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Adaptive winemaking technologies using PIWI varieties in the wine industry of Ukraine

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Abstract. In recent years, the impact of climate change has been pushing agriculture toward the implementation of innovative production methods aimed at countering the negative consequences of climate change. Researchers at our university have already conducted studies on adaptive winemaking technologies using grape varieties of domestic breeding, which are characterized by high technological performance and adaptability to climate change conditions. These grape varieties are the result of breeding efforts by specialists at the National Scientific Center "V. Ye. Tairov Institute of Viticulture and Winemaking," who focused on developing varieties with an original aromatic profile, increased yield, and resistance to diseases, pests, and low temperatures (specifically, complex-resistant grape varieties). These include such varieties as Aromatnyi, Zahreii, Iskorka, and Muscat Odeskyi — they demonstrate resistance to major grapevine diseases such as oidium and mildew, as well as the ability to withstand frosts, which is a key factor for stable viticulture in Ukraine. PIWI grape varieties are actively being introduced into viticultural practices across various regions of Ukraine. Today, vineyards with such varieties are successfully operating in the Odesa, Khmelnytskyi, Zakarpattia, and Zhytomyr regions. Today, Ukraine is becoming a research platform for studying adaptive and innovative technologies.

1. Statement of the problem

Climate change significantly affects the quality, typicity, and yield of grapes and wine. The main consequence for vineyards is the shortening of the grapevine's vegetative cycle (earlier ripening and faster maturation of grapes), which leads to lower acidity and higher sweetness of the berries, increased alcohol content, reduced anthocyanin levels in wines, and changes in their aromatic profile [1].

The increasing vulnerability of traditional Vitis vinifera varieties to fungal diseases, particularly powdery mildew, has led to intensified use of plant protection products. However, the constant spraying of vineyards is increasingly viewed as an undesirable practice due to its negative impact on the environment and the decline in consumer trust in the products. There is a growing social demand for sustainable development and a reduction in pesticide use [2].

The winemaking industry requires solutions for adapting to climate change, controlling grape ripening, overcoming the weaknesses of certain traditional varieties, avoiding pesticide resistance, and reducing grape susceptibility to diseases. For these reasons, current trends in viticulture and enology are focused on vine crossbreeding and the exploration of new hybrid grape varieties [3].

Grape vines are among the most climate-sensitive of all agricultural crops. Climate change presents significant challenges for viticulture worldwide. Adaptation in grape and wine production has the potential both to minimize losses from the threatening consequences of climate change and to maximize benefits from favorable effects. One of the adaptive strategies adopted by the winemaking industry in response to climate change and the use of chemicals in viticulture has been the creation of hybrid Vitis varieties resistant to pests and fungal diseases. When referring to these varieties, specific reference is made to PIWI, the German acronym for PilzWiderstandsfähige, which literally means resistant to fungal diseases. PIWI vineyards are resilient both from an agronomic and economic perspective. The characteristics of these grape varieties differ from those of Vitis vinifera, requiring adjustments and changes in winemaking technology to maintain high wine quality.

2. Research materials and methods

One of the leading research institutions playing a key role in the development of the viticulture sector in Ukraine is the National Scientific Center "V. Ye. Tairov Institute of Viticulture and Winemaking" of the National Academy of Agrarian Sciences of Ukraine. The Institute is a scientific center with a long history and a significant contribution to the formation of the grapevine variety pool in Ukraine. Over many years of research, the Institute's staff has created more than 130 varieties of table and technical grapes, distinguished by high yields, quality indicators, and adaptability to Ukraine's climatic conditions. Additionally, 112 clones of 52 existing varieties have been obtained, which expands the variety pool with consideration for their adaptive potential to various soil and climatic conditions [4]. During research, optimal ecological niches for grapevine cultivation have been identified, ensuring the production of goods that meet modern technological and European quality standards. The Institute also possesses an ampelographic collection that includes over 700 grape varieties of different genetic and geographical origins. An important resource for breeding work is the Institute's hybrid collection, which includes more than 15,000 seedlings and is actively used in the creation of new competitive varieties [4]. In modern conditions, the choice of grape varieties for winemaking should be based not only on traditional assortment criteria but also on consideration of the impact of climate change. Specifically, the increase in average annual temperature, reduction in precipitation, and changes in carbon dioxide concentration in the atmosphere significantly affect the quality of grape raw materials. The rise in temperatures during the growing season leads to its shortening and disrupts the typical growth rhythm of the grapevine. As a result, noticeable changes occur in the chemical composition of the berries: the content of fructose increases, which is less effectively fermented by yeast, total acidity decreases, particularly the concentration of malic acid, and the level of anthocyanins — key components of color and antioxidant activity — decreases. These changes lead to an increase in sugar content, which in turn results in a higher ethanol volume fraction in the wine, as well as affecting the aromatic and taste profile of the final product. The grape variety plays one of the key roles in forming the original wine profile; therefore, varieties of generative breeding, which are adapted to specific cultivation conditions, may represent a raw material potential for wine production. Grape varieties of generative breeding, such as Aromatnyi, Zahreii, Iskorka, and Muscat Odeskyi, which are resistant to frosts and grapevine diseases such as oidium and mildew,were the subject of research (Table 1).

Table 1. Grape Varieties Studied in the Work.

Variety Name	Origin	Crossbreeding Scheme	Ripening Period Days
Aromatnyi	76% V. vinif, V. labruska,V. rupestris	Vartish Chylaha x Romulus	Mid-early 130..140
Zahreii	75 % – V. vinifera, V. amurensis V.rupestris	Aligote x Ovidiopolskyi	Mid-late 130..140
Iskorka	88,5 % – V. vinifera, V. rupestris, V. amurensis,	(Pino Siryi x (Irshai Oliver + Muscat White)) x (Muscat Odeskyi + Zala Dyond)	Medium13 2..140
Muscat Odeskyi	76 % – V. vinifera, V. amurensis V. rupestris	Muscat Synii Rannii x Pierrelle	Early-medium, 130..140

The research methods used were standardized and special, including physicochemical, biochemical, analytical, organoleptic, and experimental-statistical methods for analyzing grapes, wine materials, and wines.

These grape varieties of generative breeding have specific varietal characteristics that were taken into account when improving the existing technology for the production of young white dry table wines (Table 2).

Table 2. Physicochemical Indicators of Wine Materials from Grape Varieties of Generative Breeding.

Indicator	Wine materials from grape varieties of generative breeding			
	Aromatnyi	Zahreii	Iskorka	Muscat Odeskyi
Volumetric fraction of ethyl alcohol, %	10,5	10,0	12,2	11,2
Mass conc. of titr. acids, g/dm³	6,0	5,6	7,2	6,4
Mass conc. of volatile acids, g/dm³	0,78	0,82	0,74	0,87
Mass conc. of total extract, g/dm³	20,8	20,4	21,7	20,1
pH	3,50	3,51	3,25	3,49
Mass concentration, mg/dm³				
Free SO_2 (sulfur dioxide)	16,6	15,3	14,2	16,7
Total phenolic compounds	278	380	505	399
Polymeric forms of phenolic compounds	29	26	27	34

The basis of the wine's aromatic complex is formed by primary aromas. Most of the aromatic compounds responsible for a particular grape variety are present in a bound glycoside form, non-volatile, and odorless. Examples of non-volatile precursors include monoterpene alcohols bound to monosaccharides or disaccharides [5]. In experimental samples, the mass concentration of terpenoid alcohols in both free and bound forms and the mass concentration of linalool were determined (Table 3).

Table 3. Physicochemical Indicators of the Aromatic Complex of Wine Materials from Grape Varieties of Generative Breeding.

Sample Name	Mass concentration, mg/dm³					
	Amino-nitrogen	Terpenoid alcohols			Higher alcohols	Complex esters
		Free	Bound	Linalool		
Aromatnyi	192	1,56	0,43	0,185	259	55
Zahreii	194	2,31	0,55	0,122	263	53
Iskorka	167	2,57	0,75	0,119	205	49
Muscat Odeskyi	275	6,07	6,42	0,317	213	57

As a result of the research, it was established that the physico-chemical and organoleptic indicators of wine materials from grapes of generative selection varieties – Aromatnyi, Zahreii, Iskorka, Muscat Odeskyi – are suitable for the production of white table wines. However, a number of peculiarities were revealed: the mass concentrations of phenolic substances in wines from generative selection varieties exceed 250 mg/dm³, and the reduced extract amounts to more than 20 g/dm³, which contributes to obtaining extractive and full-bodied white dry wines, whose aroma and taste do not correspond to this type.The varietal aromatic complex is mainly represented by terpene alcohols.

A sensory analysis of wine materials and wines was conducted in order to determine the overall intensity of the main aroma and taste descriptors. During the sensory analysis, it was established that wine materials from Aromatnyi grape variety are characterized by a caramel-fruity aroma with a delicate spicy note and a fresh taste; from the Zahreii variety – a distinctly expressed aroma of ripe tropical fruits and a rich, long aftertaste.

Wine materials from the Iskorka grape variety are distinguished by a floral-fruity aroma, predominantly of stone fruits with a refined muscat note; and from the Muscat Odeskyi variety – citrus notes and an intense rose aroma, which distinguishes it from classical varieties of the muscat group.

A comprehensive analysis of grapes from generative selection varieties made it possible to state the following: the onset of full aromatic ripeness of the grapes occurs after technological ripeness. This fact is important, since for the production of white table wines with specific consumer properties (alcohol by volume less than 12%; titratable acidity – 6 to 7 g/dm³), the mass concentration of sugars in the grapes should not exceed 200 g/dm³, and the mass concentration of titratable acids should be no less than 6.5 g/dm³; the phenolic complex of generative selection varieties represents a complex system: technological reserve of phenolic compounds (756–1092 mg/dm³), mass concentrations of total phenolic compounds (264–701 mg/dm³), high activity of the PPO enzyme (more than 7 units), must maceration capacity (112–149%), must oxidative capacity (68–89%); The studied features of the varietal potential of selected grape varieties indicate the need to justify the choice of optimal modes and parameters at each stage of grape processing for the production of high-quality white dry table wines [5].

The consequences of global warming are now being felt in viticulture worldwide. Observed changes in winemaking regions across the globe have shown an average warming of 1.3 °C during the growing season from 1950 to 2000, and the forecast for the next 50 years predicts an average warming of 2 °C [6]. The temperature during the growing season in Europe increased by 1.7 °C from 1950 to 2004, leading to an increase in heat accumulation, a reduction in frost damage, changes in ripening profiles, shifts in pest outbreaks and their intensity, changes in soil fertility and erosion, as well as irrigation requirements [7].

The warming trends seriously threaten viticulture and its sustainable development. In many winemaking regions, drought and rising temperatures affect vineyard productivity, disrupting vine physiology and accelerating grape metabolism. In white varieties, especially those intended for sparkling wines, accelerated ripening leads to excessive sugar content and insufficient acidity and aromas at harvest, resulting in unbalanced wines [8]. Under these conditions, grapes contain more sugar and fewer organic acids. The composition of secondary metabolites, particularly aromatic compounds, changes drastically. The intensification of drought due to reduced summer precipitation leads to the early cessation of shoot growth, smaller berry size, increased phenolic compound content in the skin, reduced malic acid concentration, and altered aroma profiles. In the coming decades, the strengthening of these trends is highly likely [1]. In response to these challenges, the winemaking industry has turned to the combination of technological advances, new cultivation methods, and varieties to mitigate the effects of climate change and maintain wine quality [9]. Innovative solutions have been developed that allow grape growers to adapt their agricultural management systems to climate change [10]. A significant breakthrough in this field is the use of fungal-resistant grape varieties, specifically PIWI (Pilzwiderstandsfähige). These varieties have been developed to increase resistance to common grapevine diseases, reducing the need for pesticide application. This not only helps grape growers cope with the increased

number of pests due to climate change but also reduces the impact of viticulture on the environment [11]. Disease-resistant grapevines, obtained through genetic crossbreeding, are an important tool for the sustainable development of the winemaking sector. This removes limitations and leaves relative decisions regarding the strategies for implementing and using these grapevines to producers and their communication strategies. The reduction in pesticide use depends on many factors, including the characteristics of the resistant vines, the climatic trend of the production year, cultivation methods, and so on. The reduction in pesticide use related to wine also depends on the percentage of PIWI grapes used [11].

A considerable number of studies describe the resistance of these new varieties under different environmental conditions. Depending on the quantity and types, they exhibit varying degrees of resistance; nevertheless, it has been confirmed that these varieties are more resistant than the traditional V. vinifera [12]. PIWI grapevines represent an alternative to classical varieties in winemaking regions [13]. The chemical composition of PIWI grape berries and wine can significantly differ from that of V. vinifera, which may lead to a sensory profile that noticeably differs from V. vinifera wines and cause difficulties during winemaking. Many of these issues are particularly noticeable in wild species of *Vitis* and in earlier generations of hybrids, but similar problems also arise with most PIWI. However, their composition varies greatly between varieties [14]. Wines made from PIWI grapes typically have a high level of titratable acidity and a low content of condensed tannins, as well as an acceptable total soluble solids content and pH. Due to the different chemical composition of PIWI, winemaking protocols must differ from those used for conventional grapes(14).Most Common PIWI Grape Varieties (Table 4)

Table 4. Most Common PIWI Grape Varieties.

Country	Regions	PIWI Varieties
Germany	Pfalz, Baden, Franconia	Solaris, Regent, Johanniter, Cabernet Cortis
Switzerland	Ticino, Valais	Divico, Divona
France	Alsace, Languedoc	Souvignier Gris, Muscaris
Italy	Trentino-Alto Adige, Friuli	Bronner, Johanniter, Souvignier Gris
Austria	Styria, Lower Austria	Muscaris, Souvignier Gris, Donauriesling
Denmark / Sweden	Zealand, Scania	Solaris, Rondo, Regent
Ukraine	Zakarpattia, Khmelnytskyi, Odesa, Zhytomyr regions	Solaris, Muscaris, Cabernet Cortis, Johanniter
Slovakia	Western Slovakia	Hibernal, Malverina, Laurot
Poland	Lesser Poland, Świętokrzyskie	Rondo, Regent, Johanniter

PIWI grape varieties are actively used in different wine regions of Ukraine. These vineyards are located in the Odesa, Khmelnytskyi, Zakarpattia, and Zhytomyr regions. One of the first to plant PIWI grape varieties was Odesa region, specifically the variety Sauvignon Ritos, which is obtained from the crossbreeding of Sauvignon Blanc and Bianca, and has good resistance to downy mildew and powdery mildew.

In the Khmelnytskyi region, along with other grape varieties, Solaris and Johanniter are also grown. Solaris is the most famous PIWI grape variety, which was developed in 1975 in Germany at the Freiburg Institute of Oenology. Its exceptional resistance to fungal diseases reduces the need for chemical treatments and ensures the health and quality of the wine. Johanniter grapes are an early-ripening wine variety. It was developed in 1968 in Germany by Dr. Johann Zimmermann, the director of the Freiburg Institute of Oenology. In 2014, the varietal white wine Johanniter won first place among white wines in a tasting organized by the Sommelier Association of Ukraine.

In the heart of the Zhytomyr region, various PIWI grape varieties are also grown. This region lies within the mixed forest zone, with the southern part located in the forest-steppe zone. The soil and agro-climatic conditions are favorable for the development of agriculture and forestry [15]. Zhytomyr region belongs to a humid, moderately warm agro-climatic zone. The climate of the region is moderately continental. Considering the region's characteristics, PIWI grape varieties were selected and planted. This vineyard has become a scientific research site for studying adaptive and innovative technologies. Various grape varieties are represented here, including Solaris, Johanniter, Irsai Olivér, Devin, Dornfelder, Dunaj, Blaufränkisch, and Zweigelt.

The study of the impact of a combination of agro-climatic factors on the development of the main morphological, biological, and quality characteristics of grapes will be carried out based on the analysis of sources [16–18].

According to the analysis of precipitation, in most months of the year, the amount was sufficient, while in some months, it significantly exceeded the norm for agricultural crops. Moisture is a critical factor affecting the technological characteristics of grapes. Specifically, increased precipitation during the active growing season, especially during berry growth, promotes the accumulation of organic acids and aromatic compounds in the berries. Over the two years of observation, an uneven moisture regime during the growing season was noted, which could negatively impact harvest quality. To ensure optimal conditions for quality grape formation in the studied region, the recommended amount of precipitation from April to September is 250–350 mm. [19].

The agro-meteorological conditions of 2024 were particularly favorable for growing PIWI grape varieties, which are characterized by early and medium ripening periods. High average monthly air temperatures created optimal conditions for the full ripening of berries and timely reaching of technical maturity. Furthermore, the absence of precipitation during the last month before harvest reduced the risk of berry damage by grey rot and prevented the activation of the enzyme laccase, which can negatively affect the quality of the grapes.

The meteorological conditions of 2023 and 2024 contributed to good ripening of the varieties and allowed the harvest dates to be set for Solaris and Muscaris in the third decade of August, and for Johanniter and Devin in the second decade of September. The evaluation of the physicochemical and biochemical indicators was conducted according to the current regulatory documentation and grape variety evaluation methodology. Carbohydrate-Acid Complex of PIWI Grape Varieties (Table 5).

Table 5. Carbohydrate-Acid Complex of PIWI Grape Varieties.

Indicator	**Grape Variety Name**			
	Solaris	Johanniter	Muscaris	Devin
Harvest Date	21.08…23.08	11.09…14.09	29.08	10.09…13.09
Mass Concentration, g/dm³				
sugars	230…220	190…200	210	210
Titrated Acids	7,4	7,6	9,8	7,9
pH Value	3,17…3,3	3,05…3,1	3,2	3,08…3,25

*Note: The data in the table are presented for 2 years of research.

As part of the study, the first wines were produced and a sensory analysis of the wine materials and wines was conducted to determine the overall intensity of the main aroma and flavor descriptors. Grapes as raw material are the main factor influencing wine quality. A thorough investigation and study of the physicochemical, biochemical, and organoleptic characteristics of grapes of new varieties makes it possible to improve the technological production scheme and to take into account all the specific features of the raw material. Sensory analysis was carried out on wines produced from PIWI grape varieties in order to determine the overall intensity of the main aroma and flavor descriptors. During the tasting, tasting sheets developed in accordance with the OIV international 100-point wine scoring system were used [20]. This scoring scale enables the evaluation of wine quality and classifies wines into five categories, ranging from "excellent" to "unsatisfactory." To study such important wine components as "appearance," "bouquet," "taste," and "overall impression (harmony)," the profile method of sensory evaluation was applied, specifically the creation of a wine flavor spectrum, in accordance with DSTU ISO 5495:2005. This method involves representing a complex concept of an organoleptic property as a set of simple components, which are assessed by tasters based on quality, intensity, and sequence of perception. This method is considered the most informative, as it encompasses all aspects of sensory quality and allows identification of the most relevant components of the bouquet and taste. During the tasting, panels of bouquet and flavor descriptors were presented, and tasters assigned their scores based on a conditional five-point scale.

To conduct the research, a specialized panel of 10 selected highly qualified experts was formed and calibrated in accordance with the international standard DSTU ISO 8586:2019 [21]. The tasting was carried out in the sensory analysis laboratory established at the Odesa National University of Technology and accredited in accordance with ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories" in the field of "Sensory analysis of food products."

During the study of the organoleptic quality indicators of wines made from PIWI grape varieties, certain descriptors were identified.

The descriptors of white wines made from PIWI grape varieties included pineapple, mango, and passion fruit, as well as notes of muscat melon, sweet fruits, apple, and wildflowers. The wines exhibited balanced acidity and a rich texture.

The wine produced from the Solaris grape variety demonstrated a rich and complex bouquet and flavor profile, featuring notes of tropical fruits such as pineapple, mango, and passion fruit, along with floral nuances and citrus hints. The wine exhibited balanced acidity and a full-bodied texture.

The wine produced from the Helios grape variety had an intense bouquet and flavor profile, with pronounced notes of apple, citrus fruits, and wildflowers. It also featured moderate acidity and a relatively low alcohol content.

The wine produced from the Johanniter grape variety was unfortunately oxidized, which was evident both in its color and aroma. The primary aromatic descriptor was oxidized apple, with no characteristic descriptors present. The taste also lacked a balance between acidity and fruitiness.

The wine produced from the Dunay grape variety exhibited cherry and chocolate as its key aromatic descriptors. This wine had a distinctive character with pronounced fruity notes and a well-defined roundness. The overripe cherry nuances transitioned into intriguing chocolate undertones. On the palate, the wine presented richness and a pleasant astringency.

The wine produced from the Dornfelder grape variety featured blackberry, red currant, and floral notes as its main aromatic descriptors. On the palate, it revealed a rich, velvety base with a touch of light astringency.

3. Conclusions

Ukraine has its own climate-resistant grape varieties, the advantages and disadvantages of which have been studied. Based on these studies, adapted winemaking technologies were developed, tested, and scientifically validated, with the findings published in Ukrainian professional journals. Under current conditions, these varieties are used in winemaking across various viticulture regions of the country and participate in professional tasting competitions.

Today, new breeding developments, in particular the varieties of the PIWI group, are of considerable interest among grape growers and winemakers, which has led to their introduction in the form of experimental and industrial plantations in Ukraine. Due to the relevance of this topic, research into the properties of modern PIWI varieties in the conditions of the domestic climate was initiated. The first results obtained indicate the prospects of this direction, which serves as the basis for further research within the framework of scientific cooperation.

As climate change impacts traditional wine regions, PIWI varieties offer a sustainable alternative that can thrive in more challenging growing conditions. The use of PIWI grape varieties for high-quality wine production has great future potential, and testing to determine their suitability for different terroirs is also important. PIWI varieties contribute to improved disease control in both organic and conventional viticulture, reduce production costs and reduce copper accumulation in soils. The future of winemaking with disease-resistant grape varieties presents both challenges and opportunities.

Further research work involves expanding the range of studies aimed at studying the biological characteristics, agronomic adaptability and enological potential of PIWI grape varieties. Experimental studies will be carried out within the framework of scientific cooperation between Odessa National University of Technology, Polesie National University and international partners. Special attention will be paid to the study of varieties in the context of climatic adaptation, resistance to pathogenic factors, as well as product quality in organic and sustainable viticulture and winemaking systems.

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