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Microbial–Plant Interactions in the Prevention of Environmental Risks

A. E. Gabidova[a] and V. A. Galynkin[b]

[a] *Center for the Support of Innovation Medical and Pharmaceutical Technologies, Pirogov Russian National Research Medical University, ul. Ostrovityanova 1, Moscow, 117997 Russia*

[b] *St. Petersburg State Institute of Technology, Moskovskii pr. 26, St. Petersburg, 190013 Russia*
e-mail: 7731254@mail.ru

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Abstract—Microbial–plant interactions constitute the basis of life on the Earth. Plants supply oxygen and food for humans, animals, and a considerable part of the microcosm. Microorganisms return nutrients to plants by decomposing and consuming both dead and often living plants as substrates. The latter case may be regarded as parasitism of microorganisms on plants. However, on the whole microorganisms and plants successfully coexist with each other. The importance of the microbial–plant interactions problem can be judged to some extent by the fact that most microorganisms live in the root region of plants. Deforestation considerably reduces the population of microorganisms in soil and changes their qualitative composition.

Keywords: microbial–plant interactions, risks, epiphytic and rhizosphere microorganisms, civilization

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The human history comprises five periods characterized by different durations and magnitudes of human effect on nature. Extreme load of the environment induces local ecological disasters. Conservation of microbial–plant biocenoses is the base problem in the prevention of environmental risks. The existence of such complexes indicates that medicinal plants (i.e., phytopreparations) are most bacterized.

Nowadays problems of risk management of the environment and world civilization persist on a global scale, and they cannot be considered separately from each other. Moreover, these two components are directly connected with human who is an integral component of the environment and simultaneously a component (brick) of civilization. Just humans determine now the state of the environment.

Development of human civilization is a complex, contradictory, and uneven process driven by the desire of humans to satisfy their needs most completely. Development of mankind due to his desire to prosperous and safe life in general has always been progressive. Technological progress and extension and deepening of knowledge gradually improved the quality of human life and opportunities.

In the course of its existence, the human population while tending to meet more completely their physical needs and developing the economy simultaneously improved the social organization and created a social economic safety system. As a result, the level of human safety increased despite increase of the number of harmful effects. V.I. Vernadskii was the first to write "*Man has destroyed pristine nature. He introduced numerous hitherto unknown chemical compounds and forms of life, cultural breeds of animals and plants. He changed the course of all geochemical reactions. The planet acquired a new appearance and come to the state of continuous disturbances*." While doing anything, humans do not recognize that they violate natural processes and produce undesirable changes and do not foresee the consequences. However, until sometime, anthropogenic disturbances have been compensated by self-regulatory mechanisms of the biosphere, whereas at the present stage of the development of the planet the production system and the scope of human activity have reached a level comparable with natural phenomena. According to V.I. Vernadskii, "*mankind has become a geological force comparable with the force of nature.*" Five periods can be

distinguished in the human history, which are characterized by different durations and magnitudes of the human effect on the environment [1, 2].

The first period covers the most primeval Stone Age and primitive communal lifestyle. The human activity was limited to gathering, fishery, and hunting. At early stages of the development of human society there was the unity of mankind and nature, i.e., humans completely depended on nature. This period was the longest in the history of human–nature interactions, and the effect of humans on the environment was minimal. The biosphere was in its original state, i.e., none of the biosphere components contained any unnatural compound.

The second period is characterized by extensive development of cattle breeding and agriculture, as well as of handicrafts. This period started from the beginning of land use, i.e., since VIII–VII century BC until establishment of industrial production in the XV century AD. It corresponds to slaveholding and feudal social systems. During that period the environment was extensively transformed: forests were cut over, arable lands were irrigated, and landscapes changed. Plant destruction led to death of the main rhizosphere microflora in soils. First environmental disasters occurred.

The third period lasted since XVI until XIX century. It was the time of establishment and development of capitalism and growth of industrial production. Revolutionary transformations occurred in science and technology, in particular mechanized production appeared and developed and science was created as a system of knowledges on the world. Demands for various mineral resources (coal, metals) increased, and industrial enterprises appeared. The production and population are concentrated in industrial areas. Urbanization started, and load on the environment increased. Considerable amounts of industrial wastes entered into air, soils, and ground and surface waters. Pollutants got into human organism with inhaled air and drinking water. The volume of nonhydrolyzable wastes sharply increases.

The fourth period (since the end of the XIX century till the end of the XX century) is characterized by progress in science and technology, concentration of production, and appearance of large industrial associations affecting many regions of the world. The Earth population started to dramatically grow, from 1.6 billion in 1890 to 3.6 billion by 1970. Rapid growth of the human population was called demographic explosion. The production of petroleum and gas increased at a tremendous rate, and chemical industry developed in an accelerated mode. The use of fertilizers and pesticides in agriculture increased. According to the World Health Organization (WHO) data, by the beginning of the XXI century, about 500000 chemical compounds and substances were used in industry and agriculture; among these, more than 40000 are harmful for humans and about 12000 are toxic. Excess load on the environment caused ecological disasters. In this connection, the problem of environmental pollution was recognized, and the necessity of developing environmental protection strategy was perceived. Simultaneously, newest fields of science and technology appeared: cybernetics, automation, nuclear power engineering, and design of artificial materials.

The fifth period (since late 1980s till present) is the development of postindustrial or information society. Beginnings of something new are now formed, and one should learn to distinguish and support them. This is a man who knows and is able, active, and creative. This is a humanized reproduction based on the priority of the consumer sector and advanced resource-saving technologies. This is a new system of economic, social, and political relations. "*This is the primacy of mental world, flowering of individual abilities and talents, and rise to new heights of national and universal culture*." The predominant production resource is information and knowledge, research and development are the main driving force of the economy, and the most valuable qualities of employees are education level, professional skills, trainability, and creativity. The present needs include new forms of control over the global world which now develops uncontrollably. Nowadays, the human society must realize that only a moral man could ensure the existence and development of the next generations.

In order to solve problems related to the environmental crisis let us consider factors that favored degradation of the biosphere. The problems of utilization of nonrenewable resources and anthropogenic pollution will inevitably increase in parallel with the economic development of all countries. When the number of large cities increases (urbanization), natural environment can no longer satisfy biological and social needs of their population. Elevated concentration of chemical compounds in air, water, and soil, reduces the resistance of humans to pathogenic microorganisms [3].

Anthropogenic effects disturb the balance of microorganisms and plants, which leads to impairment of biological niches. Microorganisms are permanent satellites of not only humans and animals but also higher plants, including those used as a source of herbal medicinal products. Furthermore, in the beginning of XXI century infective diseases continue to cause damage to mankind. Biological risks arising from infective diseases and infectious agents impend over the whole planet. In particular, among 51 million people dying annually over the world, almost 17 million dies from infections, whereas the mortality from cardiovascular diseases amounts to 9.7 million. The state of the environment occupies one of the most important places among problems of the modern society. A huge amount of foreign living organisms and synthetic chemical compounds circulate in the biosphere [4].

Microbial–plant interactions constitute the basis of life on the planet, and these interactions began to establish long before humans had appeared. It should be noted that both freshwater and marine macro- and microscopic plants are colonized by microorganisms and that their interactions are governed by the local conditions, including soils, air, and aquatic environment. In terms of the circulation of matter in nature, plants supply oxygen and foods to humans, animals, and a considerable part of microbiota, while microorganisms return nutrients to plants by decomposing and consuming as substrates both dead plants and living ones. Microorganism are evolutionally more ancient than plants. First bacteria appeared more than 5 billion years ago (the Archean Eon), protophytes and unicellular algae appeared in the Proterozoic Eon (1.6 billion years ago), and first microscopic terrestrial algae were likely to appear between the Proterozoic and Paleozoic Eons (0.6–0.5 billion years ago). Only in the early Devonian Period (about 0.4 billion years ago) higher plants became quite diverse and had roots and primordial vessels. It is believed that fungi appeared in the Cambrian Period, i.e., at least 0.6 billion years ago. Insofar as plants appeared later than bacteria, their interaction developed gradually. Plants possess such specific properties that allow them to compete successfully with microorganisms. Interactions between microorganisms and plants led to the appearance of microbial–plant biocenoses whose composition depended on the environmental conditions in particular regions.

Epiphytic microorganisms living on the surface of plants do not damage the latter but act as antagonists of some phytopathogens growing on common plant excretions and organic contaminations of the plant surface. Epiphytic microflora prevents phytopathogens from entering into plant tissues and thus enhances plant immunity. Epiphytic microflora is represented mostly by the gram-negative bacteria *Erwinia herbicola*, *Pseudomonas fluorescens*, and (more rarely) *Bacillus mesentericus* and small amounts of fungi. Microorganisms reside not only on leaves and stems but also on seeds. Damage of the surface of plants and their seeds favors accumulation of large amounts of dust and microorganisms thereon. The composition of plant microflora depends on the particular species, its age, type of soil, and temperature of the environment. The population of epiphytic microorganisms changes in parallel with the humidity. A large amount of microorganisms reside in soil in the region contacting the roots of plants (rhizosphere). The rhizosphere often contains non-spore-forming bacteria (pseudomonades, mycobacteria, etc.); actinomycetes, spore-forming bacteria, and fungi occur as well. The rhizosphere microorganisms transform various substrates into compounds accessible for plants and synthesize biologically active substances (vitamins, antibiotics, etc.); they exist in symbiosis with plants and act as antagonists of phytopathogenic bacteria. Microorganisms residing on the plant root surface (rhizoplane microflora) include a larger fraction of pseudomonades than in the rhizosphere. The symbiosis of fungal mycelia with the roots of higher plants is called *mycorrhiza*. Micorrhiza enhances the growth of plants [3].

Plants growing on cultivated soils are contaminated with microorganisms to a greater extent than those of forests and meadows. Especially large amount of microorganisms inhabit the lower, root part of plants due to transfer from soil. Microorganisms extensively populate plants growing on irrigated lands and landfills, near manure piles, and in pastures. Plants therein can be contaminated with pathogenic microorganisms and provide a nutrient medium for their growth. One way to prevent growth of microorganisms on plants is drying of the latter. During plant's life microorganisms perform the medium-forming function and provide general food. They decompose and mineralize plant debris and organic matter as a whole, thus returning to soil mineral elements necessary for plant growth and releasing CO_2 and some other gases to the atmosphere. Microorganisms produce plant growth stimulators and substances that are toxic for

plants. In fact, microorganisms create soil. Bacteria play the key role in nitrogen supply to ecosystems. Symbiotic nitrogen-fixing bacteria, especially those of the genuses *Rhizobium*, *Bradyrhizobium*, *Azospirillum*, are active and most studied. Microorganisms, namely fungi, are also important in phosphorus supply to plants. In other cases, e.g., by absorbing zinc from soil, microorganisms could favor plant diseases. Rhizosphere microorganism can also directly protect some plants relative to others. In addition, microorganisms exert many adverse effects on plants. Apart from direct parasitism, indirect adverse effects are possible. Plants provide food for microorganisms, primarily for heterotrophic ones, both aerobic and anaerobic. In some waterlogged soils plant root excretions are direct sources of carbon and energy. Plants ensure physical protection of microorganisms and also mediate their dissemination. During the plant growth period, microorganisms are physically transferred both into deeper soil layers and onto the soil surface and into near-surface space; therefore, plants together with animals act as carriers (or so-called vectors) of microorganisms. When plants are eaten by animals of various organization levels, microorganisms enter into the gastrointestinal tract of those animals. A part of microorganisms die here as a result of physicochemical and biological (enzymatic) processes, while the other part is transported by excrements to plant surface and soil again. The interaction between microorganisms and plants begins with seed germination in soil. It should, however, be noted that plant seeds falling into soil are already populated by microorganisms, i.e., microbial–plant interactions start long before. Fairly frequently microorganisms are already present inside a mature seed, which is especially true of phytopathogens. Plant seeds could bear bacterial cells, their endospores or cysts, conidiospores and/or hypha fragments of actinomycetes, mycelial fragments of fungi and/or their conidiospores, and protozoan cysts. The abundance and diversity of microorganisms colonizing seed surface are largely determined by the biology of microorganisms themselves. A plant germinating from a seed and growing in soil encounters with various microscopic biological species, such as microscopic animals, protozoa, fungi, bacteria, and viruses. The plant appears in contact with these species through both developing root system and surface parts, i.e., the stem (being a germ as yet). The root contacts with microorganisms that are not specific for it, i.e. with those that do not infect it, as well as with root-specific ones that infect it. The infecting microorganisms include nonpathogenic and typical pathogens. The amount of microorganisms colonizing the surface part of plants may reach 10^8 cells per gram of fresh leaves or 10^6 cells per square centimeter; these values are quite comparable with the population of microorganisms in one gram of soil.

The number and diversity of microorganisms, e.g., bacteria, strongly depend on a particular plant species and its inhabitance, climate, weather conditions, and some other factors. Localization of microorganisms on the surface of leaves is genus- and even species-specific. Parasitism is a particular case of interactions between plants and microorganisms. Phytopathogenic fungi are more abundant than phytopathogenic bacteria.

Phytopathogenic microorganisms include bacteria, viruses, and fungi. Diseases caused by bacteria are called bacterioses. Pseudomonades, mycobacteria, erwinia, corynebacteria, agrobacteria, etc., act as infectious agents. Their transmission is mediated by infected seeds, infected plant debris, soil, water, air, insects, mollusks, and nematodes. Increased humidity and reduced temperature favors proliferation on vegetating or mowed plants of fungi of the genera *Fusarium*, *Penicillium*, *Aspergillus*, and others, which cause mycotoxicoses in humans. The following actions are performed against phytopathogenic microorganisms: cultivation of hardy plants, clean-up and treatment of seeds, decontamination of soils, removal of infected plants, and extermination of infection carriers inhabiting plants.

Analysis of the history of civilization shows that the development of science and technology is aimed at maximum exploitation of natural resources and satisfaction of human and social needs by all means. The consequences of such impacts on the environment are depressing. Industrial landscapes and destruction of life in entire regions are negative results of anthropogenic impact on the environment. Therefore, it is very urgent to change the character of interactions between humans and nature. Even the great antique philosophers taught that nature can be ruled over only in obedience to its laws. Anthropogenic load on the environment has now reached such a level that led to the global environmental crisis. The are numerous phenomena whose development over the next several generations will lead to irreversible changes in habitat and interactions of humans with their traditional environmental niche, so that it will become unsuitable

for life of modern man and development of civilization (in the modern sense). The present transition to the post-industrial society may be either technocratic–information or humanistic–noospheric. Russia can enter the sixth step of civilization only after transition to the innovative technologies [6, 7].

Environmental safety is a complex of measures aimed at reducing harmful consequences of modern industrial production and discharges into atmosphere and protecting the biosphere and human society from risks arising from anthropogenic and natural impacts on the environment. This term also implies a system of management and control which could ensure prediction of emergency and, in case of occurrence, elimination of its further development. The modern state of the environment may be characterized as environmental crisis featuring pollution of the biosphere and critical state of natural resources. In keeping with the concept of sustainable development, humanity should not only be aimed at reducing anthropogenic load on ecosystems but also accept responsibility for restoration of natural balance [5].

Destructive human activity gave rise to a conflict between the human society and nature and created risks which were called environmental. The most important function of any biocenosis, biogeocenosis, and biosphere is regular reproduction of living matter and energy accumulated therein and conservation of microbial–vegetable cover. The total production of dry organic matter on the Earth amounts to 150–200 billion t per annum. Forests can be defined as the second extreme pole of the biosphere with respect to their biomass and the role in biological regulation on the planet, whereas the first is marine biocenoses which produce annually 30 billion t of biomass. By 1900, 65 mammalian species and 140 bird species completely disappeared from the Earth. At present, about 600 vertebrate species are on the verge of extinction. Among 250 thousand higher plant species, about 1/10 disappeared almost completely. Processes responsible for the reduction of biodiversity are mostly anthropogenic. Several animal or plant species disappear every day. The data on habitat conditions in different biogeograhic regions of the world indicate that as a result of anthropogenic activity a large number of species disappear at a rate considerably exceeding the rate of natural disappearance. Anthropogenic activities damaged 63% of lands and destroyed the same amount of microbial–plant complexes, i.e., microbiocenoses were completely destroyed. Plant and animal resources also become nonrenewable as well as ecosystems. These global dramatic changes of the environment affect the economy and human health. The human society in its development exceeded admissible environmental limits determined by the natural capacity of the biosphere. The long period of arbitrary independence of humanity from the laws biosphere has ended, and now man depends on these laws.

Environmental safety is ensured at global, regional, and local levels.

The global level of control over environmental safety implies prediction and monitoring of processes occurring in the biosphere as a whole and in all its components. In the second half of the XX century these processes included global climate change, greenhouse effect, ozone layer depletion, desertification, and pollution of the World Ocean. The global control and management are aimed at conservation and restoration of the natural mechanism of reproduction of the environment, which is driven by a combination of living organisms in the biosphere.

Impressive advances in science and technology created for some time an illusion of complete independence of humans from nature and their total control over the environment. In recent time, these views are replaced by recognition of interrelations between the human activities and natural medium. This new concept characteristically implies understanding of probable negative and even irreparable consequences of anthropogenic transformation of human habitat (anthropopression) and the necessity of not only assessment but also prediction of both immediate and remote consequences of anthropogenic impacts on the environment.

While considering relations between the environment and human health, it should be emphasized that the most urgent problem worldwide is diseases and untimely deaths caused by biological agents present in the environment (water, food, and soil) as a direct consequence of biological contamination.

Human impact on the environment depends on the type and volume of consumed natural resources, amount of wastes, and ways of their disposal. Most nonrenewable resources of the Earth are consumed in West Europe, North America, and Japan.

In view of the above stated, herbal medicinal products constituting the base of phytopreparations are

more contaminated by microflora (by origin) than synthetic medicines and are thus most probable carriers of spores of microorganisms and fungal conidia. Microbial contamination of plants is determined by the environment (soil, air, water). A wide diversity of bacterial microorganisms, fungi, yeasts, and viruses, as well as contaminations produced by gnawing animals and insects, can be found on the surface of plants and inside them. More than thousand known plant diseases are caused by viruses. A relatively large number of plant diseases are caused by mycoplasmata.

Inevitably, this microbiological background depends on several environmental factors and exerts an important impact on the overall quality of herbal products and preparations. The main natural habitat of phytopathogens is soil, but they also present in water and air and are transferred therefrom to all growing parts of plants [5].

Almost all plants are subject to bacterial infection. The quantitative and qualitative compositions of plant microflora depend on the environment (soil, air, water). In particular, industrial enterprises and wastes strongly affect microbial–plant interactions. Plant raw materials are more liable to microbial contamination and degradation since huge amounts of microorganisms are transferred to different parts of plants from soil and air, and they use plants as nutrient medium rich in carbohydrates, proteins, and fats.

Procurement of herbal raw materials (drying, conservation) substantially affects the amount of microbes therein and their activity. Even when the norms and regulations of medicinal plant harvesting are met, a little of soil containing microorganisms remains on the roots, and the leaves and flowers are populated with microorganisms from air.

Plant microflora is mainly represented by spore-forming and non-spore-forming bacteria, mold and yeast fungi, actinomycetes, cocci, and pigmented and fluorescent microbes. Spore-forming and osmophilic bacteria can be found in canned fruits and berries. In the manufacture of foods from plant raw materials it is necessary to strictly follow industrial sterilization conditions to ensure the absence of reference and pathogenic microorganisms in the final product.

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