Current status and prospects of plant biotechnology in Kazakhstan

Kabyl Zhambakin1 · Kuanysh Zhapar1

Received: 12 December 2019 / Accepted: 29 January 2020 / Published online: 11 February 2020 © The Author(s) 2020

Abstract
Biotechnological methods are becoming an integral part of biological research. This review presents some of the most significant scientific results of Kazakhstan biologists in the field of plant biotechnology over the past 10 years. One of the recent important areas of application of biotechnological methods is the conservation and study of plant genetic resources and bioremediation. Studies on the flora lead to the identification of new sources of previously unknown biologically active materials, especially among wild plants growing in Kazakhstan. In addition, various biotechnological approaches are used to increase the efficiency of breeding practices for the production of new crop varieties.

Keywords Kazakhstan · Biotechnology · Plant breeding · Molecular markers · Phytoremediation · Genetic resources

Introduction
The current status of plant biotechnology in Kazakhstan is characterised by a certain improvement, which is undoubtedly a result of the development of biotechnological approaches for preserving and exploring genetic resources, bioremediation, crop breeding as well as medicinal applications. However, it should be noted that the main reason why Kazakhstan remains far behind the developed countries is insufficient funding of science. Particularly, over the past 3 years, the total cost of research and maintenance of the infrastructure of scientific organisations did not exceed 0.17% of the country’s GDP (Belyaeva et al. 2019) (Fig. 1), which is significantly lower than that of the neighbouring countries such as Russia (1.1%) and Uzbekistan (0.19%) (World Bank Data 2017). Lack of funding most negatively affects fundamental sciences, such as plant biology. Nevertheless, Kazakhstan has achieved some progress in the development and use of modern biotechnological methods, such as plant cell and tissues culturing, molecular marking and genetic engineering. A number of scientific institutions and universities are involved in plant biotechnology research, and most of the significant and promising results in this area have been obtained by the Institute of Plant Biology and Biotechnology (IPBB, Almaty), the National Center for Biotechnology (NCB, Nur-Sultan), Aitkhozhin Institute of Molecular Biology and Biochemistry (IMBB, Almaty), Al-Farabi Kazakh National University, (KazNU, Almaty) and L.N. Gumilyov Eurasian National University (ENU, Nur-Sultan).

Fundamental research
Fundamental biological science in Kazakhstan was developed in the middle of the last century and is mainly associated with the large-scale development of virgin lands. Most cutting-edge studies are performed in the area related to the development of crop resistance to environmental stress factors due to the sharp continental climate of Kazakhstan. With the collapse of the Soviet Union and the subsequent destruction of the infrastructure of scientific institutions, as well as the system of training scientists, fundamental research in the country was significantly restricted. However, over the past 10 years, the interest in fundamental science has been growing due to joint projects with leading global research institutions.

Some research institutions with projects that showed the most promising results in plant biotechnology are presented below.

Advanced research in cell biology and molecular genetics is being conducted at L.N. Gumilyov Eurasian National University, including the effect of viral infection on the
activation of oxidative stress enzymes in plants. For the first
time, the role of the enzyme aldehyde oxidase in the activation
of plant defence mechanisms as a response to viral path-
ogen invasion is shown. Moreover, the study demonstrated
the participation of the viral suppressor of RNA interference
in the increase of reactive oxygen species levels in plants. An
important role of molybdenum ions in the development and
elongation of barley root system was also discovered; this
metal had a stimulating effect on salt resistance (Batyshina
et al. 2018).

Al-Farabi Kazakh National University has traditionally
been holding the leadership in biochemistry. For instance,
a study conducted in 2014 determined that the putative
wheat AP endonuclease, referred to as TaApe1L, contains
AP endonuclease, 3′-repair phosphodiesterase, 3′-phos-
phatase and 3′→5′ exonuclease activities. Surprisingly, in
contrast to bacterial and human AP endonucleases, adding
Mg²⁺ and Ca²⁺ (5–10 mM) to the reaction mixture inhib-
ited TaApe1L activity, whereas the presence of Mn²⁺, Co²⁺
and Fe²⁺ cations (0.1–1 mM) strongly stimulated the DNA
reparation activity. After the optimisation of the reaction
conditions, it was found that wheat enzyme requires a low
divalent cation concentration (0.1 mM), a slightly acidic pH
(6–7), a low ionic strength (20 mM KCl) and a temperature
at around 20 °C. Steady-state kinetic parameters of enzy-
matic reactions indicate that TaApe1L removes 3′-block-
ing sugar-phosphate and 3′-phosphate groups with high
efficiency (kcat/KM = 630 and 485 µM min, respectively),
but possesses an extremely low AP endonuclease activity in
comparison to human homologue APE1 (Joldybayeva et al.
2014).

The IMBB was the first to establish a new cap-independent
mechanism of mRNA binding to the 40S ribosomal sub-
unit during translation initiation in plants. This mechanism
is explained by a complementary interaction between the
5′-untranslated sequence (5′-NTP) of mRNA and the central
domain of 18S rRNA. It was experimentally proven that the
increasing level of 5′-NTP complementarity to this 18S
rRNA region leads to a multiple increase in the efficiency
of mRNA translation. The results are highly important not
only in fundamental, but also in applied science, allow-
ing to construct artificial mRNAs with high translational
activity. These highly active mRNAs are necessary in cell-
free protein synthesis technology and in genetic engineer-
ing to obtain transgenic plants producing valuable proteins
(Akbergenov et al. 2003, 2004).

The IPBB has developed a highly sensitive and highly
specific identification system for Erwinia amylovora, a
causative agent of bacterial burn in fruits, which is based
on the loop isothermal amplification (LAMP) method, which
does not require agarose gel electrophoresis. It only needs
an amplifier with the ability to conduct analyses in the field,
and this system is 100–1000 times more sensitive than PCR
(Galiakparov et al. 2019).

Conservation and study of genetic resources
of the Kazakhstan flora

Traditionally, biological diversity in Kazakhstan has been
the basis of biological research in the country. Kazakhstan
has rich and diverse natural resources, and studying these
resources is not only important from a fundamental point of
view, but also carries a huge potential in applied science. In
this regard, for the first time in Kazakhstan, the IPBB has
developed a modern technique for the cryopreservation of
plant tissues and organs in liquid nitrogen (− 196 °C), which
is used for reliable and long-term preservation of valuable
genetic materials in a viable state. A cryogenic collection
of economically important crops (varieties, hybrids and
wild forms of apple, currant, raspberry, cherry, strawberry,
grape, potato, rice, etc.) has been established and is con-
stantly being updated. A list of cultures in the collection was
included in the Botanic Gardens Conservation International
(BGCI) database (Romadanova et al. 2016a). Cryopreser-
vation is not only used for the long-term preservation of
the plant genetic diversity in Kazakhstan, but also for the
recovery of crops from phytopathogens (Kushnarenko et al.
2017; Romadanova et al. 2016b).

Modern genomic technologies and bioinformatics are
widely used to study the genetic diversity of endemic,
rare, endangered and wild-growing valuable plant species
of Kazakhstan. In a study conducted in IPBB, three DNA
markers, namely ITS, matK and rbcL were selected to ana-
lyse the genetic diversity of the collected plants. The ITS is
a hallmark of the nuclear genome, whereas matK and rbcL
are markers of the chloroplast genome. Results of the study
were used for the statistical analysis of population diversity,
using the MEGA 6 software. Genetic diversity was studied
at intraspecific, intrageneric and intrafamily levels of plant organisation. Based on the phylogenetic analysis of the studied plant molecular systematics, hypotheses on speciation processes were put forward on examples of studies of individual species, genera and families (Abugalieva et al. 2017; Almerekova et al. 2017; Turuspekov et al. 2017a, b).

Kazakhstan flora in pharmacology

Kazakhstan contains a great variety of medicinal plants that produce phytochemicals with high biological activity. In particular, species such as licorice and kok-saghyz are among the most popular ones.

Licorice (Glycyrrhiza glabra L.) is widely used in Kazakhstan as a medicinal plant both for therapeutic and preventive purposes. The interest in studying this plant is growing due to its in vitro antitumor activity on human myeloid leukaemia.

Nowadays, myeloid leukaemia is a serious issue in Kazakhstan, calling for the development of novel therapeutic approaches based on the use of plant phytochemicals with anti-leukaemic activity. For instance, a joint study done by IPBB and the Ben Gurion University of Negev (Beer Sheva, Israel) in 2014 showed that licorice root extract inhibited the growth of leukaemia cells (Bari et al. 2014).

Another promising plant species is kok-saghyz (Taraxacum kok-saghyz), also known as Kazakh dandelion or Russian dandelion, which is listed in the Red Book of Kazakhstan and thereby protected by the Government. Roots of this plant accumulate high amounts of natural rubber (up to 27%) and inulin (up to 40%). Natural rubber of kok-saghyz does not cause allergies and is used in the manufacturing of a number of medical products, such as gloves for surgeons.

Inulin is a polysaccharide with prebiotic properties and used as a part of preventive and therapeutic measures for patients with type II diabetes as well as for people in risk groups, such as those with hereditary factors (Uteulin and Baitulin 2017). The IPBB is the author of the first Kazakhstan variety of Dandelion kok-sagyz “Saryzhaz”. Saryzhaz roots contain up to 40% of inulin polysaccharide and up to 10% of non-allergenic natural rubber for the manufacturing of a wide range of medical products (Uteulin et al. 2018).

Nowadays, Kazakhstan researchers are discovering new sources of valuable phytochemicals to apply in pharmacology. The international research and production holding “Phytochemistry”, located in Karagandy City, is one of the world-leading organisations developing plant-derived medicines. On the basis of the laboratory, a full technological cycle has been developed from the production of medicinal raw materials, including its processing, to the release of finished dosage forms of phytopreparations. They have studied over 500 species of plants growing in Kazakhstan, of which more than 400 showed promising results in terms of obtaining new biologically active compounds. Up to today, 72 new original herbal remedies have been developed and introduced into production. More than 2000 new derivatives have been synthesised, a number of which showed significant antimicrobial, antiviral, antifungal, antitumor, analgesic, phagocyte-stimulating, anthelmintic, neurotropic and other types of activities (Adekenov 2016, 2017; Schepetkin et al. 2018; Suleimenov et al. 2010).

The IPBB identified valuable sources of essential oils in the wild flora of Kazakhstan. For the first time, the components of the essential oils of Kotukh wormwood (Artemisia kotuchovii Kupr.), Ili honeysuckle (Lonicera iliensis Pojark.) and Iliy ferula (Ferula iliensis Krasn. Ex Korovin) (Schepetkin et al. 2015; Utegenova et al. 2018) were identified.

Antimicrobial activity against Staphylococcus aureus, Escherichia coli and Candida albicans was determined in seven samples of essential oils, including an endemic species Ferula iliensis (ferula of Ili), in which it was observed for the first time. The antioxidant activity of essential oils was tested in five species from Kazakhstan. For the first time, it was established that the essential oil isolated from ferula of Akichken (Ferula akitschensis) and ferula of Ili (F. iliensis), as well as their six components (sabinene, α-pinene, γ-terpinene, depleated acetate, geranyl acetone and 2-nonenal), activated Ca²⁺ influx into neutrophils. The essential oil obtained from Kotukh wormwood stems inhibited fMLF tripeptide-induced Ca²⁺ entry into human neutrophils, with a minimum inhibitory concentration of 12.5 μg/ml. This is the first mentioning in the scientific literature of the effect of essential oils and their components on the level of Ca²⁺ in human neutrophils (Kushnarenko et al. 2016; Schepetkin et al. 2016).

Phytoremediation

Nowadays, worldwide threats to ecosystems and biodiversity are multi-dimensional, from localised habitat loss because of pollution to the global effects of climate change. Soil contamination by xenobiotics around industrial areas in agriculture, oil and gas complexes, mining and processing industries as well as military test sites considerably threatens environmental and human health. One of the essential steps to prevent toxic effects of pollutants on the environment and human health is the remediation of contaminated soils, either via the separation of xenobiotics from the soil or via physicochemical soil treatment. These technologies are extremely energy-intensive and require large investments. As worldwide practice shows, phytoremediation is the most cost-effective and environmentally friendly method.
of restoring contaminated soils, representing a good alternative to physical or chemical methods of reclamation.

According to the “International Scientific and Technical Programs and Projects for 2013-2015”, the project “Developing Phytoremediation Methods for Soils Contaminated with Pesticides based on the Construction of Microbial and Plant Associations” was completed at the IPBB. As a result of the project, the efficiency of phytoremediation of soils contaminated with organochlorine pesticides using plant-microbial symbiotic systems has increased. The advantage of using the recommended wild plants for phytoremediation lies in the absence of expensive purification procedures. Optimising environmental conditions using a natural destructor allows to increase the restoration of land contaminated with persistent organic pesticides (Nurzhanova et al. 2013).

In 2016, the IPBB won a NATO G4867 grant for the project “New Phytotechnology for the Restoration of Contaminated Lands”, the priority “Environmental Protection and the Transition to a Green Economy”; years of implementation 2016-2019. Performers: University of Kansas, USA; National University of Life and Environment, Ukraine; Jan Evangelista Purkyne University, Czech Republic; Lviv Polytechnic National University, Ukraine (Nurzhanova et al. 2019).

Molecular markers in plant breeding

There are several positive examples for the use of molecular markers in crop breeding. At the same time, several factors can limit the implementation of these technologies in practical breeding. Work in this direction should be carried out in close contact with molecular geneticists and breeders. The IPBB formed a deep history of cooperating with the main breeding institutes of the republic for strategic crops for the country.

Wheat production in Kazakhstan is seriously constrained by several biotic stresses, including rust diseases (stem, stripe and leaf rusts) and leaf spotting diseases (tan spot, Septoria tritici blotch).

Of the 170 wheat entries screened for predominant stem rust, Puccinia graminis f. sp. tritici races from Kazakhstan and Kenya, 21 entries resistant to Kazakhstan Pgt races and 10 entries resistant to race Ug99 were identified. The genes Sr24/Lr24 were identified in seven wheat entries (Kokhmetova et al. 2011).

The evaluation of Central Asian wheat germplasm for stripe rust Puccinia striiformis f. sp. tritici (Pst) resistance allowed to select the lines KR12-18 (#18) and KR11-03 (#5) as new varieties in Uzbekistan and Georgia, respectively. Analyses of 152 Kazakhstan Pst samples showed avirulence of Yr5, Yr10 and Yr15 genes. The genes Yr1 in KR12-5075 and Yr6 in KR11-03 and KR12-5003 were postulated (Kokhmetova et al. 2018a, b).

To effectively use leaf rust Puccinia recondita f. sp. triticici resistance genes, (Lr) winter wheat entries for the presence of important Lr genes were screened, and 17 out of 30 entries carried Lr1, while six carried Lr26 and Lr34, three carried Lr10 and Lr37, two carried Lr19 and Lr68. The highest resistance was found in five Kazakh and in two foreign cultivars (Kokhmetova et al. 2016).

A collection of 64 common wheat germplasms was evaluated for tan spot Pyrenophora tritici-repentis resistance in greenhouse, using the molecular marker Xfcp623, diagnostic for the Tsn1 gene. Most of the entries were susceptible to Ptr race 1. As a result, 27 wheat entries with resistance to race 1, combined with resistance to Ptr ToxA and field resistance, were selected (Kokhmetova et al. 2019).

Sensitivity to Ptr ToxB is not always correlated with susceptibility to race 5 and is dependent on the genetic background of the host. These results are a subject of interest for increasing the efficiency of breeding, based on the elimination of genotypes with dominant alleles Tsn1 and Tsc2, sensitive to toxins Ptr ToxA and ToxB (Kokhmetova et al. 2018a, b).

Molecular genetic certification of domestic apple cultivars grown in Kazakhstan was also carried out, in which disease-resistant genotypes of domestic and wild apple trees were identified. A DNA bank of 71 domestic apple cultivars growing in Kazakhstan was established at the IPBB, revealing differences between the genotypes of some apple cultivars. For the first time, a molecular-genetic approach was applied using markers based on chloroplast DNA. Data on 17 microsatellite and 2 chloroplast markers were used to create genetic passports of 71 apple cultivars. Varieties and genotypes of wild apple trees with one or both loci associated with resistance to bacterial burns were identified; one of the genotypes resistant to apple bacterial burn is also potentially resistant to scab (Omasheva et al. 2018).

The Institute of Plant Biology and Biotechnology was a member of the 7th European framework program “Genetics and Physiology of Wheat Development before the Flowering Phase: New Selection Methods to Improve Adaptation and Yield Potential”. The consortium included 20 research teams from around the world, with a project duration from 2012 to 2015. Within the framework of the program, 90 spring wheat varieties of Kazakhstan, registered in the GSI Ministry of Agriculture of the Republic of Kazakhstan, were genotyped using a chip for 90,000 SNP markers, applying the new-generation technology of Illumina Ltd. Results were obtained for 65,000 SNP markers, of which 35,000 were identified as polymorphic for the studied 90 varieties. The same set of varieties was simultaneously studied in the field of breeding institutions in Northern, Central and Southern Kazakhstan (Turuspekov et al. 2017a, b).
In collaboration with the John Innes Center (Norwich, UK), a genetic map of hexaploid wheat from crossing varieties of Pamyat Aziev (Russia) and Paragon (Great Britain) was constructed. The genetic population of common wheat consists of 92 recombinantly inbred lines, studied using the Illumina chip technology for 15,000 SNP markers (Amalova et al. 2019).

The IPBB developed DNA passports of domestic varieties of wheat, barley, rice, oats, soybeans, using DNA markers. Valuable genotypes of wheat and barley were identified and characterised by high yields and grain quality. For the first time, using the associative gene mapping method, new DNA markers were identified, which are associated with resistance to the most dangerous barley diseases in Kazakhstan—stem rust and dark brown spotting. The results obtained here allow breeding studies of grain and leguminous crops at the genomic level (Abugalieva et al. 2016; Kokhmetova et al. 2017; Turuspekov et al. 2016; Volis et al. 2016).

In cooperation with the Ministry of Agriculture and independently over the past few years, the IPBB created and transferred to the state variety test new highly productive and stress-resistant environmental varieties of agricultural crops (12 varieties—wheat, barley, rice).

**Cell and tissue culture in plant breeding**

On a global level, there is a high competition among varieties and hybrids of crops, which has led to the fact that along with traditional methods of selection, biotechnologies are intensively applied to increase the efficiency of the selection process. In particular, in vitro culture allows selection at the level of cells and tissues for tolerance to environment stress factors, enhancing selection mutagens. Somatic cells and tissues, isolated microspores and nuclei of distant hybrids, etc. are used as explants. All of these methods are widely used in scientific studies in Kazakhstan.

In the IPBB, on the basis of haploid biotechnology, double haploid interspecific hybrid rapeseed lines with rape and mustard are created as the starting material for creating drought-resistant domestic rapeseed varieties. At the same time, a GISH analysis of plants showed the presence of donor sections of chromosomes of *Brassica rapa* and *Brassica juncea* in the genome of doubled haploids of rape hybrids, which confirmed the successful hybridisation process. Assessment of drought tolerance during germination of doubled haploid interspecific hybrid seeds on PEG 6000 showed the superiority of hybrid seeds during germination and the relative water content in seedlings, which proves the superiority of hybrid forms in relation to the parent. Double haploid interspecific hybrid lines are transferred to Kazakhstan breeding centres specialising in the breeding and testing of new varieties of rapeseed.

Based on cell and tissue culture methods, perspective lines of wheat, barley, sorghum, rape, safflower and rice with economically valuable traits are created for inclusion in breeding programs, aiming at the creation of new varieties (Rysbekova et al. 2016; Zhambakin et al. 2014).

The IPBB has developed a viral vector using a deconstructed virus strategy for the production of recombinant vaccines against sheep pox virus (SPPV), in addition to proteins significant for medicine (human alpha-fetoprotein, hAFP) (Chervyakova et al. 2016).

**Genetic engineering**

Genetic engineering is the most effective method for obtaining plant lines with targeted traits, in particular against the background of the recent developments in molecular genetics.

The IMBB has been using methods for producing transgenic plants resistant to phytopathogenic viruses, drought and cold for a long time, developing transgenic tobacco and potato plants expressing antisense RNAs complementary to different regions of the genomic RNA of the potato virus Y. Several lines of transgenic potato were submitted for experiments to the Institute of Potato and Vegetables (NIIKOH) of the Ministry of Agriculture of the Republic of Kazakhstan, and numerous lines of transgenic potato showed significant resistance to Y-virus and are therefore promising for further selection. By inducing RNA interference, GM potato lines with multiple resistance to the viruses PVY, PVM, PVS (Karpova et al. 2017) were obtained.

There are highly developed new technologies for the production of transgenic bacteria and plants as well as transplastomic plants to produce recombinant vaccine proteins against sheep pox virus (SPPV), in addition to proteins significant for medicine (human alpha-fetoprotein, hAFP) (Chervyakova et al. 2016).

The IPBB has developed a viral vector using a deconstructed virus strategy for the production of recombinant proteins in plants. The genome of the grape virus A has been...
modified to clone a recombinant gene instead of the virus envelope protein gene. The bird flu hemagglutinin (HA) gene is cloned into the viral vector, and using agroinfiltration of *N. benthamiana*, the HA gene is transiently expressed in plants and isolated by metal chelate chromatography (Gritsenko et al. 2019). As a result, transgenic rapeseed lines resistant to abiotic stress factors were obtained.

The IPBB employees, in cooperation with the IMBB, the genetic agrotransformation of the rape haploid plants hypocotyls with the target *AtCBF3* gene has been performed. Cytological analysis for ploidy was carried out, followed by doubling of the chromosomes and transplanting into the soil under controlled conditions. Dihaploid transgenic lines were obtained, and the desired insert and transgene expression was confirmed. The obtained lines showed increased resistance to cold compared with the control under laboratory conditions (Nargilova et al. 2014).

For more than 5 years, the IPBB, in collaboration with the Korean Research Institute of Bioscience and Biotechnology (KRIBB), has been jointly researching the introduction of sweetpotato into Kazakhstan (Daurova et al. 2017, Daurov et al. 2018). However, sweetpotato is still not grown at an industrial scale in Kazakhstan, despite its value for a healthy diet.

First experiments on the cultivation of sweetpotato in Kazakhstan have shown certain risks associated with low positive temperatures that may occur in South Kazakhstan during the growth period.

In this regard, further joint research aimed at obtaining cold-resistant lines of sweetpotato, using genetic transformation. Promising genes were identified, including for *IbCBF3*, *IbBZR1* and *IbWRKY31* (Zhapar et al. 2019). According to literature data, those genes play key roles in plants under abiotic and biotic stress. A construct with target genes and the stress-inducible promoter SWPA2 was created; stress-inducible promoters were chosen as they are regulated by stress factors that trigger the expression mechanisms.

An Agrobacterium transformation with the target genes (*IbCBF3*, *IbBZR1*, *IbWRKY31*) was also carried out and transgenic plants were obtained; those plants will be tested for resistance to abiotic stresses.

In the future, due to the achievements of breeding and biotechnology, it will be possible to eliminate the main limiting factors for growing heat-demanding plants in northern regions. In addition, the sustainability and productivity of tropical plants that are already being cultivated will increase.

## Conclusions

This review provides information on the most significant results in the field of plant biotechnology in Kazakhstan. We did not include the results from the production of virus-free planting material of vegetatively propagated crops, since Kazakhstan still has certain problems, despite years of scientific and production work in this area, mainly due to insufficient monitoring of viruses in the planting stock.

Unfortunately, over the past 5 years, no increase in the cost of biotechnological services rendered; on the contrary, in most areas, there was a significant decrease (Belyaeva et al. 2019) (Table 1). This situation is alarming, since the condition of biotechnological services is one of the main indicators of the successful development of the country’s economy.

The further development of plant biotechnology in the country is associated with an acute need for the conservation and study of plant genetic resources at the global level, primarily for practical and commercial purposes. To increase the efficiency of the breeding process, it will be necessary to develop molecular genetics, cellular and genetic engineering, as well as to edit crop genomes. Such a development is impossible without a significant increase in funds, both from state and private investments.

## Acknowledgements

This article was supported by the governmental program of the Republic of Kazakhstan «The Development of Advanced Technologies to Produce Crops Resistant to Stress Factors in Utilizing Adaptive Mechanisms of Plants» (Prog. No. STP O.0798) and «Mutagenesis in vitro for Production of High Quality and High-oleic Oil Lines of *B. napus*, *B. rapa* and their Hybrids» (No. AP05130871).

## Funding

Funding was provided by Ministry of Education and Science of the Republic of Kazakhstan.

## Open Access

This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are...
included in the article’s Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article’s Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Abugalieva S, Didorenko S, Anuarbek S, Volkova L, Gerassimova Y, Sidorik I, Turuspekov Y (2016) Assessment of soybean flowering and seed maturation time in different latitude regions of Kazakhstan. PLoS ONE 11(12):e0166894

Abugalieva S, Volkova L, Genievskaya Y, Ivaschenko A, Kotukhov Y, Sakauova G, Turuspekov Y (2017) Taxonomic assessment of Allium species from Kazakhstan based on ITS and matK markers. BMC Plant Biol 17(2):258

Adekenov SM (2016) Chemical modification of arglabin and biological activity of its new derivatives. Fitoterapia 121:16–30

Akbergenov RZ, Zhanybekova SS, Polimbetova NS, Madin KI, Hohn DK, Abduraimov YO, Mambetaliyev M, Sansyzbay AR, Kovalov YK (2019) Phenotypic variation of common wheat mapping population based on nuclear ribosomal DNA ITS sequences. BMC Plant Biol 17(S1):19–27

Ali AM, Kakimzhanova AA, Karimova VK (2010) Method for producing virus-free potato minitubers at the aeroponic installation. Patent RK N 22559, 2010/06/15.

Almerekova S, Mukhitdinov N, Abugalieva S (2017) Phylogenetic study of the endemic species Oxytropis almaatensis (Fabaceae) based on nuclear ribosomal DNA ITS sequences. BMC Plant Biol 17(1):9–27

Amalova AY, Yermekbayev KA, Griffiths S, Abugalieva SI, Turuspekov YK (2019) Phenotypic variation of common wheat mapping population Panawati Azeya x Paragon in south-east of Kazakhstan. Int J Biol Chem 12(1):71–173

Baryshina Z, Yergaliyev TM, Nurbekova Z, Masalimov ZK, Sagi M, Amalova AY, Yermekbayev KA, Griffiths S, Abugalieva SI, Turuspekov YK, Mukhitdinov NM, Baser КHC, Ozeк T (2016) Investigation of essential oils from three natural populations of Allium turgidum from Kazakhstan and CIMMYT for resistance to tan spot. Vavilov J Gen Breed 22(4):751–753

Batyrshina Z, Yergaliyev TM, Zhatybayeva M, Mambetaliyev M, Sansyzbay AR, Kovalov YK (2019) Comparative assessment of using LAMP method. Patent RK N 33633, 2019/05/14

Bissenbaev AB, Saparbaev M (2014) Cloning and characterization of virus homologue of apurinic/apyrimidinic endonuclease ApelL. PLoS ONE 9(6):e101795

Bisson M, Duret A, Habersetzer S, Crühse M, Hanke C, Hofmann C, Kalender T, Reichmann H, Schirmel A, Voigt S, Wernike A, Weber M, Zipfel P, Liewald D (2019) Comparative assessment of using Miscanthus × giganteus for remediation of soils contaminated by

Daurov AK, Daurov DL, Zhapar KK, Volkov DV, Zhambakin KZ, Shramekova MK (2017) Obtaining transgenic sweetpotato plants with the DREB1A gene. News of NAS RK. Biol Med Ser 2:71–77

Galiakarpov NN, Omashova MY, Smailov BB, Pozhariskiy AS (2019) Set of synthetic oligonucleotides for diagnosis of bacterial blight on fruit crops using of LAMP method. Patent RK N 33633, 2019/05/14

Gritsenko DA, Kenzhebekova RT, Deryabina ND, Galiakarpov NN (2019) Development of a “deconstructed” vector based on the genome of grapevine virus A. Plant Biotechnol Rep 13(2):169–177

Joldybayeva B, Purok P, Grin IR, Zharkov DO, Ishenko AA, Tudek B, Bissenbaev AB, Saparbaev M (2014) Cloning and characterization of a wheat homologue of apurinic/apyrimidinic endonuclease ApelL. PLoS ONE 9(6):e101795

Kakimzhanova A, Karimova V, Magzumova G (2013) Creating valuable forms and varieties of potatoes that are resistant to fungal diseases. Curr Opin Biotechnol 24(1):125

Karpova O, Aleksandrova A, Nargilova R, Iskakov B (2017) Expression of potato virus S gRNA fragments in transgenic potato plants triggers RNA-interference against related and unrelated viruses. J Biotechnol 256:105

Kokhmetova AM, Morganov A, Rsaliyev S, Yessenbekova G, Tyupina L (2011) Wheat germplasm screening for stem rust resistance using conventional and molecular techniques. Czech J Gen Plant Breed 47:146–154

Kokhmetova A, Madenova A, Purnhauser L, Kampitova G, Urazaliev R, Yessenbekova G (2016) Identification of leaf rust resistance genes in wheat cultivars produced in Kazakhstan. Cereal Res Commun 44(2):240–250

Kokhmetova AM, Ali S, Sapapahova Z, Atishova MN (2018a) Identification of genotypes-carriers of resistance to toxins Ptr ToxA and Ptr ToxB Pyrenophora tritici-repentis in collection of common wheat. Vavilov J Gen Breed 22(8):978–986

Kokhmetova A, Sharma R, Rsaliyev S, Galymbek K, Baymagambetova K, Ziyaev Z, Morganov A (2018b) Evaluation of Central Asian wheat germplasm for stripe rust resistance. Plant Genet Resour 16(2):178–184

Kokhmetova A, Atishova M, Kurbabieva M (2019) Phytopathological screening and molecular marker analysis of wheat germplasm from Kazakhstan and CIMMYT for resistance to tan spot. Vavilov J Gen Breed 23(7):879–886

Kushnarenko SV, Karasholakova LN, Ozek G, Abidkulova K, Mukhitdinov NM, Baser KH, Ozek T (2016) Investigation of essential oils from three natural populations of Lonicera ilicis. Chem Nat Compd 52(4):751–753

Kushnarenko S, Romadanova N, Aralbayeva M, Zholamanova S, Alexandrova A, Karpova O (2017) Combined ribavirin treatment and cryotherapy for efficient potato virus M and potato virus S eradication in potato (Solanum tuberosum L.) in vitro shoots. In Vitro Cell Dev Biol Plant 53(4):425–432

Nargilova RM, Shadymov EA, Pisarenko AM, Karpova O (2014) Obtaining transgenic plants expressing the gene for transcription factor AtCBF3. In: International Scientific Conference on Plant Biol and Biotechnol. Almaty, Kazakhstan. National Science Report (2018) Almaty: Nat Acad Sci Rep Kaz, p 120

Nurzhanova A, Kalugin S, Zhambakin K (2013) Obsolete pesticides and application of colonizing plant species for remediation of contaminated soils in Kazakhstan. Environ Sci Pollut Res 20:2054–2063

Nurzhanova A, Pidlisnyuk Y, Abit K, Nurzhanov Ch, Kenessov B, Stefanovska A, Erickson L (2019) Comparative assessment of using Miscanthus × giganteus for remediation of soils contaminated by
heavy metals: a case of military and mining sites. Environ Sci Pollut Res 26(13):3320–1333
Omasheva ME, Pozharsky AS, Smalov BB, Ryabushkina NA, Galiazarov NN (2018) Genetic diversity of apple cultivars growing in Kazakhstan. Rus J Genet 54(2):176–187
Romadanova NV, Mishustina SA, Matakovka GN, Kushnarenko SV, Rakhimbaev IR, Reed BM (2016a) In vitro collection of Malus shoot culture for cryogenic bank development in Kazakhstan. Acta Hortic 1113:271–277
Romadanova NV, Mishustina SA, Gritsenko DA, Omasheva MY, Galiazarov NN, Reed BM, Kushnarenko SV (2016b) Cryotherapy as a method for reducing the virus infection of apples (Malus sp.). CryoLetters 37(1):1–9
Rysbekova AB, Kazkeev DT, Usenbekov BN, Mukhina JM, Zhanbyrbaev EA, Sarbaeva IA, Zhambakin KZ, Bertaev HA, Bataeva DS (2016) Selection of pre-selection material with colored pericarp based on genotyping of Rc and Pb genes. Genet 10:1–11
Schepektin IA, Kushnarenko SV, Özek G, Kirpotina LN, Utgenova GA, Kotukhov YA, Danilova AN, Özek T, Başer KHC, Quinn MT (2015) Inhibition of human neutrophil responses by essential oil of Artemisia kotuchovii and its constituents. J Agric Food Chem 63:4999–5007
Schepektin IA, Kushnarenko SV, Özek G, Kirpotina LN, Utgenova GA, Abidkulova KT, Özek T, Başer KHC, Kovrizhina AR, Khlebnikov AI, Quinn MT (2016) Modulation of human neutrophil responses by the essential oils from Ferula species against methicillin-resistant Staphylococcus aureus. Molecules 23(7):1679–1696
Uteulin KR, Baitulin IO (2017) On the need to restore degraded populations of kok-saghyz. Rep Natl Acad Sci Rep Kaz 312(2):56–61
Uteulin KR, Rakhimbaev I, Baitulin IO, Zhambakin KZ (2018) Certificate of the author of the selection achievement. Variety of dandelion, kok-saghyz “Saryzhaz” No. 4395. RSE “National Institute of Intellectual Property” of the Ministry of Justice of the Republic of Kazakhstan
Volis S, Ormanbekova D, Yermekbayev K, Abugalieva S, Turuspekov Y, Shulgina I (2016) Genetic architecture of adaptation to novel environmental conditions in a predominantly selfing allopolyploid plant. Heredity 116:485–490
Zhambakin KZ, Zatybekov AK, Volkov DV, Shamekova MH (2014) Production of rapeseed mutant lines by male gametophyte culture. J Biotechnol 185:29–30
Zhapar KK, Shamekova MK, Zhambakin KZ (2019) Gene engineering for production cold-tolerant sweetpotato (ipomoea batatas). Rep Natl Acad Sci Rep Kaz 1(323):29–39

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.