My Life Under the Star of Biology

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Abstract Contributing to this book has been a small but very pleasant challenge. While it is very easy to write about an individual vocation, it is actually difficult to objectively evaluate your scientific achievements, because that involves balancing the subjective and objective aspects of your scientific activity which, of course, may follow different individual paths since, as stated by Diego: "different is the motivation, the ambition, the inclination, the intuition, the feeling, the education, the belief, the eligibility". But translation of this individual attitude, that is, the level of subjectivity, to the level of objectivity, which will be shared and perceived by the international scientific community, depends not only on the results that will be obtained using generally recognized methods of scientific research, own observations and logic, but also from your personal understanding on how to correctly use these tools. Having traveled the path in biology for more than 40 years, I witnessed the phase transition of biology from destructive to synthetic science. Of course, there is no clear dividing line between these two because the deeper we dive into the structure of the cell and its components, the more we understand the primary functional connections, we set the basis for the resynthesis of individual life processes, at the cell and even whole organism levels. This is the paradigm of what now we call the golden age of biology. Obviously, I was not only a witness of this transition, but also one of the participants in its implementation, passing the way from the basics of biochemistry to cell biology, genomics and molecular biotechnology. So, I will try to describe this path and how I see its continuation under the guiding star of biology.

1 Motivations: How I Developed an Interest in Science

Biology has been present in my life since childhood thanks to my father, Borys Blume, who was a school biology teacher. Naturally, back in those bright days of childhood, he introduced me into the world of living nature that surrounded us.

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Thanks, perhaps, to this, during all my school years, I was very attracted by classical biology: botany and zoology. Also, my father's life experience, who remembered well from his studentship the flourishing of genetics in the late 20s–early 30s, followed by its oppression by Lysenko during the notorious period of the 40–50s of the last century, provided me with a reasonable basis for an entire perception of modern biology.

That was how I came to Kyiv University being already a somewhat formed biologist. Having graduated from high school with distinction (I was awarded with a gold medal), I had an advantage at the entrance examination, which meant that I could be enrolled at the university if my comprehension of biology was confirmed as excellent. The entrance exam was hard but successful, and I became a student of the Faculty of Biology. My student period of life (1973–78) fell on a still turbulent period in the development of biochemistry, which increasingly fueled the development of molecular biology (Frey 2002). This trend coincided with efforts to formalize the educational process at my university. After the first year of study, we were suggested to specialize, separately from other biologists, in either biochemistry or biophysics. I chose biochemistry despite my personal preference was genetics. At that time, genetics in our country was barely reviving as an academic discipline after it had nearly collapsed during the difficult times of Lysenko's persecution campaign. As before, my decision to choose biochemistry was mostly determined by an advice and scientific expertise of the people closest to me. My elder brother, Oleg Blume, was at that time, as well as his wife Yevgenia Kopachevska, already an established lichenologist, maintaining strong scientific ties with colleagues in Europe and the USA. He emphasized that even the development of lichenology as a classical discipline would certainly require the use of both biochemical and molecular genetic tools. In fact, Oleg was one of the first to apply molecular genetic methods to solve specific issues of lichen taxonomy (Blum and Kashevarov 1986; DePriest 2004). It was he who advised me to focus on modern priority areas of biology development, and Yevgenia supported him, although she was very concerned about the development of classical areas of botany and zoology in Ukraine. So, I became a biochemistry student.

The peculiarity of our system of higher education was, and still is, that universities are structurally separate from leading research institutions. As in the Soviet Union times, we have universities with a research potential designed more to follow the educational process rather than to pursue advanced knowledge. On the other hand, research institutes, primarily those under the auspices of the National Academy of Sciences of Ukraine, despite all current challenges and chronic inability to carry out relevant reforms, are still an outpost of fundamental science and advanced research developments. Therefore I, a student of the Department of Biochemistry, had to face a personal challenge, had to set my personal path answering to the following question: where could I possibly acquire skills and practical research experience? Again, the choice was limited to two priority directions, which at that time sounded loudest in the Ukrainian academic community: molecular neurophysiology led by Academician Platon Kostyuk (Verkhratsky et al. 2010) or molecular biophysics and plant physiology led by Academician Dmytro Grodzynsky (Grodzinsky 1976). Since I liked plant biology more, I preferred experimental work at the Institute of Plant

Physiology, headed by Dmytro Grodzynsky, where I started studying the structure and functions of chromatin in plants. It was an invaluable experience for a young man who was looking for his ways in contemporary biological science. Influenced by the work of Don and Ada Olins, who at that time had just described the nucleosomal structure of chromatin (Olins and Olins 1974) and the discovery of the role of cAMP as a second messenger (Sutherland 1972), I began to investigate about the spatial structure of histones using electron paramagnetic resonance and nuclear magnetic resonance. These experimental endeavors led me into the topic of post-translational modifications of histones, the study of which gained a new lease of life on the edge of reconstruction of the nucleosomal structure of chromatin (Bannister and Kouzarides 2011). The department got intesively involved in this subject and I was offered, by my Head, Prof. Mykola Kucherenko, the possibility of joining the experimental laboratory where I could continue my studies on histone post-translational modifications induced by radiation injury.

The completion of the diploma thesis bridged me to postgraduate studies at Kyiv University, where as Assistant Professor at the Department of Biochemistry, I defended my Ph.D. thesis at the Institute of Biochemistry at the National Academy of Sciences of Ukraine (March 1982). I still believe that I was fortunate to have both a prominent academic supervisor and a rather hot research topic. Also, although a postgraduate student, I had sufficient freedom of choice for my own experiments and all resources needed for my research, which seemed to be a rare exception under the Soviet planned economy rule. Moreover, I already had a small group of junior colleagues (students and those who entered the postgraduate school after me), with whom I carried out additional research, beyond the scope of my dissertation objectives. I deeply appreciate the creative support I got from my academic supervisor. Due to such favourable opportunities, I defended my second thesis for the degree of Doctor of Biological Sciences (which is equal to habilitation) in February 1988 and became one of the youngest Doctors of Sciences not only in Ukraine, but in the whole USSR. Although I was already an Assistant Professor at the Department of Biochemistry, I did not feel enthusiastic about devoting all my further professional life to lecturing at the university, as it would have taken a major bulk of my working time (up to 1000 h per academic year). It so happened that I decided to move at the National Academy of Sciences of Ukraine to do research, even before defending my second thesis.

At that time, the star of Yuri Gleba glowed brighter and brighter in the sky of biological science, and in 1987 he invited me to join his team at the M.G. Kholodny Institute of Botany. His considerable efforts were then focused on obtaining somatic plant cell hybrids (Kumar and Cocking 1987; Gleba 1995), and I was suggested to investigate the cellular mechanisms of cytoskeleton function in such hybrids. Thus, I started exploring the structure and functions of microtubules and, in particular tubulin, their buiding block protein, thereby opening the door to the world of cell biology and plant biotechnology. In June 1990, we separated into the Institute of Cell Biology and Genetic Engineering, which I took over to run shortly after Y. Gleba's departure to the USA.

A little earlier, back in 1989, an agreement with Kyiv University was signed on setting up a Department of Cell Biology and Genetic Engineering, which would have been fully staffed with faculty and infrastructure by our Institute. Nowadays, graduates from this Department work not only in Ukraine, but also in a number of European countries, in the USA and Canada. This department issued a ticket to life to my wife, Alla Yemets, who, having received a MSc degree, successfully completed the Ph.D. program in cell biology at the department and came to work in our Institute. At present, she is a Professor, an Associate Member of the National Academy of Sciences of Ukraine and a member of the Scientific Committee of National Council of Ukraine for Science and Technology Development, the Ukraine's national think-tank. She was also a driving force for the establishment of the National Research Foundation of Ukraine. I cannot imagine all the years we have lived together without her support, and essential participation in the implementation of those research initiatives that allowed us to better understand specific details of the mechanisms of functioning of plant microtubules, including relevant tubulin amino acid mutations and post-translational modifications.

It is here worthwhile to note that I have always strived to remain active into research, not surrending to the heavy administration charges, although the life circumstances often pushed me to reach higher and higher levels in the management of science. Staying in science supporting and being part of a team capable of doing up-to-date fundamental research while confronting the difficult times of a new State formation, and the related socio-economic re-organization of society, has been quite a challenge and has obviously asked for some compromise of which I had already a taste, from 1992 to 2008, when Yuri Gleba, left the institute to work for American Cyanamid (later, American Home Products; Princeton, New Jersey) before founding first Phytomedics (USA) and then Icon Genetics and Nomad Bioscience, in Germany. During all that period, I was delegated to act as a Director of the Institute of Cell Biology and Genetic Engineering. Thus I had to take the responsibility for the correct functioning of the entire Institute while trying to develop and support my own laboratory. It thus turned out that the combination of research activities with a somewhat higher level of administrative freedom, always shared with the other research groups of the Institute, gave me exceptional opportunities to establish a team (and update it again after each wave of brain drain) motivated to solve cutting edge challenges in the vast field of cell biology, molecular genetics and plant biotechnology. So, it became quite consequential that after this productive period I was asked by the President of the National Academy of Sciences of Ukraine, Borys Paton (Osipian 2018) to reorganize a small institute by merging it with my Department at the Institute of Cell Biology and Genetic Engineering. This led to the establishment of the new Institute of Food Biotechnology and Genomics where I have been acting as the Director since then.

2 Work Done: My Personal Scientific Approach

Looking back at my pathway in science and analysing my attainments, I cannot see any particular reason to be dissatisfied with what I have achieved. Naturally, at the beginning of this path, during my student and postgraduate years, all my experimental outputs, even phenomenological or purely correlative, seemed to me great achievements, but discussing them with senior colleagues, deeply immersed in the perusal of scientific literature and actively participating in scientific events, I quickly adjusted my perception better defining my tasks. In fact, while I was growing a feeling of disaffection about the results of my PD thesis, which looked to me a bit shallow, I came across to the functional significance of certain post-translational modifications of histones, a more inspiring study to which I devoted a good share of my creative search.

In order to better clarify the functional role of some post-translational modifications of histones such as phosphorylation, acetylation, methylation and poly(ADP)-ribosylation, I worked out a protocol for the in vivo synchronization of DNA replication and protein synthesis during the cell cycle. At that time, most investigators used partial hepatectomy as the most attractive approach to address the same issue but it turned out to be inadequate, given the acute post-surgical effects of such an intervention at the level of the whole organism. Quite differently, I relied on the use of cycloheximide, an effective reversable inhibitor of protein synthesis, to synchronize the growth cycle in the cells derived from experimental animals. The idea of using this cell-based approach was successful, and the use of cycloheximide to block the cycle, turned out to be very effective not only for synchronizing hepatocytes at the phase of DNA replication, but also for analyzing the mechanisms of action of both radiations and radioprotectors on DNA and protein synthesis (Aslamova et al. 1983) as well as identifying the occurrence of specific histones post-translational modifications (Aslamova el al. 1984).

At that time, research on radiobiological effects and protection was a rather promising topic, well supported by the state, even as fundamental research. A combination of all these opportunities allowed me to deepen my studies on both the enzymatic systems that lead to the post-translational modifications of nuclear proteins and the relationships of these modifications with different phases of the cell cycle. Ultimately, I was capable of identifying certain regularities of the effect of histone post-translational modifications on the supramolecular (nucleosomal) structure of chromatin, developing an additional understanding of the biochemical mechanisms of regulation of the structural and functional properties of chromatin which are based on the intranuclear involvement of secondary messengers such as cAMP and cGMP.

Unfortunately, the Berlin Wall was then an obstacle to the wider publication of our research findings but my move to the National Academy of Sciences and the beginning of the research on the molecular organization of the plant cytoskeleton (microtubules and microfilaments), and their involvement in intracellular signaling coincided with the times of “perestroika” and the fall of that very wall. It so happened that my previous expertise in the field of histone post-translational modifications could effectively apply to the study of post-translational modifications of plant tubulin (Smertenko et al. 1997). This turned out to be a great change because tubulins, compared to histones, allow a much wider range of possible practical exploitations, a perspective and a goal that, since then, I would always have treasured combining the development of biotechnological applications to the progress made in different research branches such as: cellular and genetic engineering, structural bioinformatics, genomics, molecular assisted breeding. That was probably due to the fact that I subconsciously followed the words of Louis Pasteur: "There is no such thing as a special category of science called applied science; there is science and its applications, which are related to one another as a fruit is related to the tree that has borne it".

When I was elected to the Academia Europaea (2021), my nominators and prominent scientists, members of that Academy, Prof. Ilan Chet (https://www.ae-info.org/ae/Member/Chet_Ilan) and Prof. Oleg Krishtal (https://www.ae-info.org/ae/Member/Krishtal_Oleg) formulated the following three reasons in favor of my candidacy:

- Top scientist in biochemistry and cell molecular biology of the plant cytoskeleton with original investigations on post-translational modifications of plant tubulin, including description of phosphorylation and nitration on tyrosines. He developed functional genomic approaches for understanding plant tubulin interaction with antimicrotubular drugs and for developing relative biotechnological tools to be used in practice.
- Multidisciplinary aspects of the nominant's research activity like development of plant structural bioinformatics, new approaches for plant genetic transformation, green synthesis of quantum dots as well as novel biotech aspects for generations of liquid biofuels.
- Personal contribution to the European scientific collaboration, representing the case of a Eastern European scientist capable of gathering top specialists in plant cytoskeleton and launching a new tradition of the meetings.

Also, my knowledge on ***plant cell biology,*** developed in the late 80s and early 90s gave me the opportunity to investigate the role of microtubules in the processes of plant somatic hybrids production and stabilization. My research team managed to obtain a number of plant cell lines carrying mutations in microtubular proteins that were successfully used by A. Yemets to produce symmetric and asymmetric somatic hybrids and create transgenic plants with resistance to antimicrotubular herbicides such as: dinitroanilines, phosphoroamidates, and phenylcarbamates (Yemets et al. 2008).

Simultanously and for the first time, we obtained cell-biological evidences of the role of tubulin post-translational modifications (phosphorylation, acetylation, polyglutamylation and tyrosination/detyrosination) in the regulation of plant microtubule function. Among them, we described the phosphorylation of plant tubulin on tyrosine residues (Blume et al. 2008), and reported about the functional significance of tubulin nitrotyrosylation (Yemets et al. 2011).

Currently, our attention is focused on cellular and molecular signaling mechanisms underlying the effects of abiotic factors on plant cells, and we are investigating about the role of cytoskeletal structures in these processes. We analyse the role and the place of cytoskeleton structures like microtubules and microfilaments, in the response of plant cell to ultraviolet (UV-B) irradiation, cold, high temperatures, heavy metals, herbicides with antimitotic activity as well as in the autophagy mechanisms. In particular, the ability of UV-B radiation to cause the phenomenon of programmed plant cell death was revealed and the participation of the cytoskeleton in mediating the action of UV-B was demonstrated. The mechanisms of participation of microtubules and post-translational modifications of their proteins (in particular tubulin acetylation) in the development of autophagy at the stage of autophagosome formation were also unraveled.

Eventually, these attainments in the biological study of the plant cytoskeleton led me to start research in the field of ***structural bioinformatics,*** in Ukraine. We were the first to develop original structural biological approaches for 3D-modelling of plant tubulin (Blume et al. 2003). Over the last decade, we have used and introduced new tools for the 3D-modelling of the main cytoskeletal and cytoskeleton-related proteins such as plant and bacterial FtsZ-proteins, tubulins, kinesins, protein kinases and phosphatases and for identification of the spatial effects of post-translational modifications of tubulin. Additional efforts have been oriented toward the creation of the databases and the search of low-molecular weight compounds with high affinity to the targeted cytoskeletal proteins; in silico high throughput screening of biologically active compounds and the molecular design of new compounds with herbicidal, fungicidal, antituberculosis, antiprotozoal, anthelmintic and antitumor biological activity.

An important part of my efforts has been and still is focused on ***plant molecular genetics, genomics and molecular biotechnological*** investigations as the development of the molecular markers for genes associated to specific agronomic traits, including QTL-loci; the development and implementation of the molecular genetic approaches for the identification of wheat and barley genes conferring resistance to the pathogens causing leaf, stem and yellow rust; the screening of the existing wheat and barley collections for the presence of resistance genes to these diseases; the study of the genetic diversity of wild relatives of cultivated cereals (e.g., *Aegilops* sp.) as a potential source of useful genes. The identification of genes encoding for proteins associated with the cytoskeleton, for their pyramiding in order to achieve resistance of new genotypes of cereals to highly pathogenic races of stem rust, continues to be particularly attractive to me.

A number of more technical oriented projects aimed at the improvement of the efficiency of *Agrobacteruim*-mediated and biolistic plant transformation and the development of new methods for gene transfer using nanoparticles, carbon nanotubes and other nanopolymers have been also successfully accomplished. In fact, transformation techniques for transgenic plant production with the desired traits such as herbicides or insect pest resistance have been developed in different plants such as: barley, sugar beet, potato, flax, finger millet, false flax (camelina), soybean, and, naturally, tobacco. Genetics experiments aimed to study the possible involvement of cytoskeletal proteins in the acquisition of plant resistance to herbicides with antimitotic activity allowed us to identify and isolate the mutated forms of those tubulin genes responsible for the resistance trait and, eventually, to obtain plants resistant to these chemicals. New safe and environmentally friendly marker system for the selection of the transformed plant lines based on mutant tubulin gene has also been developed. Transgenic plants were used as "green factories" for the production of pharmacologically valuable products such as lactoferrin.

I particularly value our recent achievements in the development of new methods in ***nanobiotechnology***, namely the production ("green synthesis") of nanoparticles and quantum dots by biological systems (Borovaya et al. 2014). Completely original work accomplished on the development of these methods for obtaining quantum dots of various compositions, which can be used to visualize subcellular structures, including those of the cytoskeleton, is now of a particular interest for us (Yemets et al. 2022).

With my effective participation, new varieties of false flax, finger millet, sweet sorghum, and miscanthus for ***biofuel production*** were obtained using molecular breeding approaches. Original technologies for bioethanol production from sweet sorghum and finger millet have been developed as well as the technology of biodiesel production based on camelina oils (Blume et al. 2022a) and bioethanol for engines has been developed and the pilot equipment has been constructed.

Due to my scientific accomplishments, in 1995, I was elected an Associate member and, in 2006, a full member of the National Academy of Sciences of Ukraine. Also, I was awarded the Academy premia: after V.Y. Yuriev (genetics) (2002), after M. G. Kholodny (plant physiology) (2019), and honors "For Scientific Achievements" (2016). In 2011, the Parliament of Ukraine awarded me with the Certificate of Achievements, in 2012 I became the laureate of the State Prize of Ukraine in the field of science and technology, and in 2016 I received the Honorary State Title "Distinguished Person in Science and Technology in Ukraine".

My scientific outlook has been significantly impacted by my visits abroad as a Visiting Expert at the Canadian Food Inspection Agency (Ottawa, 1996), Professorship from DFG at the University of Freiburg (invited by Prof. P. Nick, 1997), visiting scientist at John Innes Centre during 1998–2003 (Norwich, with Prof. C. Lloyd), an invited professor at Shiller Univerity of Jena/Institute of Molecular Biotechnology (2001), a visiting professor at Antwerpen University (2005–2006, with Prof. J.-P. Verbelen) and the Cochran Fellowship in Agricultural Biotechnology (USDA/USA) in 2010. Due to that, when in July 2008 I was appointed Director of the Institute of Food Biotechnology and Genomics at the National Academy of Sciences of Ukraine, with which the Department of Genomics and Molecular Biotechnology headed by me was soon merged, I had already shaped a vision of how and where to direct the efforts in the development of a new academic institution. Professor Marc Van Montagu wrote to me the following: "*Dear Yaroslav, congratulations, that will be a very important opportunity and responsibility. Ukraine badly needs a restoration of its agriculture. Plant biotechnology can be a great help. Hope that you will receive the necessary financial support and that you can associate with the best of breeding capacity that is left, for developing novel crops*". Despite all the upheavals and difficulties that challenged the consolidation of the Ukraine's statehood (from the Global

Financial Crisis of 2008–10 to the current Russian invasion), over the short period of its existence, the Institute headed by me has become an advanced academic institution, with cutting edge developments not only in the field of cell biology, molecular genetics and plant biotechnology, but also in structural bioinformatics, population genetics of plants, food biotechnology, microbiological synthesis and biotechnology of liquid fuels (bioethanol and biodiesel).

3 Science Today and Tomorrow

"Omnis cellula ex cellula"—aphorism coined by the naturalist, doctor and physiologist François Vincent Raspail (1794–1878), from which Rudolf Virchow (1821–1902) popularized the second principle of cell theory: "Every cell has originated from another cell, by division of this one."

I decided to recall these catchphrases here because their profound meaning is directly related to what I have been doing for most of my life in science. Earlier, when I was a student at Kyiv University and nearly every day passed by the portrait of S.G. Navashin (1857–1930), and the room where he worked, I had no idea that my life pathways would have become so closely intertwined with his scientific work, directly connected with the two quotes.

Serhiy Navashin, being a professor at Kyiv University, discovered double fertilization in plants in 1898 (Korzh 2008) but the fact that, while describing double fertilization, he also paid considerable attention to the study of mitotic division in the generative cells of the pollen tube of the lily (*Lilium martagon* L.), has gone barely noticeable.

His early works in this direction, contemporary with that of the Polish-German scientist Eduard Strasburger, who actually introduced the terms "prophase", "metaphase", "anaphase" and "meiosis" (1884), and other coeval researchers, demonstrated that mitosis was based on a same mechanism of division, involving filamentous structures, in both the generative nucleus and the meristematic cells. At that time, researchers had long been unable to visualize and identify microtubules as the main structural element of the mitotic spindle but, as S. Navashin sharply noted, "Looking and seeing—these are two different things."

Much later, in the second half of the twentieth century, during a new wave of instrumental and methodological development of cytology, which, in fact, gave birth to a new biological discipline called "cell biology", it became clear that microtubules are a necessary component of the cytoskeleton of any eukaryotic cell and form not only the mitotic spindle, but also the interphase network (Brinkley 1997). Thanks to such structural and dynamic plasticity, microtubules not only ensure mitotic division, but also maintain the shape of cells, provide intracellular transport and mobility of flagella and cilia, participate in the positioning of organelles and sustain several other cellular events. Each single microtubule, capable of assembling with many others, is made up by the side to side adjoining of 13 protofilaments. Although this rule of the lucky 13, the magic number, is quite strict, especially in plants, where such the structure of microtubules was established for the first time (Ledbetter and Porter 1964), some deviations have been described. However, it was just few years later (Borisy and Taylor 1967; Weisenberg et al. 1968) that the heterodimeric protein tubulin, the actual building block of protofilaments and hence of microtubules, was discovered (Breviario et al. 2013). So knowledge of the real composition of the microtubules went from the superstructure level of the mitotic spindle to the elementary, constitutive level of tubulin, in a direction, big to small (Borisy et al. 2016), that is commonly experienced in Science. Here I have intentionally refered to the history of the microtubule research to make it clear that when I joined experimental biology, the microtubules and, in fact, the mitotic spindle, were perceived as cellular structures not very well described and not fully understood. And when I shifted my research from the study of histones and the structure of chromatin to the study of tubulin and the structure of microtubules, the time coincided with the rapid development of modern cell biology. Such development was based, as I always say to students, on three pillars: in vitro cell culture, recombinant DNA technology, and in vivo visualization of cellular structures.

At that time, my vision of scientific problems and my immersion into the world of the cytoskeleton deepened thanks to acquaintance and cooperation, which sometimes turned into friendly relations, with scientists such as William Vance Baird and Don Durzan (USA), Clive Lloyd and John Doonan (UK), Konrad Boehm and Peter Nick (Germany), Vladimir Vicklicky and Pavel Draber (Czech Republic), and definitely, Diego Breviario (Italy). Some time later, I felt that the development of cell biology of the cytoskeleton was based not only on the three pillars just mentioned, but two more had to be added referring to: genomic and transcriptomic databases and structural bioinformatics.

Understanding these circumstances led me to organize several full-fledged symposia devoted to the plant cytoskeleton: “The Plant Cytoskeleton: Molecular Keys for Biotechnology” (Yalta, Ukraine, 1998), “The Plant Cytoskeleton: Functional Diversity and Biotechnological Implications” (Kyiv, Ukraine, 2002, jointly with C. Lloyd and A. Yemets), “The Plant Cytoskeleton: Genomic and Bioinformatic Tools for Biotechnology and Agriculture” (Yalta, Ukraine, 2006, in partnership with W.V. Baird and A. Yemets).

Thanks to these events, I was lucky enough to meet such scientists as Ilze Foissner (Austria), Jean-Pierre Verbelen and Kris Vissenberg (Belgium), Diana Simmonds and Larry Fowke (Canada), Pavla Binarova, Miroslav Ovecka, Jan Petrašek, Katerina Schwarzerova and Viktor Zarsky (Czech Republic), Catherine Bergounioux, David Bouchez, Anne-Catherine Schmit, Marylin Vantard and Cécile Raynaud (France), Frantisek Baluska and Dieter Volkmann (Germany), Einat Sadot (Israel), Clara Conicella and Alessandra Moscatelli (Italy), Tijs Ketelaar and Andre van Lammeren (Netherlands), Susana Moreno Diaz de la Espina (Spain), Patrick Hussey and Jeremy Hyams (UK), Federica Brandizzi, Karl Hasenstein, Bo Liu and Susan Wick (USA). Among the participants of these events were scientists, such as Consuelo de la Torre (Spain), who was one of the first elected ordinary members of the Academia Europaea in 1988, and Shoji Okamura of Japan, who fought courageously to solve the problems of tubulin phosphoproteomics, and the Canadian Geoffrey Wasteneys from Australia, who is currently a Canada Research Chair in Plant Cell Biology and Professor at the University of British Columbia in Vancouver. Of course, all these contacts significantly contributed to the establishment, and further development of our research in Ukraine. That is to say that good international collaboration is a fundamental key for scientific success, regardless the place where you actually carry out your research.

In my life, there have been and still are active various science-related commitments and responsibilities, which contributed to the establishment of new bilateral contacts and to the broadening of my personal horizons. In fact, I have been: a member of the Advisory Panel on Life Science and Technology at NATO Scientific Affairs Division (2001–04); a member of the Steering Committee of Public Research and Regulation Biotechnology Initiative (since 2006), headed for a long time by Marc Van Montagu; the President and a member of the Board of Directors of the Black Sea Biotechnological Association (since 2010); the National Representative in the Programme Committee on Food Security, Sustainable Agriculture and Forestry, Marine, Maritime and Inland Water Research, and the Bioeconomy for EU Horizon 2020 Program (2017–20); the founder of the Ukrainian cluster of European Plant Science Organisation (EPSO). Along this way, I met many extraordinary scientists and prominent personalities who could hardly be named personally. But I cannot help mentioning such good friends and recognized scientists as Atanas Atanasov from Bulgaria, George Fedak from Canada and Edgar Cahoon from the USA. And up to now I am grateful to each one of them for creative collaboration in those areas of research that go beyond the framework of the cytoskeleton and shaped my current vision of genomics, molecular biotechnology, marker-assisted breeding and production of biofuels.

As for my vision of the further development of biology as a science in general, I like to quote Mark Twain when he said, "Predicting is a dangerous art—especially when it involves the future". This is even more true now since In Ukraine we are currently living and working under conditions of a full-scale war, especially so for my family that have chosen science as the mainstream of its professional activities (https://www.chemistryworld.com/news/ukrainian-researchers-persevering-amid-war/4015691.article). Nevertheless, despite all the hardships and troubles of the martial law, we still feel we are living in the golden age of the biological sciences and we try to give our contribute to its progress.

Speaking about this, I think we can reasonably say that up to the first half of the twentieth century, biologists tried to disassemble the organism and the cell down to the smallest units, but, as the cultural and technical progress was taking place, they started moving on the reconstruction of cells and organisms, as well as those metabolic pathways that ensure normal life processes. Here, today, it is appropriate to say that we are only at the very beginning of a long and exciting reconstructive path.

In the early 2000s, I managed to organize a high-level on-line conference dedicated to hot issues in plant biotechnology discussing the use and the achievements of genetic engineering in view of their possible associated risks (Blume, 2002). Only twenty years have passed, and these issues have noticeably lost their sharpness, because genome-edited products, which have resulted from the successful implementation of CRISPR technologies, have entered the consumer market. Ten years ago, within the framework of the journalism project Ukraine Next—a daily magazine in 24 h (https://issuu.com/ukrainext/docs/ukrainext), in the essay "Our place in the biological tomorrow", I briefly outlined my vision about the perspectives in biology and biotechnology. I was under the spell of the opening lecture given by Craig Venter at the congress of the European Federation of Biotechnologists held in Barcelona (2009). The man who, depending on the party, is either called an adventurer or a "superstar" was the one who, in June 2000, together with Francis Collins and in the presence of US President Bill Clinton, announced the deciphering of the complete human genome sequence. In Barcelona, he talked about the synthesis of the first living organism in the history of mankind, the so-called laboratory mycoplasma (*Mycoplasma laboratorium*). This organism contained in its genome the minimum possible set of genes, all synthesized artificially. It was at that time that I wondered: "What are we going to talk about in ten years' time?"

Now, that even more years have passed by, living material assembly of bacteriogenic protocells is a fact (Xu et al. 2022). Thousands of genomes of bacteria, fungi, animals and plants have been deciphered. By next-generation sequencing or high-throughput sequencing methods, we can now decode individual human genomes in a week and at reasonable cost (300–400 US dollars). What all this mean? At the very least, this announce the outbreak of a revolution in the way of diagnosing hereditary diseases which will soon bring us at the threshold of an indivual, "personalized" medicine. Hence, we can now cultivate legitimate hopes about the cure of some of the most relevant human diseases such as cancer, diabetes, Alzheimer's and Parkinson's, osteoporosis, cystic fibrosis and other illnesses.

Associated to this there are also new ways of developing pharmacology and gene therapy as well as further developments in synthetic biology. The time is not far off when we will be able not only to transfer blocks of genes to reproduce the synthesis of complex biomolecules or induce change in metabolic pathways, but also to work out reliable tools for developing entirely new organisms and cell factories fueled for a given purpose.

The beginning of the third millennium was marked by the birth of another new science discipline that is stem cell biology. While it is well known that each individual cell acts as a universal unit for the implementation of all the molecular biological processes, based on its inherent genetic information, it is the stem progenitor cells that are in charge of the correct cell reproduction and differentiation processes in a multicellular organism. Accordingly, the stem cells play a fundamental role in the development of modern biotechnology. In fact, stem cells can be isolated from any multicellular organism, propagated outside the body, and then differentiated into different tissues and even organs, which can then be used for transplants. Every month we receive new evidence of progress in this cutting edge technology. Literally, while writing these lines, I have read information about obtaining a mouse embryo with a beating heart from stem cells (Amadei et al. 2022).

I keep in my library the book "Life at the Speed of Light: From the Double Helix to the Dawn of Digital Life" with a gift signature of its author—the very same Craig

Venter I mentioned above. When I first heard his story about teleporting biological life to Mars, I was quite skeptical, to say the least. However, after carefully re-reading this book and comparing the author's thoughts with the seven-mile steps of genomics (O'Brien 2022), I am now well aware that the time is not far off, when the transfer of ordered genetic information for the purpose of reproducing a living organism at a distance will become as much a reality as the 3-D printing is today.

These are just a few words about the role of modern biology in the development of modern society and although it is not very easy to extrapolate them to predict what is stored for tomorrow, we understand that the cultural and technical progress based on Science cannot be stopped. It feeds an irreversible flow as it is that of our lives. So better we take time to think about it and see where and how we can possibly control its development. What can and should we do to make the fantasy of tomorrow a reality in our society? What will we use as a fulcrum to turn the world upside down? First of all, an unlost taste for serious science, which is not always appreciated by those on whom its further development ultimately depends such as: young people, who still hope to realize their professional knowledge and skills and human "islands" in academic institutions that have retained the ability to adequately perceive today's challenges and maintain decent positions thanks to their openness to the outside world and strong dedication to work. In our society, it is necessary to constantly fight for promoting both trust in science and respect for scientists. It is necessary to support those "islands" that tomorrow may grow to become a land and form new continents. Not only civil society, but also politicians should not only listening to them, but also realize that the future of their country directly depends on their ability to ensure the development of advanced science. And biology is a vivid example of how new realities that we sometimes don't see or don't want to see, are already knocking at our doors. For us, these realities are a hope for a better medicine, a healthy food, a healthy environment and an efficient economy.

4 Advice to the New Generation of Scientists

Certainly, my assertions about science, my own accomplishments in it and the vision of what place the biological science occupies in nowadays society and where it is going, are based on my personal life experience and achievements. However, I think it is appropriate to add here that technological progress and human welfare can only be successfully obtained by promoting the integration of Science with humanities, overcoming any kind of spurious segregation, concerning age or professional specificity. In other words, we, as a scientists and mentors, must fruitfully interact with the younger generation in the effort of making them better than us, as good parents aim to do for their children.

Although I already mentioned that, from the very beginning of my professional career, daily occupation as a teacher at the university did not particularly attract me, and I preferred to work for a scientific institution, I very quickly felt the need to build bridges between the research institute where I was working and the university where I used to study.

That is why, I enthusiastically supported Yuri Gleba's proposal to set up a Department of Cell Biology and Genetic Engineering as a shared body between the university and the institute to directly raise the best graduates to work at our institute. However, when this happened, it cost me a lot of effort to organize the tuition process at the Department, to select students and engage them in the research activities carried out at our academic Institute. Afterward, when I headed the joint Department, my research laboratory, being an integral part of the academic institute, remained for a long time based at the Faculty of Biology at the University. Nonetheless, this work has turned out to be rather rewarding, since, at each wave of new entries, our Institute is often chosen by the best students. Only then, due to the freedom of choice in shaping the tuition syllabus, I began to enjoy my work of university lecturer teaching several courses, also with the help and contribution of Alla, my wife. More importantly, we were capable of involving the best professionals from the National Academy of Sciences, including those institute staff who at that time, were working abroad, as well as foreign colleagues. I recollect with pleasure, how in 1997 some of the lectures of my course on the cytoskeleton were given by Prof. Peter Nick, who at that time worked at the University of Freiburg. Having successfully defended her Ph.D. Thesis, Alla Yemets joined the teaching by giving lectures for our students. Her contribution to the development of the Department became especially tangible after her prolonged internship at the Syngenta Genomic Centre in Jealott's Hill, UK (International Research Centre now) in 2004.

After Ukraine had signed the Bologna Declaration in 2005, a gradual transformation of educational programs for university students was launched, and we continued training a separate group of master studentsi at the Department of General and Molecular Genetics where cell biology has become a separate educational program for MSc degree. In 2019, I was invited to take the position of professor at the Department of Biochemistry. Currently, Alla continues teaching genetics, while providing her share to our common course on genomics which I took over when the works on the decoding of the Arabidopsis (The Arabidopsis Genome Initiative 2000) and the human genome (Venter et al. 2001) were published. It was at that time that I received an invitation from the National University of Kyiv-Mohyla Academy to prepare, for the first time in Ukraine, a course on genomics. A year later, Alla and I started teaching such a course also at Kyiv National University. Actually, this was the beginning of my personal journey into the world of genomics which, apart teaching, contributed to the further expansion of my scientific interests and the initiation of new directions of my research. Among those students there was Rostyslav, our son, who started there his actual career of young scientist and continues it at the National Academy now as Ph.D. student (Blume et al. 2022b).

Nonetheless, our work with young people has never been limited to the training of university students. A feature of our academic system has been, and still remains, the fact that research institutes have always had Ph.D. programs and have been supporting Ph.D. and Dr.Sci (Hab.) defense degrees. For the past five years, our institute has already been training young scientists under new Ph.D. programs, which have become the next educational level (after the MSc degree) on the way to a scientific career. This meant that we had to be licensed and accredited as an educational body, like any other classical university. In total, under my supervision and during this time period, 30 young scientists received a Ph.D. degree, and 6 scientists more, those who had me as the scientific advisor for the preparation of their Doctor of Sciences degree theses. The National Academy of Sciences of Ukraine acknowledged these achievements by awarding me with the honours “For Training New Academic Generation” (2017). It is quite natural that behind each of such cases of personal mentoring there has been a separate story of human relationships.

For such bilateral interactions, tutor-apprentice, to be effective and lead to the desiderable result, one needs to master a rare and precious quality throughout all his/her professional and personal life: listen to the opinions and the arguments of other scientists and people with extreme respect and full interest. It is not good enough to be curious and original, it is important to feel in somebody else’s shoes, at least try to be quite tolerant in all aspects and quite warm toward people. Of course, this applies not only to the model of interaction between the mentor and his/her students, but also to the principles of building healthy and productive relationships between the manager and his/her subordinates.

At the same time, it is important to instil in young scientists the ability to honestly assess their attitude to science and find their own, specific interests in it. If for this purpose they need to change the team, and this might look the best way for effective professional growth, then they must do so. In accordance, they may apply to a different scientific topic or even move to another country being prepared and determined to follow it forward. These changes are expecially recommended, if one feels inadequate in his/her current niche of investigation, or feels a lack of fair judgments about his competence, value and a personal attitude. Also, if it turns out that your ambitious goals are unattainable, do not dispair since, once you have acquired a certain amount of scientific knowledge, there are many other parallel pathways to gratify yourself in the world of science that could fit you better, such as: technology transfer and business, and public educational activities. Anyhow, my most strong recommendation is to do as much as you can in science and for science, so as not to reproach yourself later for not doing something you could have done. This applies not only to my teaching and relations with young scientists. This is the motto of my own life.

References

Amadei G, Handford CE, Qiu C, De Jonghe J, Greenfeld H, Tran M, Martin BK, Chen D-Y, Aguilera-Castrejon A, Hanna JH, Elowitz MB, Hollfelder F, Shendure J, Glover DM, Zernicka-Goetz M (2022) Embryo model completes gastrulation to neurulation and organogenesis. Nature 610:143–153. https://doi.org/10.1038/s41586-022-05246-3

Aslamova LI, Blume (Blyum) YB, Tsudzevich BA, Kucherenko NE (1983) Study of DNA synthesis in the liver of rats exposed to X-radiation and treated with serotonin after the removal of the cycloheximide block. Radiobiologiya 23(2):157–160

Aslamova LI, Blume (Blium) IB, Tsudzevich BA, Kucherenko NE (1984) Synthesis and phosphorylation of histones and nonhistone proteins as affected by irradiation and serotonin in cycloheximide-synchronized hepatocytes. Radiobiologiia 24(4):445–450. PMID: 6473720
Bannister A, Kouzarides T (2011) Regulation of chromatin by histone modifications. Cell Res 21:381–395. https://doi.org/10.1038/cr.2011.22
Blum OB, Kashevarov GP (1986) The DNA homologies as a proof of the legitimacy of the establishment of the lichen genera *Lasallia* Merat (Umbilicariaceae). Dok Akad Nauk Urk SSR Ser B 1986:61–64
Blume (Blium) IB (2002) Biotekhnologiia v sovremennom mire: pol'zai riski [Biotechnology in the modern world: benefits and risks]. Tsitol Genet 36(1):59–79 (in Russian). PMID: 12012599
Blume RY, Rakhmetov DB, Blume YB (2022a) Evaluation of Ukrainian *Camelina sativa* germplasm productivity and analysis of its amenability for efficient biodiesel production. Ind Crop Prod 187(Part B):115477. https://doi.org/10.1016/j.indcrop.2022.115477
Blume RY, Yemets AI, Korkhovyi V, Radchuk V, Rakhmetov DB, Blume YB (2022b) Genome-wide identification and analysis of cytokinin oxidase/dehydrogenase (ckx) gene family in finger millet (*Eleusine coracana*). Front Genetics 13:963789. https://doi.org/10.3389/fgene.2022.963789
Blume YB, Nyporko AY, Yemets AI, Baird WV (2003) Structural modeling of the interaction of plant α-tubulin with dinitroaniline and phosphoroamidate herbicides. Cell Biol Int 27(3):171–174. https://doi.org/10.1016/S1065-6995(02)00298-6
Blume YB, Yemets AI, Sulimenko V, Sulimenko T, Chan J, Lloyd C, Draber P (2008) Tyrosine phosphorylation of tubulin in plant cells. Planta 229(1):143–150. https://doi.org/10.1007/s00425-008-0816-z
Borisy GG, Taylor EW (1967) The mechanism of action of colchicine. Colchicine binding to sea urchin eggs and the mitotic apparatus. J Cell Biol 34(2):535–548. https://doi.org/10.1083/jcb.34.2.535
Borisy G, Heald R, Howard J, Janke C, Musacchio A, Nogales E (2016) Microtubules: 50 years on from the discovery of tubulin. Nat Rev Mol Cell Biol 17(5):322–328. https://doi.org/10.1038/nrm.2016.45
Borovaya MN, Naumenko AP, Matvieieva NA, Blume YB, Yemets AI (2014) Biosynthesis of luminescent CdS quantum dots using plant hairy root culture. Nanoscale Res Lett 9(1):2407. https://doi.org/10.1186/1556-276X-9-686
Breviario D, Gianì S, Morello L (2013) Multiple tubulins: evolutionary aspects and biological implications. Plant J 75:202–218. https://doi.org/10.1111/tpj.12243
Brinkley W (BR) (1997) Microtubules: a brief historical perspective. J Struct Biol 118(2):84–86. https://doi.org/10.1006/jsbi.1997.3854
DePriest PT (2004) Early molecular investigations of lichen-forming symbionts: 1986–2001. Ann Rev Microbiol 58:273–302
Frey PA (2002) Surprises and revelations in biochemistry: 1950–2000. Biochem Mol Biol Educ 30:152–162. https://doi.org/10.1002/bmb.2002.494030030067
Gleba Y (1995) Cellular genetic engineering of plants. Euro Rev 3(2):113–117. https://doi.org/10.1017/S1062798700001411
Grodzinsky DM (1976) Plant Biophysics (Translated from Russian). Keter Publishing House, Jerusalem, p 236
Korzh VP (2008) Sergei Gavrilovich Navashin: two anniversaries. Cytol Genet 42:139–146. https://doi.org/10.3103/S0095452708030018
Kumar A, Cocking EC (1987) Protoplast fusion: a novel approach to organelle genetics in higher plants. Ame J Botany 74:1289–1303. https://doi.org/10.1002/j.1537-2197.1987.tb08742.x
Ledbetter MC, Porter KR (1964) Morphology of microtubules of plant cells. Science 144:872–874. https://doi.org/10.1126/science.144.3620.872
O'Brien SJ (2022) A decade of GigaScience: A perspective on conservation genetics. GigaScience. 11:giac055. https://doi.org/10.1093/gigascience/giac055
Olins AL, Olins DE (1974) Spheroid chromatin units (v bodies). Science 183(4122):330–332. https://doi.org/10.1126/science.183.4122.330

Osipian AL (2018) The Last Pharaoh of Ukraine's Science. Inside Higher Ed. Retrieved 21 Feb 2018. https://www.insidehighered.com/blogs/world-view/last-pharaoh-ukraine%E2%80%99s-science
Smertenko A, Blume YB, Viklický V, Opatrný Z, Dráber P (1997) Posttranslational modifications and multiple isoforms of tubulin in *Nicotiana tabacum* cells. Planta 201(3):349–358. https://doi.org/10.1007/s004250050077
Sutherland EW (1972) Studies on the mechanism of hormone action. Science 177:401–408
The Arabidopsis Genome Initiative (2000) Analysis of the genome sequence of the flowering plant *Arabidopsis thaliana*. Nature 408:796–815. https://doi.org/10.1038/35048692
Venter JC, Adams MD, Myers EW, Li PW, Mural RJ et al (2001) The sequence of the human genome. Science 291(5507):1304–1351. https://doi.org/10.1126/science.1058040. Erratum In: Science (2001) 292(5523):1838
Verkhratsky A, North RA, Petersen OH, Krishtal O (2010) In memoriam: Platon Kostyuk (1924–2010). Cell Calcium 48(1):91–93. https://doi.org/10.1016/j.ceca.2010.07.003
Weisenberg RC, Borisy GG, Taylor EW (1968) The colchicine-binding protein of mammalian brain and its relation to microtubules. Biochemistry 7(12):4466–4479. https://doi.org/10.1021/bi00852a043
Xu C, Martin N, Li M, Mann S (2022) Living material assembly of bacteriogenic protocells. Nature 609:1029–1037. https://doi.org/10.1038/s41586-022-05223-w
Yemets AI, Baird WV, Blume YB (2008) Modified tubulin genes as selectable markers for plant transformation. In: Blume YB, Baird WV, Yemets AI, Breviario D (eds) The plant cytoskeleton: key tool for agro-biotechnology. Springer, Nertherlands, pp 435–454. https://doi.org/10.1007/978-1-4020-8843-8_21
Yemets AI, Krasylenko YA, Lytvyn DI, Sheremet YA, Blume YB (2011) Nitric oxide signaling via cytoskeleton in plants. Plant Sci 181(5):545–554. https://doi.org/10.1016/j.plantsci.2011.04.017
Yemets A, Plokhovska S, Pushkarova N, Blume Y (2022) Quantum dot-antibody conjugates for immunofluorescence studies of biomolecules and subcellular structures. J Fluoresc 32:1713–1723. https://doi.org/10.1007/s10895-022-02968-5

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