Chapter

Aspects of the Particular Genetics of Grapes Prolonged for All Horticulture Crops

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Abstract

The modern level of knowledge development in the field of fundamental sciences makes it possible to reliably investigate the processes of evolution. The purpose of our research was to determine the need to establish the existing evolutionary transformations in resistance to abiotic and biotic stress factors of the biosphere in a grape plant, which may be natural for all horticulture crops, and on the other hand, based on the postulate of natural and experimental evolution, to prove the processes of natural evolution as a result of experimental breeding. The results obtained in the study of particular issues of genetics of grapes, based on the existence of general biological regularities, can be prolonged for interpretation, with reference to other horticulture crops. We studied the genetics of grapes, in particular crossability, the inheritance of signs and characteristics, the establishment of regularities in the display of selection value, and heterosis, allowing us to formulate the principles of modeling a new variety. Investigating the process of creating grape varieties that are resistant to biotic factor, it was suggested to consider it from the point of view of the coevolution of the plant and pathogen.

Keywords: grapes, evolution, general and particular genetics, resistance to abiotic and biotic stress factors, crossability, new variety modeling

1. Introduction

Genetic resources of Vitaceae grape family from the various centers of origin and vine-growing regions in the world were taken from one of the oldest Eurasian collections of grapes at the All-Russian National Research Institute of Viticulture and Winemaking (ARNRIVW) "Magarach." They have been studied on display of genetically determined sign of frost and mildew resistance. It is established that the grape frost and mildew resistance sign in genome was formed and fixed by evolution at separate forms in the various centers of origin. Suggested sources of high frost and mildew resistance of various botanical taxa from the various centers of origin for selection of frost- and mildew-resistant grape varieties are selected also.

Regularities governing the expression of resistance to *Plasmopara viticola (Berk. and M.A. Curtis) Berl. and De Toni*, *Uncinula necator (Schwein) Burrill*, and *Botrytis cinerea Pers.*, the causing agents of mildew, oidium, and gray rot, respectively, and the inheritance of this characteristic in the F_1 progeny were established in grapevine.

The nature of the inheritance of resistance to these pathogens in grapevine seems to be identical despite the fact that they differ in the ecogeographical origin, biological characteristics, and the form of host-pathogen relations (obligate/facultative, pathogenic/saprophyte types). The inheritance of resistance obeys the principle of hypothetic heterosis, which means that the progeny does not contain forms with resistance superior to that of the more resistant parent but does contain forms with resistance surpassing the average level of resistance of the two initial forms. Evidence was also gained in support of the theory suggesting that forms of grapevine with resistance to pathogens emerge only in the course of long-term coevolution of the biological objects. Basic principles of grape breeding were established and confirmed by the findings arising from the search of initial forms of grapevine and by the highlighted regularities governing the inheritance of resistance to pathogens in the crop. Breeding for resistance to pathogens was viewed as a specific target without respect to other desired characteristics since this issue was tackled with an aim to determine breeding and genetic regularities of the process and, for the first time, in terms of the interaction of two biological objects, the host plant and the pathogen, each with its own variation and evolutionary patterns.

The existence of different centers of origin of cultivated plants and grapevine in particular suggests formation of specific biological features in the autochthonous varieties in those centers in the process of evolution. The biological specificity of the autochthonous grapevine varieties was to gain a foothold at the genetic level. At the same time, expression of these traits in the progeny should also be specific. The conducted research has shown that crossing capacity of the Crimean autochthonous grapevine varieties with the varieties and forms of different species and ecogeographical origin has a specific characteristic and proves that crossing capacity can be perceived as an independent genetically determined biological feature.

Global and local climate changes demanded creation of new cultivars, in particular in viticulture. Thus, the problem of breeding new grapevine cultivars that would correspond to the present-day biosphere conditions emerged. As an answer to this, an immunobreeding program "Analogue" was developed at the "Magarach" Institute. The program aims at improving the efficiency of grape breeding and achieving cultivars that would comprise resistance to a variety of pests, diseases, and unfavorable environmental factors and would, at the same time, produce fruit of the quality that would be comparable to the best samples of their international analogues.

The suggested concept of the models is based on 16 most desired selection traits that had been chosen from the existing selection pool, identification of the original forms for crossbreeding, and multivariate analysis. To facilitate cooperation with other research centers, the information obtained was encoded according to the International Organisation of Vine and Wine (OIV)-Bioversity International descriptor.

Using the developed models for the creation of new cultivars will, on the one hand, help solve ecological problems in the vineyards and, on the other, ensure high economic effectiveness of viticulture and winemaking and, at the same time, obtain grape cultivars for different purposes.

2. Materials and methods of investigation

2.1 Materials and methods for gene pool diversity investigation

On the ampelographic collection of the "Magarach" Institute in the field during the years with critical sub-zero temperatures that damage the grape plant, 16 species of the Vitaceae family, 32 varieties of complex interspecific origin, 15 hybrid varieties of *V. vinifera* L. × *V. amurensis* Rupr., 6 varieties of hybrids

V. labrusca L., and 64 samples of the cultivated vine *V. vinifera* sativa D.C., including varieties *V. vinifera* occidentalis Negr., *V. vinifera* pontica Negr., and *V. vinifera* orientalis Negr. and 30 hybrids of *V. vinifera* L. were studied. The study of resistance to frost and agrobiology study of samples were carried out by the method of ampelographic description and agrobiology evaluation of grapes [1]. The degree of damage to annual shoots was assessed on a scale from 0 to 5 on the degree of damage to the phloem, and the analysis of the restoration capacity of the bush on the fruit links and perennial wood was carried out according to the percentage of blossoming shoots on a scale from 0 to 9 points. Estimation of resistance to mildew from 1 to 9 points was carried out according, as well as to frost, to OIV descriptor [2] on the basis of long-term observations (2000–2017) in the years of mildew epiphytotic. A higher score characterized less damage or better restoration ability of the plant, which reflects its higher resistance to stress factors or abiotic (frost) or biotic (mildew) nature.

To study the resistance to mildew, samples of various genetic origins were also selected on the ampelographic collection "Magarach":

- 27 species of the Vitaceae Lindley family, of which 3 are species of the genus *Ampelopsis* Michaux, 2 species of the genus *Parthenocissus* Planch., and 22 species of the genus *Vitis*.
- 198 varieties of complex interspecies origin, which are hybrids of 3 or more species of grapes.
- 18 hybrids of *V. vinifera* L. × *V. amurensis* Rupr.
- 27 hybrids *V. labrusca* L.
- 5 hybrids of *V. riparia* Michx.
- 150 samples of cultivated vine *V. vinifera* sativa D.C. and the European-Asian species (*V. vinifera* L.), which are represented by the varieties of 3 ecogeographical groups: *V. vinifera* sativa convar. Pontica Negr., *V. vinifera* sativa convar. Occidentalis Negr., and *V. vinifera* sativa convar. Orientalis Negr. [3].

2.2 Materials and methods for investigation of host-pathogen relationship

The research was done using a total of 28 hybrid populations of grapevine obtained via hybridization of 31 initial forms, of which 23 and 14 forms entered as the female and the male parents, respectively, and 6 forms were used in both qualities. The genetic resources employed consisted of 1378 hybrid forms belonging to hybrid populations, each containing at least 25 forms [4]. This enabled good reliability of results indicating the inheritance of the characteristic in the progeny [5]. The reliability of the results was confirmed statistically [6]. Initial forms differing in resistance to the causing agents of mildew, oidium, and gray rot (*Plasmopara viticola* Berl. et de Toni, *Uncinula necator* Burr., *Botrytis cinerea* Pers.) were chosen with a view to establish regularities governing the expression of the characteristic in the F_1 progeny. The resistance was assessed by means of a five-point numerical scale, "1" and "5" being the highest and the lowest levels, respectively [7].
The inheritance of resistance in the progeny was analyzed using conventional methodologies [8].

2.3 Materials and methods for crossability investigation

The research was conducted by the Department of Breeding, Genetics and Ampelography of the All-Russian National Research Institute of Viticulture and Winemaking “Magarach” on the field of plant breeding plots located on the southern coast of the Crimea and on the hydroponic culture of the vegetation plot in the period of 2008–2015. The seedlings were grown on gravel in hydroponic channels. For the cultivation of grape seedlings, we used chemically inert fraction of diorite aggregate sized 3–5 mm, which is a good conductor of the nutrient solution to the plant roots that keeps water on its surface well, serves as a support for the roots, and provides good aeration of the root system. For the growth of grape seedlings, we used hydroponic solution of variable composition [9, 10].

During the investigation period, 43 combinations of cyclic crosses were performed. As female initial forms, we used varieties and hybrids with female flower type: 4 Crimean autochthonous grape varieties (‘Kefessia’, ‘Krona’, ‘Sary Pandas’, ‘Kok Pandas’) and 2 interspecific hybrids (‘Muscat Jim’ and Magarach № 31-77-10). As male initial forms, we used 3 Crimean autochthonous grape varieties (‘Shabash’, ‘Kokur Belyi’, ‘Gevat Kara’); 3 autochthonous varieties from other centers of origin of grapes (‘Rkatsiteli’, ‘Chardonnay’, ‘Sauvignon vert’); 2 varieties of the Institute of “Magarach” selection (‘Bastardo Magaraci’ and ‘Rubinovyi Magaracha’), derived by crossing within the species of *Vitis vinifera*; and 11 interspecific varieties (‘Podarok Magaracha’, ‘Citronnyi Magaracha’, ‘Aurora Magaracha’, ‘Pervenets Magaracha’, ‘Riesling Magaracha’, ‘Spartanets Magaracha’, ‘Krasen’, ‘Antey Magarachsky’, ‘Alminskyi’, ‘Granatovyi Magaracha’, and ‘Pamyati Golodrigi’).

We studied hybrid seed formation, fully formed seed (seeds with a viable germ and well-developed endosperm) formation, seed germination, and development of seedlings, including vigorous ones as they are most viable and potentially more productive. The reliability of the results was confirmed by experimental data processing using mathematical and statistical processing methods [4, 5, 6, 8].

2.4 Materials and methods for plant breeding modeling investigation

Based on the formulated research objectives, the expressiveness of traits in the researched grapevine gene pool was studied with the purpose of their subsequent use as gene resource pool and in hybrid progeny. Acquisitions were described according to the OIV Official List [1].

Fourteen grapevine cultivars as initial forms along with 3704 hybrid seedlings obtained from 40 combinations of cyclic crossings were studied. The study and selection of seedlings were conducted based on the methodology developed by the Department of Breeding, Genetics and Ampelography of the “Magarach” Institute [11]. The degree of the manifestation of traits was coded [12]. The obtained primary data on the degree of manifestation of traits in original forms and hybrid seedlings was processed by methods of mathematical statistics [6]. Combinational ability, breeding value, and hypothetic heterosis [4, 8, 13] were estimated.

3. Genetic diversity in grape family Vitaceae

Genetic resources of cultivated plants with valuable biological characteristics, used for food production, ensure stable development and functioning of ecologically safe agricultural sector in conditions of constant changes in natural and climatic factors and social circumstances. Population growth and economic development of countries make significant changes in the living conditions of all organisms and ecological systems of the planet [14].

Mobilization of genetic resources of grapes in ampelographic collections, as shown by scientists of many countries [15–17], plays an important role in the conservation and use of the gene pool of grapes. One of the important tasks of collecting and preserving the gene pool of the genus *Vitis* in many countries of the world is the preservation of local varieties of grapes that are exclusively part of the natural heritage and do not grow in other vine-growing regions [18, 19]. Most of the local and uncommon varieties of grapes are now preserved only through collections [20]. It is known that the local assortment of grapes has been formed for a long time under certain conditions of a specific region and has a number of valuable features [21]. The study of the genetic resources of grapes collected on ampelographic collections from different centers of origin of grapes will allow us to identify new sources for breeding, to form an idea of the evolution of the grape culture.

Genetic resources of the grape of the "Magarach" Institute are collected in an ampelographic collection, one of the largest and oldest collections of grapes in the world, which was noted at international scientific forums and Internet sites [22]. The beginning of the formation of the collection dates back to 1814 and the existence of the "Magarach" Institute (1928) and coincides with the period of the beginning of collecting varieties of vine in Europe. The uniqueness of the collection of the Magarach Institute is that over two centuries it was replenished with samples from various vine-growing regions of the world, Europe, Asia, Africa, and North America, and most of them have survived to this day.

Proceeding from the tasks of general and private ampelography as a branch of botany, the extensive gene pool of grapes in the collection of the "Magarach" Institute has been studied and studied for the purpose of classifying samples, based on their origin in different centers and their evolutionary variability. Continuous work in this direction made it possible, in particular, to clarify the classification of the Eurasian species of grapes *Vitis vinifera* L., isolating subspecies, varieties within the subspecies of wild forest grapes, ecogeographical groups, and groups and types of cultivars.

Samples of the ampelographic collection were studied not only as separate botanical species, differing in morphological and morphometric characteristics, for the purpose of forming botanical taxons but also as genetically formed and fixed in the genotype biological specificity, in particular resistance to stress factors of the biosphere.

The analysis of the safety indices of the main and replacement buds, the degree of frost damage of the annual vine, as well as the restoration ability of the specimens of the samples of the collection showed that in the species of the genus *Parthenocissus* Planch., 100% safety of the main and replacement buds was recorded. Also high frost resistance was noted in species of the genus *Vitis* such as *Vitis* Linn., *Vitis amurensis* Rupr., North American species *Vitis cinerea* Arnoldi, *Vitis longii* Br., *Vitis riparia* Michx., and *Vitis solonis* Planch. Preservation of the main buds in these species was 95–98%, replacing 98–100%.

Analysis of varieties of grapes of interspecies origin showed that in hybrid varieties *Vitis vinifera* L. × *Vitis amurensis* Rupr., safety of the main buds was 1–25%, replacing 30–65%. The lesions of the annual vine were not detected. Varieties showed a good restorative capacity (**Figure 1**): on the fruit links, the percentage of developed shoots was 25–75% and on the bush stem from 50 to 100%. However, half a century of experience with the hybrids *Vitis vinifera* L. × *Vitis amurensis* Rupr. did not reveal genotypes combining a high level of frost resistance (−40°C) with signs of the quality of berries of cultured grapes. Created genotypes exhibit an average level of frost resistance in comparison with parental species (−25–26°C

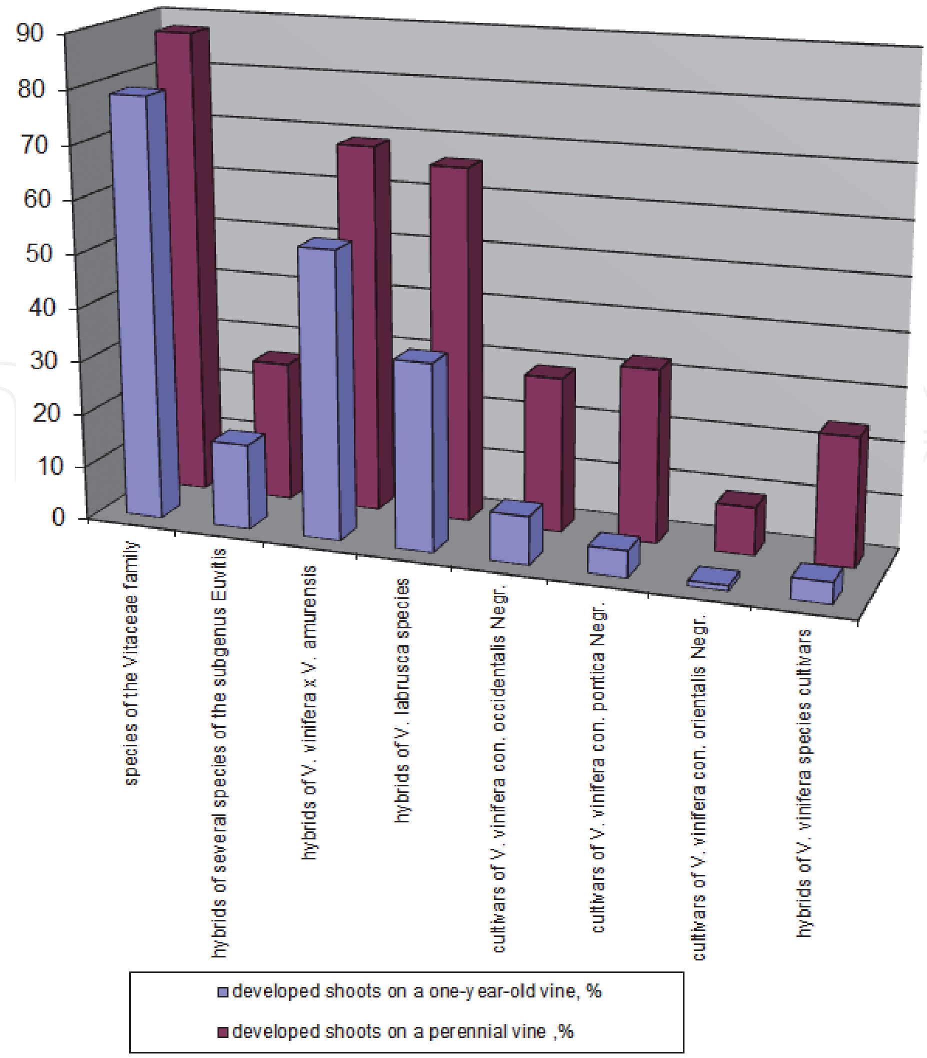

Figure 1.
Frost resistance of the grape samples of the ampelographic collection "Magarach" various origins.

table varieties and 27–28°C technical varieties). Similar results are given by crosses with frost-resistant American species.

Increased frost resistance is also possessed by some cultural representatives of the species *Vitis vinifera* L. due to the high ecological plasticity of the species. Under the influence of natural and artificial selection in various regions of formation, some varieties of cultured grapes have acquired adaptive properties with respect to low negative winter temperatures. Such varieties are of particular value for breeding, because unlike wild representatives of the genus *Vitis*, they do not carry the heredity of wild genotype, which reduces the quality of grapes and wine in hybrid forms in the heredity. In general, analyzing the safety indices of the main and replacement buds, the degree of frost damage of the annual vine, as well as the restoration ability of *Vitis vinifera* L. varieties, according to the degree of frost resistance, they can be divided into three groups:

- Varieties with increased resistance to frost. These are the cultivars *V. vinifera occidentalis* Negr. ('Aligoté', 'Cabernet-Sauvignon', 'Merlot', 'Riesling', 'Italia', 'Riesling Rhine', 'Sauvignon Green'), cultivars *Vitis vinifera pontica* Negr. ('Rkatsiteli', 'Saperavi'), and cultivars-hybrids *Vitis vinifera* L., parental forms of which have increased resistance to frost: 'Odesskii chernyi' ('Alicante Bouschet' × 'Cabernet-Sauvignon') and 'Sukholimanskii belyi' ('Chardonnay' × 'Plavay').

- Varieties with poor frost resistance. These are the varieties *Vitis vinifera pontica* Negr. ('Fetyaska', 'Furmint', 'Chausch white') and cultivars-hybrids *Vitis vinifera* L. ('Odesskii souvenir', 'Sverkhrannii bessemyannyi', and 'Suruchenskii belyi').

- Not frost-resistant varieties. These are cultivars of the ecogeographical group *Vitis vinifera orientalis* Negr. ('Asma', 'Karaburnu', 'Muscat Alexandria', 'Muscat white') and cultivars-hybrids *Vitis vinifera* L., created on the basis of cultivars of the eastern ecogeographical group: 'Irsai Oliver' ('Pozhoni white' × 'Pearl Saba'), 'Beauty Tsegleda' ('Chasla white crispy' × 'Chasla pink royal'), 'Muscat Hamburg' ('Muscat Alexandrian' × 'Frankenthal'), and others.

A comparative analysis of the regenerative capacity of bushes after the defeat of extreme winter frosts by groups of different origin showed (**Figure 1**) that the wildest species of the *Vitaceae* L. family are the highest adaptive capacity, the less the hybrids *Vitis vinifera* L. × *Vitis amurensis* Rupr. 53.8% of bloomed shoots on fruit segments and 68.8% of blossom shoots on perennial wood. Below these, the *Vitis labrusca* L hybrids: 35.0 and 66.2%, respectively. Varieties of complex interspecific origin have an average of 12.5 and 16.0% of blossoming shoots on fruit segments, but in terms of the number of restored shoots, they exceed the local varieties *Vitis vinifera occidentalis* Negr. and *Vitis vinifera pontica* Negr.

Mildew resistance studies have shown that 27 species of the Vitaceae Lindley grape family possess the highest possible. The assessment of the degree of resistance was 9 points (**Figure 2**). Also the hybrids of *Vitis riparia* Michx. possess the maximum resistance to mildew among which are 'North White', 'Taiga Emerald', and others with an average resistance score of 9.

In cultivars-hybrids *Vitis vinifera* L. × *Vitis amurensis* Rupr., average resistance is 8.6 points. The degree of resistance is 9 points for 'Aksay', 'Golubok', 'Far Eastern Tikhonov', 'Dyushes', and 'Zarya Severa'; the degree of resistance is 7 points for cv. 'Anushayut', 'Bruskam', 'Karin', 'Kunlean', and 'Russian early'; and the degree of resistance is 5 points for cv. 'Cherry Early', 'Dniester Pink', and 'Negru de Yaloven'. In the cultivars-hybrids of *Vitis labrusca* L., the average score of resistance is 8.6, among them are resistant cultivars (9 points): 'Alpha', 'Lyathes', 'Romulus', 'Lusay'l', and 'Isabella'. The cultivars 'Madella', 'Menu', and 'Lydia' had 7 points.

Less resistant varieties of complex interspecific origin have an average resistance score of 8.06. Varieties with maximum resistance of 9 points include 'Antey Magarachsky', 'Bianka', 'Aurora', 'Golubok', 'Golden Muscat', 'Podarok Magaracha', and 'Tair'. Relatively resistant varieties with a degree of resistance of 7

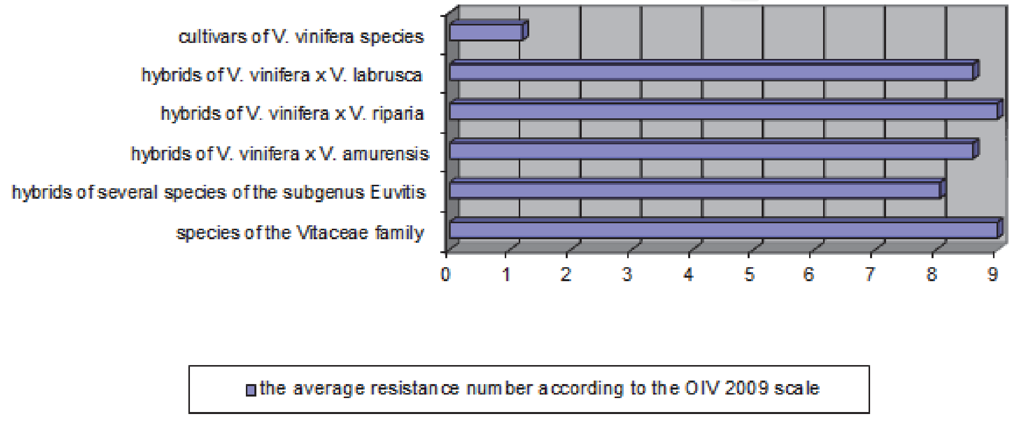

Figure 2.
Mildew resistance of the grape samples of the ampelographic collection "Magarach" various origins.

points include ‘Agavam’, ‘Armalaga’, ‘Artages’, ‘Biruinz’, ‘Villar Blanc 12-375’), ‘Vostorg’, and ‘Citronny Magaracha’. For the varieties ‘AsmaMagaracha’, ‘Victoria’, ‘Druzhba’, and ‘Skorenskiy red’, the degree of resistance was 5 points.

The average resistance score for cultivars of *V. vinifera* sativa D.C. is 1.2. Most cultivars of *V. vinifera* sativa D.C. are not resistant to mildew as the evolutionary pathogen and variety samples of this species were developed in different centers of origin of the grapes and were geographically isolated. These are such varieties as ‘Cardinal’, ‘Kishmish black’, ‘Goruli mtsvane’, ‘Kok habah’, ‘Murza raisin’, and ‘Artin zerva’.

Relative resistance to the pathogen is noted in some local varieties like ‘Chausch black’, ‘Chilar’, ‘Chinuri’, ‘Chol Ber’, ‘Shaani white’, ‘Shaani black’, ‘Aygesard’, ‘Bayan shirei’, ‘Varyushkin’, ‘Tresso black’, ‘Vereya’, ‘Chersonesus’, ‘Hindogny’, and ‘Tsolikouri’, whose resistance levels were 7 points, and varieties ‘Chausch white’, ‘Albilo Crimean’, ‘Mattrassa’, ‘Misket Cherven’, ‘Sabash’, whose resistance level to mildew was 5 points.

Botanical diversity of grapes culture, reflected in the classification and taxonomy of varieties and forms of the grape Vitaceae family, reflects the process of natural evolution and natural and artificial selection. Scientists in various countries in the eighteenth to twentieth centuries carried out a grandiose work that made it possible to differentiate representatives of the Vitaceae family in botanical taxons. The conducted researches established that all this botanical variety of the Vitaceae family was formed in different centers of origin of the grape culture on the planet. Depending on the abiotic conditions in the centers of origin of culture, a genome was formed in the form of individual botanical taxa in particular within genera and species differentiated in resistance to abiotic stress factors. Biotic conditions in these same centers of origin formed the genome in the form of the same individual botanical taxa, within the genera and types of grapes as a host plant, differentiated by resistance to biotic stress factors and the pathogen gene in the process of conjugate evolution. In the end result, samples of grapes were formed in each separate center of origin of the culture, differentiated not only according to botanical characteristics but also on a set of biological characteristics, in particular, resistance to biotic and abiotic stress factors of the biosphere, as frost and mildew resistance.

Speciation, specifically the formation of the species *Vitis vinifera* L., is directly related to the existence of wild forest grapes, belonging to the relics of Eurasia. The studies established a significant difference, including morphological and morphometric features and molecular genetic markers, between forms of wild forest grapes from various regions of Eurasia. Consequently, it may be considered necessary to continue these studies in order to isolate in the centers of origin of the culture of the grapes individual foci or subcenters of origin.

4. Plants as host and pathogen coevolution

Grapevine, like any plant species defined botanically as an independent hierarchical unit, has its own habitat [23], which, in turn, embraces individual foci of origin [24].

For each agricultural crop, including grapevine, both habitats of varieties in commercial cultivation and foci of origin of different botanical forms are determined [3]. Such varieties make up the commercial assortment of a crop, and botanical forms constitute the family of Vitaceae [25, 26]. The objective of this research was to establish genetically determined regularities governing resistance to pathogens in grapevine based on accessions from different foci of origin and newly bred forms obtained via sexual hybridization [27].

A considerable amount of research into the capacity of hybridization in grapevine and the inheritance of characteristics, including resistance to mildew, oidium, and gray rot in the F_1 progeny, has been done in the "Magarach" Institute. Regularities governing the expression of the biological specificity of the capacity of hybridization or the inheritance may be either general or particular; one can speak about either general biological regularity, the nature of the combining ability of two definite forms of grapevine, or the possibility to observe a certain degree of the expression of the characteristic in the F_1 progeny.

Ecogeographical foci of origin of initial forms, the interrelationships of these foci with the origin of individual groups of forms which may be grouped into botanical taxa, the degree of genetic relatedness of forms obtained via inbred and distant hybridization, the resistance of initial forms to a given pathogen, the presence of forms with different levels of resistance (assessed by use of a numerical scale) in the progeny, and the average resistance scores across the population may serve as the key elements in considering different approaches in attempting to examine the outcome of breeding varieties and forms of any crop, including grapevine, for resistance to pathogens. All this helps investigate the genetics of the inheritance of resistance. The results obtained may be interpreted from a standpoint of the abovementioned approaches, e.g., a genetic formula of initial forms may be described, these initial forms may be assessed as sources and/or donors of the characteristic in question, and the effectiveness of the transmission of the characteristic during hybridization with definite individual forms may be determined. The influence of abiotic factors on the effectiveness of the capacity of hybridization in grapevine and the effectiveness of the transmission of characteristics to the progeny has not been studied so far.

In order to develop breeding programs, including those aimed to achieve grape varieties resistant to pathogens, we need to know the biological peculiarities of the plant and the specificity of desired characteristics. Breeding grape varieties for resistance to biotic factors may require consideration of the biology and ecogeographical origin of the pathogens in question.

Though the causing agents of mildew, oidium, and gray rot are all fungi, they do differ biologically. *Plasmopara viticola* and *Uncinula necator*, the causing agents of mildew and oidium, respectively, are capable to grow only on grapevine as the obligate pathogens, while *Botrytis cinerea*, the causing agent of gray rot, is a cosmopolite, polyphage, and saprophyte. Biological differences of the pathogens suggest that the inheritance of resistance to them as a genetically determined characteristic is governed in grapevine by specific regularities.

Nevertheless, the results obtained indicate that the nature of the inheritance of resistance to these pathogens in grapevine seems to be identical despite the fact that they differ in biological characteristics and the form of host-pathogen relations (obligate/facultative, pathogenic/saprophyte types). Neither was the inheritance of resistance affected by the feeding patterns of the pathogens. Therefore, in developing programs of breeding grape varieties with resistance to the pathogens, their biological peculiarities need not be taken into account, and also attempts may be made to combine resistance to all three diseases in one genotype. Results highlighting these conclusions are shown in **Tables 1** and **2**.

The data in **Table 1** indicates that resistance of initial forms and their combining ability are the principal factors underlying resistance of the progeny. Another finding is that the outcome is not affected by using initial forms with better resistance as the male or the female parent.

The possibility to achieve resistance to a set of pathogens has been viewed differently in the beginning of grape breeding activities. Some researchers favored the possibility of breeding simultaneously for a set of desired characteristics, while

Resistance scores of				
Initial forms		F_1		
Female parent	Male parent	Mildew	Oidium	Gray rot
5	3	4.0	4.0	3.9
-”-	2	3.4	3.7	2.8
-”-	1	2.6	2.7	2.8
4	4	3.7	4.0	3.8
-”-	3	3.5	3.7	3.5
-”-	2	3.4	3.4	3.1
-”-	1	3.0	3.1	2.3
3	5	4.3	3.9	4.1
-”-	4	3.8	3.6	3.7
-”-	3	3.4	3.1	3.0
-”-	2	3.3	2.9	2.7
-”-	1	2.5	2.2	2.3
2	5	4.4	3.3	3.6
-”-	4	3.6	3.4	3.1
-”-	3	3.4	2.9	3.0
-”-	2	2.1	2.3	2.3
-”-	1	2.0	1.9	1.8
1	4	3.6	3.4	3.3
-”-	3	2.9	3.0	2.3

Table 1.
Effect of resistance of initial forms of grapevine to pathogens on the inheritance of the characteristic in the F_1 *progeny.*

others suggested breeding for resistance to a certain pathogen followed by subjecting the intermediate cross to saturation hybridization, which added resistance to the second element of the set, etc., in a stepwise fashion. The advent of complex infection backgrounds has enabled the breeder to assess the newly bred genetic resources for resistance to a set of pathogens and to confirm that hybrids with resistance to the set of the pathogens in question have been achieved provided the appropriate choice of initial forms. Data in **Table 2** shows regularities governing the inheritance of resistance to the set of the pathogens in question in grapevine.

Table 2 highlights the inheritance of resistance to three pathogens in grapevine, in which pathogens differ in their biological characteristics and host-pathogen relations and are capable, during the vegetation period, to compete at the infection stage. Nevertheless, the fact that a number of populations exist, such as ‘Nimrang’ × ‘Magarach 124-66-26’, ‘Plechistik’ × ‘Magarach 124-66-26’, and ‘Plechistik’ × ‘*Antaeus magarachskii*’, with “3” as the average score of resistance to the three pathogens across the population supports the suggestion that simultaneous breeding for resistance to a set of pathogens is possible.

In a study of regularities governing the inheritance of resistance to various pathogens in grapevine, both theoretical peculiarities and practical aspects of their use need to be taken into account. It appears that they should be viewed in terms of the possibility to achieve definite forms of grapevine with resistance to a set of

Cross-combination	Resistance scores of F_1		
	Mildew	**Oidium**	**Gray rot**
'Nimrang' × 'Magarach 124-66-26'	3.1	2.2	3.1
'Madeleine angévine' × 'Magarach 124-66-26'	4.8	3.0	3.1
'Queen of vineyards' × 'Magarach 124-66-26'	2.8	2.9	3.5
'Plechistik' × 'Magarach 124-66-26'	2.9	3.2	2.6
'Tachly' × 'Seyve Villard 20366'	3.3	3.0	2.2
'Seyve Villard 20365' × 'Italia'	4.9	3.3	3.7
'Magarach 4-68-25' × 'Krymskaya Zhemchuzhina'	4.0	2.8	4.0
'Seyve Villard 12283' × 'Sverkhrannii bessemyannyi Magaracha'	4.3	3.9	3.0
'Kefessia' × 'Antaeus magarachskii'	2.5	3.3	2.1
'Plechistik' × 'Antaeus magarachskii'	2.6	3.4	2.8

Table 2.
Comparative inheritance of resistance to different pathogens of grapes.

pathogens and to reproduce the results achieved in repeated crossings provided the use of the same initial forms. The understanding of such regularities remains incomplete since grapevine is a complex heterozygous organism. However, for a number of individual characteristics, including resistance to definite pathogens, certain results have been obtained and expressed as the scores of a universal numerical scale.

Natural selection reigns in the plant kingdom, and new forms of a given crop may emerge and become established in plant communities. It is highly probable that mutations or events of natural hybridization give rise to such forms. New forms of both types arise due to a change in forms of a crop within one botanical species, in which the forms, as a rule, grow geographically isolated from other species of a given crop. That is why the richest diversity of grapevine known prior to the 1860s when the first purposeful crossing of two forms of the crop took place should be viewed as the outcome of formication within individual species which, in turn, come from the European-Asian, North American, South American, or East Asian foci of origin of grapevine.

Over centuries of coevolution, grapevine, phylloxera, and the causing agents of mildew, oidium, and gray rot have been subject to slow permanent changes, leading to an increased virulence of the pest and the pathogens and to the development of defense reactions by the crop. This long-term process has brought about the emergence of stable forms of grapevine. Scientists stated that resistant forms emerge as a result of coevolution of the host plant and the pathogen, and that is why they should be searched for in the birthplace of the latter [28–30].

The successful implementation of breeding programs aimed to achieve varieties of the future envisages, as an indispensable prerequisite, the involvement of the global genetic resources of an agricultural crop into the breeding process. The diversity of the global genetic resources suggests the possibility in combining properties inherent in species formed at different ecogeographical conditions in one genotype.

The use of a species for breeding purposes means that the entire diversity of a species in a habitat needs to be collected and studied. Forms should be collected in sufficiently large quantities to enable studies of the variation of the species for characteristics in question and the ability of forms to transmit them to the progeny.

Breeding new generations of grape varieties distinguished for excellent quality of the fruit and good yielding capacity and also resistant to major diseases and pests of the crop is an important task throughout the viticulture world. In the absence of artificial infection backgrounds which help the breeder test resistance of the grape genetic resources to definite pathogens, resistant varieties and forms can be revealed against natural epiphytotics.

The grape plant, as a biological object, exists and develops in the biosphere, being in permanent contact with and affected by biotic and abiotic factors. Careful consideration is given to the effects of biotic factors on development of a plant organism, including grapevine, due to the specific nature of the phenomenon, the essence of which lies in the fact that two biological objects, the host plant and the pathogen, change as affected by each other and abiotic factors.

The fact that variation of biological objects is governed by the abovementioned regularities enables evolutionary models to be built. Besides, and this is of no less importance, this knowledge can be applied in purposeful creation of forms of a crop which possess a desired set of useful characteristics, including resistance to pathogens. The expression of such characteristics must be high enough to allow cultivation of these forms in the field without appropriate protection measures.

Grapevine may be attacked by pests and diseases whose causing agents are of different natures: viruses, bacteria, and fungi. The biology and the life cycle of the fungi *Plasmopara viticola*, *Uncinula necator*, and *Botrytis cinerea*, the causing agents of mildew, oidium, and gray rot, respectively, have most exhaustively been studied. The development of grapevine as affected by the former, the reaction of the grape plant to damage, and the degrees of resistance of forms, varieties, and different species of the crop to these pathogens have also been studied in detail.

Different degrees of resistance to the causing agents of the abovementioned diseases in individual grape varieties suggest that purposeful breeding of varieties is possible which combines resistance to the set of the pathogens in question and other desired economical characteristics in their genotypes. To this end, we need to know regularities governing the capacity for hybridization of various initial forms and the inheritance of characteristics, including resistance to pathogens, in the F_1 progeny. Since grapevine is a vegetative propagated crop, we may limit our studies of the inheritance of characteristics to the F_1 progeny, and the transmission of characteristics to the progeny is governed both by the capacity for hybridization of initial forms and their combining ability, which determine the transmission of a characteristic to the progeny and the degree of its expression in the F_1 hybrids.

A number of regularities governing the expression of resistance to *Plasmopara viticola*, *Uncinula necator*, and *Botrytis cinerea*, the causing agents of mildew, oidium, and gray rot, respectively, and the inheritance of this characteristic in the F_1 progeny were established in grapevine as a result of our long-term research aimed to breed for resistance of the crop to these fungal pathogens. The nature of the inheritance of resistance to these pathogens in grapevine seems to be identical despite the fact that they differ in biological characteristics and the form of host-pathogen relations. The inheritance of resistance obeys the principle of hypothetic heterosis, which means that the progeny does not contain forms with resistance superior to that of the more resistant parent but does contain forms with resistance surpassing the average level of resistance of the two initial forms.

Evidence was also gained in support of the theory suggesting that forms of grapevine with resistance to pathogens emerge only in the course of long-term coevolution of the biological objects. That is why the search for forms of grapevine with resistance to the given pathogens, which remains important today, should be based on that principle.

In conclusion, it should be mentioned that basic principles of grape breeding were established and confirmed by the findings arising from the search of initial forms of grapevine and by the highlighted regularities governing the inheritance of resistance to pathogens in grapevine. Breeding for resistance to pathogens was viewed as a specific target without respect to other desired characteristics since this issue was tackled with an aim to determine breeding and genetic regularities of the process and, for the first time, in terms of the interaction of two biological objects, the host plant and the pathogen, each with its own variation and evolutionary patterns.

5. Crossability of plants as a genetic determined sign

In this stage of scientific knowledge and expertise, the concept of evolutionary development of the flora on Earth is based on the existence of certain centers of origin of cultivated plant species, including grapes [24]. A fundamental contribution to the development of the theory of centers of origin was made by Vavilov [31]. Negrul has further developed this theory [32], highlighting the ecological and geographical areas forming the autochthonous grape varieties. These varieties form separate ecogeographical groups of autochthonous grape varieties. The "Black Sea" area is one of such ecogeographical zones, where autochthonous grape varieties are formed [33]. Within the bounds of this zone, modern scientists have identified specific subcenters of origin of the grapes, one of them being Crimea [21, 34], where relict endemic wild forest vines exist to date. This resulted in the formation of a specific set of autochthonous grape varieties with characteristic biological features in the Crimea, due to which they are used in the breeding programs developed by the "Magarach" Institute [3].

It should be noted that the process of breeding new varieties, as a rule, involves analysis of the combining ability of the initial forms with regard to the inheritance of the degree of trait expression in the progeny. At the same time, it has to be kept in mind that in the course of generative hybridization, the formation of a germ and seeds, along with hybridization efficiency, differs between various initial forms, and we can assume that this is a genetically predetermined feature. Therefore, the autochthonous grape varieties of the Crimea are characterized by specific crossability that has become part of their DNA in the process of natural evolution. The present work focuses on the analysis of this phenomenon.

It is known that the majority of the Crimean local grape varieties has a functionally female flower type and is, therefore, not resistant to the biotic and abiotic environmental factors. This affects the stability of fertilization and vine yielding capacity. It is possible to increase the adaptive capacity of the Crimean local grape varieties not only by the selection method but by the hybridization method as well. It is worthwhile to evaluate the hybridization efficiency of the Crimean autochthonous grape varieties, which, first and foremost, require determining the parameters, based on which such studies may be performed. The formation of a new genotype of a plant consists of two principal stages: (1) hybridization, to include formation of berries and seeds, and (2) the development of seedlings and of their vegetative propagation later on.

According to the earlier data, the berry formation in different breeding combinations is characterized by biological traits of the initial female plant, while it is not dependent on the male form, which has been supported by the number of berries per bunch of a cross-combination. Therefore, there is no need to consider the number of bunches and berries per bunch in the further study of grape crossing capacity. When assessing crossing capacity, it is more important to pay attention to the number of the formed seeds, including the fully formed ones, as compared to the number of berries with formed seeds, and to the number of seedlings obtained in the end of the process, including the vigorous ones.

8096 hybrid seeds were obtained as a result of the crosses. As can be seen from the data presented in **Table 3**, which characterize the extreme contrasts among the obtained results, the greatest number of seeds was formed in combinations with 'Muscat Jim' as female form, from 853 to 546 seeds, and the minimum number was formed in the combination of 'Krona' × 'Krasen' (3 seeds).

On average, fully formed seeds accounted for 85%, while the number of fully formed seeds in 'Krona' variety in three cross-combinations reached up to 100%. Less than mean value, from 80 to 46% of fully formed seeds were formed in almost all backcrosses involving 'Kok Pandas' as the female form. Above-average percentage of fully formed seeds was observed in populations of 'Kefessia' × 'Rubinovyi Magaracha' and 'Kefessia' × 'Bastardo Magaraci', 97% and 98%, respectively. Seed germination analyses revealed the lowest percentage in cross-combinations of 'Kok Pandas' with 'Sauvignon vert' (32%), 'Chardonnay' (41%), and 'Rkatsiteli' (46%). Seed germination in combinations of 'Kok Pandas' with interspecific varieties of 'Aurora Magaracha' and 'Riesling Magaracha' made 60%. The maximum viability was observed in the seeds of 'Sary Pandas' variety in combinations with interspecific male forms of 'Citronnyi Magaracha' (82%) and 'Riesling Magaracha' (78%). A lower percentage of germination was observed in cross-combinations of 'Sary Pandas' × 'Sauvignon vert' (76%) and 'Sary Pandas' × 'Chardonnay' (73%). The average seed germination value for all the populations was rather high and reached up to 51.2%.

As a result, we were able to grow 4143 seedlings, out of which only 258 were vigorous (16.7%). Of particular interest in terms of this indicator was the combination of 'Krona' × 'Alminskyi' (17%) and 'Krona' × 'Rubinovyi Magaracha' (15%). Of similar powerful growth force were seedlings in the populations of Magarach № 31-77-10 × 'Gevat Kara' (14%) and Magarach № 31-77-10 × 'Kokur White' (13%). We were not able to single out any vigorous seedlings in combinations of 'Sary Pandas' × 'Chardonnay', 'Sary Pandas' × 'Pervenets Magaracha', 'Kok Pandas' × 'Aurora Magaracha', 'Kok Pandas' × 'Spartanets Magaracha', 'Kok Pandas' × 'Citronnyi Magaracha', and 'Kok Pandas' × 'Rkatsiteli'. The average number of vigorous seedlings in all populations was 6.2%.

The crossability efficiency of the grapes as to the formation of fully formed seeds and their germination capacity with the resulting vigorous seedlings is determined primarily by the use of a particular female form in a cross and its ripening period. In the present study all the female forms had an average ripening period, which provided a sufficiently high percentage of germination. To analyze the effect on the viability of the offspring, we took six initial female forms, which were cyclic crossed with male forms, and grouped them into unified complexes (**Table 4**). The number of seeds produced in these crosses fluctuated significantly from 484 seeds for 'Krona' to 2668 seeds for 'Kok Pandas'. The average sample value was 188.3 of hybrid seeds, while the coefficient of variation for the populations made 38 of seeds. At the same time, the percentage of fully formed seeds out of their total number in cross complexes fluctuated insignificantly, from 87.3% (for 'Sary Pandas') to 95.2% (for 'Kefessia'), with the exception of 'Kok Pandas', which showed 67.9%, as evidenced by the excess of the variation coefficient. The mean value for seed germination capacity in all the complexes made 58.9%. The greatest number of vigorous seedlings was observed in female forms of Magarach № 31-77-10 (13.5%), 'Krona' (10.2%), and 'Muscat Jim' (10%). 'Kok Pandas' produced the lowest percentage of vigorous seedlings that amounted to 1.1%. In all the populations, the vigor of seedling growth varied considerably, with its rate reaching up to 78.7%.

From the analysis of the obtained data, we may conclude that 'Krona' produced the least number of hybrid seeds that came up to 484, 10% of them produced vigorous seedlings, while 'Kok Pandas', although having formed the highest number

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Crossbreeding combinations		Number of hybrid seeds	Fully formed seeds, %	Germinating capacity of hybrid seeds, %	Number of seedlings in a combination	Number of vigorous seedlings	Vigorous seedlings, %
Female form ♀	**Male form ♂**						
'Muscat Jim'	'Kokur Belyi'	853	95	47	403	47	12
'Muscat Jim'	'Shabash'	549	95	46	250	18	7
'Kok Pandas'	'Sauvignon vert'	478	48	32	153	1	1
'Kok Pandas'	'Aurora Magaracha'	376	93	60	224	1	1
'Magarach № 31-77-10'	'Kokur Belyi'	216	81	48	104	14	13
'Kefessia'	'Rubinovyi Magaracha'	161	97	63	101	5	5
'Kefessia'	'Bastardo Magaraci'	65	98	65	42	3	7
'Sary Pandas'	'Chardonnay'	88	98	73	64	0	0
'Sary Pandas'	'Citronnyi Magaracha'	33	55	82	27	1	4
'Krona'	'Rubinovyi Magaracha'	71	94	56	40	6	15
'Krona'	'Citronnyi Magaracha'	48	88	58	28	4	14
'Krona'	'Alminskyi'	10	90	60	6	1	17

Table 3.
Crossability efficiency of the Crimean autochthonous varieties with varieties of different origins.

Female form, ♀	Hybrid seeds, pieces	Fully formed seeds, %	Germinating capacity of hybrid seeds, %	Vigorous seedlings, %
'Magarach № 31-77-10'	768	90.0	50.0	13.5
'Krona'	464	93.9	61.5	10.2
'Muscat Jim'	2207	94.7	46.0	10.0
'Kefessia'	1208	95.2	60.1	5.2
'Sary Pandas'	781	87.3	68.9	4.8
'Kok Pandas'	2668	67.9	50.0	1.1
$\bar{x}$	188.3	87.1	58.9	6.1
σ	214.6	14.9	10.2	4.8
V	38.0	17.1	17.3	78.7

Table 4.
The effect of maternal forms on crossability.

of fully formed seeds amounting to 2668, showed the smallest percentage of vigorous seedlings (1.1).

In combination of crosses of *V. vinifera* with complex interspecific varieties chosen for the analysis, when different female varieties were used in hybridization with either the same male variety or with different ones, we were able to obtain a sufficiently high number of seeds. For the crossability of the male form analysis, the initial varieties were grouped into complexes, taking into account all the indicators resulting from the hybridization of one male form with all the female forms.

As can be seen from the data, the mean value for the obtained hybrid seeds made 116 (**Table 5**). The lowest number of seeds was obtained in cross-combinations, where 'Podarok Magaracha' was the male form (18 seeds). The greatest number of

Male form, ♂	Hybrid seeds, pieces	Fully formed seeds, %	Germinating capacity of hybrid seeds, %	Vigorous seedlings, %
'Alminskyi'	72	94.0	64.0	11.0
'Podarok Magaracha'	18	72.0	56.0	10.0
'Pamyati Golodrigi'	52	93.0	61.4	9.5
'Granatovyi Magaracha'	62	89.5	59.5	6.0
'Antey Magarachsky'	155	90.5	58.0	5.0
'Aurora Magaracha'	422	93.0	62.5	5.0
'Krasen'	168	90.3	62.3	4.0
'Riesling Magaracha'	754	95.3	61.7	3.7
'Citronnyi Magaracha'	456	77.3	63.3	3.5
'Spartanets Magaracha'	534	82.0	58.5	3.5
'Pervenets Magaracha'	209	69.5	60.5	1.0
$\bar{x}$	116	86.4	61.2	5.5
σ	136	13.2	8.0	4.6
V	117	15.3	13.1	83.6

Table 5.
The effect of paternal forms of interspecific origin on the crossing capacity.

seeds was observed in crosses with 'Riesling Magaracha' (754 seeds). The number of fully formed seeds out of their total amount was high enough and ranged from 69.5% for 'Pervenets Magaracha' to 95.3% for 'Riesling Magaracha'. The analyzed crosses were also characterized by a sufficiently high percentage of seedlings from fully formed seeds, which varied in the range from 56.0 to 63.3%, while all the indicators of seed germination were within the variation coefficient (13.1). The number of the obtained vigorous seedlings varied significantly (up to 83.6%).

The greatest number of vigorous seedlings was produced from combinations with the following varieties—'Alminskyi' (11.0%), 'Podarok Magaracha' (10.0%), and 'Pamyati Golodrigi' (9.0%). The values of the rated indicator for 'Granatovyi Magaracha', 'Antey Magarachsky', and 'Aurora Magaracha' varieties did not differ substantially from the mean in the sampling (5.5%). The smallest number of vigorous seedlings was observed in combinations with 'Pervenets Magaracha' (1.0%).

From the analysis of the obtained data, we can conclude that 'Podarok Magaracha', 'Alminskyi', and 'Pamyati Golodrigi' form a small number of seeds but can be reasonably used in crosses with the Crimean autochthonous grape varieties to produce vigorous seedlings. 'Pervenets Magaracha', on the contrary, does not transfer the powerful growth force to its progeny in these combinations.

To analyze the crossing capacity of the Crimean indigenous grape varieties, we carried out interspecific hybridization within *V. vinifera* species (**Table 6**).

As a result, the largest number of seeds was obtained from crossings with 'Kokur White' (1069 seeds), while the lowest number was obtained from crosses with 'Bastardo Magaraci' (112 seeds). The mean value of the resulting seeds made 649, with a slight variation coefficient in all the populations, which made 63. The standard deviation of the obtained hybrid seeds showed quite a considerable variation of 409. The percentage of fully formed seeds (seeds with a viable germ and well-developed endosperm) in variations made an average of 88.3%. 'Bastardo Magaraci' (99%) and 'Rkatsiteli' (77%) showed extreme values, which exceeded the variation coefficient as compared to the average value. As to the seed germination capacity, the hybrid varieties can be divided into two groups by reference to the mean value. The germination capacity of hybrid seeds obtained from crosses with 'Shabash', 'Kokur belyi', and 'Gevat Kara' was less than the average in variations of 54.9%; for

Male form, ♂	Hybrid seeds, pcs.	Fully formed seeds, %	Germinating capacity of hybrid seeds, %	Vigorous seedlings, %
'Kokur Belyi'	1069	88.0	47.5	12.5
'Gevat Kara'	1357	96.5	48.5	12.5
'Rubinovyi Magaracha'	232	95.5	59.5	10.0
'Bastardo Magaraci'	112	99.0	66.0	8.5
'Shabash'	549	95.0	46.0	7.0
'Rkatsiteli'	511	77.0	59.7	4.3
'Sauvignon vert'	681	80.3	56.0	3.7
'Chardonnay'	683	86.0	55.7	3.0
$\bar{x}$	649	88.3	54.9	7.7
σ	409	7.8	7.0	3.8
v	63	9.0	12.8	49.7

Table 6.
The effect of V. vinifera male forms on crossability.

the remaining species of *V. vinifera*, this indicator exceeded the mean value. The highest seed germination capacity was observed for 'Bastardo Magaraci' (66.0%).

Assessing male forms as to the transfer of the powerful growth force feature to the offspring, it may be noted that the largest number of vigorous seedlings was obtained in combinations with 'Kokur Belyi' and 'Gevat Kara' (12.5%). The mean values, 7.7% for variations, were exceeded by 'Rubinovyi Magaracha' (10.0%) and 'Bastardo Magaraci' (8.5%). The smallest percentage of the vigorous seedlings was observed for 'Chardonnay' (3.0%).

By comparing the impact on crossability of the Crimean autochthonous grape varieties of different male forms represented by varieties of *V. vinifera* species and those of interspecific origin, it is possible to ascertain some consistent patterns.

The observed variation coefficients of crossability indicators as to the formation of hybrid seeds obtained from intraspecific crosses within the species of *Vitis vinifera* are almost twice lower than in interspecific crosses. The established mean value for cross-combinations of the fully formed seeds differs insignificantly among intraspecific (within the species of *Vitis vinifera*) and interspecific crosses, with difference between them of only 1.9%. The established average percentage of seed germination capacity has determined a higher viability of hybrid seeds obtained as a result of cross-species hybridization.

The analysis of the studied cross-combinations allowed concluding that as a result of crossings within the species of *Vitis vinifera* the mean value of the obtained vigorous seedlings was almost 1.5 times lower than in interspecific crosses.

Thus, we were able to establish the genetically determined specificity of the crossability of the Crimean autochthonous grape varieties. By all crossability indicators of the Crimean autochthonous grape varieties, the variability was lower within the species of *Vitis vinifera* than in the interspecific hybridization. Using autochthonous variety 'Krona', as a female form, and interspecific variety 'Alminskyi', as male form, proved most efficient for obtaining vigorous progeny.

6. Modeling at plant breeding

In the middle of the twentieth century, there existed the so-called model of ideal variety of a grapevine—a concept that comprised the ultimate complex of the desired basic phenological and agrobiological characteristics in varieties that were to be cultivated on a vineyard [35]. But global and local climatic changes along with the change in biosphere conditions demanded creation of new cultivars, in particular in viticulture [36]. The global problem was not only to preserve the grapevine gene pool diversity but also to breed new grapevine cultivars that would correspond to modern conditions of biosphere [37].

Scientists in different countries discuss the problem and methods of creating a new genotype with given parameters [27], including the one on the basis of modeling [38]. A program for immunobreeding "Analogue" that is based on models of new grapevine cultivars was developed [39] and is being implemented at the "Magarach" Institute. The program aims to improve the efficiency of grape breeding and to achieve varieties, whose characteristics would be distinguished for genuine novelty. The breeding objective of the program is the development of new grape cultivars that would combine resistance to a variety of pests, diseases, and unfavorable environmental factors and would, at the same time, produce fruit of the quality comparable to the best samples of the existing international analogues. To achieve this, new baseline material is searched for, accumulated in collections, studied, and involved in generative hybridization.

Thanks to the existence of individual species of grapevine with peculiar traits of interest, and in pursuit of the increased heterogeneity of grapes under commercial cultivation, the grape breeding program "Analogue" aims at developing a new generation of grape cultivars based on the initial forms obtained from different centers: the European center (*Vitis vinifera L.*), the East Asian center (*Vitis amurensis* Rupr.), and the North American center (*Vitis riparia* Michx., *Vitis cinerea* Engelm., etc.).

The suggested concept of the models is based on 16 most desired selection traits that are used for the replenishment of the selection database, selection of the original forms for crossbreeding, evaluation of the selected hybrid forms, and multivariate analysis. Presently, the models of table grapevine cultivars are implemented in new varieties [3]. Using the developed models for the creation of new cultivars will help solve ecological problems in the vineyards, ensure high economic effectiveness of winegrowing, and receive grape cultivars for different purposes.

The basic signs defining phenotype and breeding value of genotypes (**Table 7**) are included in a model of a table grapevine variety. Varieties are distributed based on ripening time: super early (less than 105 days); very early (105–115 days); early (115–130 days); middle (130–140 days); and late (more than 140 days).

Since botanical, phenological, morphological, agrobiological, economic, physiological, and other signs are measured in different units and scales, it is necessary to formulate appraisal of trait manifestation in points. In other words, it is necessary to translate the quantitative and qualitative data into a uniform system. For this purpose the scope of a sign variation in the investigated set of cultivars was subdivide into 5 gradations with an interval of 2 (1, 3, 5, 7, and 9). The minimum value of the attribute is code 1, while the maximum is code 9. The presented model mapped genetic regularities of the maximum score in transgress hybrids. Formation of the maximum score is carried out based on quantitative (weight of a berry and that of a bunch) and qualitative (shape and color of a berry) attributes that are associated with the ripening times.

The conducted hybridological analysis and mathematical and statistical processing of the experimental data highlighted the most valuable combinations of crosses on complex inheritance of phenotypic traits of elegance with a bias toward early ripening (**Table 8**).

Combinations of 'Flora' × 'Rishel'e' (43.9%), 'Present to Zaporozhye' × 'Rishel'e' (63.9%), and 'Flora' × 'Find of Mariupol' (100%) have the highest breeding value in terms of the ripening period. The degree of the

Ripening time	Super early	Very early	Early	Middle	Late
	9	**7**	**5**	**3**	**1**
Berry weight	5	7	9	7	5
Bunch weight	5	7	9	7	5
Berry shape	3	5	7	9	3
Berry coloration	9	7	5	3	1

Legend. Sign expression in points: Berry weight: 5 points, 6 g; 7 points, 8 g; 9 points, more than 10 g; Bunch weight: 5 points, 500 g; 7 points, 800 g; 8 points, 1000 g; 9 points, more than 1200 g; Berry shape: 3 points, rounded; 5 points, egg-shaped; 7 points, cylindrical; 9 points, elongated-elliptic; Berry coloration: 1 point, blue-black; 3 points, violet; 5 points, red; 7 points, pink; 9 points, yellow-green.

Table 7.
Model of a table grapevine cultivar according to the expression of phenotype traits.

Crossing combination	Ripening time	Berry weight	Bunch weight	Berry shape	Berry coloration
'Flora' × 'Rishel'e'	43.9	33.7	10.3	43.9	39.8
'Flora' × 'Cardinal'	12.4	0.0	10.3	0.0	45.4
'Flora' × 'Find of Mariupol'	100	20.0	20.0	40.0	100.0
'Talisman' × 'Cardinal'	9.1	100.0	50.0	0.0	40.9
'Talisman' × 'Kodryanka'	11.3	100.0	51.0	0.0	30.2
'Present to Zaporozhye' × 'Rishel'e'	63.9	84.8	20.0	9.8	25.6
'Present to Zaporozhye' × 'Cardinal'	10.9	84.6	20.0	0.0	32.0
'Flamingo' × 'Rishel'e'	11.5	8.0	8.0	0.0	23.0
'Flamingo' × 'Arcadia'	9.8	75.0	25.0	0.0	38.2

Table 8.
Breeding value of grapevine populations (%).

hypothetical heterosis of the hybrid offspring as to this trait ranged from 0.6 to 66.7% (**Table 9**).

Populations that include 'Talisman' variety show the highest breeding value of the inheritance of a big berry, reaching up to 100%. The high breeding value is due to the biological capacity of the 'Talisman' variety to generate a very big berry, the weight of which reaches up to 24 g, and a high degree of transmission of this trait to its progeny in populations.

Hereby, the overall combining ability of the 'Talisman' variety influence on the increase of the berry weight in progeny as compared to the average indices of the original forms happens with a fairly low severity of 1.25%. Reverse causality between heterosis and breeding value is observed in combination of 'Flora' × 'Cardinal'. In this case there is a zero degree of inheritance of giant berries; however, there is a significant (63%) superiority of the hybrid progeny over the average index of a berry weight, characteristic of both parents.

The breeding value of the inheritance of a bunch weight in represented populations ranged from 8 to 51%. It should be noted that the highest conjugate of

Crossing combination	Ripening time	Berry weight	Bunch weight	Berry shape	Berry coloration
'Flora' × 'Rishel'e'	5.7	8.3	1.9	−1.9	−2.3
'Flora' × 'Cardinal'	1.4	63.0	6.7	35.0	0.2
'Flora' × 'Find of Mariupol'	66.7	9.3	5.7	−3.8	0.0
'Talisman' × 'Cardinal'	0.6	1.3	8.8	−4.5	1.3
'Talisman' × 'Kodryanka'	8.9	1.2	12.1	4.2	−12.8
'Present to Zaporozhye' × 'Rishel'e'	34.7	3.0	−5.7	−17.9	−23.5
'Present to Zaporozhye' × 'Cardinal'	5.1	5.5	0.7	−7.3	−18.7
'Flamingo' × 'Rishel'e'	9.8	7.3	−14.4	−3.1	−7.5
'Flamingo' × 'Arcadia'	14.5	−3.3	−4.3	2.7	0.8

Table 9.
Hypothetical heterosis in grapevine populations (%).

the studied traits is observed between the weight of a berry and the weight of a bunch and a distinctive relationship is observed in crosses with 'Talisman' variety. Populations, in which this variety participates, produce about 50% progeny forms with a very big bunch.

In this study preference was given to the elongated oval-shaped berries. However, very early-ripening cultivars mainly produce a rounded berry. Apparently, this feature is associated with the biological specificity of the berry formation and the origin of table grapes *Vitis vinifera orientalis* Negr. that is related to soil and climatic conditions of their origin. Many varieties of eastern ecogeographical group, 'Husaine Kelim Barmak', 'Shami Abiad', 'Fakhri', and others, have an elongated oval or cylindrical berry shape and are characterized by the average ripening time.

The main objective of a plant is to generate progeny and in the case of grapes to produce seeds. It is known that very early-ripening cultivars have zero seed germination due to the insufficient formation of a normally developed embryo and endosperm, while the seeds of the average ripening period cultivars have the highest viability. It is possible that the genetic correlation between the shape and weight of berries and the ripening period is due to the biological dependence of the length of the vegetation period and formation of a sufficient amount of biochemical compounds. However, the studied hybrid progeny has a high degree of heterozygosity. Initial forms of interspecific origin represent at least 5 generations and have more than 50 ancestors. The oval shape of a berry is intermediate between the round and cylindrical forms. Therefore, in the process of breeding early-ripening cultivars with oval berry shape, there is a sufficiently high degree of probability to obtain hybrids with this berry shape. The most valuable populations in this case were obtained by crossing with 'Flora' cultivar, specifically 40–43.9%, in the genotype of which 'Khusaine Belyi' genes are present.

Berry color is a sign closely related to the preservation of grapes. The higher the percentage of anthocyans (phenolic compounds) in the skin of the berries, the longer is the period during which they can be preserved. The economic value of this feature increases with the elongation of the vegetation period. Very early-ripening varieties do not require long-term storage, as fresh grapes are sold without storage and are in high demand. With the increase in the vegetation period, however, the potential yield of varieties increases, along with their competitiveness. Thus, it develops the need for a short-term storage of early varieties, smoothly developing into the long-term storage of late varieties. Therefore, the model of a table variety displays the optimal berry coloration resulting from the content of anthocyans (phenol compounds) and aroma compounds [30], associated with the ripening period and storage duration.

According to the existing genetically determined pattern, the dark color of a berry dominates over a lighter color. Using this pattern has created a population with sufficiently high breeding value of 23–100% for the given trait. However, the hypothetical heterosis in populations with colored varieties—'Rishel'e', 'Kodryanka', and 'Cardinal'—has a negative value, underscoring the validity of color patterns of domination.

In the assessment, populations were grouped into separate complexes by the aggregate of model characteristics. Experimental data on the breeding value and heterosis were obtained (**Figure 3**). Using this approach in the analysis, it is possible to consider the overall breeding value of each population and reveal the general and specific combining ability of the initial forms. As a result, the most effective cross-breeding combinations were identified with the purpose of obtaining model for early-ripening table cultivars. The following combinations have the biggest breeding value: 'Present to Zaporozhye' × 'Rishel'e', 'Talisman' × 'Cardinal', and 'Flora' × 'Find of Mariupol'. The overall positive combining ability is characteristic

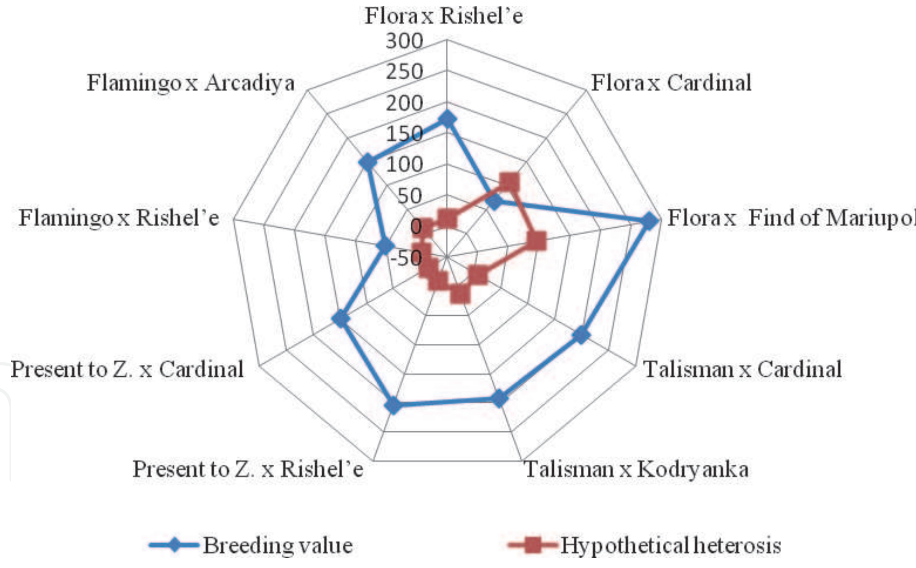

Figure 3.
Degree of expressiveness of model signs in grapevine populations.

of the original forms of 'Flora' and 'Talisman', negative —'Present to Zaporozhye'. The positive specific combining ability was observed in 'Flamingo' variety in crosses with 'Arcadia' variety. By the total common indicators, of special interest is the combination of 'Flora' × 'Find of Mariupol'.

The analysis of the inheritance of the aggregate model features allowed creation of new table cultivars of very early-ripening period with big berries and bunches: 'Solnechnaya grozd' ('Flora' × 'Find of Mariupol'), 'Liviya' ('Flamingo' × 'Arcadia'), and 'Academician Avidzba' ('Present to Zaporozhye' × 'Rishel'e').

The conducted research established global and local climate change and the associated change in the biotic stress factors of the biosphere. This problem results in a need to cultivate new grape cultivars that are environmentally plastic and resistant to the biotic and abiotic factors of the biosphere. The targeted creation of new grape cultivars based on formulation of models and their subsequent implementation is perceived as the most successful approach.

The hybridological analysis of the newly created grape hybrid gene pool revealed the most effective combinations of crosses for early-ripening cultivars with a big berry. Also, the general and specific combining ability for certain initial forms that appear in the progeny was identified. Overall, the model practice allowed obtaining new early-ripening grape cultivars with big berries that are being successfully cultivated in the vineyards under different environmental conditions.

7. Aspects of the general and particular in the formation of programs of fundamental scientific research in horticulture

The modern conditions of the biosphere and the cultivation of agricultural crops, which include horticulture and grapes in particular, determine the need for the formation of scientific research programs, the implementation of which would improve the efficiency of agricultural production, in particular of these crops. The analysis of the complex of scientific researches makes it possible to note that genetic selection and physiological-biotechnological priorities can be considered as priority directions and effective implementation of specific scientific developments is possible only after taking into account the existing environmental factors of biotic and abiotic nature.

It is really possible to make an intellectual breakthrough in solving the problems of improving the methodology and scientific foundations of breeding genetic research, as well as increasing the efficiency of agricultural production only on the basis of the development and implementation of national programs. The leading role in the development of these programs should be carried out by the national scientific institutions of the country, to which the All-Russian National Research Institute of Viticulture and Winemaking "Magarach" belongs in Russia. At the present time, in the "Magarach" Institute has developed and is implementing a genetic selection program for the breeding of new grape varieties "Analogue." This program provides for the modeling of new grape genotypes based on the developed models. In turn, the formation of models of new varieties of grapes is based on established patterns of manifestation and inheritance of selectable features selected for each model according to breeding value, crossability, hypothetical heterosis, and other genetic selection patterns.

Participation of scientists of the Magarach Institute in international European scientific projects, including EU projects, gives grounds to say that the research in the institute corresponds to the modern world level of development of both fundamental biological and agronomic sciences.

Among a number of prerequisites necessary for the stable and efficient functioning of any crop production, a special place belongs to the sustainability of its development. This concept includes a whole range of organizational, economic, social, and environmental assessments. The most important of them for agricultural production is the requirement to adequately meet the needs of living people, without depriving this opportunity for future generations, the need to harmonize the way of life with the ecological capabilities of the region, and the introduction of certain restrictions on the exploitation of natural resources due to the ability of the biosphere to cope with the consequences of human activities. This is consistent with the international convention on the ecological status of the biosphere on the planet.

Sustainable development is the main condition for the effective functioning of agricultural production. At the heart of sustainable development of agricultural production are several main factors. One of them is environmental conditions, the requirements for which are presented by living organisms—soil, plants, animals, birds, and insects—which are diverse due to the biological characteristics and diversity of living organisms themselves. The yield of crops and, as a consequence, the economic efficiency of production are determined by the extent to which the living conditions correspond to the requirements of the biology of living organisms. No other circumstances, the provision of machinery, pesticides, and fertilizers, although important, cannot replace this requirement. From this basic condition follows the main task for agriculture, which consists in creating in each soil climatic zone such biocenoses, whose biological requirements would be most adequate to the conditions of their functioning. Only in this case, it is possible to count on their optimum productivity. The main functional unit of the agricultural biocenosis is a variety. Naturally, in these conditions, it is necessary to pay priority attention to the use of biological reserves of the plants themselves of agricultural crops. In other words, it is necessary to go as far as possible toward the creation and use of new selection varieties of grapes that meet modern requirements of agricultural technology and the conditions of the biosphere to the maximum.

This is also confirmed by the fact that in the complex of biological sciences that solve the tasks of increasing the productivity of agricultural production, the most solid positions belong to genetics. At the same time against the background of changing climatic conditions and an increase in the epiphytotic load of phytopathogens in agrocenoses, it becomes most expedient to use varieties of a new breeding generation and clones of traditional varieties resistant to biotic and abiotic factors.

This direction of selection is characteristic for scientific research in Russia and in all developed countries of Europe and the world.

Increasing the efficiency of agricultural production, including horticulture crops and grapes, is really possible only on the basis of the large-scale use of modern scientific and technical developments. The increase in the level of scientific and technological achievements and their use will enable the most fully to realize the high biological potential of the plant and thereby increase the supply of food to the population. At the same time, the priority areas of research are the creation of a new generation of winter-hardy, immune, and productive varieties providing high-quality agricultural products, which are the basis of adaptive horticulture growing.

The criteria for breeding new generations of varieties of horticulture crops can be based on the same principles used in breeding programs adopted for individual crops, particularly for grapes. Based on knowledge of the existence of separate centers of origin of cultures, the evolutionary variability of plants, and the coevolution of plants and pathogens, it is possible to select the necessary initial forms for generative hybridization, which currently remains the main method in breeding. It is also possible to use the laws of genetically determined patterns of crossing and inheritance of signs and characteristics in individual crops when selecting other horticulture crops. Improvement of the methodology of breeding for the purpose of breeding a variety with the necessary parameters is possible, in particular, based on the development and implementation of models of new varieties, which take into account the knowledge of general and private genetics.

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References

[1] OIV. OIV Descriptor List for Grape Varieties and Vitis Species. 2nd ed. Paris: O.I.V. (Off. Int. Vigne Vin); 2001. p. 227

[2] OIV. Codes des caracteres descriptifs des varietes et especes de Vitis. 2009. Available at: http://www.oiv.int/fr/ and http://www.oiv.int/oiv/info/frplubicationoiv#listdesc

[3] Volynkin V, Polulyah A, Klimenko V, Lihovskoi V, Oleinikov N, Levchenko S, et al. Breeding for Ukrainian table grape varieties. Vitis. 2015;**54**:157-158

[4] DeLattin G. On the genetics of grapevines. Present results of the factor analysis of Vitis. Vitis. 1957;**1**:1-8

[5] Peakall R, Smouse PE. Genalex 6: Genetic analysis in excel. Population genetic software for teaching and research. Molecular Ecology Notes. 2006;**6**:288-295

[6] Tukey JW. Data analysis, computation and mathematics. Quarterly of Applied Mathematics. 1972;**30**:51-65

[7] Seehausen O. Hybridization and adaptive radiation. Trends in Ecology and Evolution. 2004;**19**:198-207

[8] Cabezas JA, Cervera MT, Ruiz-Garcia L, Carreño J, Martínez-Zapater JM. A genetic analysis of seed and berry weight in grapevine. Genome. 2006;**49**:1572-1585

[9] Schippers PA. Composition changes in the nutrient solution during the growing of plant in recirculating nutrient culture. Acta Horticulturae. 1980;(98):103-118. DOI: 10.17660/ActaHortic.1980.98.9

[10] Peralbo A, Flores F, López-Medina J. Recirculating nutrient solution in strawberry. Acta Horticulturae. 2005;(697):101-106. DOI: 10.17660/ActaHortic.2005.697.11

[11] Golodriga PY. The methodology for the selection and evaluation of hybrid grape seedlings. In: Proceedings of the All-Russian Viticulture and Enology Scientific and Research Institute "Magarach", V. XII. 1963. pp. 25-35. (in Russian)

[12] Melkonyan M, Volinkin VA. Methods of Ampelographic Description and Assessment of Agrobiological Evaluation of Grapes. Yalta: Institute of Grape and Wine "Magarach"; 2002. pp. 27. (in Russian)

[13] Klimenko VP. Guidelines for Quantitative Genetics of Grapes. Yalta: Institute of Vine and Wine "Magarach"; 1998. pp. 24. (in Russian)

[14] FAO. The Future of Food and Agriculture—Trends and Challenges. Rome: Food Agric. Org. United Nations (FAO); 2017. 34 p

[15] Eiras-Dias JEJ. Status of the Vitis national collection in Portugal. In: Report of a Working Group on Vitis. Rome, Italy: Bioversity International; 2008. pp. 93-94

[16] Lacombe T. Status of the French Vitis National Collection. In: Report of a Working Group on Vitis. Rome, Italy: Bioversity International; 2008. pp. 73-74

[17] Maghradze D, Maletic E, Maul E, Faltus M, Failla O. Field genebank standards for rapevines. Vitis. 2015;**54**:273-279

[18] Pelengic R, Koruza B. Slovenia grapevine germplasm. Acta Agriculturae Slovenica. 2012;**99**(3):429-432

[19] Li SH, Archbold D, London J. Collection, conservation, evaluation and

utilization of *Vitis amurensis* germplasm resources in China. Acta Horticulturae. 2015;(1082):79-86

[20] Dettweiler E. Genetic resources—Gene banks. Vitis. 1990;**29**:57-59

[21] Volynkin V, Polulyakh A, Chizhova A, Roshka N. Ukraine: Native varieties of grapevine. Caucasus and Northern Black Sea region Ampelography. Vitis. 2012:405-473

[22] Dettweiler E, This P, Eibach R. The European network for grapevine genetic resources conservation and characterization. In: Materials of XXV Congress mondial de la vigneet du Vin. France, Paris. 2004. pp. 1-10

[23] Soltis DE, Morris AB, McLachlan JS, Manos PS, Soltis PE. Comparative phylogeography of unglaciated eastern North America. Molecular Ecology. 2006;**15**:4261-4293

[24] Pe'ros J-P, Berger G, Portemont A, Boursiquot J-M, Lacombe T. Genetic variation and biogeography of the disjunct Vitissubg. Vitis (Vitaceae). Journal of Biogeography. 2011;**38**: 471-486

[25] Barrett HC, Carmer SG, Rhodes AM. A taximetric study of interspecific variation in Vitis. Vitis. 1969;**8**:177-187

[26] Soejima A, Wen J. Phylogenetic analysis of the grape family (Vitaceae) based on three chloroplast markers. American Journal of Botany. 2006;**93**: 278-287

[27] Töpfer R, Hausmann L, Eibach R. Molecular breeding. In: Adam-Blondon A-F, Martinez-Zapater J-M, Kole C, editors. Genetics, Genomics and Breeding of Grapes. Enfield, New Hampshire, USA: Science Publishers; 2011. pp. 160-185

[28] Myers N, Mittermeier RA, Mittermeier CG, da Fonseca GAB, Kent J. Biodiversity hotspots for conservation priorities. Nature. 2000; **403**:853-858

[29] Ricklefs RE. Historical and ecological dimensions of global patterns in plant diversity. Biologishe Skrifter (Royal Danish Academy of Sciences and Letters). 2005;**55**:583-603

[30] Levchenko SV, Volynkin VA. The aroma-forming substances of hybrid seedlings of grape. Acta Horticulturae. 2014;(1046):523-530

[31] Maghradze D, Turok J. Project of bioversity International on conservation and sustainable use of grapevine genetic resources in the Caucasus and northern Black Sea region: Activities and results. In: Maghradze D, Rustion L, Turok J, Scienza A, Faila O, editors. Caucasus and Northern Black Sea Region Ampelography. Vitis – Journal of Grapevine Research. 2012. pp. 17-25

[32] Forni G. The origin of "Old World" viticulture. In: Maghradze D, Rustion L, Turok J, Scienza A, Faila O, editors. Caucasus and Northern Black Sea Region Ampelography. Vitis – Journal of Grapevine Research. 2012. pp. 27-38

[33] De Lorenzis G, Simone Di Lorenzo GB, Failla O, Musayev MK, Salimov V, Maghradze D, et al. Study of genetic diversity in *V. vinifera* subs. sylvestris in Azerbaijan and Georgia and relationship with species of the cultivated compartment. Act Horticulturae. 2015;(1074):49-53

[34] Volynkin V, Polulyahk A. Origin of grapevine varieties in Crimea and *Vitis vinifera subsp*. sylvestris classification. Vitis. 2015;**54**(Special Issue):227-228

[35] Golodriga PY, Troshin LP. Biology and technology program for the creation of highly complex-resistant varieties of grapes. In: Golodriga PY, Guzun NI, Nedov PN, editors. Prospects of Breeding and Genetics of Grapes on the

Immune System. Kiev, USSR: Naukova Dumka; 1978. pp. 259-264 (in Russian)

[36] Jones GV, White MA, Cooper OR, Storchmann K. Climate change and global wine quality. Climate Change. 2005;**73**:319-343

[37] Duchene E, Huard F, Dumas V, Schneider C, Merdinoglu D. The challenge of adapting grapevine varieties to climate change. Climate Research. 2010;**41**:193-204

[38] Chaïb J, Torregrosa L, Mackenzie D, Corena P, Bouquet A, Thomas MR. The grape microvine—A model system for rapid forward and reverse genetics of grapevines. The Plant Journal. 2010;**62**: 1083-1092

[39] Volynkin VA, Klimenko VP, Oleinikov NP. Grape selection for immunity based on the models of grape varieties. In: VI International Symposium On Grape breeding, Yalta, Crimea, 4–10 September. 1994, 1994. pp. 72-73