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Sustainability in the winemaking industry and the assessment of grape seed characteristics during processing: Evidence from Azerbaijan

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Abstract. In the context of Azerbaijan's evolving winemaking landscape, this study investigates the sustainability of viticulture with a particular focus on grape seeds, which are crucial for grapevine propagation, oil extraction, and overall vineyard health. The research aimed to examine the morphological, technological, and biochemical characteristics of grape seeds to optimise grape production methods and promote sustainable viticultural practices. To achieve this, seed samples from twelve grape varieties, both local and introduced, were carefully collected and analysed under varying irrigation conditions, including both irrigated and rainfed settings, to allow for a comprehensive assessment. The investigation revealed significant effects of irrigation on seed properties. Specifically, seeds from irrigated grapes were found to be larger, heavier, and richer in oil content compared to those from rainfed grapes. Detailed analyses showed that the nitrogen content of the seeds ranged from 0.96% to 1.46%, cellulose content varied from 18.8% to 25.3%, ash content ranged from 1.9% to 3.1%, nitrogenous compounds fluctuated between 5.5% and 7.2%, and non-nitrogen extractive substances registered between 16.6% and 22.0%. Notably, correlations between seed properties and the efficiency of cold press oil extraction were identified, providing valuable insights. This research ultimately

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contributes to the advancement of sustainable viticulture practices in Azerbaijan, ensuring the long-term health and productivity of vineyards within the region

Keywords: agriculture; viticulture; technological characteristics; biochemical composition

INTRODUCTION

The production process of goods within the wine industry has a substantial economic impact. Unfortunately, this production also generates a considerable amount of waste, posing to significant challenges to the ecosystem. During processing, between 25% and 40% of various grape components, including stems, seeds, peels, and so forth, are disposed of as waste. Of this waste, grape seeds account for 38% to 50% of grape pomace and typically constitute approximately 5% of the total grape mass. Notably, the global wine industry annually discards approximately 3 megatons of grape seeds. Grape seeds are rich in carbohydrates, fibres, lipids, minerals, polyphenols, and proteins.

Leveraging grape seeds for various purposes in winemaking exemplifies a commendable practice within the framework of the circular economy (Vorobyiev & Lebovka, 2020). Anthocyanin dyes, oils, or catechol polymers can be extracted from grape seeds. Following the drying process, grape seeds exhibit an oil content ranging from 3.95% to 20.71%. Their composition, particularly the cell wall comprising cellulose, hemicellulose, and proteins, endows grape seeds with significant properties. Grape seed oil is notably rich in linoleic and oleic acids, both of which are monounsaturated fatty acids. Furthermore, the presence of antioxidant and anti-inflammatory bioactive compounds, alongside phenols, provides grape seeds with versatility for applications in agriculture and pharmaceuticals (Mikailov & Farzaliev, 2018; Bosso *et al.,* 2020). The extraction technique employed to obtain grape oil can potentially increase product yield by up to 13% while ensuring the production of high-quality grape oil without incurring additional costs associated with purification or chemical processing. The efficiency of oil yield during grape seed pressing is primarily determined by the degree of grinding. Notably, grape seeds are distinguished by their specific structure, characterised by a high shell content and the hardness of their shell structure.

Numerous scientific studies have been conducted focusing on sustainability, economic viability, and efficient production technologies within the winemaking sector. A. Soceanu *et al.* (2021) analysed sustainability frameworks from six wine-producing nations, seeking commonalities and opportunities for improvement, to advance sustainability practices within the wine industry. K. Abiri *et al.* (2020) conducted research investigating the morphological and pomological traits of 55 grape varieties. Their findings revealed a notable positive correlation between parameters such as bunch length and width, as well as berry length and width. The considerable morphological variability observed in Iranian grape varieties suggests a vast gene pool, which contributes to grape breeding efforts. Based on the results, it was concluded that selecting parameters based on their correlative relationships could lead to further enhancements in product quality. V. Salimov *et al.* (2022) conducted research focused on exploring the polymorphic characteristics and variability of several grape varieties discovered for the first time through scientific expeditions organised in various wine-growing regions of Azerbaijan from 1998 to 2020.

The findings revealed that the gene pool of Azerbaijani grapes is characterised by its diversity and polymorphism. T. Panakhov and M. Guseinov (2019), along with S. Takhirov and M. Guseinov (2020), conducted a study examining the morphological characteristics and chemical composition of six Vitis vinifera grape varieties. Their findings suggested that Ribier and Matrouh Eswed had the lowest seed count per berry, while Black Rose, Red Globe, and Roumi Ahmer displayed high carbohydrate and protein content, indicating their suitability for animal feed production. Additionally, Black Rose, Red Globe, Roumi Ahmer, and Rich Baba showed promise for oil production due to their elevated oil yield. Another study, led by G. Monteiro *et al.* (2021), investigated eight distinct grape cultivars – Red Globe, Michele Palieri, Balbal, Antep Karası, Alphonse Lavallee, Pembe Gemre, Uzbek, and Efes Karası – that were grown in the Tekirdag region of Turkey.

Several comprehensive studies similar to this one have been undertaken, exploring diverse aspects of grape cultivation, viticultural methods, and the evaluation of grape quality. These investigations by M. Akram *et al.* (2021) encompass a range of factors, such as grapevine genetics, environmental conditions, vineyard management practices, and processing techniques, all contributing to a deeper understanding of grape production and its significance within the wine industry. Through this research, the authors aim to provide insights that lay the groundwork for integrating grape seeds as a valuable resource within the Azerbaijani wine industry. The process of extracting oil from grape seeds represents a novel endeavour in Azerbaijan. The principal aim of the research was to determine the foundational resources for seed oil extraction. Through an analysis of Azerbaijan's vineyards as a case study, the article aims to examine the

relationship between sustainable viticultural practices and grape productivity, to advance sustainability within the Azerbaijani wine industry.

MATERIALS AND METHODS

The study utilised statistical data sourced from the State Statistics Committee of the Republic of Azerbaijan (ARDSK, 2023) to examine the current state of the viticulture and winemaking sector, assessing indicators of growth rate and sustainability depicted graphically. Moreover, productivity and harvest variables were subjected to covariance and correlation analyses for comparative evaluation. The empirical scientific and technological studies within the research were conducted in laboratory settings focusing on production-related aspects. The research involved grape variety seeds planted and cultivated at the Shamakhi Experimental Station of the Scientific Research Institute of Viticulture and Winemaking, as well as the Absheron Auxiliary Experimental Farm, during the years 2022 to 2024. The economic-technological, morphological, and biological traits of 45 recently discovered local grape varieties were examined, alongside the determination of classification features and geographical origins. Accordingly, the study encompassed an exploration of the morphological and biochemical components of seeds derived from specific grape varieties cultivated under both irrigated and rainfed conditions in Azerbaijan. The investigation extended to scrutinising seed oiliness, the efficiency of oil extraction via the screw press method, morphometric attributes of the seeds, biochemical markers, and distinctive traits of the varieties to elucidate their influence.

When researching grapevine sustainability and grape seeds, it is important to assess morphological indicators such as seed size, colour, and mass; technological indicators including germination rate, seed viability, and seedling growth parameters; as well as biochemical indicators such as oil content, nitrogen levels, cellulose content, ash content, and other compounds like phenolics and antioxidants. The grape seeds, which served as the subject of the study, were air-dried for 7 to 10 days in sunlight and 15 to 20 days in shade following their separation from grape processing residues. Subsequently, these seeds, without undergoing grinding or crushing, were processed using a screw press device (Kochmaksan, Model No. – KMS10, Turkey), and the resultant oil was extracted. No chemical or thermal treatment was applied to the seeds before pressing. Ten kilograms of seeds from each variety, cultivated under both irrigated and rainfed conditions, were subjected to the screw press, and the quantity of oil released per total seed weight was determined. Additionally, certain morphological and ampelodescriptive characteristics of grape seeds were identified using appropriate methodologies.

During the research, various measurements were conducted using specialised devices: moisture levels were assessed using the KERN DBS 60-3 device (Germany), while nitrogen and nitrogenous compounds were analysed with the KjelFlex K-360 device (Sweden). The crude ash content was determined using the Mikrotest MKF-07 device (Russia), and dry matter was calculated based on analysis results from multiple parameters and the indicator from the Perten DA-7250 device (Sweden). The oil content was assessed by washing with hydrocarbons in the BUCHI FatExtractor E-500 device (Switzerland), and cellulose NDF, ADF, and ADL analyses were conducted using the ANKOM 200 Fiber Analyzer (USA), followed by the calculation of results with specialised formulas. Vaccine content was determined through spectroscopy using the Perten DA-7250 device. Furthermore, correlation analyses employing the Pearson method were performed to explore relationships between variables and indicators that positively influence seed oil extraction. The methodology involved analysing nitrogen indicators and cellulose content in grape seeds grown under both irrigated and rainfed conditions. Additionally, the study examined ash content, nitrogenous compounds, non-nitrogen extractive substances, dry matter content, tannin content, and crude oil percentage in grape seeds from 12 varieties grown under irrigation conditions.

The research conducted on plants, including the collection of plant material, adhered to ethical standards by institutional, national, or international guidelines. Specifically, the study followed the principles outlined in the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979), ensuring compliance with regulations designed to preserve biodiversity and protect endangered species.

RESULTS AND DISCUSSION

The pattern suggests effective selection and propagation of grape varieties by Azerbaijani viticulturists, highlighting their commitment to sustainable practices aimed at ensuring long-term economic sustainability. However, careful assessment is essential to ascertain the sustainability of the observed harvest growth, safeguarding against the depletion of critical resources. The graphical representation in Figure 1 illustrates an increasing trend in both grape productivity and total harvest in Azerbaijan over the past 22 years, indicating the genetic diversity inherent in the cultivated grapevine varieties.

Covariance and correlation analyses were utilised to explore the relationships among variables, focusing here on grape productivity and harvest in Azerbaijan. The provided table presents the covariance and correlation metrics for these variables: productivity and harvest (Table 1).

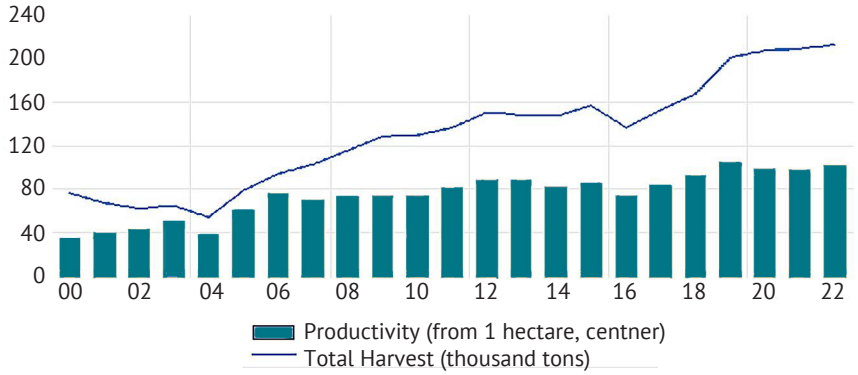

***Figure 1**. Total harvest and productivity in the viticulture sector in Azerbaijan*
***Source:** ARDSK (2023)*

***Table 1.** Covariance and correlation analysis in the viticulture sector*

Covariance	Productivity	Harvest
Productivity	418.6336	
Harvest	934.2581	2,353.287

Correlation	Productivity	Harvest
Productivity	1.000000	
Harvest	0.941266	1.000000

***Source:** compiled by the authors*

Covariance measures the joint variability of the variables, with a positive value suggesting a tendency for them to move together. In this instance, the positive covariance (418.6336) suggests a beneficial correlation between grape productivity and harvest, highlighting potential sustainability in agricultural practices. The correlation coefficient, derived from covariance and standard deviations, evaluates the strength and direction of the linear relationship, with values ranging from -1 to 1. A correlation coefficient of 1 denotes a perfect positive linear relationship, -1 signifies a perfect negative linear relationship, while 0 indicates no linear relationship between the variables, informing assessments of sustainability in grape cultivation practices. During the study, the seed mass was determined as part of the mechanical analysis of grape clusters. Following this determination, the seeds were categorised according to the descriptors established by the International Organisation of Vine and Wine. It was observed that the size and mass of grape seeds varied between varieties cultivated under irrigated and rainfed conditions.

Under irrigation, five varieties (Madrasa (technical), Khyndogny (technical), Bayanshira (technical), Cabernet Sauvignon (technical), and Merlot (technical)) exhibited large seeds, while seven varieties (Ag Kharji (technical), Hana grna (universal), Genjevi (universal), Mahmudu (table), Agadaiyee (table), Moldova (universal), and Doyna) had very large seeds. Among the varieties grown under rainfed conditions, only two (Khyndogny (technical), and Moldova (universal)) had larger seeds, while the others (Madrasa, Bayanshira, and Cabernet Sauvignon (technical)) had seeds of average mass. Overall, when comparing irrigation and rainfed conditions, it is evident that the same varieties grown under irrigation (Madrasa, Khyndogny, Bayanshira, and Cabernet Sauvignon) produce larger seeds. Additionally, notable differences were observed in the colouration of grape seeds among the various varieties grown under both conditions. The seeds of the twelve different varieties exhibited diverse colourations: three were dark brown (Madrasa, Doyna, and Moldova), three were light brown (Khyndogny, Agadaiyee, and Hana grna), two were reddish-brown (Bayanshira and Ag Kharji), three were brown (Genjvi, Mahmudu, and Merlot), and one was dark brown with a reddish tint (Cabernet Sauvignon) (Table 2). This variation is reflected in the mass of 100 seeds. In grapes cultivated under irrigation, the mass of 100 seeds ranged from 4.2 g (Madrasa) to 10.2 g (Ag Kharji). Conversely, for grapes grown under rainfed conditions, this range varied from 3.8 g (Madrasa) to 5.2 g (Moldova). Notably, among grapes grown under irrigation, relatively large seeds were observed in the Madrasa, Bayanshira, Khyndogny, Cabernet Sauvignon, Merlot, Doyna, Agadaiyee, Mahmudu, Genjevi, Moldova, Hana grna, and Ag Kharji varieties. In contrast, grapes grown under rainfed conditions tended to have relatively smaller seeds.

***Table 2**. Some morphological, technological and biochemical indicators of grape seeds*

Grape variety	Colour	Seed: mass (OIV 243)	Mass of 100 seeds, g	Seed size (length/width), mm	Moisture, %	Nitrogen,%	Cellulose, %	Ash, %	Nitrogen compounds, %	Non -nitrogenous extractive substances, %	Dry substance, %	Tannin substance, %	Oiliness, % (crude oil)	Oil extraction during cold pressing, %
In irrigation condition														
Madrasa (technical)	Dark brown	big, OİV243-7	4.2	6.4/3.8	12.4	1.17	24.0	2.1	6.0	19.0	65.0	4.0	11.9	4.00
Khyndogny (technical)	Light brown	big, OİV243-7	6.2	7.2/4.6	14.6	1.22	21.8	2.8	6.4	18.2	64.4	3.8	12.6	4.08
Bayanshira (technical)	Reddish brown	big, OİV243-7	5.2	6.7/4.2	20.0	1.18	22.4	3.1	5.5	21.4	62.4	4.6	11.2	4.42
Ag Kharji (technical)	Reddish brown	bigger, OİV243-9	10.2	7.6/4.6	18.2	0.98	25.3	2.4	7.2	20.0	67.4	3.6	14.6	6.18
Hana grna (universal)	Light brown	bigger, OİV243-9	10.0	7.8/4.8	22.3	1.42	24.4	2.8	6.5	22.0	68.4	4.2	18.8	6.80
Genjevi (universal)	Brown	bigger, OİV243-9	8.2	7.4/4.4	24.4	1.33	22.1	2.8	6.2	19.8	64.2	4.6	18.7	4.67
Mahmudu (table)	Brown	bigger, OİV243-9	8.0	7.2/4.8	14.5	1.10	18.8	2.1	6.3	18.2	63.8	4.0	18.4	4.92
Agadaiyee (table)	Light brown	bigger, OİV243-9	7.7	7.8/4.6	21.2	1.08	19.8	2.2	5.8	18.7	67.8	3.8	18.6	5.24
Cabernet Sauvignon (technical)	Dark brown with a red tint	big, OİV243-7	6.2	7.2/3.8	9.8	1.17	24.4	2.6	5.9	18.6	61.4	4.2	14.1	3.86
Moldova (universal)	Dark brown	bigger, OİV243-9	8.5	7.2/3.6	18.4	1.46	25.2	3.0	5.8	21.0	66.4	4.4	18.6	5.22
Merlot (technical)	Brown	big, OİV243-7	6.2	5.8/3.8	17.2	1.12	22.3	2.5	6.7	16.6	58.7	4.4	12.4	3.92
Doyna	Dark brown	bigger, OİV243-9	7.7	6.2/4.0	16.4	0.96	18.8	1.9	6.9	20.4	63.3	4.6	12.6	3.98
In rainfed condition														
Madrasa (technical)	Dark brown	medium, OİV243-5	3.8	5.4/3.2	6.8	0.84	25.6	2.0	5.8	17.8	58.4	4.8	11.4	1.43
Khyndogny (technical)	Light brown	big, OİV243-7	4.2	6.3/4.2	7.4	0.68	24.6	1.8	5.7	18.0	52.6	4.6	9.8	1.56
Bayanshira (technical)	Reddish brown	medium, OİV243-5	3.8	6.2/4.1	8.2	1.02	25.4	1.8	5.4	17.2	60.4	4.0	10.4	1.32
Moldova (universal)	Dark brown	big, OİV243-7	5.2	6.4/3.8	8.0	1.03	26.2	1.7	6.8	19.0	61.2	4.8	12.4	1.86
Cabernet Sauvignon (technical)	Dark brown with a red tint	medium, OİV243-5	3.8	5.2/3.2	6.2	0.78	24.6	1.7	5.6	17.6	54.8	4.2	9.2	1.38

***Source:** compiled by the authors*

S. Chelik's (2011) observations indicate that grape seeds contain moisture levels ranging from 25% to 45%, carbohydrates between 34% and 36%, fat content ranging from 13% to 20%, tannin at 4% to 6%, nitrogenous substances ranging from 4.0% to 6.5%, mineral substances at 2% to 4%, and fatty acids at 1%. As stated

by J. Yu *et al.* (2021) and D. Kök *et al.* (2017), once grape seeds are obtained from the winery and dried, the composition of the raw materials typically exhibits an oiliness indicator ranging from 15.2% to 17.5%, moisture content ranging from 6.2% to 8.0%, and a fluctuating amount of phenolic compounds within the range of 2.81% to 4.26%. The authors emphasise that the quality of seeds intended for grape oil production varies depending on factors such as variety, growing conditions, cultivation zone, and the method of seed separation from the residue.

The sizes of the grape seeds examined varied across different varieties. Specifically, the dimensions (including length and width) of grape seeds grown under irrigation conditions were measured as follows: Madrasa – 6.4/3.8 mm, Khyndogny – 7.2/4.6 mm, Bayanshira – 6.7/4.2 mm, Ag Kharji – 7.6/4.6 mm, Hana grna – 7.8/4.8 mm, Genjevi – 7.4/4.4 mm, Mahmudu – 7.2/4.8 mm, Agadaiyee – 7.8/4.6 mm, Cabernet Sauvignon – 7.2/3.8 mm, Moldova – 7.2/3.6 mm, Merlot – 5.8/3.8 mm, and Doyna – 6.2/4.0 mm. Additionally, the dimensions of grape seeds (length and width) grown under rainfed conditions were recorded as follows: Madrasa – 5.4/3.2 mm, Khyndogny – 6.3/4.2 mm, Bayanshira – 6.2/4.1 mm, Moldova – 6.4/3.8 mm, and Cabernet Sauvignon – 5.2/3.2 mm. A comparison between seeds grown under irrigation and rainfed conditions revealed that grape seeds from rainfed grapes were smaller in size compared to those from irrigated grapes. Additionally, notable differences were observed in the moisture content of grape seeds between the two growing conditions. These differences in moisture content ranged from 9.8 g (Cabernet Sauvignon) to 24.4 g (Genjevi) for seeds grown under irrigation conditions. Specifically, the moisture content of grape seeds grown under irrigation conditions was recorded as follows: Cabernet Sauvignon – 9.8%, Madrasa – 12.4%, Mahmudu – 14.5%, Khyndogny – 14.6%, Doyna – 16.4%, Merlot – 17.2%, Ag Kharji – 18.2%, Moldova – 18.4%, Bayanshira – 20.0%, Agadaiyee – 21.2%, Hana grna – 22.3%, and Genjevi – 24.4%. On the other hand, the moisture content of grape seeds grown under rainfed conditions ranged from 6.2 g (Cabernet Sauvignon) to 8.2 g (Bayanshira), with the following values: Cabernet Sauvignon – 6.2%, Madrasa – 6.8%, Khyndogny – 7.4%, Moldova – 8.0%, and Bayanshira – 8.2%.

During the research, an analysis was conducted to determine the nitrogen indicators of grape seeds grown under both conditions. It was found that the nitrogen indicators of grape seeds grown under irrigation conditions ranged from 0.96% to 1.46%. Specifically, the nitrogen indicators for grape seeds grown under irrigation conditions were as follows: in Doyna – 0.96%, Ag Kharji – 0.98%, Agadaiyee – 1.08%, Mahmudu – 1.10%, Merlot – 1.12%, Madrasa – 1.17%, Cabernet Sauvignon – 1.17%, Bayanshira – 1.18%, in Khyndogny - 1.22%, Genjevi – 1.33%, Hana grna – 1.42%, and Moldova – 1.46%. In contrast, the nitrogen indicators of grape seeds grown under rainfed conditions were found to range from 0.68 to 1.03%. These values were recorded as follows: Khyndogny – 0.68%, Cabernet Sauvignon – 0.78%, Madrasa – 0.84%, Bayanshira – 1.02%, and Moldova – 1.03%. Subsequently, analyses were conducted to determine the amount of cellulose in the seeds of grape varieties grown under both conditions was determined. The amount of this substance in the composition of seeds of grape varieties grown under irrigation conditions was in the range of 18.8 to 25.3%. Specifically, this indicator was observed in Mahmudu – 18.8%, Doyna – 18.8%, Agadaiyee – 19.8%, Khyndogny – 21.8%, Genjevi – 22.1%, Merlot – 22.3%, Bayanshira – 22.4%, Madrasa – 24.0%, Hana grna – 24.4%, Cabernet Sauvignon – 24.4%, Moldova – 25.2%, and Ag Kharji – 25.3%. The cellulose content in grape seeds grown under rainfed conditions ranged from 24.6% to 26.2%, with the following values: Khyndogny – 24.6%, Cabernet Sauvignon – 24.6%, Bayanshira – 25.4%, Madrasa – 25.6%, and Moldova – 26.2%.

When investigating the ash content in grape seeds from varieties grown under both irrigation and rainfed conditions, it was found to range from 1.9% to 3.1% in seeds from irrigated grapes. Specifically, in seeds from grapes grown under irrigation conditions, the ash content was determined as follows: Doyna – 1.9%, Madrasa – 2.1%, Mahmudu – 2.1%, Agadaiyee – 2.2%, Ag Kharji – 2.4%, Merlot – 2.5%, Cabernet Sauvignon – 2.6%, Khyndogny – 2.8%, Hana grna – 2.8%, Genjevi – 2.8%, Moldova – 3.0%, and Bayanshira – 3.1%. In contrast, the ash content in grape seeds from varieties grown under rainfed conditions ranged from 1.7% to 2.0%, with the following values: Cabernet Sauvignon – 1.7%, Moldova – 1.7%, Khyndogny – 1.8%, Bayanshira – 1.8%, and Madrasa – 2.0%. Furthermore, while conducting morphological, technological, and biochemical analyses of seeds obtained from grape varieties grown under irrigation conditions, the nitrogenous compound content in the seeds was also studied. The nitrogenous compound content in grape seeds ranged from 5.5% to 7.2%. Specifically, in seeds from grapes grown under irrigation conditions, the nitrogenous compound content was observed as follows: Bayanshira – 5.5%, Agadaiyee – 5.8%, Moldova – 5.8%, Cabernet Sauvignon – 5.9%, Madrasa – 6.0%, Genjevi – 6.2%, Mahmudu – 6.3%, Khyndogny – 6.4%, Hana grna – 6.5%, Merlot – 6.7%, Doyna – 6.9%, and Ag Kharji – 7.2%. Conversely, the nitrogenous compound content in grape seeds from varieties grown under rainfed conditions varied from 5.4% to 6.8%, with the following values: Bayanshira – 5.4%, Cabernet Sauvignon – 5.6%, Khyndogny – 5.7%, Madrasa – 5.8%, Moldova – 6.8%.

During the study, the quantity of non-nitrogen extractive substances in the seeds of twelve grape varieties grown under irrigation conditions was examined. The analysis revealed that the amount of non-nitrogen

extractive substances in the seeds ranged from 16.6% to 22.0%. This indicator varied among the different grape varieties, with values as follows: Merlot – 16.6%, Khyndogny – 18.2%, Mahmudu – 18.2%, Cabernet Sauvignon – 18.6%, Agadaiyee – 18.7%, Madrasa – 19.0%, Genjevi – 19.8%, Ag Kharji – 20.0%, Doyna – 20.4%, Moldova – 21.0%, Bayanshira – 21.4%, and Hana grna – 22.0%. In comparison, the quantity of non-nitrogen extractive substances in the seeds of grape varieties grown under rainfed conditions ranged from 17.2% to 19.0%, with values as follows: Bayanshira – 17.2%, Cabernet Sauvignon – 17.6%, Madrasa – 17.8%, Khyndogny – 18.0%, and Moldova – 19.0%.

Additionally, the amount of dry substance in grape seeds was determined during the study. It was found that the quantity of dry substance in the seeds of grape varieties grown under irrigation conditions ranged from 58.7% to 68.4%. Specifically, the dry substance content in grape seeds grown under irrigation conditions was observed as follows: Merlot – 58.7%, Cabernet Sauvignon – 61.4%, Bayanshira – 62.4%, Doyna – 63.3%, Mahmudu – 63.8%, Genjevi – 64.2%, Khyndogny – 64.4%, Madrasa – 65.0%, Moldova – 66.4%, Ag Kharji – 67.4%, Agadaiyee – 67.8%, and Hana grna – 68.4%. Conversely, the amount of dry substance in the seeds of grape varieties grown under rainfed conditions was lower, ranging from 52.6% to 61.2%, with values as follows: Khyndogny – 52.6%, Cabernet Sauvignon – 54.8%, Madrasa – 58.4%, Bayanshira – 60.4%, and Moldova – 61.2%. Furthermore, the tannin content in the seeds of the twelve grape varieties grown under irrigation conditions was examined. The tannin content was found to range from 3.6% to 4.6%. The tannin content varied among different grape varieties, with values as follows: Ag Kharji – 3.6%, Khyndogny – 3.8%, Agadaiyee – 3.8%, Madrasa – 4.0%, Mahmudu – 4.0%, Hana grna – 4.2%, Cabernet Sauvignon – 4.2%, Moldova – 4.4%, Merlot – 4.4%, Bayanshira – 4.6%, Genjevi – 4.6%, and Doyna – 4.6%. For grape varieties grown under rainfed conditions, the tannin content ranged from 4.0% to 4.8%, with values as follows: Bayanshira – 4.0%, Cabernet Sauvignon – 4.2%, Khyndogny – 4.6%, Madrasa – 4.8%, and Moldova – 4.8%. The oil composition of grape seeds is a crucial factor determining their economic significance. In the study, the percentage of crude oil was determined in the examined seed samples. It was evident that, depending on the cultivation conditions, the oil content in grape seed varieties varied significantly. The oiliness indicators of seeds from varieties grown under irrigation conditions ranged from 11.2% to 18.8%. Specifically, these indicators were as follows: Bayanshira – 11.2%, Madrasa – 11.9%, Merlot – 12.4%, Doyna – 12.6%, Khyndogny – 12.6%, Cabernet Sauvignon – 14.1%, Ag Kharji – 14.6%, Mahmudu – 18.4%, Moldova – 18.6%, Agadaiyee – 18.6%, Genjevi – 18.7%, and Hana grna – 18.8%. In grape varieties grown under rainfed conditions, this indicator ranged from 9.2% to 12.4%, with values as follows: Cabernet Sauvignon – 9.2%, Khyndogny – 9.8%, Bayanshira – 10.4%, Madrasa – 11.4%, and Moldova – 12.4% (Fig. 2).

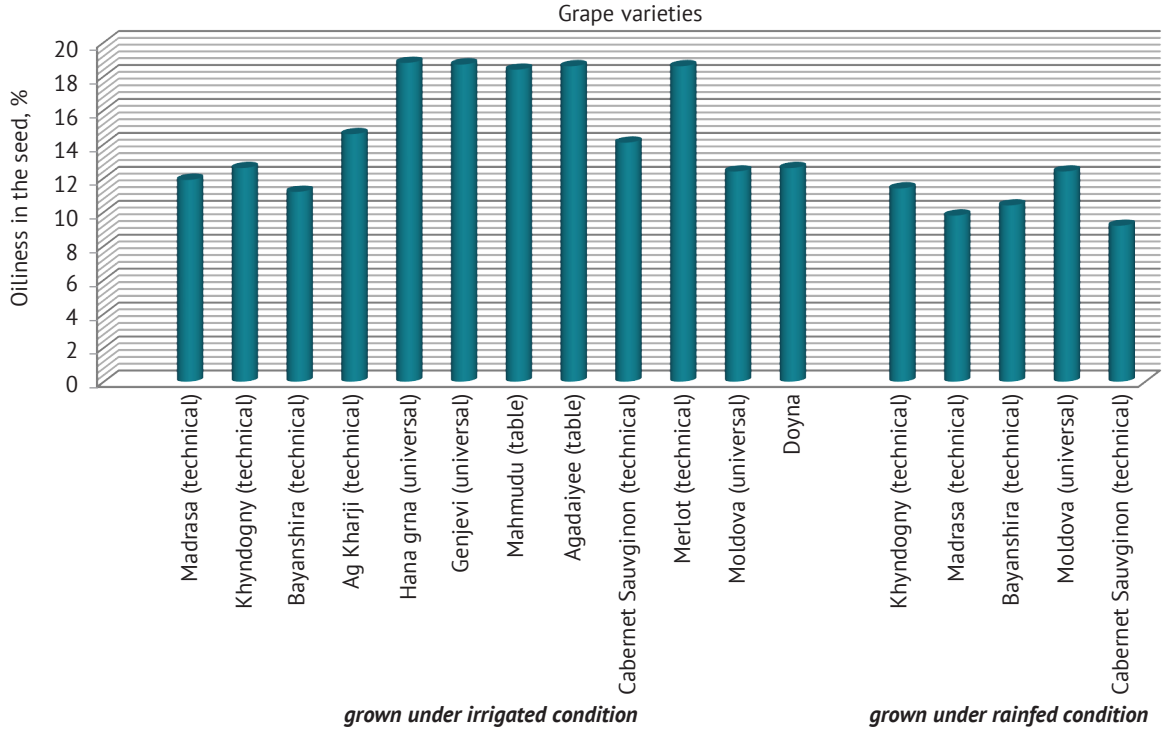

***Figure 2**. Oil extraction from the seeds of grape varieties grown under irrigation and rainfed conditions (using the cold press method)*

***Source:** compiled by the authors*

Based on statistical analysis, it became evident that there is a correlation between certain morphological, technological, and biochemical indicators of grape seeds and the oil extraction process. The study clarified that cultivation conditions exert a significant influence on the morphological, and biochemical indicators of grape seeds, as well as on oil extraction. Furthermore, the factors influencing oil extraction from the seeds were identified. Calculations conducted using the Pearson correlation method determined that the highest correlation with the amount of oil extracted via the cold press method was associated with seed mass, size, and the mass of 100 seeds. Notably, the correlation coefficient ranged between r = 0.72 and 0.80. Specifically, the correlation dependence between the mass of 100 seeds and oil extraction was most pronounced, with a correlation coefficient of r = 0.80 (Fig. 3).

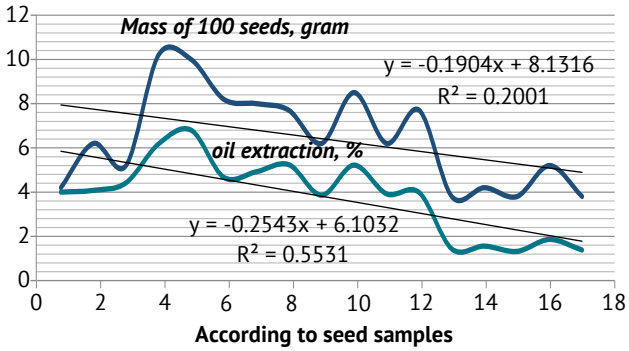

Figure 3. *Correlation dependence between the mass of 100 seeds and oil extraction*
Source: *compiled by the authors*

The morphological and biochemical composition of grape seeds varies depending on the prevailing growing conditions, highlighting the need for a broader scope of research. Improving technologies and updating protocols in the oil extraction process is essential to accommodate the distinct morphological and biochemical compositions of seeds from different grape varieties. Challenges arise in seed supply, storage, analysis, and preparation for oil extraction due to the novelty of these procedures. When using the cold press method to extract oils from seeds of various origins, notable distinctions are observed in the colour, taste, aroma, and overall appearance of the resulting products. However, in conducting biochemical analyses on oils derived from diverse grape varieties and grapes cultivated under differing conditions, the primary focus is on determining fatty acids. Unfortunately, the lack of appropriate devices and equipment remains a significant obstacle in this regard.

This study examines the potential of grape seeds in Azerbaijan, focusing on the impact of irrigation conditions on seed composition, oil content, and extractability using the screw press method. Despite existing research on the cultivation conditions of both local and foreign grape varieties in Azerbaijan, there remains a gap in understanding varietal characteristics, morphological traits of seeds, their sizes, and particularly their biochemical composition, notably the fat content. The Scientific Research Institute of Viticulture and Winemaking has conducted novel research into the biochemical assessment of grape seed varieties cultivated under diverse environmental conditions. This pioneering study included the determination of oil yield and explored the influence of cultivation conditions on oil production. Furthermore, the research analysed the morphological and biochemical composition of the seeds.

The winemaking industry has a long-standing history intertwined with ancient technologies and customs. To ensure its sustained existence, the wine industry must actively incorporate sustainable practices into its operations, acknowledging the critical need for long-term viability amid ongoing environmental and economic shifts (Santini *et al.,* 2013; Demirkol & Tarakci, 2018). A pivotal aspect of sustaining the viticulture sector lies in enhancing the quality of wine. This can be achieved by reducing chemical inputs and embracing responsible practices, thereby fostering long-term viability in business operations. A thorough understanding of the elements influencing soil quality is paramount, given their significant impact on the soil's efficacy in supporting plant growth, biodiversity, water retention, and pollution management. By discerning these factors, measures can be implemented aimed at sustaining soil health and preserving its critical ecosystem services (Cataldo *et al.,* 2021). Furthermore, beyond the adoption of sustainable practices, the preservation of vital natural resources such as soil, water, and biodiversity is essential for sustaining the long-term viability of the wine industry. Among the varied spectrum of grape cultivars native to Azerbaijan and adjacent regions, prominent varieties such as White Shani, Bayanshire, and Madrasa are recognized for their significant contributions to the area's abundant viticultural legacy (Sharifov, 2010). By preserving and promoting indigenous grape varieties that thrive in distinctive local climates, Azerbaijani winemakers both honour their cultural heritage and actively engage in biodiversity preservation efforts.

In the winemaking industry, the foremost drivers of sustainability initiatives include environmental values, individual preferences, and professional satisfaction (Gabzdylova *et al.,* 2009). This comprehensive strategy ensures that winemakers not only excel in producing exceptional wines but also play a pivotal role in advancing a more sustainable and harmonious world. The modern concept of a solar winery requires either the infrastructure or the winemaking procedures to actively utilise solar energy harvested from radiation incidents in the winery (Smyth *et al.,* 2011; Flores, 2018). Solar wineries employ photovoltaic (PV) panels to convert solar energy into electricity, strategically placing them on

winery rooftops, structures within vineyards, or nearby land to maximise sunlight absorption. This eco-friendly method reduces dependence on traditional energy sources, supports environmental preservation by reducing carbon emissions, and promotes the integration of renewable energy in the wine sector. The economic potential of renewable energy sources is estimated at 27 gigawatts, with solar energy constituting 23,000 megawatts of this estimate (AREN, 2024). The areas where this potential is most promising include the central river valleys, as well as the northern and western regions of Azerbaijan, where viticulture has flourished.

CONCLUSIONS

In the primary empirical segment, the investigation elucidates the nuanced interplay between grape variety traits, cultivation environments, and diverse morphological and biochemical features of grape seeds. The results emphasise that both the inherent characteristics of grape varieties and the environmental contexts of cultivation exert notable impacts on the dimensions, weight, fat content, and, consequently, the oil extraction capacity of grape seeds. Comparative analyses of grape seeds from different varieties grown under irrigated and rainfed conditions reveal discernible variations in key parameters. Specifically, grape seeds from vines grown under irrigation demonstrated a broader range of characteristics compared to those from rainfed vines. Seeds from irrigated grapes exhibited larger mass (4.2-10.2 g), greater dimensions (5.8/3.8-7.8/4.8 mm), and a higher oiliness index (11.2-18.8%). Conversely, seeds from rainfed grapes showed diminished values in these indicators, reflecting a reduction of 30-45%. Moreover, the investigation into oil extraction methods highlighted notable distinctions between grapes cultivated under different conditions. Cold pressing of seeds from irrigated grapes yielded oil extraction rates ranging from 3.86% to 6.80%, whereas seeds from rainfed grapes produced lower extraction rates of 1.32% to 1.86%. These findings underscore the distinct profiles of grape varieties cultivated under irrigation versus rainfed conditions, emphasising the nuanced effects of cultivation practices on seed characteristics and oil extraction potential.

In essence, the research underscores the importance of considering both grape variety characteristics and cultivation conditions when assessing the quality and potential utility of grape seeds. Understanding these factors is vital for optimising agricultural practices, refining seed processing techniques, and harnessing the economic potential of grape seeds in various industries. To enhance efficiency and enrich the raw material base for grape seed oil production, further investigation is imperative. This necessitates the resolution of existing challenges and the application of innovative approaches through additional research initiatives.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Стійкість у виноробній промисловості та оцінка характеристик виноградного насіння під час переробки: докази з Азербайджану

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Анотація. У контексті розвитку виноробства в Азербайджані ця стаття досліджує сталість виноградарства з особливим акцентом на виноградне насіння, яке має важливе значення для розмноження виноградної лози, видобутку олії та загального здоров'я виноградників. Метою дослідження є вивчення морфологічних, технологічних та біохімічних характеристик виноградного насіння для вдосконалення методів виробництва винограду та просування практики сталого виноградарства. Для цього були ретельно зібрані та проаналізовані зразки насіння дванадцяти сортів винограду, як місцевих, так і інтродукованих, за різних умов зрошення, включаючи зрошувані та незрошувані ділянки, що дозволило провести всебічну оцінку. Дослідження виявило значний вплив зрошення на властивості насіння. Зокрема, було виявлено, що насіння зрошуваного винограду було більшим, важчим і багатшим за вмістом олії порівняно з насінням незрошуваного винограду. Детальний аналіз показав, що вміст азоту в насінні коливався від 0,96 % до 1,46 %, вміст целюлози – від 18,8 % до 25,3 %, вміст золи – від 1,9 % до 3,1 %, азотистих сполук – від 5,5 % до 7,2 %, а неазотистих екстрактивних речовин – від 16,6 % до 22,0 %. Важливо відзначити, що були виявлені кореляції між властивостями насіння та ефективністю екстракції олії холодним пресуванням, що дає цінну інформацію. Це дослідження в кінцевому підсумку сприяє просуванню практики сталого виноградарства в Азербайджані, забезпечуючи довгострокове здоров'я та продуктивність виноградників у регіоні

Ключові слова: сільське господарство; виноградарство; виноробство; технологічні характеристики; біохімічний склад