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RESEARCH ARTICLE

Ecological plasticity and stability of grape varieties as an indicator of economic efficiency of their cultivation

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Abstract

The research was conducted at the experimental sites of the National Scientific Center "Institute of Viticulture and Winemaking named after V. Ye. Tairov" from 2011 to 2020. A study of the ecological plasticity and stability of promising table and wine grape varieties was carried out according to the level of manifestation of productivity as one of the most dependent characteristics on growing conditions. Varieties and hybrid forms with the high level of stability and plasticity were ascertained. The suitability of experimental genotypes for intensive and extensive cultivation was determined. Estimation of the economic efficiency of growing new varieties was demonstrated using the promising 'Persei' variety as an example. Cost reduction due to a decrease in chemical load and increase in profit due to consistently high productivity, quality, and non-necessity of extra special care was proven.

Keywords: Grapes, Breeding, Extensive and intensive cultivation technologies, Variety, Ecological stability, Productivity, Profitability

Introduction

The assortment of grapes, as with any agricultural crop, needs constant improvement in accordance with changes in cultivation conditions and agricultural market trends. Scientific evidence clearly states that climate change is the primary challenge for viticulture in the coming decades (Giorgi and Lionello 2008, Fraga, et al. 2012, Hannah, et al. 2013). The main tangible effect of climate change is an increase in average temperatures during the growing season, which can already be observed. Several climate-based models predict a temperature increase of up to 3.7°C by the end of the century based on the reference 1985-2005 period (Malheiro, et al. 2010; IPCC, 2014).

Although the most acclaimed wine is produced in countries with the Mediterranean climate, the impact of climate change on viticulture and winemaking goes beyond the economic and cultural dynamics of this industry. Future tendencies point to the deterioration of numerous natural plant mechanisms affecting vine growth, physiology, and berry ripening, which can cause serious losses in grape yield and its quality. Given the overall potential impact of climate change on agriculture, assessment of the magnitude of potential risk to grapevines will contribute to the development of reasonable and reliable adaptation strategies for grape growers (Iglesias, et al. 2007). Several studies investigate a connection between increased summer stress and reduced yield and quality of grapes (Petrie

and Clingeleffer, 2005). For example, water stress causes decreased productivity by inhibiting photosynthesis, which means that only a limited number of berries can reach ripeness (Zulini, et al. 2007). In addition to disrupting carbon metabolism, water stress also affects nitrogen metabolism and its assimilation due to a decrease in nitrate reductase activity (Bertamini, et al. 2006).

Plant adaptation, namely the interaction between a plant and the environment, is based on such contradictory concepts as variability and stability, plasticity and immutability, etc. Adaptability is determined by many factors ranging from genetic and biochemical to physiological and morphological ones.

Thus, one of the main directions of physiological and biochemical adaptation mechanisms of a grape plant is the adaptation to a complex of adverse environmental factors. That is why based on adaptive selection, breeding programs are being developed in the National Scientific Center "Institute of Viticulture and Winemaking named after V. Ye. Tairov". Their purpose is to create varieties with the high level of expression of adaptive properties, which is confirmed by long-term trials in different environmental conditions: extreme overwintering conditions, extreme lack of moisture supply, and epiphytoties of fungal diseases (Herus, et al. 2014).

Like any living organism, a grape plant reacts to adverse environmental conditions by physiological and biochemical reactions of adaptability. Due to this, it was able to adapt to a complex of unfavorable abiotic and biotic factors that went beyond the limits suitable for its normal vital activity. After all, due to increase in the level of manifestation of genetically determined adaptive properties, it is possible to extend the narrow range of adaptive possibilities and expand the limits of optimal growing conditions. In practice, the most effective method is the creation of new genotypes that would combine high productivity and produce quality from non-resistant donors and high adaptability from wild species. By long-term selection among many plants of one hybrid combination plants with consistently high adaptability are picked out, which is demonstrated by consistent productivity, regardless of the growing conditions.

Indicators of the genotype reaction to a change in the environmental conditions (ecological plasticity and stability of a variety) are substantiated by the possibility of achievement of the level of manifestation of a certain valuable trait in different growing conditions.

Ecological stability is important for the economic efficiency of growing a grape variety. It implies a consistent level of manifestation of economically valuable characteristics regardless of the variability of growing conditions, of course, only if these conditions do not go beyond the limits suitable for the survival of a plant. It means that the minimum level of ecological plasticity should not significantly deviate from the recommended level.

Knowledge of the level of ecological plasticity and stability characterizes the modification and genotypic variability of individual plant properties and traits.

Since the studied varieties are presented as highly adaptive, this hypothesis was tested by the long-term research on the adaptive potential of promising cultivars, hybrid forms, and reference varieties.

Materials and Methods

Location of the research. The study was conducted from 2011 to 2020 at the experimental sites of the National Scientific Center "Institute of Viticulture and Winemaking named after V. Ye. Tairov", Tairove, Odesa district, Odesa region, Ukraine. All grapevines were grafted on the 'Vitis riparia × Vitis rupestris 101-14' rootstock. The training system is a horizontal double cordon on a three-wire vertical trellis. The height of a trunk is 75-80 cm. Plants spacing is 3 × 1.5 m. The vineyards are not irrigated. The reference varieties were planted and studied under the same conditions as the hybrid forms. The research material was 18 hybrid forms and varieties. Among the studied hybrid forms and varieties, there were 9 table ones, of which 3 were reference varieties: 'Arkadia' (valued for large berry size and excellent taste), 'Original' (valued for its visual appearance and high adaptive properties) and 'Vostorg' (valued for winter hardiness and pathogen resistance); 9 wine varieties and hybrid forms, including 3 reference varieties: 'Muskat odesskii' (valued for muscat flavor and adaptability), 'Aligote' (a standard of quality among white grape varieties), 'Cabernet Sauvignon' (a standard of quality among red varieties).

The studied varieties and hybrid forms have a complex interspecific origin that determines their high adaptability, in particular, pathogen resistance. However, this complex origin affects the specificity of plant response to conditions during the growing season. Determining the patterns of manifestation of the main characteristics of productivity depending on the level of optimality of growing conditions was the main task of this research.

The study of the main signs of adaptability, productivity and quality was carried out using methods common in viticulture (Pogosyan, 1974, Lazarevskij, 1963, Amirdzhanov, et al. 1986, Decyna, et al. 2019, Hangildin, et al. 1981, Gurev, 1981).

Results and Discussion

This article presents an analysis of the stability of the main characteristics of productivity and quality over 10 years of research (2011–2020). Each year differed significantly in its suitability for grape cultivation.

Tab. 1 shows the results of ecological plasticity and stability assessments. The significant influence of growing conditions on productivity and quality of the yield was proven, especially during years with fungal epiphytoties, extreme overwintering conditions, and an extreme lack of moisture. The set of Ij indices characterizes the variability of the growing conditions. 2015 turned out to be the most unfavorable year with extreme overwintering conditions, which significantly affected the yield level. The hot and dry conditions of 2020 were also not optimal for grape plants.

Table 1. Ecological plasticity and stability of table and wine varieties and hybrid forms, 2011-2020.

Variety, hybrid form	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Productivity, 2011-2020	Environmental plasticity	Environmental stability
'Odissey'	7,7	20,3	18,7	14,1	8	12	9	14	23	3,5	13,0	1,2	15,7
'Zagrava'	8	10,2	20,9	11,8	4,8	12	10,5	14,2	12,6	11,2	11,6	0,9	6,5
'Persei'	11,1	13,2	10	20,7	4,4	29	22	19	25	11	16,5	2,0	18,1
'Tairian'	5,3	11,1	12,1	11,3	7,2	17	13,2	19,4	15,2	2,9	11,5	1,6	5,2
'Kalisto'	14,6	11,5	10,2	12,9	7,9	17,5	14,3	23,1	12,8	11,4	13,6	1,2	4,3
'Fontan'	26,5	10,9	24,1	11,5	10	27,8	31,1	32,1	26	12,6	21,3	2,7	16,5
'Arkadia', ref.	11,7	20,3	22,1	10	4,5	16	20	24	23	16,5	16,8	1,8	9,9
'Vostorg', ref.	16	11,8	11,1	11,7	7,1	14	14,5	18,7	20,1	9,8	13,5	1,2	3,0
'Original', ref.	28,9	11,9	11,8	11,4	12,7	24	36	17	14	9,5	17,7	1,2	38,7
'Aromatny'	15,7	17,5	12,4	20,2	12,5	16,2	15,8	17	12,1	10,7	15,0	-0,2	5,8
'Zagrey'	15	17	18,9	20,9	12,1	11,5	10,7	9,8	10,1	12,4	13,8	0,2	9,1
'Odeskyi zhemchug'	19,4	14,2	11	16,5	11,2	13	15	14	11	12	13,7	0,2	4,0
'Jarilo'	10,9	17	16,7	19,5	13,5	11,5	10,8	10,6	10,3	10,1	13,1	-0,2	6,5
'Selena'	11	10,7	11,9	10,3	11,5	14,3	4,8	19,6	10,7	8	11,3	0,6	6,9
'Idyliia muskatna'	10	10	10,7	6,4	5,8	10,2	12,4	9,3	10,7	9,6	9,5	0,4	1,5
'Muskat odesskii', ref.	14,4	14,3	16,6	10,2	3,6	5,9	8,8	17,1	18,1	11,5	12,1	1,1	9,0
'Cabernet Sauvignon', ref.	8,2	11,8	12,6	9	6,4	14,3	10,5	17,7	10,3	12,2	11,3	0,8	3,3
'Aligote', ref.	13,5	10,8	13,8	12,6	6,3	7,8	10,5	16,6	11,4	8,6	11,1	0,8	2,7

The conditions of 2012 and 2014 were unfavourable due to fungal epiphytoties, but not critical. In favourable conditions of 2013, 2016, and 2018, the yield level was not lower than the average one. In 2018, the varieties demonstrated their highest productivity and quality potential. It was demonstrated in yield ranging from 9.3 to 32 t/ha, a tasting score of no less than 7.75 points on a 10-point scale for table varieties, and the sugar content in the juice of wine varieties not less than 20 mg/100 cm^3.

Ecological plasticity describes how a variety responds to improved growing conditions. The higher this characteristic is, the more positive will be the plant reaction to growing conditions close to optimum for this variety. As expected, the group of table varieties was more plastic. The index of their ecological plasticity varied from 1.21 to 2.69. The 'Zagrava' variety stood out with a plasticity index of less than one (0.92). It reacted less to changes in growing conditions.

All other varieties and hybrid forms can express their full potential only under advanced agricultural practices, which includes irrigation, fertilizers, modern trellising, etc. 'Persei', 'Tairian', 'Fontan' varieties and hybrid forms, and the 'Arkadia' reference variety had the highest ecological plasticity with the coefficient ranging from 1.56 to 2.69. 'Odissey', 'Kalisto', 'Vostorg' and 'Original' varieties and hybrid forms with an index of ecological plasticity of 1.21-1.24 are the most suitable for extensive cultivation, although they can also show better results in improved conditions. Tab. 2 shows the potential productivity for each variety in the local conditions.

Table 2. Potential productivity of table and wine varieties and hybrid forms, 2011-2020.

Variety, hybrid form	Estimated potential productivity, t/ha									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
'Odissey'	13,12	12,89	14,34	12,65	6,34	14,92	14,64	17,62	15,09	8,69
'Zagrava'	11,69	11,51	12,59	11,34	6,66	13,02	12,81	15,03	13,15	8,40
'Persei'	16,69	16,31	18,66	15,92	5,76	19,59	19,13	23,94	19,86	9,53
'Tairian'	11,59	11,29	13,14	10,98	2,95	13,88	13,52	17,32	14,09	5,93

'Kalisto'	13,71	13,48	14,90	13,25	7,10	15,46	15,19	18,10	15,63	9,38
'Fontan'	21,46	20,95	24,11	20,43	6,75	25,36	24,75	31,22	25,72	11,84
'Arkadia', ref.	16,94	16,60	18,72	16,25	7,05	19,57	19,16	23,51	19,81	10,47
'Vostorg', ref.	13,57	13,34	14,79	13,10	6,79	15,37	15,09	18,07	15,54	9,14
'Original', ref.	17,81	17,58	19,02	17,34	11,09	19,60	19,31	22,27	19,76	13,41
'Aromatny'	15,00	15,03	14,82	15,07	15,98	14,74	14,78	14,34	14,71	15,64
'Zagrey'	13,86	13,82	14,06	13,78	12,71	14,16	14,11	14,62	14,19	13,10
'Odeskyi zhemchug'	13,75	13,71	13,95	13,67	12,60	14,05	14,00	14,51	14,08	12,99
'Jarilo'	13,08	13,11	12,92	13,14	13,95	12,85	12,88	12,50	12,82	13,65
'Selena'	11,32	11,21	11,90	11,10	8,10	12,18	12,05	13,46	12,26	9,21
'Idyliia muskatna'	9,54	9,46	9,98	9,37	7,14	10,18	10,08	11,14	10,24	7,97
'Muskat odesskii', ref.	12,13	11,93	13,19	11,72	6,23	13,70	13,45	16,05	13,84	8,27
'Cabernet Sauvignon', ref.	11,36	11,21	12,15	11,05	6,99	12,52	12,34	14,26	12,63	8,50
'Aligote', ref.	11,15	11,00	11,97	10,83	6,61	12,36	12,17	14,16	12,47	8,18

It should be noted that theoretical and actual productivity sometimes does not match, and the estimated yield is not always higher than the actual yield. Data from the research on ecological stability show how unstable the variety is depending on the growing conditions. 'Odissey', 'Persei', 'Fontan', and 'Original' table varieties have the highest ecological stability, namely the greatest dependence on growing conditions.

This does not mean that their cultivation is economically impractical. It shows that under favorable conditions their yield level will be higher. And long-term research showed that it has never been below the minimum recommended 10 t/ha. 'Kalisto', 'Zagrava', and 'Tairian' demonstrated high ecological stability, with indices ranging from 4.3 to 6.5, comparable to the 'Vostorg' reference variety.

The group of wine varieties and hybrid forms showed high ecological stability. Their index of ecological stability ranged from 1.5 to 9.1. 'Idyliia muskatna', 'Odeskyi zhemchug', and 'Aligote' and 'Cabernet Sauvignon' reference varieties showed the lowest dependence of the yield level on the conditions of the growing season.

As a result of this study, it can be concluded that the conditions of the extreme year 2015 had the biggest effect on the yield level of the studied varieties and hybrid forms. The most favorable year was 2018.

The actual productivity of these varieties is at a fairly high level, sufficient for the economic feasibility of their extensive cultivation. Thus, intensive cultivation could result in a significant economic benefit.

Primarily, these are 'Persei', 'Tairian', 'Fontan' varieties and hybrid forms and the 'Arkadia' reference variety with an ecological plasticity coefficient ranging from 1.56 to 2.69. If cultivated intensively, they can fully reveal their potential.

A higher level of ecological stability was noticed in a group of wine varieties and hybrid forms. Among the table genotypes, 'Odissey', 'Persei', 'Fontan', and 'Original' varieties demonstrated the highest ecological stability.

One of the important directions of viticulture development is meeting the demand of consumers and grape producers in the Ukrainian market. The formation of demand depends on two main factors: market capacity and the purchasing power of the population. According to scientifically based standards, the annual amount of grape consumption is about 8 kg per person. Taking into account the fact that in 2017 the population of Ukraine was estimated at 44.83 million people, the capacity of the grape market was 358,000 tons, which is comparable to the gross amount of production of all grapes in Ukraine in all farm categories. According to official statistics, Ukrainians consume, on average, only 0.5 kg of grapes per year, the potential for growth reaches approximately 336,000 tons just for table grapes. Given the average yield in Ukraine in recent years has been 75 t/ha, it is necessary to additionally cultivate 44,800 ha or double the area of fruiting vineyards. Local producers have an incentive to increase the volume of grape production, as the market is not saturated and there is a considerable potential for increasing the amount of supply.

In 2017, Ukraine imported about 47,000 tons of grapes for almost 34.4 million US dollars. The main importers were Turkey, Iran, and India. Fresh table grapes and raisins were mostly imported from Turkey and Iran, respectively. In general, 80.1% of all fresh grapes were imported from Turkey. Although its price was comparatively higher than that of Moldovan grapes, Ukrainian consumers preferred Turkish produce. The competitiveness of the latter was higher due to its better quality.

Grapes are grown in many Ukrainian regions, but natural and climate conditions for their cultivation are the most favorable

in the south. High efficiency and competitiveness of the Ukrainian viticulture industry can be achieved only with the guaranteed and balanced combination of necessary conditions and factors.

An important aspect of the development of table viticulture on the local market is the cultivation of new varieties. They have the potential to spread to industrial vineyards due to their high plasticity and complex resistance to environmental stress factors, which reduces the cost of the produce. Visual appearance, exclusive taste, and aromatic properties can be considered advantages as well.

The main reason for decreasing expenses for growing new table varieties is genetically determined resistance to pathogens and reducing the chemical load on vineyards. Tab. 3 shows the estimated economic efficiency of cultivation of new varieties using 'Persei' as an example.

Table 3. Estimated economic efficiency of cultivation of new varieties bred in the National Scientific Center "Institute of Viticulture and Winemaking named after V. Ye. Tairov" (average productivity for 2015-2017 period).

No.	Characteristics	Varieties	
		'Original', ref.	'Persei'
1	Productivity, t/ha	24,2	18,9
	marketable produce, t/ha	20,6	15,7
	non-marketable, t/ha	3,6	3,2
2	Sale price of produce, UAH/t** incl.		
	marketable	17000,0	15000,0
	non-marketable	4000,0	4000,0
3	Production costs per 1 ha, UAH.*** incl.	93834,2	56295,5
	salary	73474,0	35932,5
	fertilizers and plant protection products	13600,0	13600,0
	materials	1400,0	1400,0
	fuel and oil	3360,0	3360,0
	amortization	2000,0	2000,0
4	Revenue from produce sales, UAH/ha	364600,0	248300,0
	marketable	350200,0	235500,0
	non-marketable	14400,0	12800,0
5	Cost of 1 t of produce, UAH	3877,4	2978,5
6	Profit from the sale of produce, UAH/ha	270765,8	192004,5
7	Profitability level, %	288,6	341,0

Note: ** calculated according to prices in 2019; *** data obtained based on expenses of the Department of Selection, Genetics, and Ampelography.

This also ensures the ecological safety of the produce, since the technology based on the cultivation of classic varieties of *Vitis vinifera* L. requires 10%-20% fewer chemicals when growing varieties with complex genetic origin.

In 2019, the average cost of growing one hectare of table grapes in Ukraine varied from 80,000 to 100,000 UAH. [136] The estimation of the costs of growing 1 hectare of vineyard was performed according to the flowcharts created in the National Scientific Center "Institute of Viticulture and Winemaking named after V. Ye. Tairov". Vineyard care requires the use of a large amount of manual labor, which is converted into monetary equivalent. Harvesting, transportation, sorting, and packing are the most capital-intensive

stages. The 'Original' reference variety is an interspecific hybrid. It has a sufficiently high level of resistance and does not require additional treatments with plant protection agents, so the number of chemical treatments was limited to 5-6 times per growing season. There were no differences in plant protection between the reference variety and the studied one.

The estimated economic efficiency data showed that the new varieties differ in the amount of expenses per 1 ha. Primarily, this is due to the cost of harvesting. The new 'Persei' variety has a unique property. It demonstrates uniform ripening and high marketability of its bunches. That is why, unlike other table varieties that need to be harvested 3 times, 'Persei' is harvested only once, which reduces the cost of its harvesting and transportation.

The organoleptic properties of the new 'Persei' variety are somewhat inferior to the 'Original' reference variety, therefore, the wholesale price of the new variety is 2 UAH lower. The non-marketable portion of its produce was sold for 4 UAH per kg.

The most important and integral characteristic of the economic efficiency of any crop, including grapes, is the level of profitability, which is presented in a percentage and reflects the final result of grape cultivation. It shows how much profit is obtained per 1 UAH of expenses on cultivation. The level of profitability of the new 'Persei' variety is 341%, which is 52.4% higher than the reference variety. It indicates the potential of its cultivation in the viticultural regions of Ukraine for the mass production of high-quality and environmentally safe produce available to a consumer.

Conclusion

Thus, a group of wine varieties and hybrid forms showed high ecological stability according to their productivity. The coefficient of their ecological stability varied from 1.5 to 9.1. 'Idyliia muskatna', 'Odeskyi zhemchug' varieties and hybrid forms, and 'Aligote' and 'Cabernet Sauvignon' reference varieties showed the lowest dependence of their productivity on the conditions of the growing season.

Among the table varieties and hybrid forms, 'Persei', 'Tairian', 'Fontan', and the 'Arkadia' reference variety with the coefficient of ecological plasticity ranging from 1.56 to 2.69 had the highest ecological plasticity. A higher level of ecological stability was observed in a group of wine varieties and hybrid forms compared to a group of table genotypes.

The most promising varieties and hybrid forms ('Persei', 'Jarilo', 'Zagrey', 'Odeskyi zhemchug', 'Tairian', 'Kalisto', etc.) were transferred to different regions of Ukraine to study their ecological plasticity in different growing conditions.

Using the 'Persei' variety as an example, the proven economic effect of the cultivation of new varieties allows us to show the potential of their cultivation in comparison with the widespread high-quality and high-productivity varieties.

A significant reduction of both expenses and manual labor, for the cultivation of the 'Persei' variety demonstrates its potential for further production. Excellent taste and marketability characteristics ensure a decent market price for this product and prove the possibility of obtaining a consistent profit from its cultivation.

Outstanding characteristics of the new 'Persei' variety confirm its potential for use on an industrial scale, and its intensive cultivation will be able to fully reveal the potential of this highly productive, exclusive, and high-quality variety.

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