pathway as foliar nutrition throughout leaves. Evaluation, determination and calculation the part of foliar of dose very difficult because it depend of a lot of parameters such as density of trichomes on leaves face (Figure 2), width of cuticle layer, might exist air roots system, ability effectiveness foliar nutrition metabolism for determinate species of top plant and intensively fallout dust carry out by help of rose winds on plant located areas [8, 12].

The autoradiography investigation of soil samples shown that in the soil sample from Yaniv site consist the density alpha-tracks more than on the soil sample from Chistogalovka site. Respectively, our analysis plants which grown at contaminated areas reveal that the density α-tracks fallout radiation appears on upper leaves of phase rosette and on the top leaves of the top apex of the plants white blow (*Erophila verna (L.) Bess.*) from Chistogalovka experimental site. However, in contaminated areas the total dose chronic irradiation captured did not richen high magnitude but in wild and cultural plants we observed a lot changes: for example - changes color and amount of flowers and term of bloom, creating plenty sterile branches of plant as well as decreasing harvest of seeds (Table 2).

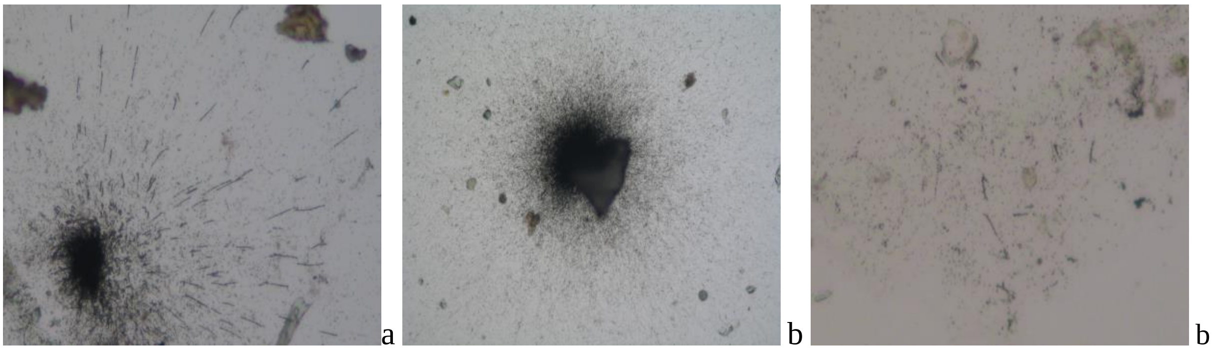

Fig. 1. The autoradiography of soil sample from Yaniv site (a) the track α-particles appeared more than on the soil sample from Chistogalovka site (b).

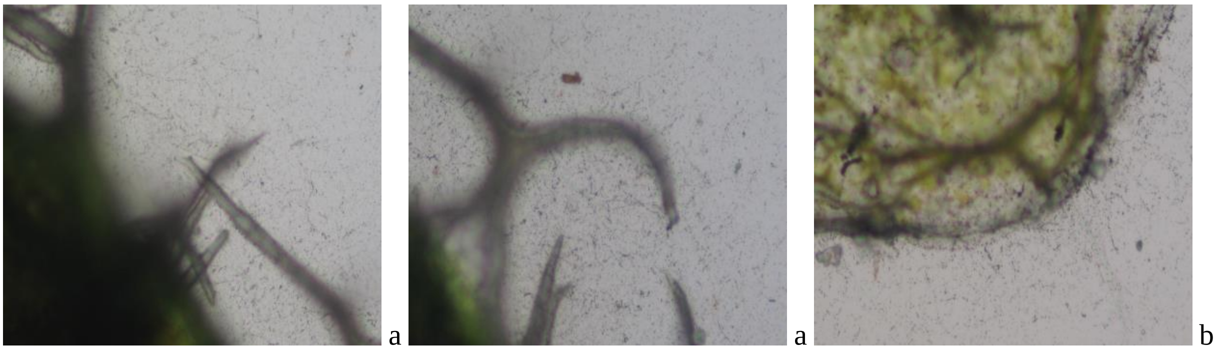

Fig. 2. The tracks fallout radiation appears on upper leaves (a) of phase rosette and on the top leaves of the top apex (b) of the plants white blow (Erophila verna (L.) Bess.) from Chistogalovka.

We observed that plant white blow (*Erophila verna (L.) Bess.*) for autoradiographic investigation from Chistogalovka and Yaniv contaminated soil sites the distribution kind of α-tracks of radionuclide essential was differed. In Yaniv contaminated soil site was estimated more alpha-particle tracts might origin from reactor fuel as “hot particle” whereas in Chistogalovka appear a lot of beta- and gamma- decay events. The radionuclides will be penetrated the leaves through the cuticle as anion, also are captured common in gaseous phase as very small dust particles herewith stomata cells. Thus extra-root nutrition ingoing, which included nano- or micro-size “hot” particles may be, had essential role of plant behavior in environment and form of local dose by help of density α-track with high relative biological effectiveness. Contamination with radionuclide in natural experimental fields significant added α-tracks by very small flying dust with radioactivity particles less than “hot particles” in environment by help foliar pathway into top leaves and apex of plant.

As shown in Table 2, only by test-system as plants *Crepis tectorum* amount of inflorescence significantly differed for plant grown at high-level contaminated areas (Yaniv and Chistogalovka). For cultured plants we also received decrease of harvest seed at contaminated area (Chistogalovka) compare at control area (Chernobyl). Similar suggestion true also cultural plants grown under influence chronic irradiation at Chernobyl zone. The seed yield for rape, flax, soybean, maize, and barley significantly differed from control variants (Figures 3 and 4). But another traditional investigations based on the coarse methods such as; gross plant phenotype, seed germination, growth, seed development, mutations and blooming, these ones do not significantly verified from control plants sometimes.

Table 2. Seed fertility of plants Crepis tectorum, collected at Chernobyl alienated zone and germinated in laboratory conditions.

Variants	Yaniv		Chistogalovka		Zhukin (control)	
	Fertility	Sterility	Fertility	Sterility	Fertility	Sterility
Amount of plants	11		12		11	
Amount of inflorescence	190		160		236	
Variability of seed in the inflorescence	34-102	0-25	23-112	0-14	26-92	0-23
Number of seeds in the inflorescence	62.0	3.6	57.9	2.5	57.9	4.7
%	94.49	5.51	95.23	4.17	91.92	8.08

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Nowadays investigated new fine methods and apply its for our experiments shed light some hidden metabolic processes that weak observed by help of traditional coarse methods approaches which carry out in living cell to declining harvest seeds at radioactivity contaminated areas. Necessary mentioned that genetic mutations in plant under chronic irradiation 10 - 15 cSv had very small rate yield [8]. We did not received also significant validate results by help of test-system chromosome aberration for plants soybean and flax. However, we observed high validate data for harvest seeds and content of oil in seeds for wide group of species of plants and this changes keep on transferred transgeneration plasticity on inheritor plants (Table 3).

As shown in Table 3 in contaminated area (Chistogalovka) amount synthesis oil from soybean seed and rate parameter (oil: protein = 0.47) were decreased. For seed flax observed content oil increased vice versa rate parameter (oil: protein = 1.46) did not changed in despite of control variant. This circumstance leads us to propose that the oil from flax as appropriate alternative fuel from cultural plant for agricultural applying in contaminated Chernobyl zone.

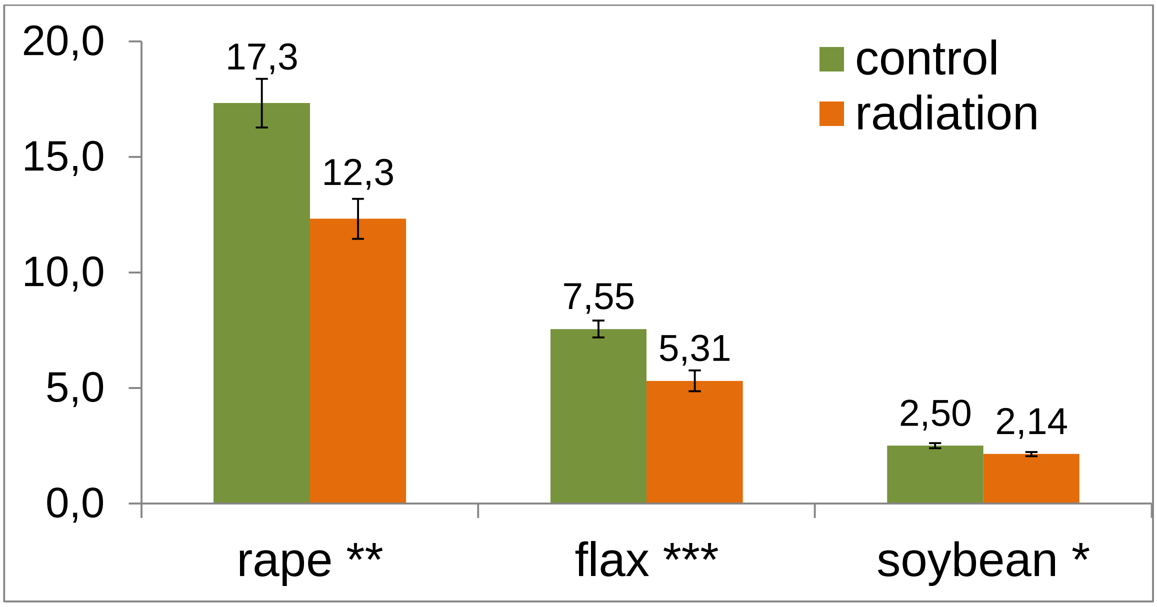

Fig. 3. Amount harvest of seeds in the rape, flax and soybean fruit depend of condition growth of plant (Chistogalovka-experimental field (green) and Chernobyl-control (red))

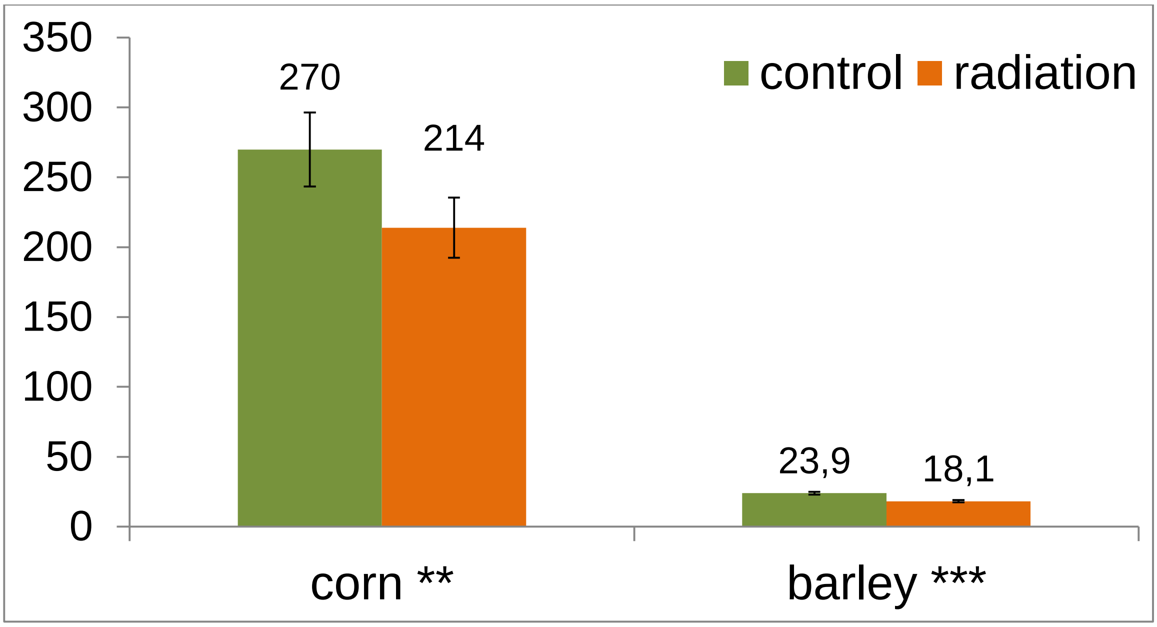

Fig. 4. Amount harvest of seeds in the maize corn and barley fruit depend of condition growth of plant (Chistogalovka-experimental field (green) and Chernobyl-control (red))

We used discovery proteomics, based on the two-dimensional gel electrophoresis to reveal molecular changes on the protein level. Narrow range immobilized pH gradient strips, ensured virtual absence of overlapping protein spots. We clearly separated 698 soybean protein spots from mature seeds, 9.2% of them had a different relative volume, because of the development in the contaminated environment of the Chernobyl zone. Using ultrahigh performance liquid chromatography coupled to a tandem mass spectrometry, we identified 26 sequences. Out of 720 flax spots, the relative amount of 4.9% was significantly different in the experimental samples. We clearly identified 28 flax seed proteins, those abundance changed as a result of chronic irradiation.

Table 3. Accumulation oil in seeds soybean and flax grown on contaminated area

Seeds	Dry mass, %	Oil, % per dry mass	Protein, % per dry mass	Rate: oil/protein
Soybean, control	92.09±1.2	25.49±1.02	29.82±1.01	0.85
Soybean, Chistogalovka	90.96±1.1	20.74±1.10	43.98±1.43	0.47
Flax, control	92.20±1.3	39.74±1.45	26.98±1.12	1.47
Flax, Chistogalovka	91.36±1.2	44.83±1.42	30.81±1.19	1.46

All soybean and flax proteins, affected by growth in radionuclide-contaminated soil during one generation, were sorted into 11 functional categories. Interestingly, 2 classes (storage proteins and cell growth) were unique to the first object, on the other hand 4 (proteins synthesis, transcription, secondary metabolism and unclassified) – for the second. Seed storage proteins of soybean responded dominantly to the chronic irradiation. Their complex ambiguous behavior in the contaminated environment of the Chernobyl zone, adds arguments in favor of the hypothesis about additional functions of this group. Seems likely that redistribution of individual seed storage proteins is a crucial factor enabling plants to survive under chronic influence of radionuclide contamination. Nonspecific reaction, similar to the heavy metals stress, is another fundamental component of the response to chronic irradiation. It includes cysteine synthase hyperaccumulation in the seeds from contaminated field. This stress enzyme limits the synthesis of phytochelatins. Additionally, we identified 4 dehydrins: three of them were more abundant and one less abundant in seeds from the field in the Chernobyl Nuclear Power Plant exclusion zone. Also, data showed that the content of the peroxisomal betaine aldehyde dehydrogenase increased by 30% upon low-dose impact. It is likely that the specific protective activity of a glycine betaine against a radiation works in mature soybean seeds.

Several components of signaling pathways are among the proteins of flax seeds, which abundance changed under the influence of radionuclide contamination. Lipoxygenase content decreased in the proteome of flax grown in the soil contaminated by radionuclides. This may mean that the signaling pathway that includes oxylipins is inhibited; the logical consequence is reduced resistance to phytopathogens. Also we showed lower content of GF14ω, a member of the 14-3-3 family of molecular adapters. Adapter proteins control key cellular functions that have global impact on the molecular physiology of plants. Since all flax proteins involved in signaling had lower abundance in seeds grown under the influence of radionuclides, it is appropriate to assume that they are links of one chain. Additionally, we showed that abundance of two glycolytic enzymes – fructose-1,6-biphosphate aldolase and 3-phosphoglycerate kinase increased by 50% in flax seeds collected from contaminated field. Alternative glycolytic reactions in cytoplasm provide metabolic flexibility necessary for plant development and adaptation to environmental stress factors. Homologue of the pumilio ribonucleic acid binding protein 5 APUM5 is a specific repressor of translation and participates in the defense against viral attack. Reduced amount of several isoforms of this protein as a result low-dose influence can mean that flax immune system is suppressed. The contents of the two family members of the elongation factor 1α are increased in the conditions of radiation stress, indicating the principal activation of the protein synthesis.

To improve further the concept of response to chronic irradiation we investigated proteome changes during seeds maturation in the second generation of plants grown in experimental areas. This allowed supplementing and improving the accuracy of the integrated model. We evaluated the abundance of 211 soybean proteins from the radionuclide-contaminated and control fields. Several isoforms of the sucrose binding protein that transports energetic precursors for seed storage compounds had lower abundance in radioactively contaminated conditions. Sucrose synthase isoforms (cleaves imported sugar) showed complementary behavior. Hence, soybean seeds in the territories, which are contaminated by radionuclides, received less energy; this was accompanied by a reduced accumulation of β-conglycinins. Phosphoenolpyruvate carboxylase and pyruvate dehydrogenase homologue directly influenced the activity of citric acid cycle in mitochondria. We followed 79 identified flax proteins on different seed developmental stages. This allowed showing increased abundance of glycolytic enzymes phosphoglycerate kinase and enolase on the early stages of seed development due to the impact of radionuclide contamination. Such trend is consistent with the increased content of multiple glycolytic enzymes in the first generation. Nevertheless, key changes took place in chloroplasts. Pyruvate decarboxylase and ketoacyl synthase had similar patterns of changes: they were more abundant early in the development, but their amount decreased in mature seeds. These proteins are involved in the fatty acids biosynthesis; also, we detected accumulation of lipids as a phenotypic manifestation in the seeds of flax grown in the field at the Chernobyl Nuclear Power Plant exclusion zone.

For our experiments we created proteomic database, which in free access web-site www.chernobylproteomics.sav.sk was presented. On base proteomics analysis of first generation soybean and flax seeds provided evidence suggesting that soybean adaptation to heavy metal stress, protection against radiation damage, and mobilization of seed storage proteins are involved in plant adjustments to increased levels of ionizing radiation. These results were confirmed also in second generation of soybean and flax seeds. Furthermore, the analysis of second generation of soybean seeds indicated there have been adjustments to carbon metabolism in the cytoplasm and plastids, increased activity of the tricarboxylic acid cycle, and decreased condensation of malonyl-acyl carrier protein during fatty acid biosynthesis [9]. The analysis of protein synthesis profiles after flowering until forming matured seeds indicated increasing production of pyruvate and *de novo* fatty acid biosynthesis. Based on identities of proteins that change in abundance in response to chronic irradiation, it has been postulated that epigenetic changes involves: a, signal system transduction activation; b, a non-specific heavy metal response; c, direct protection against radiation damage; and d, alteration in the seed store proteins. Consequently, for cultured plants we suggested that seeds produced in the radio-contaminated soil conditions, tolerate chronic irradiation through changes in the abundance of proteins from several signaling cascades, along with metabolic and protein-folding adjustment. Researchers might use this postulate in order to develop an approach for producing plants able to withstand the influence of chronic radiation of the nuclear contamination areas. Plants respond to biotic and abiotic environmental factors not only by changes in their development and physiology, but also by altering the phenotypes expressed by their offspring [5]. Thus based on these and previous data we hypothesis that alterations in fatty acid biosynthesis are part of plant response on radioactivity contaminated environment and on abiotic stress in general.

4. Conclusions

The magnitude of the Chernobyl nuclear accident did not prevent plants to thrive, and reproduce in the radio-contaminated soil. Nowadays genome of plants grown in radio-contaminated Chernobyl area is relatively well characterized and to complement genomics and mutagenic studies with proteomics data is fine method approach in our understanding of plant behaviors in radio-contaminated environment (Figure 5).

The proteomics map of proteins provides molecular characterization of seeds harvested of technical crop soybean and flax plants that might be used for agricultural re-cultivation of remediated areas [14, 15]. This research will provide information about changes in protein abundances in mature oilseeds that might directly influence fatty acids biosynthesis in radio-contaminated environment and oil obtained from seeds which grown in radioactive Chernobyl area may be used for technical purposes.

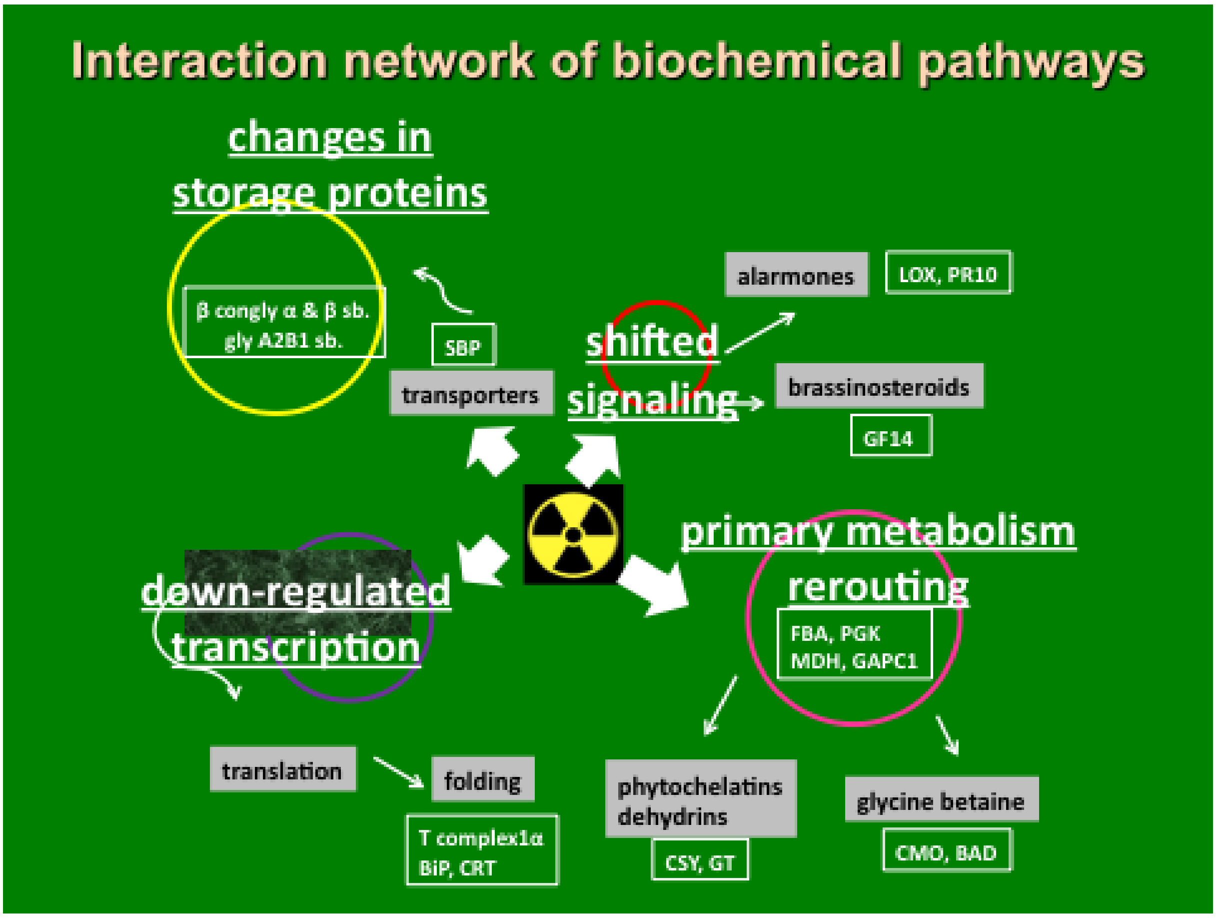

Fig. 5. Chronic irradiation influenced interaction network of biochemical pathways: changes in storage proteins, shifted signaling transduction, down-regulated transcription and primary metabolism rerouting. Proteomics proved to be efficient for elucidation of mechanisms of plant's reaction to low-dose chronic ionizing radiation, improving understanding of metabolic network adjustment. Epigenetic changes of genome function closely depend of net signal system pathways.

4.1. ***Pros and cons***. Under influence abiotic stress factor similarly chronic irradiation at contaminated Chernobyl zone the seed harvest of plant decreased and accumulation low level radionuclide in seed give us hope receive vegetative oil with low level radioactivity which permit for technical purpose, for example as biodiesel fuel.

The study used quantitative discovery proteomics (two- dimensional gel electrophoresis combined with tandem mass spectrometry) to show how protein components responded to environmental contamination with radionuclides. High- throughput seed proteomics enabled explanation of the possible mechanisms by which soybean and flax can withstand chronic irradiation. This work is the first comprehensive study of proteins from plants grown in the radionuclide-contaminated area of Chernobyl Nuclear Power Plant. We developed the conceptual model of ontogenetic reactions of soybean and flax toward chronic low doses of ionizing radiation. The novel analysis of physiological changes of plants in Chernobyl environment showed that: (i) storage proteins balance adjustment mediated by transporters was specific to soybean; (ii) modified signaling with effects on alarmones and reversible phosphorylation was unique to flax; (iii) primary metabolism rerouting (multifunctional glycolytic enzymes) for the synthesis of glycine betaine, phytochelatins and dehydrins, as well as increased activity of the gene expression, which in turn activated protein synthesis were general reactions.

The practical significance of the results was included. Implemented research is important for the development of future strategy for agriculture in the contaminated areas for non-food purposes, as biofuel production. Discovery proteomics elucidated complex biochemical changes of soybean and flax seeds under the influence of chronic irradiation, including known allergens. In the future, our results will help to develop an effective strategy for sustainable crop yield despite of technologically modified environment. Data obtained during the experiments, were uploaded to an online database available at http://www.chernobylproteomics.sav.sk. This portal provides access to results on proteome changes of soybean and flax seeds, due to the impact of radionuclide contamination, to wide range of users, including the scientific community in users friendly format.

In further of our experimental research on base proteomics analysis would be approved the characters of morphology changes depend of chronic irradiation, epigenetics changes, for several generations developing of plants species [16]. An achievement of the next step in this research will be investigating other plant species in radio-contaminated environments and to determinate the role expression proteins in posttranslational modifications.

All of this effort should lead to the understanding of the molecular basis of plant responsible adaptation and withstand towards chronic irradiation from contaminated sites Chernobyl alienation zone. Such fundamental scientific information can be than used for the development of strategies of non-food purpose applying, as well as for Chernobyl zone, for instance for biofuel production.

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ПРОБЛЕМЫ СТАБИЛЬНОЙ РЕМЕДИАЦИИ ЧЕРНОБЫЛЬСКОЙ ЗОНЫ ОТЧУЖДЕНИЯ

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Резюме: Из-за аварии на Чернобыльской АЭС в окружающую среду было выброшено много радиоактивных изотопов. Большая территория до сих пор загрязнена радионуклидами со сравнительно длинным периодом полураспада, такими как ^{137}Cs, ^{90}Sr и несколькими изотопами урана, которые еще много лет будут влиять на биоту. Общая доза при хроническом облучении включает экспозиционную и поглощенную дозы. Оценка, определение и расчет третьей составляющей части общей дозы представляет собой определенную сложность, так как зависит от большого количества фиксированных параметров окружающей среды.

Для осуществления этого исследования были собраны образцы двух видов диких и нескольких видов культурных растений с полей с высоким уровнем радионуклидного загрязнения (Янов, Чистогаловка) и контрольных участков (Чернобыль). Эпигенетические изменения в функционировании генома тесно связаны со взаимодействием сигнальных систем. Протеомические исследования предоставляют информацию об изменениях в содержании белка, которая может быть использована в технических целях. Накопление радионуклидов в низких концентрациях в семенах и в масле дает нам возможность внедрить идею использования сельскохозяйственных растений для стабильной ремедиации районов Чернобыльской зоны отчуждения.

Ключевые слова: Чернобыльская зона, радионуклиды ^{137}Cs и ^{90}Sr, растение, ремедиация, «горячие частицы», загрязненная территория, α-частицы, протеомика.

ÇERNOBIL ZONASININ STABİL BƏRPASI PROBLEMLƏRİ

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Xülasə: Çernobıl qəzasından sonra çox miqdarda radioaktiv izotoplar ətraf mühitə sızmışdır. Bu fəlakətin nəticəsi olaraq, Çernobıl AES yaxınlığında sahələr ^{137}Cs, ^{90}Sr və bir çox müxtəlif trans-uran izotopları uzunmüddətli yarım parçalanma dövrlü radionuklidlərlə və "isti hissəciklərlə" çirklənmişdirş və onlar uzun müddət biotaya tesir edəcəkdir. Bu elmi tədqiqatın həyata keçirilməsi üçün Çernobil şəhərində kontrol və Yaniv, Çistoqalovkada tədqiqat sahələri - yüksək səviyyədə radioaktiv çirklənmiş ərazilərdə araşdirma işləri aparılmışdır. Hüceyrədə genomun funksional vəziyyəti, epigenetik dəyişikliklər və signal sistemlərinin qarşılıqlı əlaqəsilə sıx bağlıdır. Proteomik tədqiqatların protein migdarı haqqında geniş məlumati texniki məqsədlər üçün istifadə edilə bilər. Toxum və bitki yağında aşağı konsentrasiyada radionuklidlərin yığılması Çernobıl zonasının ərazilərini sabit zəmin əsasında kənd təsərrüfatı bitkilərinin yetişdirməsi fikrini irəli sürməyə imkan verir.

Açar sözlər: Çernobıl, radionuklid ^{137}Cs və ^{90}Sr, bitki, bərpa, «isti hissəciklər», çirkli ərazi, α-trek, proteomika.