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The preliminary study of antifungal and antibacterial properties of wine by-products

Ani K. Hayrapetyan[1], Tigran A. Yesayan[1], Armine D. Chakhmakhchyan[1,2], Bella G. Babayan[1,3], Garegin G. Sevoyan[1], Alexander H. Yesayan[1,2*], Syuzanna S. Esoyan[1,2]

[1]Research Institute of Biology, Yerevan State University (YSU), 1 Alex Manoogian, 0025, Yerevan, Republic of Armenia (RA); [2]Department of Ecology and Nature Conservation, Faculty of Biology, YSU, Yerevan, RA; [3]"Agrobiotechnology Scientific Center", Branch of Armenian National Agrarian University, Republic of Armenia.

***Corresponding Author:** Alexander H. Yesayan, PhD, Research Institute of Biology, 1 Alex Manoogian, Yerevan, 0025, Armenia

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ABSTRACT

Background: Nowadays, the search for novel alternative antimicrobials has gained significant popularity. This surge is driven by the vast array of adverse effects of synthetic antimicrobials on human health and the environment. Consequently, the study of new natural sources of comparably ecologically safe and simultaneously effective antimicrobials is extremely important. In this context, the interest in wine by-products is growing due to their diverse beneficial properties. Traditionally considered industrial waste, wine by-products now offer promising opportunities. Notably, the unique climatic and geographical features of Armenian black grape varieties, such as Areni sev, make their by-products an attractive subject for study, with potential applications in agriculture.

Objective: The study aims to investigate the antifungal and antibacterial properties of wine by-products obtained from the Areni sev grape variety.

Methods: For the extraction of bioactive compounds, frozen and dry samples were homogenized. The maceration was performed in 70% hydroethanolic solution after incubation on a magnetic stirrer at room temperature. The obtained extracts were filtered through a 0.45 µm filter and evaluated for antifungal and antibacterial activity by disco-diffusion method.

Results: Hydroethanolic extracts of wine by-products have exhibited antifungal and antibacterial activities. Specifically, the frozen samples demonstrated low antifungal activity against the Penicillium canescens with a 7.5 mm growth inhibition zone. In contrast, dried samples showed no antifungal activity. The highest antifungal activity was observed against Aspergillus niger with growth inhibition zones of 18 mm (frozen samples) and 15 mm (dried samples), respectively. Regarding antibacterial activity, wine by-product hydroethanolic extracts showed extremely low efficacy. Notably, frozen samples exhibited an 8 mm growth inhibition zone against Curtobacterium flaccumfaciens and 6.35 mm against Xanthomonas vesicatoria. Extracts from dried samples demonstrated a 6.35 mm inhibition zone against Curtobacterium flaccumfaciens and a 7 mm growth inhibition zone against Xanthomonas vesicatoria.

Conclusion: Summarizing the results of the conducted experiments, it can be concluded that the used wine by-product derived from Areni sev grape has demonstrated notable antimicrobial activities, with a stronger emphasis on antifungal properties. The extracts obtained from frozen samples exhibited greater efficacy than those derived from dried samples. Future research plans include a more detailed investigation of Areni sev grape wine by-products.

Keywords: wine by-product, grape pomace, Areni sev, bioactive compounds, antimicrobial properties

Microorganism	*The growth inhibition zone (mm) ± SD*	
	Frozen by-products	*Dried by-products*
Penicillium canescens	*7,5 ± 0,7*	*0*
Aspergillus niger	*18 ± 1,6*	*15 ± 1,0*
Curtobacterium flaccumfaciens	*8 ± 0,1*	*6,35*
Xanthomonas vesicatoria	*6,35*	*7 ± 0,5*
Checker	*0*	*0*

Graphical Abstract: The Preliminary Study of Antifungal and Antibacterial Properties of Wine By-products

INTRODUCTION

Wine by-products are residual materials generated during winemaking. The global wine industry produces substantial quantities annually, including grape pomace, stems, seeds, and lees [1]. These by-products remain after grapes are pressed and fermented for wine production, accounting for 20-25% of the total weight of the grapes [2]. According to the United Nations Food and Agriculture Organization (FAO), in 2022and about 80 million tons of grapes were produced worldwide [3, 4]. In Armenia, the Ministry of Economy reported about 160-200 thousand tons of grape production for wine in 2023, resulting approximately 40-50 thousand tons of wine by-products. Traditionally discarded or repurposed for low-value applications, such as poultry feed or fertilizer, recent research reveals the potential of these by-products as sources of bioactive compounds with antifungal and antibacterial properties. The millions of tons of waste generated by this agro-industry sector can be reused, entering a new production chain to reduce environmental impact and create additional value [5]. Nowadays, wine by-products are recognized as rich sources of bioactive compounds with potential benefits in various fields [4]. Notably, grape seeds contain extractable phenolic antioxidants including phenolic acid, flavonoids, procyanidins, and resveratrol. Grape skins are rich in anthocyanins. The beneficial properties of wine by-product polyphenols in human health, the food industry [6], and agriculture have attracted significant interest from researchers. In addition to phenolic antioxidants, wine by-products contain significant amounts of lipids, proteins, fibers, and minerals. Grape seeds, for instance, contain 13–19% oil rich in essential fatty acids, approximately 11% protein, 60–70% indigestible carbohydrates, and non-phenolic antioxidants like tocopherols and beta-carotene [1]. These by-products boast diverse phenolic compounds, including flavonoids, stilbenes, and tannins, known for their antioxidant and antimicrobial properties [7]. The extraction and characterization of these compounds from wine by-products have gained considerable attention in recent years, driven by interest in their beneficial properties. Long-term antioxidant therapy has proven effective in treating and preventing various pathological processes [8].

Moreover, numerous studies have investigated the antifungal and antibacterial activities of wine by-products against microorganisms relevant to the food industry. Microbial contamination poses a significant challenge to the food industry, leading to food spoilage, economic losses, and potential health risks to consumers. The emergence of antibiotic-resistant bacteria and increasing demand for natural food preservatives have spurred research into alternative antimicrobial agents. Plant-based extracts and by-products, rich in bioactive compounds, offer promising solutions [9,10]. Specifically, grape pomace extracts have demonstrated efficacy against foodborne pathogens like *Escherichia coli*, *Salmonella*, and *Listeria monocytogenes*. Similarly, grape seed extracts have shown inhibitory effects against fungal species responsible for food spoilage, including *Aspergillus* and *Penicillium* [11]. The antimicrobial and antifungal activity of wine by-products is directly related to their phenolic compounds [12, 13]. Studies have consistently shown that phenolic compounds in grape and wine by-products possess antifungal activity [14, 15]. Notably, extracts from wine by-products have been effectively used against *Candida albicans* [16, 14, 17], a common source of fungal infections, as well as against *Aspergillus niger* [18] and *Asperilgillus flavus*, which produce mycotoxins. The antibacterial activity of wine by-products varies depending on the type of by-product, extraction methods, and bacterial strain tested [19]. However, studies have shown the effectiveness of wine by-products against a wide spectrum of bacteria, including foodborne pathogens [4]. Specifically, activity has been observed against *Escherichia coli*, *Staphylococcus aureus, Salmonella enteritidis* [13], *Bacillus cereus*, and *Pseudomonas savastanoi pv phaseolicola* [3]. *Penicillium canescens,* a common species isolated from soil, may contain toxins hazardous to health, although current evidence suggests no human toxicity. Nonetheless, air pollution-related exposure can cause allergic reactions [20,21].

Several diseases of animals and humans are caused by *A. niger*. This fungus thrives in moist environments, such as soil, old books, air conditioners, and air humidifiers. *A. niger* infections pose a significant challenge due to limited antifungal therapy options. Prolonged exposure to its mycotoxins can trigger allergies. As an aggressive species, *A. niger* suppresses the growth of other fungi and indicates environmental contamination. To mitigate this, strict adherence to sanitary and hygienic norms, including moisture control, is essential [22]. Anthocyanins, catechins, procyanidins, flavanol glycosides, phenolic acids, and stilbenes are the main phenolic components found in wine by-products. The polyphenolic composition of each by-products varies depending on the grape variety, location of growth, climate, maturity, and fermentation time [23, 24, 1]. Phenolic compounds exhibit a wide range of biological activities beneficial to human health, including neuroprotective, antimicrobial, and other health-related effects [25]. Phenolic compounds found in wine act as antioxidants, while wine production retains high phenolic content due to incomplete extraction. The antimicrobial activity of wine by-product extracts is influenced by several factors, including the grape variety, extraction method, the solvent used, and concentration of bioactive compounds. The presence of other constituents within the extracts, such as sugars and organic acids, may also influence antimicrobial efficacy.

The antimicrobial mechanisms involve disrupting cell membranes, inhibiting enzyme activity, and interfering with DNA replication and protein synthesis [26 Synergistic effects among compounds contribute to antimicrobial activities.

The potential applications of wine by-product extract as natural antimicrobial agents in the food industry are diverse. They can be incorporated into food packaging materials to extend shelf life, added directly to food products as preservatives, or used to develop novel antimicrobial coatings for food processing equipment [27]. Research on the antifungal and antibacterial properties of wine by-products continues to expand, with ongoing efforts to identify and characterize new bioactive compounds, optimize extraction methods, and evaluate their efficacy against a broader range of microorganisms. Future studies may prioritize developing standardized extracts and integrating them into commercial food products [28]. Investigating wine by-products' antifungal and antibacterial properties hold significant promise for developing natural antimicrobial agents. By valorizing these by-products, the wine industry can contribute to sustainable practices and provide innovative solutions microbial contamination challenges in the food industry and agriculture.

This introduction provides an overview of the significance of this research area, exploring the challenges associated with microbial contamination in the food industry, the potential benefits of utilizing wine by-products, and the current state of knowledge regarding their antimicrobial activities.

MATERIALS AND METHODS

Wine By-products sample processing: The wine by-product samples were obtained from a wine-producing company in the Aragatsotn Province of the Republic of Armenia. Areni sev (*Vitis vinifera L.*) Armenian autochthonous grape variety was used for the wine production. The wine by-products consisted of bark, seeds, petioles and stems. The samples were homogenized using two techniques: freezing at - 20 °C and oven-dried at +55 °C. Prior to extraction, frozen and dried samples were homogenized with a Goldmaster homogenizer for 3 minutes at 5 Hz. The particle size of homogenized samples, determined by microscopy, ranged from 1-3 mm. For maceration, 20 grams of homogenized samples were mixed with 200 ml of 70% hydroethanolic solution. The samples were incubated on a magnetic stirrer (600 rpm) for four days at room temperature, followed by filtration through a 0.45 µm filter [29].

***In vitro* evaluation of antimicrobial activity of wine by-products:** Antifungal and antibacterial activities of the studied samples were evaluated using the disc-diffusion method according to Kirby-Bauer. The test microorganisms included: *Penicillium canescens, Aspergillus niger, Curtobacterium flaccumfaciens, Xanthomonas vesicatoria*. Suslo-agar cultivation media was used for fungi cultivation while, bacteria were cultivated on a nutrient meat peptone agar cultivation media. Filter paperdisc 6.35 mm in diameter, as per WHO prescriptions. Each disc was soaked with 10 µl of the test solution [30-31]. Negative control disc was placed on the medium without the test solution. Petri dishes with microbes were incubated at 37 °C for bacteria and at 25 °C for fungi for 24 hours. The growth inhibition zone diameter was measured (in mm) over a period of 1 to 14 days, depending on the growth characteristics of the used strains. The mentioned *in vitro* study was conducted on fast-growing microorganisms [32]. The photochemical characteristics of active components were studied by the application of UV/VIS spectroscopy (using Thermo MultiSkan GO Microplate Reader) and the Attenuated Total Reflectance-Fourier Transform Infrared (ATR-FTIR) spectroscopy (using Nicolet™ iS50 FTIR Spectrometer) [33-34].

RESULTS AND DISCUSSION

The results of the study on the antimicrobial activity of grape by-products are presented in Table 1. The hydroethanolic extracts of wine by-products exhibit antifungal activity, affecting different fungal species to varying degrees. Notably *Aspergillus niger* showed the highest antifungal activity, with growth inhibition zones of 18 mm (frozen samples) and 15 (oven-dried samples) in diameter. The studied fungal species pose a significant threat to wine production and for food safety in general [35]. Comparing the effects of frozen and oven-dried samples reveals that frozen samples inhibit fungal growth more effectively. This finding suggests potential applications for developing innovative, eco-friendly biocontrol agents against phytopathogenic fungi and bacteria, offering an alternative to classical pesticides for grape protection [36-37]. Additionally, these extracts may be against spoilage microorganisms [38].

Table 1. Antifungal activity of a hydroethanolic solution of wine by-products.

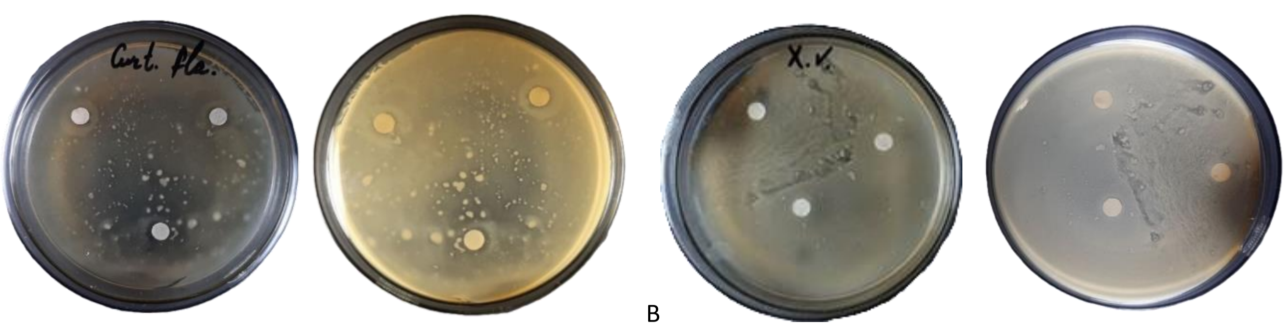
Tested microorganisms	Growth inhibition zone (mm) ± SD	
	Frozen samples	Oven-dried samples
Penicillium canescens	7,5 ± 0,7	0
Aspergillus niger	18 ± 1,6	15 ± 1,0
Negative control for a fungal growth	0	0
Curtobacterium flaccumfaciens	8 ± 0,1	6,35
Xanthomonas vesicatoria	6,35	7 ± 0,5
Negative control for a bacterial growth	0	0

A B

Figure 1. Growth inhibition A. niger (A) and P. Canescens (B) after 24 h. The left disc refers to the frozen sample, and the right disc refers to the oven-dried sample.

A low antifungal activity against P. canescens was observed, with (frozen extract samples exhibiting a 7.5 mm inhibition zone, whereas dried samples showed no antifungal effect (Fig. 1).

The hydroethanolic solutions of wine by-products demonstrated minimal antibacterial activity against phytopathogenic *Curtobacterium flaccumfaciens* and *Xanthomonas vesicatoria* bacteria [31, 39]. Notably, frozen samples of extract samples exhibited higher antibacterial activity and were more active against C. flaccumfaciens with an (8 mm of inhibition zone compared to oven-dried samples (6.35 mm). Conversely, dried samples showed greater antibacterial activity against *X. vesicatoria* (7 mm of inhibition zone) than frozen samples (6.35 mm) (Fig. 2).



A B

Figure 2. Growth inhibition of *C. flaccumfaciens* (A) and *X. vesicatoria* (B) in frozen (left disc) and oven-dried (right disc) samples of wine by-products exposed to hydroethanolic solution after 24 h. The bottom disk is the negative control.

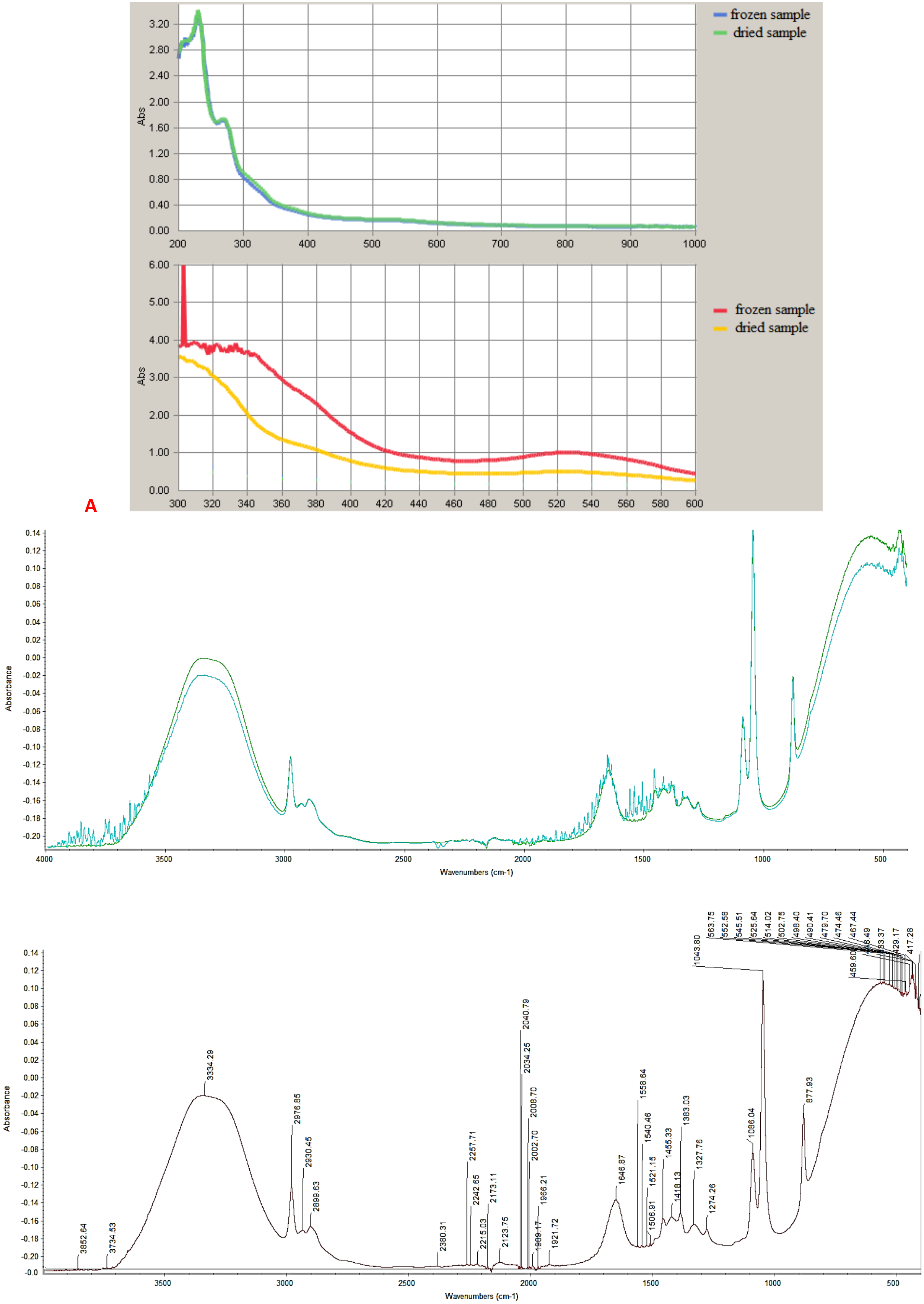


Figure 3. UV/VIS (A) and FTIR-ATR (B, C) spectral studies of wine by-products.

The spectral study of both dried and frozen samples revealed the presence of organic acid complexes (tartaric acid, etc.) known for their antimicrobial properties (Fig. 3).

The analysis showed no significant difference in chemical composition of dried and frozen hydroethanolic extracts of wine by-products obtained from Armenian Areni sev grape, as detected by FTIR-ATR and UV/VIS analyses. However, the concentration of these compounds was slightly higher in frozen samples, which may explain their increased activity in most experiments. The main components responsible for the antimicrobial effect are believed to be a mixture of complex coordinated compounds, including tartaric acid and other organic acids, phenolic compounds, resveratrol, thiamine, such as like the residues of peptide compounds, etc. [40-42].

These compounds are abundant in Areni sev grape due to its phytochemical characteristics [42]. Literature data indicates that certain chemical derivatives of organic acids (e.g., tartaric acid imides, coalmine and other complex amino salts of tartaric acid) exhibit pronounced antimicrobial activity [43]. A more detailed study and isolation of these bioactive antimicrobial compounds are planned for future research.

CONCLUSIONS

In summary, the data obtained suggest that hydroethanolic solutions of wine by-products exhibit antibacterial activity, albeit in minimal amounts. Winemaking by-products serve as valuable raw materials for producing value-added products, offering a viable alternative for waste management in the wine industry. Utilizing these by-products in various fields can help mitigate environmental concerns while generating economic benefits through commercialization. Analysis of the results reveals that the selected wine by-product possesses antifungal and antibacterial properties, although the latter is relatively weak. Notably, extraction from frozen samples proves more efficient than from oven-dried samples. We hypothesize that this disparity may be attributed to enhanced cell wall damage by ice crystals and the loss of volatile compounds in oven-dried samples. The antifungal properties of bioactive compounds extracted from Areni sev grape samples are most pronounced against *A. Niger.* Further investigation into the antimicrobial properties of wine-by-products may significantly impact wine production, presenting prospects for innovative functional food productions based on wine and its by-products.

Abbreviations: FAO, Food and Agriculture Organization: ATR-FTIR, Attenuated Total Reflectance-Fourier Transform Infrared spectroscopy; UV/VIS, ultraviolet and visual spectroscopy; WHO, World Health Organization.

Competing interests: The authors declare no conflicts of interests were disclosed in frames of this research.

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