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# THE PRIORITIES OF ACADEMICIAN A.A. ZHUCHENKO

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Abstract

For the first time in the world, A.A. Zhuchenko has carried a system analysis of the adaptive potential in cultivated plants, identified crucial features and qualitatively new mechanisms of adaptive responses of plants during ontogeny and phylogeny, substantiated and formulated the key concepts of plant genetics, ecological genetics of cultivated plants, ecological and genetic foundations of the adaptive system of plant breeding, adaptive crop production, and the strategy for adaptive intensification of agriculture.

Keywords: adaptive system of plant breeding and seed reproduction, genetic resources, ecological genetics of cultivated plants, recombinogenesis, biomonitoring, agroecology, the strategy for adaptive intensification in agriculture.

**A.A. Zhuchenko, V.A. Kotelnikova, Y.A. Ovchinnikov, and A.P. Aleksandrov** (form left to right; Biotron, Institute of Ecological Genetics of the Academy of Science of Moldova, 1982).

On September 25, 2015, it was the 80$^{th}$ anniversary of Alexander A. Zhuchenko, an academician and a distinguished scholar and statesman of Russia. His fundamental research in genetics of cultivated plants, recombinogenesis, biomonitoring, agroecology, breeding, variety testing and seed farming, his strategy for adaptive intensification of agriculture, and his school of ecological genetics (61 doctoral and candidate theses defended under his supervision) are recognized worldwide. He has published 665 research papers, including 25 monographs that are highly regarded by the academic community (T. Gichner, 1982; G. Robbelen, 1983; I. Grebenschikov, 1984; V.A. Dragavtsev, 2002; V.K. Shumny et al., 2004; V. Rich, 1987; Who's Who in the World, 1989-1990; Men of Achievement, 1991) [1-4].

Academician A.A. Zhuchenko has the world priority in developing special genetics of cultivated plants based on the first ever extensive long-standing research data on *Lycopersicon* Tourn., including evolution, systematics, physiology, embryology, cytology, applied mathematics, assessment of the world collection samples for harvest, morphological, physiological and cytological traits, creation of lines, forms, mutants, multi-tracer mutants, varieties, studying of cultivar genealogy, heterotic hybrids, creation of a methodological base to determine the frequency of recombinations, the combining ability, genetic and cytological mapping, improvement of greenhouse experiments, systems of cultivar testing and seed farming, farming technologies, etc. His monograph «Tomato genetics» (1973) was one of the first works in the world literature dedicated to special genetics of cultivated plants that discovered important genetic peculiarities and the value of tomatoes as a model object not only for general, but for special genetics of cultivated plants when conducting breeding, seed production and developing agrotechnics. According to P.M. Zhukovskii, even wheat was not honored with such a monograph, and John Carew, Dean of the Department of Horticulture at Michigan University (U.S.), noted that this book had made a great contribution to the science of plants [2].

The second half of the 20$^{th}$ century was distinguished by a growing interest in the environmentalization of many biological disciplines. One of the new areas synthesizing knowledge on genetics and ecology was ecological genetics (E.V. Ford, 1964). In 1975, the 4th (and the last) edition of ecological genetics by the British biologist E.B. Ford was published, and in 1974 the book of German geneticists K. Stern and P. Tigerstedt was issued. However, the main provisions of these and other similar publications practically did not differ from known works on population genetics. The authors studied the evolution and adaptiveness of natural populations in the conditions of certain eco-systems. Criticizing the one-sided approach of the «ecological genetics» school that emerged in the 1970s, the well-known American biologist and geneticist R.C. Lewontin, who has significantly contributed to the development of the population genetics mathematical base and the theory of evolution, writes that in the long run, it is not enough to demonstrate that hot summer is favorable for bandless snail shells, and that snails with a yellow shell occur in areas with colder winters (R.C. Lewontin, 1978). Prominent geneticists criticized the efforts to combine genetics and ecology into a single discipline as lacking integrity, especially for the formal approach to combining, and for seeking to give «ecological genetics» the status of an independent scientific discipline without revealing the fundamental principles and the effect that ecological factors have on the heritability and variability of signs in higher organisms (I.M. Lerner, 1976, etc.). In 1980, A.A. Zhuchenko published his book «Ecological genetics of cultivated plants: adaptation, recombinogenesis, agrobiocenocis» that was based on extensive experimental evidence obtained on tomato, arabidopsis, corn, wheat, drosophila etc. and accumulated at the world's first Institute of Ecological Genetics founded by him, and on generalized data on adaptation, agrobiocenology, and ecology. For the first time the adaptive potential of cultivated plants is considered as a function of interrelationship between the genetic systems of ontogenetic and phylogenetic adaptation. The book also discusses the resistance of plants to abiotic and biotic stresses, and the formation of available genotypic variability with a recombination system as an example of. The author describes the relation between the potential productivity and ecological sustainability at cultivar, agrocenosis and agroecosystem levels, as well as the habitat-forming role of plants and agrocenoses, and develops the methodology for increasing the level and broadening the range of genotypic variation in plants through induced recombinogenesis and reduced selective elimination of recombinants [1-4]. In the Biologisches Zentralblatt magazine (1984), I. Grebenscikov writes that comparing this monograph with previous publications on ecological genetics is not appropriate, as they barely touch upon agricultural plants. That is why the book of A.A. Zhuchenko should be viewed as a comprehensive one-of-a-kind profound book of particular interest to plant breeders who have to work in extreme conditions [2].

A.A. Zhuchenko and his scientific disciples (1979-1987) were the first to start extensive fundamental research and practical application of remote control over plants. A.A. Zhuchenko was the first to formulate the role of plant biomonitoring at the level of plant, population and agrolandscape for studying adaptation in the «genotype—environment» system. For the first time a problem-focused information and measurement complex comprising a number of modules was constructed for ecogenetic studies and applied research, instrumentation was developed and research experiments in biology were automated, including aerial photography and satellite imagery with simultaneous twenty-four-hour monitoring of the dynamics of readings from sensors recording plant growth and development, photosynthesis, transpiration, water uptake and yield formation in various crops and crop varieties, in phytotrons and in the field (A.A. Zhuchenko, et al., 1981) [3, 4]. To this end, the Center for Automation and Metrology (CAM) and the Institute of Ecological Genetics of the Academy of Sciences of Moldova developed and commissioned the first-ever automated research system BIOTRON (ARS BIOTRON). The ARS BIOTRON made it possible to conduct comprehensive, multi-parameter studies of the dynamics of plant adaptive responses at the organ, organism, and population levels in controlled environmental conditions, with automatic processing data obtained through special software packages. The research was conducted under the supervision of A.A. Zhuchenko at the Institute of Ecological Genetics of the Academy of Sciences of Moldova and at the Design Office «Biopribor» (research works of Z.I. Zelikovsky, Y.A. Ton, E.I. Kleiman, E.I. Blank and others) where the first-ever water flow, «leaf—air» temperature, plant growth, fruit growth and other sensors have been developed that made it possible to obtain a new information on adaptive responses of cultivated plants in controlled environmental conditions. Phytomonitoring came to be a new methodology for continuous, long-term observation of the dynamics of morphophysiological, biochemical and ecological parameters of a growing or a dormant intact plant enabling a most accurate assessment of the adaptiveness of a crop variety to a given environment. These methods provided a tool to control, in a remote mode, the responses of individual crops, crop varieties, forms and genotypes to critical environmental changes affecting plant productivity [1, 2]. The academician A.A. Zhuchenko and his scientific disciples' works won the highest appraisal of the Presidium of the Russian Academy of Sciences (RAS). Fascinated with what he saw, A.P. Alexandrov, RAS President, said that the Institute of Ecological Genetics had implemented the main science principle where the object of research was near the researcher.

The institute has for the first time ever demonstrated that reliable comparative characteristics of expression and redistribution of adaptively significant and agronomically important signs across crop species, varieties, hybrids and plant forms can only be obtained through simultaneous multi-parameter recording of data in problem-focused modules enabling not only control of temperature, humidity, light intensity and mineral nutrition values within a set range, but also assessment of the dynamics of changes in the key adaptive responses and their interrelationship. At the suggestion of academician B.E. Paton, this research and experimental base was transformed into an All-Union Biological Research Center within RAS [1-4].

In the 1980s, A.A. Zhuchenko's school for the first time addressed the problem of an increasing cost of each additional food calorie. The book «Energy analysis in agriculture» (1983) experimentally and theoretically demonstrates that an increase in the costs for production intensification is often a kind of «fee» for disruption of biological balance in agroecosystems resulting from genetic uniformity of cultivated plants at the species, population and organism levels, as well as changes in the structure of agrobiocenosis subsystems due to a more extensive use of fertilizers and pesticides. Thus, a two-fold increase in the yield potential of major farm crops requires a 10-fold increase in input depletable resources, including mineral fertilizers, pesticides, farming equipment, etc. While extensive cropping systems produced 40 to 50 food calories per each unit of anthropogenic energy, as few as 2-4 food calories, i.e. 10-20-fold less, are normally produced with chemico-technogenic intensification (A.A. Zhuchenko, E.F. Kazantsev, V.N. Afanasiev, 1983) [1-4]. The book analyzes the strategy for improving the agroecosystem productivity through more efficient utilization of natural energy resources with a primary focus on rational exploitation of edaphoclimatic conditions in each crop producing area, and an optimum agroecosystem organization pattern. Moreover, the crucial and most challenging task of breeding and farming practices involves overcoming or, at least, slowing down the exponential increase in depletable resource costs per each additional unit of yield, including food calorie. It is for this reason that a paradoxical situation developed in crop farming by the early 21$^{st}$ century, i.e. a sector relying on most energy-efficient organisms, the poikilothermic plants that consume unlimited and ecologically safe resources (solar energy, $CO_2$, N, $O_2$), turned out to be among the most resource- and energy-wasteful and environmentally unsafe sectors. Generally, each subsequent improvement over the attained maximum yielding capacity and total yield, even where the crop is grown on the best possible soil, becomes more and more input-intensive and ecologically vulnerable. The worse the edaphoclimatic and weather conditions are, the higher is the «cost» of each yield increase and the lower is the coefficient of utilization of mineral fertilizers, ameliorants and other chemical and technogenic agents (especially with increased dosages). At the same time, environmental pollution increases. In this regard, higher emphasis should be placed on the capacity of cultivated plants for more efficient utilization of anthropogenic resources and hard-to-get soil mineral nutrients and moisture. It should be noted that just three chemical elements (C, H, and O) account for 98.5 % of the weight of living organisms, with more than 95 % of a plant's dry matter being substantially the solar energy accumulated upon photosynthesis. It is believed that to synthesize 1 g of dry matter, plants use 1.5 g of $CO_2$ on average captured from 2.5 m$^3$ of air. Annually synthesized biomass amounts to 180-200 billion tons, of which less than 4 % is used as agricultural produce. And the fact that crop production has exponential growth of fossil fuel-based energy inputs per each additional unit of yield which is accompanied by water and wind erosion of soil, destruction of natural landscapes and disruption of the water regime of rivers, pollution of environment with pesticide residues, nitrosamines, etc., is at variance with both natural-science laws and common sense. At the same time, in the energy balance of yield formation, even in most technologically intensive agroecosystems, solar energy accounts for over 99 %. That is why A.A. Zhuchenko concludes that the real point of using chemical and technogenic factors (fertilizers, ameliorants, pesticides, irrigation, etc.) is not to replace photosynhesis, respiration or other processes naturally occurring in plants, soil and agrobiogeocenoses, but to manage (by means of small anthropogenic energy flows) maximum utilization of solar energy, agrophytocenoses, and their food chains and trophic levels (A.A. Zhuchenko, 1983, 2010) [4].

A.A. Zhuchenko was the first to show the importance of evolutionary, genetic, ecological and bioenergetical approaches, which is crucial to the shaping of agrobiocenotic genetics as a major branch of ecological genetics of cultivated plants, since the accumulated evidence on the genetic nature of ontogenetic and phylogenetic adaptive responses at supraorganismal levels (population, biocenosis, ecosystem, landscape, and even biosphere) is rather extensive. Therefore, it is not by chance that studies in autecological and synecological population genetics, phytocenotic and symbiotic genetics and breeding of cultivated plants becomes increasingly popular (A.A. Zhuchenko, 1980, 2010) [4].

The main subject of research in ecological genetics of cultivated plants is the adaptive potential of crop plants viewed as a function of its constituent genetic programs of ontogenetic and phylogenetic adaptation, as well as the effects of their interrelationship. A.A. Zhuchenko attributes it primarily to the dual nature of the adaptation process attained by organisms through their modification and genotypic variability. It should be noted that while in the 19th century the adaptation problem was central in biology and synthetic theory of evolution, nowadays it has become strategic in ecology, medicine, food biosafety, space research, environment improvement technologies, economics, politics, etc. As a basis for systematization and analysis of huge data arrays accumulated during biological studies of the adaptive potential of higher eukaryotes, including cultivated plants, A.A. Zhuchenko employed a discrete-system approach enabling him to functionally structure the system into its constituent elements and then, by analyzing the implementation pattern of each individual component and their interrelation, to identify the basic functioning mechanisms of the adaptive system as a whole at various levels of its organization (individual, population, species, cenosis, ecosystem, and biosphere).

A.A. Zhuchenko's fundamental research works are protected by 24 certificates of authorship and are laid down in his unique monographs: «Tomato genetics» (1973); «Ecological пenetics of cultivated plants: adaptation, recombinogenesis, agrobiocenosis» (1980); «Adaptive potential of cultivated plants: genetic and ecological bases» (1988); «Adaptive crop production: genetic and ecological bases» (1990); «Strategy for adaptive intensification of agriculture» (1994); «Basic and applied research priorities of adaptive intensification of crop production in the 21st century» (2000); «Adaptive system of plant breeding: genetic and ecological bases», in two volumes (2001); «Ecological genetics of cultivated plants» (2003); «Ecological genetics of cultivated plants and agrosphere problems: theory and practice», in two volumes (2004); «Resource potential for grain production in russia: theory and practice» (2004); «Adaptive crop production (genetic and ecological bases): theory and practice», in three volumes (2008, 2009); «Ecological genetics as an independent scientific discipline: theory and practice» (2010); «Adaptive strategy for sustainable development of agriculture in russia in the 21st century (genetic and ecological bases): theory and practice», in two volumes (2009, 2011); «Mobilization of genetic resources of flowering plants through their identification and systematization» (2012); «The role of flowering plant resource mobilization, identification and systematization in shaping the adaptive-integrated system of agrocenosis, agroecosystem and agrolandscape protection» (2012), etc. [4]. In these monographs, the author outlines ecological and genetic bases of the adaptive potential of cultivated plants, identifies qualitatively new effects of the integrated functioning of its constituent genetic systems of ontogenetic and phylogenetic adaptation, determines the priorities in managing adaptive responses in plant breeding, variety testing and seed growing to be addressed in developing comprehensive plant breeding and crop management programmes, agroecological macro-, meso- and microzoning of agricultural territories, designing adaptive agroecosystems and agrolandscapes, using an integrated plant protection programme, switching to an adaptive-innovative strategy for the intensification of crop production and agriculture in general.

The global novelty of the key theoretical concepts and practically significant conclusions set out in A.A. Zhuchenko's monographs is based on the fact that the results of the fundamental research of adaptive responses and mechanisms of biocenotic self-regulation in agroecosystems and agrolandscapes, though generalized in the synthetic theory of evolution, biocenology, ecomorphology, phytogeography and other disciplines, largely remain beyond the crop production theory and practice. However, it is the lack of proper fundamental basis and natural-scientific soundness of the agricultural development in the 20th century that came to be the main reason for its global crisis by the beginning of the 21st century. After analyzing the adverse trends in modern global and domestic agriculture, A.A. Zhuchenko suggests that they are caused by a violation of laws and principles of adaptive management of complex biological ecosystems, such as agrocenoses and agrolandscapes. Viewing the management of adaptive responses of species and varieties, as well as other agroecosystem biotic components, as a primary objective of ecological genetics of cultivated plants, he substantiates the expediency of a system analysis of adaptation, recombination and agrobiocenosion as the problems that were traditionally addressed separately. A.A. Zhuchenko has demonstrated that it is with this approach that the fundamental science achievements can help to enhance the efficiency, as well as the production and environment-improving functions of agrolandscapes. Based on this, he formulates key ecogenetic principles of the strategy for adaptive intensification of crop production. They include optimization of the spatiotemporal organization of agrophytocenoses, development of varieties and hybrids combining high potential productivity and ecological stability, designing agroecosystems and agrolandscapes based on the evolutionary approach (enhanced biodiversity of crop species, their agroecological specialization, using the mechanisms and structures of biocenotic self-regulation), spatiotemporally adaptive deployment of farm crops in macro-, meso and microzones, adaptive land management, implementing adaptive-integrated plant protection systems, transition to a strategy of adaptive agriculture intensification.

The theoretical and practical conclusions of academician A.A. Zhuchenko regarding the adaptive potential of cultivated plants open up fundamentally new possibilities of managing their adaptive responses both in ontogenesis (variety-specific crop management practices, agroecological macro-, meso- and microzoning of an agricultural territory, designing adaptive agroecosystems and agrolandscapes, an adaptive-integrated plant protection system) and phylogenesis (an adaptive plant breeding system ensuring functional interdependence of stages in the development of new varieties and hybrids, their testing by state organizations, seed growing management, as well as the development of brand new areas of selection (biocenotic, bioenergy-based, symbiotic, edaphic, ecological, design-aesthetic, etc.). In view of increasingly growing global utilization of depletable resources and environmental pollution, Russia's long-term strategic interests should have a priority focus on developing food safety subject to the sanctions and import substitution [5].

The number of A.A. Zhuchenko's supporters and followers is rapidly growing. Many called him agricultural scientist No. 1 in Russia. In 2015, the Shatilovo Agricultural Experiment Station of the All-Russia Research Institute of Legumes and Groat Crops celebrated the 19$^{th}$ Field Day. One of the first and standing organizers of this already traditional event was A.A. Zhuchenko. As a result, trust to domestic varieties ensuring Russia's food safety is growing year by year. He paid special attention to the youth by holding annual Schools of Young Scientists on Environmental Genetics of Cultivated Plants, and to the development of the A.T. Bolotov Foundation. His speeches and lectures in the Timiryazev Academy and RAS always gathered full auditoriums as every speech by A.A. Zhuchenko was full of scientific novelties. In Russia and abroad he is known and appreciated by all who are involved in farming, agriculture, biology, genetics, and ecology, and who care for the future of Russia and people living on the Earth. For us, he was the best teacher whom we admire, whom we follow, and whose ideas we develop.

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