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Alcohol-free wine based jelly candies enriched with grape pomace extracts with antioxidant and antidiabetic properties: Implications for sustainable development and health benefits

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ABSTRACT

Pinot noir and *Chardonnay* wines were dealcoholised, reducing the ethanol to final content below 0.5 mL/100 mL and concentrating their non-volatile extract. Grape pomace (wine industry by-product) was incorporated as a source of bioactive compounds. The influence of temperature and ultrasonic treatment on polyphenols extraction efficiency was assessed. The best extraction yield was found when 60 min of ultrasonic treatment followed by 60 min of shaking at 60 °C were applied. *Pinot noir* grape pomace extracts contained higher levels of phenolic acids, catechins, tannins, and anthocyanins, whereas *Chardonnay* lacked anthocyanins and resveratrol. These extracts were incorporated into the production of functional jelly candies formulated with dealcoholised wine, dietary fibers, and natural sweeteners. *Pinot noir* jellies consistently showed greater phenolic content, antioxidant activity, and stronger α-glucosidase inhibition compared to *Chardonnay*, with values nearly twice as effective as acarbose when expressed as GAE. *Pinot noir* extracts provided an intense, wine-like character of jelly candies and high functional value, but their excessive astringency requires optimization. *Chardonnay* extracts offered a milder and more consumer friendly sensory profile.

The presented *jelly candies are an innovative example of functional confectionery with nutritional and commercial relevance, aligning with current consumer demand for health-promoting, environmentally responsible and sustainable food products.*

1. Introduction

Growing enthusiasm for sustainable food systems and circular economy initiatives has intensified the pursuit of innovative applications for by-products generated by the food industry. Grape pomace serves as a prominent example of valuable by-products within the food sector. Due to its rich content of polyphenols, dietary fiber, and other bioactive compounds, grape pomace can be skillfully utilized in the development of innovative functional foods that offer nutritional benefits (Almanza-Oliveros et al., 2024; Kurćubić et al., 2024; Wang et al., 2024).

Grape pomace, which consists of a mixture of skins, seeds, and stems, represents 20–30 kg/100 kg of the weight of processed grapes, thus making its efficient use both an ecological and a financial imperative (Almanza-Oliveros et al., 2024; Telini et al., 2025; Wang et al., 2024). In this regard, there is an increasing demand for up-cycling approaches that convert grape pomace into functional food components and value-added products. At the same time, increasing interest in alcohol-free wines and dealcoholisation techniques creates opportunities for developing innovative products based on them, combining sensory appeal with functionality (An et al., 2025; Kumar et al., 2024).

Recent research has emphasized the potential of grape pomace and other winery by-products as valuable ingredients for functional food development. Their incorporation into bakery, dairy, and beverage products has been shown to improve color, flavor, and antioxidant activity, although excessive addition may increase bitterness and

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astringency (Boff et al., 2022; González-Centeno et al., 2015; Tolve et al., 2021; Tseng & Zhao, 2013). More recently, the use of winery residues in confectionery formulations has also been explored, showing improvements in texture, color stability, and phenolic retention (Gümüş et al., 2024; Kaynarca et al., 2023). These studies indicate that wine industry by-products can be successfully applied to enhance both the sensory and functional qualities of food, provided that their concentration is properly optimized.

The biological potential of grape pomace is dictated by its chemical composition. This by-product is characterized by a richness of polyphenols (flavan-3-ols: catechin/epicatechin and procyanidins, anthocyanins, flavonols: quercetin, stilbenes: resveratrol, and phenolic acids: gallic, caffeic, ferulic, and p-coumaric acids), along with dietary fiber and the lipid fraction derived from seeds. Such a composition fosters diverse biological activity and elevates the technological and nutritional quality of products that incorporate grape pomace extracts (Karastergiou et al., 2024; Kurćubić et al., 2024; Sabra et al., 2021). During the past decade, numerous studies have confirmed the strong antioxidant activity (free radical scavenging and activation of the Nrf2/ARE pathway), anti-inflammatory effects (including modulation of NF-κB and pro-inflammatory cytokines), as well as cardiometabolic benefits (lipid regulation and reduction of oxidative stress) of grape pomace extracts (Deaconu et al., 2024; Dufour et al., 2024; Machado et al., 2024; Taladrid et al., 2023).

In terms of antimicrobial properties, the potency of grape pomace extracts against pathogenic and food-spoiling bacteria and fungi varies based on the polyphenolic composition, extraction technique, and microbial strain (Galante et al., 2025). This effect is mainly related to the capacity of polyphenols to disrupt cell membranes and inhibit crucial enzymes that play a role in microbial metabolism. As a result, grape pomace extracts could act as natural preservatives, helping prolong shelf life and ensuring the safety of food products (Hassan et al., 2019).

Scholarly investigations have also demonstrated that polyphenolic compounds derived from grape pomace possess the ability to disturb the functionality of digestive enzymes, including α-amylase and α-glucosidase, which results in a deceleration of starch digestion and reduced postprandial glycemia (Deaconu et al., 2024; Taladrid et al., 2023). Furthermore, *in vivo* experiments elucidate the hypoglycemic efficacy of grape pomace supplementation, which is correlated with increased insulin sensitivity and modulation of carbohydrate metabolic pathways (Machado et al., 2024).

Another benefit of the grape pomace is the interaction between polyphenols and dietary fiber with the gut microbiota. Fermentable fiber components and polyphenol–fiber complexes demonstrate prebiotic properties, enhancing short-chain fatty acids production and influencing microbiota composition. Studies on grape pomace in animal models indicate metabolic advantages, such as impacts on body weight and insulin resistance (Li et al., 2025; Sinrod et al., 2023; Taladrid et al., 2023).

Finally, another relevant element in the sustainable use of grape pomace is the adoption of eco-friendly extraction methods for the recovery of bioactive components. Traditional solvent-based techniques, such as those using methanol or acetone, are effective but environmentally taxing and may present toxicological hazards (Mgoma et al., 2025; Wang et al., 2024). In response, innovative green extraction technologies have emerged, including ultrasound-assisted extraction, pressurized liquid extraction, enzyme-assisted extraction, supercritical CO_2 extraction, and the application of natural deep eutectic solvents (Lopes et al., 2025; Trentin et al., 2024). These methodologies not only improve polyphenols and anthocyanins recovery but also minimize energy and solvent usage. The adoption of sustainable extraction techniques is in harmony with the principles of the circular economy, reduces the carbon footprint of processing, and increases the industrial viability of grape pomace extracts as functional food ingredients (Lopes et al., 2025; Trentin et al., 2024).

The main objective of this study was to develop and characterize alcohol-free wine-based jelly candies enriched with grape pomace extracts obtained through temperature- and ultrasound-assisted extraction procedures. The work aimed to demonstrate the potential of these extracts as functional ingredients, linking extraction efficiency with antioxidant and antidiabetic properties of the final product. By integrating dealcoholized wine and upcycled grape pomace, this research contributes to current knowledge on sustainable confectionery innovations and expands the practical applications of winery by-products in health-oriented food design.

2. Materials and methods

2.1. Grapes varieties

70 kg of *Pinot noir* and 70 kg of *Chardonnay* grape varieties were used to prepare the experimental wines. These grapes were obtained from Mierzęcin Vineyard in Poland.

2.2. Vinification process

Immediately after harvest, the grapes were destemmed (crusher destemmer, Grifo DMA, Euro-Win, Poland) and sulphited (5 g $K_2S_2O_5$/hL, Sigma-Aldrich, St. Louis, MO, USA; CAS 7790-62-7). *Pinot noir* underwent a 7-day maceration at 23–26 °C, while *Chardonnay* was directly pressed. Fermentation was carried out with *Saccharomyces cerevisiae* (Lalvin EC-118, Lallemand, USA) for 4 weeks at 25 °C (*Pinot noir*) and 22 °C (*Chardonnay*). After racking, wines were stored in 10 L tanks for 6 months at 9–11 °C, then again sulphited (5 g $K_2S_2O_5$/hL) and bottled. Grape pomace was freeze-dried (19 h, 0.12 mbar, −40 °C; and next 5 h, 0.1 mbar, −42 °C; freeze-drier Alpha 2–4 LD plus, Christ, Osterode/Harz, Germany) and stored in sealed, dark containers until further processing.

2.3. Dealcoholisation process

Dealcoholisation was carried out using a Büchi R-215 Advanced Rotavapor equipped with a Büchi V-850 vacuum pump (Merck Life Science, Darmstadt, Germany). The dealcoholisation parameters were established based on pilot- and industrial-scale studies (Italiano et al., 2025) with own modifications: for 500 mL of wine: pressure 80 mbar, water bath 35 °C, for 60 min. No replenishment of alcohol or water was applied after the process. Consequently, non-volatile wine extract compounds, despite partial losses during dealcoholisation, became more concentrated. This effect was considered beneficial due to the enhancement of the flavor of the resulting non-alcoholic wine. After dealcoholisation, the wine was stored in 50 mL Eppendorf vials, at −22 °C, until further use.

2.4. Grape pomace extract preparation

Freeze-dried grape pomace was ground manually in a mortar (20 cm in diameter) for 10–15 min, until the obtained material was visually assessed as a powder. 5 g of grape pomace powder was placed in a 250 mL Erlenmeyer flask and extracted with 150 mL of solvent (ethanol in water 70 mL/100 mL, Merck Life Science, Darmstadt, Germany, CAS No. 64-17-5), corresponding to a ratio of 1 g pomace powder per 30 mL solvent. The pH was adjusted to approximately 3.5 using HCl (1 g/100 mL; POCh, Gliwice, Poland, CAS No. PA-03-1085-S). The parameters of polyphenol extraction from grape pomace were determined based on previous studies on grape pomace (Deaconu et al., 2024; Delić et al., 2024; Moutinho et al., 2023; Wang et al., 2024) and our own experimental work (Dobrucka et al., 2025). Six different extraction conditions were applied to evaluate the effect of temperature and ultrasound treatment on extraction efficiency (Table 1).

Sonication was performed in an ultrasonic bath (50 kHz, 80 W, POLSONIC-1, Poland), followed by shaking extraction (Memmert water

Table 1
Extraction conditions for bioactive compounds from grape pomace powder.

Extraction code	Ultrasound (US) treatment	Shaking conditions	Temperature	Total time
23 °C	–	130 rpm, 60 min	23 °C	1h
60 °C	–	130 rpm, 60 min	60 °C	1h
US 15 min; 23 °C	50 kHz, 80 W; 15 min	130 rpm, 60 min	23 °C	1h 15 min
US 15 min; 60 °C	50 kHz, 80 W; 15 min	130 rpm, 60 min	60 °C	1h 15 min
US 60 min; 23 °C	50 kHz, 80 W; 60 min	130 rpm, 60 min	23 °C	2h
US 60 min; 60 °C	50 kHz, 80 W; 60 min	130 rpm, 60 min	60 °C	2h

bath shaker, 130 rpm, Memmert, Poland). The obtained extracts were filtered (cellulose filters MN 611, ProfiLab24, Germany) and concentrated using a Büchi R-215 Rotavapor with a Büchi V-850 vacuum pump (Merck Life Science, Darmstadt, Germany) at 45 °C (water bath), 60 rpm, 120–70 mbar (120 mbar for first 2 min, next 100 mbar for 2 min, and 70 mbar for 30 min), and vapor temperature of 30 °C. The concentrated extracts were frozen and stored at −20 °C until further use.

2.5. Production of antioxidant enriched wine-jelly candies

Wine-jelly candies were prepared by heating 40 g of alcohol-free wine (*Pinot noir* and *Chardonnay*) to 80 °C, adding sodium citrate (0.25 g; POCh, Gliwice, Poland, CAS No. PA-11-0033), apple pectin (1 g; Batom, Kraków, Poland), inulin (10 g; DeliFood, Radziowi, Brzozów, Poland), Fiberest® Resistant Dextrin HF (20 g; Samyang Corporation, Frankfurt, Germany), erythritol (10 g; Mix Brands, Warszawa, Poland), stevia (0.02 g; NatVita, Mirków, Poland), and mixing until dissolved. The mixture was cooled to 60 °C. Depending on the type of wine used, *Pinot noir* or *Chardonnay* grape pomace extracts were added in four tested concentrations (0.5; 1.0; 1.5; 2.0 g of dry weight). The mixture was adjusted to pH 3.3 with citric acid (1 g/100 mL; POCh, Gliwice, Poland, CAS No. PA-03-2911-V), and topped up with the appropriate wine to 100 g. The solution was poured into molds, allowed to set, and stored in dark, in sealed jars at 22 °C. For analysis, 5 g of wine-jelly candies were homogenized with 25 mL of deionized water under continuous stirring at 130 rpm for 1 h and then filtered (cellulose filters MN 611, ProfiLab24, Germany).

2.6. Analytical methods

Total polyphenol content (TPC) was determined using the Folin–Ciocalteu colorimetric method (Singleton & Rossi, 1965) with minor modifications (Lasik-Kurdyś et al., 2022). Briefly, 0.3 mL of appropriately diluted samples (wine, pomace extract or jelly candies) were mixed with 4.15 mL of deionized water, 0.05 mL of Folin–Ciocalteu reagent (Sigma-Aldrich, Munich, Germany, CAS No. 47641), and 0.5 mL of sodium carbonate solution (5 g/100 mL; Al-Chem, Toruń, Poland, CAS No 363–428105601). After incubation for 20 min at room temperature, absorbance was measured at 700 nm (Halo SB-10 spectrophotometer, Dynamica Biogenet, Cambridge, UK). Results were expressed as gallic acid equivalent per liter (mg GAE/L; Merck Life Science, Darmstadt, Germany, CAS No. 149-91-7).

Total monomeric anthocyanin content was quantified using the pH differential method (Giusti & Wrolstad, 2001). Samples (wine, grape pomace extract or wine-jelly candies) were prepared in buffers of pH 1.0 (1.86 g/L KCl, Sigma-Aldrich, Munich, Germany, CAS No. P9333) and pH 4.5 (32.8 g/L sodium acetate anhydrous, Sigma-Aldrich, Munich, Germany, CAS No. S2889). For each sample (after proper dilution), absorbance was recorded at **520 nm** and 700 nm (1 cm cuvette; blank as deionized water; Halo SB-10 spectrophotometer, Dynamica Biogenet, Cambridge, UK) after 15 min of equilibration in the dark at 20–25 °C. Results were expressed as malvidin-3-glucoside equivalents per liter (mg M3G/L; Merck Life Science, Darmstadt, Germany, CAS No. 7228-78-6).

Total flavan-3-ols (catechins) assay was performed according to Sun et al. (1998). Samples (wine, grape pomace extract or wine-jelly candies) were adequately diluted in methanol (Sigma-Aldrich, Munich, Germany, CAS No. 34860). For each sample, two parallel preparations were made: reaction sample: 0.50 mL sample +2.50 mL of vanillin in methanol solution (10 mg/mL) (Sigma-Aldrich, Munich, Germany, CAS No. V1104) + 2.50 mL HCl in methanol (8 g/100 mL; Sigma-Aldrich, Munich, Germany, CAS No.320331) and control sample (without vanillin): 0.50 mL sample + 2.50 mL methanol + 2.50 mL HCl in methanol (8 g/100 mL). After mixing, tubes were incubated for **20 min at 30 °C in the dark.** The absorbance was recorded at 500 nm (Halo SB-10 spectrophotometer, Dynamica Biogenet, Cambridge, UK), and results were expressed as (+)-catechin equivalent per liter (mg CE/L; Merck Life Science, Darmstadt, Germany, CAS No. 154-23-4).

Condensed tannins were determined using methylcellulose-precipitable (MCP) and model wine buffer (Mercurio & Smith, 2008; Sarneckis et al., 2006). Model wine buffer was prepared by dissolving tartaric acid (5.0 g/L, Merck Life Science, Darmstadt, Germany, CAS No. 87-69-4) in an aqueous ethanol solution containing 0.12 mL/mL ethanol (Merck Life Science, Darmstadt, Germany, CAS No. 64-17-5), and adjusting the pH to 3.3 with a 40 g/L NaOH solution (Merck Life Science, Darmstadt, Germany, CAS No. 1310-73-2). Samples (wine, grape pomace extract or wine-jelly candies) were appropriately diluted in model wine buffer and divided into two aliquots: (i) blank: 1 mL sample + 1 mL buffer and (ii) MCP: (1 mL sample + 0.5 mL of methylcellulose solution (0.4 mg/mL, Merck Life Science, Darmstadt, Germany, CAS No. 9004-67-5) + 0.5 mL saturated ammonium sulfate solution (Merck Life Science, Darmstadt, Germany, CAS No. 7783-20-2). After mixing and incubation (15 min at 20 °C), tubes were centrifuged (3000×*g*, 10 min), and the absorbance of the supernatant was recorded at 280 nm (Halo SB-10 spectrophotometer, Dynamica Biogenet, Cambridge, UK). Tannin concentration was calculated from the absorbance difference ($\Delta A_{280} = A_{280}$ blank $- A_{280}$ MCP) against an external calibration with (+)-epicatechin (Merck Life Science, Darmstadt, Germany, CAS No. 490-46-0) and expressed as mg (+)-epicatechin equivalent per liter (mg ECE/L).

Antioxidant activity (ABTS assay) The antioxidant capacity against the ABTS radical cation was determined according to Re et al. (1999) with minor modifications (Lasik-Kurdyś et al., 2022). Briefly, 3.00 mL of ABTS working solution (2.20-azinobis-(3-ethylbenzothiazoline-6-sulphonic acid)) (Sigma-Aldrich, Munich, Germany; CAS No. A1888) was mixed with 30 μL of an appropriately diluted sample (wine, grape pomace extract or wine-jelly candies) in 10 mL test tubes. Tubes were tightly capped, mixed by vortexing and incubated in the dark for 6 min at 21 °C. Absorbance was then recorded at 735 nm using a Halo SB-10 spectrophotometer (Dynamica Biogenet, Cambridge, UK). Results were calculated from a Trolox calibration curve (Merck Life Science, Darmstadt, Germany, CAS No. 53188-07-1) and expressed as mg of Trolox equivalents per liter (mg TE/L).

Phenolic acids (gallic, caffeic, ferulic, p-coumaric, sinapic) and resveratrol were determined by high-performance liquid chromatography (Gumienna et al., 2011). Chromatographic separations were performed on an XTerra C18 column (3.9 × 150 mm, 4 μm; Waters Corporation, Taunton, MA, USA) maintained at 30 °C in a thermostated column oven. The mobile phase consisted of acetonitrile–formic acid–-water (30:10:60, v/v/v) (Sigma-Aldrich, Munich, Germany) delivered isocratically at 1.0 mL/min. Samples were injected with an autosampler equipped with a fixed 10 μL loop. Eluted compounds were monitored using a UV–Vis 966 detector (Waters Corporation, Milford, Massachusetts, USA). Identification was based on comparison of retention times and UV–Vis spectra with authentic standards of gallic, caffeic, ferulic, p-coumaric, sinapic acids and resveratrol (Merck Life Science, Darmstadt, Germany, CAS No. *149-91-7,* 331-39-5, 537-98-4, 501-98-4, 530-59-6, 501-36-0**,** respectively).

α-Glucosidase inhibitory activity was measured according to Kim et al. (2005) with modification (Lasik-Kurdyś et al., 2022). 15 μL of sample was preincubated with 100 μL of α-glucosidase solution (1 U/mL, *Saccharomyces cerevisiae*; Merck Life Science, Darmstadt, Germany; CAS 9001-42-7), in phosphate buffer pH 6.8 (Merck Life Science, Darmstadt, Germany, CAS No., 9001-42-7) at 37 °C for 10 min. Then, 50 μL of 1.51 mg/mL p-nitrophenyl-α-D-glucopyranoside (pNPG, Merck Life Science, Darmstadt, Germany, CAS No. 3767-28-0) was added. After incubation at 37 °C for 20 min, the reaction was stopped by adding 100 μL of 10.6 g/L Na_2CO_3 (Thermo Fisher, CAS No. 89031-84-5). The release of p-nitrophenol was measured at 405 nm (Halo SB-10 spectrophotometer, Dynamica Biogenet, Cambridge, UK). Acarbose (Merck Life Science, Darmstadt, Germany, CAS No. 56180-94-0) was used as a positive control. Results were expressed as IC_{50} – amount of jelly candies required to achieve 50 % reduction in the activity of α-glucosidase.

2.7. Sensory analysis

Sensory analysis of the wine-jelly candies, including overall desirability, color, aroma (taste + flavor), grape/wine flavor, sweetness, sourness, astringency, firmness and chewiness, was evaluated following the procedure adapted from previous research (Ali et al., 2021; Spinei & Oroian, 2024). A total of 60 untrained panelists (40 women and 20 men, aged 22–60 years) from the Faculty of Food Science and Nutrition (Poznań University of Life Sciences) participated in the evaluation. The evaluation was carried out using a 9-point hedonic scale. For the sensory test, alcohol-free wine-based jelly candies enriched with grape pomace extracts were prepared in silicone molds in the form of squares of approximately 5 g and presented at room temperature. During the sensory analysis, appropriate protocols for the protection of participants' rights and privacy were applied (voluntary participation, disclosure of the study requirements and potential risks, informed consent to participate in the study, protocols for protecting the rights and privacy of all participants).

2.8. Statistical analysis

All analyses were performed in quadruplicate. To evaluate the effect of dealcoholisation on the key quality parameters of the studied wines, a paired *t*-test (assuming normality) was applied, and the effect size was estimated using Cohen's d. To assess the influence of different extraction conditions of grape pomace on the yield of polyphenolic compounds, analysis of variance (ANOVA) was performed, followed by Tukey's post hoc test at a significance level of $\alpha \leq 0.05$. The relationship between extract concentration and α-glucosidase inhibitory capacity (IC_{50}) was assessed using linear regression with the least squares method, reporting slope, intercept, coefficient of determination (R^2), and the statistical significance of the trend (F test, $p < 0.05$). For this analysis JASP (https://jasp-stats.org/) and Jamovi (https://www.jamovi.org/) software were applied.

3. Results and discussion

3.1. Dealcoholisation of wines

The characterization of *Pinot noir* and *Chardonnay* wines was performed after six months of maturation. Both wines were classified as dry, with residual sugars below 4 g/L and alcohol concentrations of 13.2 ± 0.24 and 12.6 ± 0.11 mL/100 mL, for *Pinot noir* and *Chardonnay* respectively (Table 2). Total acidity was 6.32 g/L in *Pinot noir* and 7.17 g/L in *Chardonnay*, while volatile acidity did not exceed 0.57 g/L. The total phenolic content reached 2047.88 mg/L in *Pinot noir* and 237.43 mg/L in *Chardonnay*.

Vacuum distillation resulted in a substantial reduction of ethanol, enabling classification of the wines as non-alcoholic (<0.5 mL/100 mL). In parallel, the non-volatile compounds increased by 3.12–23.57 %, reflecting a concentration effect caused by the simultaneous removal of ethanol and water. The most pronounced increases were observed for total acidity (23.57 % in *Pinot noir*, 21.76 % in *Chardonnay*), glycerol (15.28 % and 11.34 %), and residual sugars (22.88 % and 18.94 %) (Table 2). However, volatile acidity was close to total reduction (−91.23 % and −92.3 %). This improved sensory quality by eliminating the risk of vinegary notes. Similar changes have been reported for vacuum distillation without back dilution, with increases of 10–30 % in extractive compounds (Italiano et al., 2025; Puglisi et al., 2022).

Analysis of phenolic compounds revealed moderate increases (3.12–10.31 %) in hydroxycinnamic acids (gallic, caffeic, p-coumaric, ferulic, sinapic), which are essentially nonvolatile below 45 °C (Akhtar et al., 2025), despite being susceptible to partial oxidative degradation during processing. The most pronounced effect was observed for resveratrol, with increases of 22.32 % in *Pinot noir* and 14.52 % in *Chardonnay* (Cohen's d was approximately 7 and 4.5, respectively, Table 3). Comparable retention of 90–100 % of polyphenols was observed also in *Cabernet sauvignon*, *Tempranillo*, and *Riesling* wines

Table 2
Chemical composition of red (*Pinot noir*) and white (*Chardonnay*) wines before and after dealcoholisation.

	Pinot noir			Chardonnay		
	With alcohol	Dealcoholized	Change (%)	With alcohol	Dealcoholized	Change (%)
Ethanol (mL/100 mL)	13.2 ± 0.24	0.41 ± 0.03	−96.97	12.6 ± 0.11	0.37 ± 0.02	−97.62
Glycerol (g/L)	10.14 ± 0.06	11.69 ± 0.08	+15,28	5.73 ± 0.04	6.38 ± 0.07	+11.34
Residual sugars (g/L)	3.19 ± 0.04	3.92 ± 0.03	+22.88	3.96 ± 0.06	4.71 ± 0.05	+18.94
Total acidity (g/L)*	6.32 ± 0.09	7.81 ± 0.06	+23.57	7.17 ± 0.06	8.73 ± 0.08	+21.76
Volatile acidity (g/L)**	0.57 ± 0.01	0.05 ± 0.01	−91.23	0.39 ± 0.01	0.03 ± 0.01	−92.3
Antioxidant activity (mg TE/L)	3606.7 ± 27.5	3861.9 ± 21.8	+7.07	793.4 ± 22.5	845.9 ± 21.7	+6.62
Total phenolic content (mg GAE/L)	2047.88 ± 178.12	2348.53 ± 154.37	+14.73	237.43 ± 15.32	262.95 ± 13.19	+10.95
Resveratrol (mg/L)	10.08 ± 0.26	12.33 ± 0.37	+22.32	0.62 ± 0.02	0.71 ± 0.02	+14.52
Gallic acid (mg/L)	82.67 ± 2.31	89.58 ± 2.66	+8.36	6.11 ± 0.19	6.74 ± 0.22	+10.31
Caffeic acid (mg/L)	14.47 ± 0.38	15.81 ± 0.31	+9.26	1.36 ± 0.05	1.49 ± 0.05	+9.56
Ferulic acid (mg/L)	0.91 ± 0.02	0.94 ± 0.02	+3.29	0.64 ± 0.02	0.68 ± 0.03	+6.25
p-coumaric acid (mg/L)	5.08 ± 0.14	5.55 ± 0.11	+9.25	3.61 ± 0.12	3.91 ± 0.12	+8.31
Sinapic acid (mg/L)	0.32 ± 0.01	0.33 ± 0.01	+3.12	0.57 ± 0.02	0.61 ± 0.02	+7.01
Flavan-3-ols (catechins) (mg CE/L)	95.92 ± 2.18	102.76 ± 3.02	+7.13	5.53 ± 0.19	6.06 ± 0.21	+9.58
Condensed tannins (mg ECE/L)	1253.78 ± 27.76	1383.31 ± 29.12	+10.33	32.95 ± 1.01	35.98 ± 1,12	+9.19
Anthocyanins (mg M3G/L)	517.48 ± 12.94	569.73 ± 11.09	+10.09	–	–	–

Values are expressed as mean ± SD of quadruplicate measurements ($p \leq 0.05$).
[a] * calculated as tartaric acid.
[b] **calculated as acetic acid.

Table 3
Paired *t*-test results and effect sizes (Cohen d) for key chemical parameters of *Pinot noir* and *Chardonnay* wines after dealcoholisation.

	Pinot noir			Chardonnay		
	Cohen d *	paired *t*-test**	P***	Cohen d*	paired *t*-test**	P***
Ethanol (mL/100 mL)	−74.84	−91.7	8.49e-08	−155.58	−190.6	4.55e-09
Glycerol (g/L)	21.92	26.8	1.14e-05	11.4	14	0.00015
Residual sugars (g/L)	20.65	25.3	1.45e-05	13.58	16.6	7.65e-05
Total acidity (g/L)	19.48	23.9	1.83e-05	22.06	27	1.11e-05
Volatile acidity (g/L)	−52.0	−63.7	3.64e-07	−36.0	−44.1	1.58e-06
Antioxidant activity (mg TE/L)	8.47	10.4	0.00048	2.33	2.9	0.04613
Total phenolic content (mg GAE/L)	1.81	2.2	0.09169	1.79	2.2	0.09452
Resveratrol (mg/L)	7.01	8.59	0.00151	4.51	5.53	0.00531
Gallic acid (mg/L)	2.75	3.42	0.02819	3.05	3.75	0.02055
Caffeic acid (mg/L)	3.82	4.71	0.01011	2.62	3.19	0.03341
Ferulic acid (mg/L)	3.75	4.55	0.01166	1.55	1.92	0.13763
p-coumaric acid (mg/L)	1.51	1.84	0.14011	2.51	3.06	0.03771
Sinapic acid (mg/L)	1.02	1.22	0.25431	2.02	2.44	0.07103
Flavan-3-ols (catechins) (mg CE/L)	2.65	3.18	0.03851	2.66	3.24	0.03211
Condensed tannins (mg ECE/L)	4.48	5.52	0.00511	2.82	3.48	0.02542
Anthocyanins (mg M3G/L)	4.31	5.28	0.00721			

[a] * Cohen effect size: calculated as the difference between the post- and pre-dealcoholisation, means divided by the pooled standard deviation (*SD* pooled). $0.2 \leq d < 0.5$ – small effect; $0.5 \leq d < 0.8$ – medium effect; $d \geq 0.8$ – large effect.
[b] ** significance level $\alpha < 0.05$.
[c] *** The higher the absolute P value, the stronger the effect of the process.

processed by vacuum distillation and spinning cone technology (Cuenca-Martínez et al., 2025; Sam et al., 2021).

Statistical analysis confirmed that the most significant effects were observed for ethanol and volatile acidity (Cohen d > 20, $p < 0.001$), followed by substantial increases in residual sugars, total acidity, and glycerol (Cohen d > 10, $p < 0.001$), which is the effect of the wine concentration after ethanol removal (Pickering, 2000). Within the phenolic fraction, increases in resveratrol, gallic acid, caffeic acid, ferulic acid, condensed tannins, and anthocyanins were associated with large effects (Cohen d: 2 to 5, $p < 0.05$). These results are in line with other studies (Kumar et al., 2024; Slegers et al., 2015), in which it was also observed that polyphenols remain relatively stable and undergo concentration during dealcoholisation process. The lowest changes, often not statistically significant, were noted for low-abundance phenolic acids (p-coumaric, sinapic), which are more susceptible to losses through membrane sorption or oxidative degradation (Pickering, 2000).

3.2. *Influence of temperature and ultrasound on the extraction of polyphenols from grape pomace*

In both types of grape pomace, temperature emerged as the primary factor influencing extraction efficiency with ultrasound (US) further amplifying this effect. In *Pinot noir*, the total polyphenol content (TPC) increased almost four times between 23 °C and 60 °C, while incorporating the US at 60 °C resulted in an additional significant increase (Table 4). Comparable trends were observed for ABTS, catechins, tannins, and anthocyanins, highlighting that the quantitative increase

Table 4
Polyphenols content and antioxidant activity in the concentrated grape pomace extracts.

	Pinot noir					
	23 °C	60 °C	US 15 min; 23 °C	US 15 min; 60 °C	US 60 min; 23 °C	US 60 min; 60 °C
TPC (mg GAE/g DW)	51.63 ±1.511^{c}	203.27 ±7.115^{b}	54.94 ±1.974^{c}	212.66 ±6.127^{a}	53.43 ±1.562^{c}	214.71 ±5.544^{a}
Antioxidant activity (mg TE/g DW)	70.08 ± 3.25^{c}	95.11 ± 6.76^{b}	82.59 ± 4.51^{b}	117.64 ± 6.01^{a}	80.09 ± 2.75^{c}	115.13 ± 6.51^{a}
Resveratrol (mg/g DW)	0.43 ± 0.022^{c}	0.61 ± 0.027^{b}	0.48 ± 0.021^{c}	0.68 ± 0.032^{a}	0.44 ± 0.026^{c}	0.72 ± 0.029^{a}
Gallic acid (mg/g DW)	0.13 ± 0.006^{d}	0.18 ± 0.005^{b}	0.16 ± 0.006^{c}	0.22 ± 0.008^{a}	0.13 ± 0.005^{d}	0.21 ± 0.007^{a}
Caffeic acid (mg/g DW)	0.28 ± 0.009^{c}	0.41 ± 0.014^{b}	0.31 ± 0.009^{c}	0.44 ± 0.016^{a}	0.27 ± 0.008^{d}	0.47 ± 0.014^{a}
Ferulic acid (mg/g DW)	0.18 ± 0.008^{c}	0.22 ± 0.009^{a}	0.17 ± 0.007^{c}	0.24 ± 0.008^{a}	0.16 ± 0.005^{c}	0.21 ± 0.007^{b}
p-coumaric acid (mg/g DW)	0.05 ± 0.001^{d}	0.11 ± 0.001^{b}	0.06 ± 0.001^{c}	0.11 ± 0.001^{b}	0.05 ± 0.001^{d}	0.14 ± 0.001^{a}
Flavan-3-ols (mg CE/g DW)	5.63 ± 0.211^{b}	7.57 ± 0.302^{a}	5.81 ± 0.204^{b}	8.02 ± 0.317^{a}	5.89 ± 0.231^{b}	8.19 ± 0.298^{a}
Condensed tannins (mg ECE/g DW)	21.15 ± 0.972^{d}	31.98 ± 1.326^{b}	23.88 ± 0.892^{c}	34.71 ± 1.279^{b}	25.06 ± 0.918^{c}	38.55 ± 1.412^{a}
Anthocyanins (mg M3G/g DW)	28.19 ± 1.164^{d}	41.53 ± 1.957^{b}	31.09 ± 1.713^{c}	43.12 ± 1.726^{a}	33.26 ± 1.361^{c}	46.91 ± 1.822^{a}
	Chardonnay					
TPC (mg GAE/g DW)	16.47 ± 0.076^{d}	25.84 ± 1.126^{b}	20.01 ± 0.873^{c}	31.05 ± 1.439^{a}	21.66 ± 1.034^{c}	31.55 ± 1.572^{a}
Antioxidant activity (mg TE/g DW)	30.04 ± 3.26^{c}	45.05 ± 4.51^{b}	32.54 ± 3.75^{c}	55.06 ± 4.51^{a}	42.55 ± 3.25^{b}	52.56 ± 2.75^{d}
Resveratrol (mg/g DW)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Gallic acid (mg/g DW)	0.04 ± 0.001^{d}	0.09 ± 0.001^{b}	0.06 ± 0.001^{c}	0.09 ± 0.001^{b}	0.06 ± 0.001^{c}	0.11 ± 0.003^{a}
Caffeic acid (mg/g DW)	0.09 ± 0.001^{d}	0.14 ± 0.005^{b}	0.12 ± 0.005^{c}	0.14 ± 0.006^{b}	0.13 ± 0.002^{b}	0.18 ± 0.004^{a}
Ferulic acid (mg/g DW)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
p-coumaric acid (mg/g DW)	0.02 ± 0.001^{b}	0.02 ± 0.001^{b}	0.02 ± 0.001^{b}	0.01 ± 0.001^{a}	0.02 ± 0.001^{b}	0.03 ± 0.001^{a}
Flavan-3-ols (mg CE/g DW)	5.63 ± 0.211^{b}	7.57 ± 0.302^{a}	5.81 ± 0.204^{b}	8.02 ± 0.317^{a}	5.89 ± 0.231^{b}	8.19 ± 0.298^{a}
Condensed tannins (mg ECE/g DW)	9.17 ± 0.413^{c}	16.08 ± 0.745^{a}	12.05 ± 0.668^{b}	16.19 ± 0.803^{a}	11.92 ± 0.615^{b}	16.31 ± 0.861^{a}
Anthocyanins (mg M3G/g DW)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d. – not detected.
Values are expressed as mean ± SD of quadruplicate measurements ($p \leq 0.05$); different letters in row indicate a significant differences between the applied extraction parameters ($p \leq 0.05$, separately for *Pinot noir* and *Chardonnay*).

encompassed compounds with substantial antioxidant properties. In *Chardonnay*, both TPC and ABTS also increased with temperature and US, although the absolute values remained considerably lower. These results align with other studies that indicate that higher temperatures improve diffusion and solubility, while ultrasound cavitation introduces mechanical and thermal effects that accelerate mass transfer and disrupt cell walls (Deaconu et al., 2024; Moutinho et al., 2023; Seguenka et al., 2024).

At the level of individual phenolic acids, *Pinot noir* extracts heated at 60 °C (particularly when combined with US) exhibited elevated levels of gallic, caffeic, ferulic, and p-coumaric acids, indicating that the synergistic effects of heat and sonication enhance the extraction of both hydroxybenzoic and hydroxycinnamic acids. In *Chardonnay*, only the concentrations of gallic and caffeic acids increased, while resveratrol, ferulic acid and anthocyanins were absent, which is characteristic of white grape pomace (Deaconu et al., 2024; Wang et al., 2024). Catechins and tannins concentrations increased in both pomaces at 60 °C and with US, although their levels remained lower in *Chardonnay*.

The recovery of anthocyanins from *Pinot noir* was also improved with temperature and with the US. A peak of 46.91 mg M3G/g DW was reached when 60 °C and 1 h of US was applied (Table 4).

Anthocyanins are indicated in the literature as compounds that play a significant role in antioxidant activity and can withstand sonication. However, they are susceptible to overheating and oxidation, making moderate temperatures and moderate US treatment the optimal conditions for extraction (Delić et al., 2024).

In general, the findings of our investigation support the assertion that temperature and ultrasonic extraction represent two very efficacious parameters for improving the recovery of polyphenols and the antioxidant activity derived from grape pomace. The conditions of approximately 60 °C, 70 mL/100 mL ethanol concentration, and a slightly acidic pH level serve to maximize both the TPC and radical scavenging capacity (Moutinho et al., 2023). Comparative studies that evaluate traditional extraction methods alongside ultrasonic extraction further elucidate that US significantly increases the polyphenols yield and enhances antioxidant activity, with the most pronounced advantages documented at moderately elevated temperatures (40–60 °C) and ethanol concentrations ranging from 50 to 70 mL/100 mL (Deaconu et al., 2024). It has been demonstrated that prolonged or excessively vigorous ultrasonic treatment may lead to significant degradation of anthocyanins, and higher temperatures should be limited to a shorter time during the extraction process (Delić et al., 2024; Seguenka et al., 2024).

The distinct compositional profiles of *Pinot noir* and *Chardonnay* indicate that the stronger extraction responses observed in *Pinot noir* result from its higher phenolic content. Red grape pomace is particularly enriched in flavan-3-ols, proanthocyanidins, and anthocyanins, compounds closely related to higher ABTS activity. In contrast, white grape pomace lacks anthocyanins and is mainly characterized by hydroxycinnamates, which leads to a weaker extraction yield and lower antioxidant performance (Wang et al., 2024).

3.3. Characteristic of wine-jelly candies enriched with grape pomace extracts

For further analyses, the most polyphenol rich and antioxidant active extracts were chosen. These were variants obtained after 60 min ultrasonic treatment followed by 60 min shaking at 60 °C for both *Pinot noir* and *Chardonnay* - US 60 min; 60 °C (Table 4).

The enrichment of wine-jelly candies with increasing concentrations of grape pomace extract (0.5–2.0 g DW/100 g) resulted in a dose dependent increase in phenolic compounds and antioxidant activity in both *Pinot noir* and *Chardonnay* formulations, with consistently higher absolute values in *Pinot noir* jellies (Table 5). For total phenolic content, *Pinot noir* jellies contained 288.52–609.85 mg GAE/100 g, while *Chardonnay* counterparts ranged only between 36.75 and 84.66 mg GAE/100 g (Table 5). Antioxidant activity followed the same trend, increasing from 352.91 to 525.61 mg TE/100 g in *Pinot noir* jellies and from 92.61 to 170.19 mg TE/100 g in *Chardonnay* jellies. Among individual phenolics, resveratrol together with gallic, caffeic, ferulic, and p-coumaric acids were consistently more abundant in *Pinot noir* (0.16–7.33 mg/100 g) compared to *Chardonnay* (0.05–0.73 mg/100 g). The differences were even more pronounced for catechins and tannins: *Pinot noir* jellies contained 11.91–24.02 mg/100 g catechins and 125.14–181.17 mg/100 g tannins, while the equivalents of *Chardonnay* reached only 1.14–3.02 and 10.66–34.74 mg/100 g, respectively.

Table 5
Polyphenols content and antioxidant activity in 100 g wine-jelly candies with different extract dosage.

Concentration per 100 g of jelly candies	*Pinot noir (g DW of extract/100 g jelly candies)*			
	0.5	1.0	1.5	2.0
TPC (mg GAE/100 g)	288.52 ± 9.32	395.95 ± 11.41	502.36 ± 12.11	609.85 ± 17.41
Antioxidant activity (mg TE/100 g)	352.91 ± 20.04	395.46 ± 15.02	468.04 ± 22.53	525.61 ± 30.03
Resveratrol (mg/100 g)	0.98 ± 0.02	1.01 ± 0.02	1.05 ± 0.03	1.10 ± 0.02
Gallic acid (mg/100 g)	7.02 ± 0.39	7.13 ± 0.27	7.23 ± 0.19	7.33 ± 0.22
Caffeic acid (mg/100 g)	1.44 ± 0.06	1.66 ± 0.05	1.91 ± 0.06	2.12 ± 0.09
Ferulic acid (mg/100 g)	0.16 ± 0.004	0.25 ± 0.008	0.36 ± 0.017	0.47 ± 0.022
p-coumaric acid (mg/100 g)	0.47 ± 0.03	0.55 ± 0.02	0.61 ± 0.05	0.69 ± 0.05
Flavan-3-ols (mg CE/100 g)	11.91 ± 0.72	15.89 ± 0.77	19.91 ± 0.85	24.02 ± 1.15
Condensed tannins (mg ECE/100 g)	125.14 ± 6.25	143.54 ± 6.84	163.47 ± 8.01	181.17 ± 8.19
Anthocyanins (mg M3G/100 g)	63.14 ± 3.05	90.01 ± 3.67	112.85 ± 4.58	135.58 ± 7.06
	Chardonnay (g DW of extract/100 g jelly candies)			
TPC (mg GAE/100 g)	36.75 ± 1.36	52.62 ± 2.54	68.91 ± 3.04	84.66 ± 3.74
Antioxidant activity (mg TE/100 g)	92.61 ± 5.01	117.64 ± 5.02	150.17 ± 5.11	170.19 ± 4.89
Resveratrol (mg/100 g)	0.052 ± 0.02	0.054 ± 0.02	0.053 ± 0.02	0.053 ± 0.02
Gallic acid (mg/100 g)	0.55 ± 0.01	0.62 ± 0.02	0.68 ± 0.03	0.73 ± 0.03
Caffeic acid (mg/100 g)	0.21 ± 0.006	0.28 ± 0.019	0.36 ± 0.019	0.45 ± 0.021
Ferulic acid (mg/100 g)	0.053 ± 0.001	0.052 ± 0.002	0.053 ± 0.002	0.052 ± 0.001
p-coumaric acid (mg/100 g)	0.31 ± 0.001	0.32 ± 0.02	0.35 ± 0.01	0.36 ± 0.02
Flavan-3-ols (mg CE/100 g)	1.14 ± 0.05	1.76 ± 0.08	2.51 ± 0.11	3.02 ± 0.16
Condensed tannins (mg ECE/100 g)	10.66 ± 0.34	19.02 ± 0.79	25.89 ± 1.11	34.75 ± 1.35
Anthocyanins (mg M3G/100 g)	n.d.	n.d.	n.d.	n.d.

Values are expressed as mean ± SD of quadruplicate measurements ($p \leq 0.05$).

Anthocyanins, detected exclusively in *Pinot noir* jellies, increased proportionally with the addition of extract amount, from 63.14 to 135.58 mg/100 g (Table 5). Generally, these results demonstrate that *Pinot noir* jellies provide a markedly richer phenolic and antioxidant profile than *Chardonnay* jellies, while extract enrichment enhances the bioactive potential in both types.

The principal component analysis (PCA) explicitly validated the differentiation between samples of *Pinot noir* and *Chardonnay* jellies (Fig. 1). The first component (PC1), which elucidated 97.3 % of the total variance, effectively separated the two varietals along the horizontal axis. *Pinot noir* was found to cluster in the positive quadrant of PC1 and exhibited a strong correlation with the concentrations of anthocyanins, tannins, flavan-3-ols, and TPC, along with individual phenolic acids and resveratrol concentrations. On the contrary, the *Chardonnay* jelly

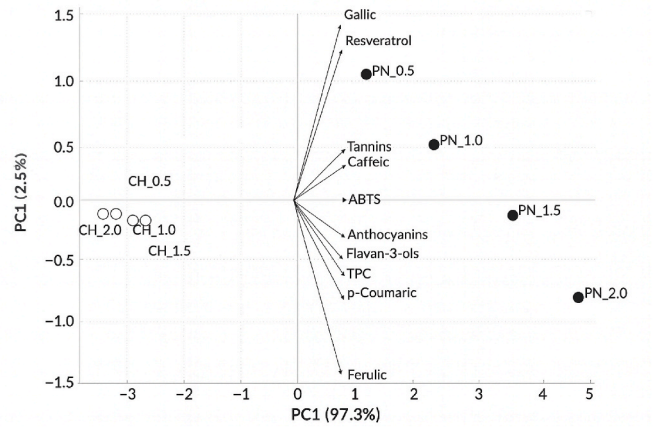

Fig. 1. PCA biplot of phenolic composition and antioxidant activity of *Pinot noir* and *Chardonnay* wine-jelly candies.

samples, located in the negative quadrant of PC1, were characterized by decreased levels of these compounds and constituted a compact homogeneous aggregation (Fig. 1).

The secondary component (PC2, accounting for 2.5 % of the variance) only differentiated the *Pinot noir* with addition of extract of 0.5 g DW/100 g jellies, which demonstrated a stronger association with resveratrol and gallic acid, while the other *Pinot noir* samples exhibited a shift along PC1 in accordance with increasing extract concentration. The lack of distinct differentiation within *Chardonnay* suggests a greater homogeneity within this varietal. The PCA findings, which clearly separated *Pinot noir* from *Chardonnay* samples, emphasized anthocyanins, tannins, and total polyphenol content as essential distinguishing markers.

Numerous recent studies have highlighted the potential of enriching innovative food products with grape pomace or its extracts, particularly in bakery goods, meat products, dairy, beverages, and gluten-free formulations (Antonić et al., 2020; Giosuè et al., 2024; Kurćubić et al., 2024). On the contrary, the number of studies focusing on gummy confectionery remains very limited. Spinei and Oroian (2024) reported the influence of the size of grape pomace particles (*Vitis vinifera var. Băbească Neagră*) on the functional and physicochemical properties of gummies. Other authors, Trentin et al. (2024) optimized polyphenol extraction conditions to obtain anthocyanin rich, antioxidant extracts, which were then applied to pectin-based gummies prepared with water or fruit juice supplemented with sugar or sugar syrups. In our study, the innovative aspect lies in the use of dealcoholized wine as the liquid base, combined with pectin and inulin as sources of dietary fiber, and the complete elimination of added sugars, resulting in an unconventional snack with a more savory flavor profile and simultaneously high functional value.

Our research is in line with current trends, highlighting the significant role of red grape pomace as a phenolic rich resource for development of functional foods. Such applications not only promote consumer health, but also support sustainability by utilizing agricultural by-products.

3.4. Alpha-glucosidase inhibition potential

The analyzed inhibitory potential against α-glucosidase was strongly dependent on both the grape variety and the level of pomace extract incorporated into the jelly candies (Figs. 2 and 3).

Pinot noir jellies exhibited significantly lower IC_{50} values (27–71 mg/mL) compared to *Chardonnay* (266–520 mg/mL), indicating a significantly stronger inhibition of α-glucosidase. Increasing the concentration of grape pomace extract enhanced the inhibitory effect in both varieties. These results are consistent with the higher content of polyphenols, anthocyanins, and tannins in *Pinot noir* (Fig. 2), compounds known to interfere with carbohydrate hydrolyzing enzymes (Tadera et al., 2006; Xiao et al., 2013). Anthocyanins and proanthocyanidins, frequently function as competitive or mixed type inhibitors by directly competing with oligosaccharides for binding sites or modifying the flexibility of enzymes. Furthermore, high-molecular weight tannins have the potential to create enzyme–polyphenol complexes that physically block the access of carbohydrates to the catalytic center (Adisakwattana et al., 2012; McDougall et al., 2005). Together, these mechanisms disturb the hydrolysis of complex carbohydrates into glucose, resulting in a reduction of the postprandial glycemic response (Kwon et al., 2008).

The observed activity suggests that *Pinot noir* enriched jellies may provide functional benefits related to postprandial glycemic control, while *Chardonnay*, although showing some inhibitory effect, demonstrated considerably lower bioactivity. When expressed as total polyphenol equivalents (IC_{50} in mg GAE/mL), *Pinot noir* jelly candies exhibited values between 0.163 and 0.205 mg GAE/mL, which were significantly lower than those of acarbose (0.347 mg GAE/mL) (Fig. 3). This indicates that the phenolic compounds present in *Pinot noir* jellies are approximately two times more effective in inhibiting α-glucosidase compared to the pharmaceutical standard. *Chardonnay* jellies also showed lower IC_{50} values than acarbose (0.191–0.223 mg GAE/mL), although the inhibitory effect was consistently weaker than that of *Pinot noir* at equivalent polyphenol concentrations. Interestingly, while *Pinot noir* reached a plateau effect at concentrations of 1.0–2.0 g extract DW/100 g jelly relatively, *Chardonnay* displayed slightly increasing IC_{50} values with higher enrichment levels, suggesting varietal differences in the bioactivity of polyphenolic compounds. These findings confirm that not only the concentration but also the composition of polyphenols plays a critical role in modulating α-glucosidase inhibition.

Linear regression analysis was performed to evaluate the dose response relationship between extract concentration added to jellies and α-glucosidase inhibitory capacity (IC_{50}) (Table 6). The slope parameter reflects the rate of change in IC_{50} with increasing addition of pomace

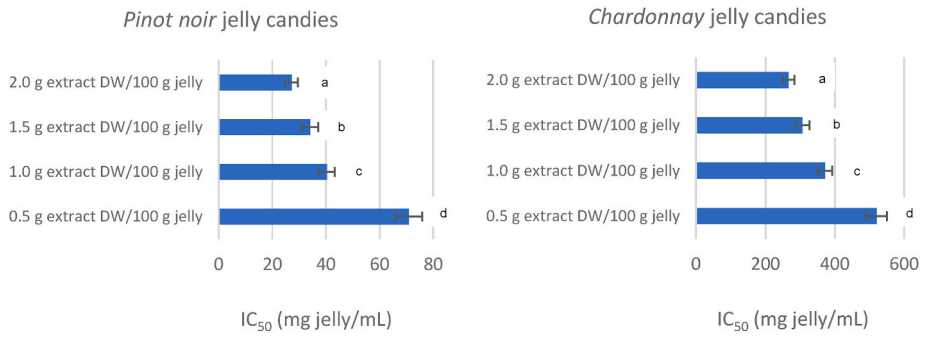

Fig. 2. IC_{50} (mg jelly/mL) of α-glucosidase inhibition by wine-jelly candies enriched with grape pomace extracts from *Pinot noir* and *Chardonnay* Different letters indicate statistically significant differences at $p \leq 0.05$.

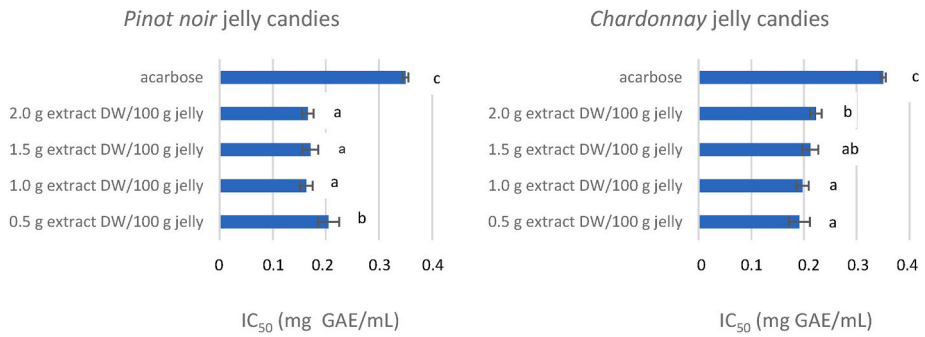

Fig. 3. IC_{50} values normalized to polyphenol content (mg GAE/mL) for α-glucosidase inhibition by *Pinot noir* and *Chardonnay* jelly candies, with acarbose as reference.

Table 6
Linear regression parameters describing the relationship between extract concentration and α-glucosidase inhibitory capacity (IC_{50}) in *Pinot noir* and *Chardonnay* jelly.

Grape variety	Slope	Intercept	R^2	P
Pinot noir	−27.468	77.455	0.8472	0.080
Chardonnay	−165.55999	573.34999	0.9177	<0.05

Slope indicates the rate of decrease in IC_{50} with increasing extract concentration. R^2 denotes the proportion of explained variance. Statistical significance was considered at $p < 0.05$.

extract, while the intercept represents the extrapolated IC_{50} value at zero extract concentration. *Chardonnay* showed a steep negative slope (−165.6), indicating that IC_{50} decreased significantly with higher extract levels, while *Pinot noir* showed a more moderate slope (−27.5) (Table 6).

However, *Pinot noir* jellies had a much lower intercept value, confirming that their inhibitory capacity was stronger in all the tested doses. This suggests that although *Chardonnay* benefits more strongly from incremental extract addition, *Pinot noir* consistently outperforms because of its intrinsically higher phenolic activity.

Comparable inhibitory effects have been reported for grape pomace extracts, where procyanidins and anthocyanins were identified as the main contributors to enzyme inhibition (Adisakwattana et al., 2012; Barrett et al., 2013; Sri Harsha & Lavelli, 2024). Recent studies also confirmed that red grape pomace extracts show significantly higher α-glucosidase inhibitory activity than those of white grapes, indicating their richer phenolic profiles (Lopes et al., 2025). *In vivo* experiments further support these results, since oral administration of grape pomace extracts reduced postprandial hyperglycemia in diabetic mice (Kwon et al., 2008). Reviews underline that grape pomace represents a promising source of natural inhibitors of α-amylase and α-glucosidase, linking their bioactivity not only to polyphenols but also to dietary fiber (Xiao et al., 2013). These findings support our results, confirming that phenolic rich grape derivatives, particularly red varieties, can act as effective natural modulators of postprandial glycemia and represent valuable functional ingredients for innovative food products. In line with previous studies, our research demonstrates how winemaking by-products can be transformed into value-added functional jelly candies, thus combining sustainability with measurable health benefits.

3.5. Sensory evaluation of wine-jelly candies enriched with grape pomace extracts

Sensory evaluation of jelly candies enriched with grape pomace extracts revealed clear differences between *Pinot noir* and *Chardonnay* with increasing supplementation levels. In *Pinot noir*, overall desirability was highest at 1.0–1.5 g DW extract/100 g jellies (score 8), but much lower at 2.0 g DW extract/100 g jellies (score 4) (Fig. 4). This decrease was mainly due to excessive astringency and reduced aroma perception, despite consistently high scores for color and texture (firmness and chewiness). This may be caused by the fact that red grape pomace, rich in tannins and anthocyanins, can enhance phenolic sensations and simultaneously generate bitterness and excessive mouth drying effects at higher doses (Kammerer et al., 2004; Spinei & Oroian, 2024).

In contrast, *Chardonnay* jellies showed a steady increase in overall desirability with rising extract levels, reaching the highest acceptance at 2.0 g DW extract/100 g jellies (score 9). Improvements were particularly noticeable in aroma, flavor, and color, while astringency remained moderate and did not negatively affect evaluators' perception (Fig. 4).

Similar trends have been reported in various food matrices. Tolve et al. (2021) and Boff et al. (2022) found that the addition of white grape pomace to bakery and dairy products improved color, flavor, and overall

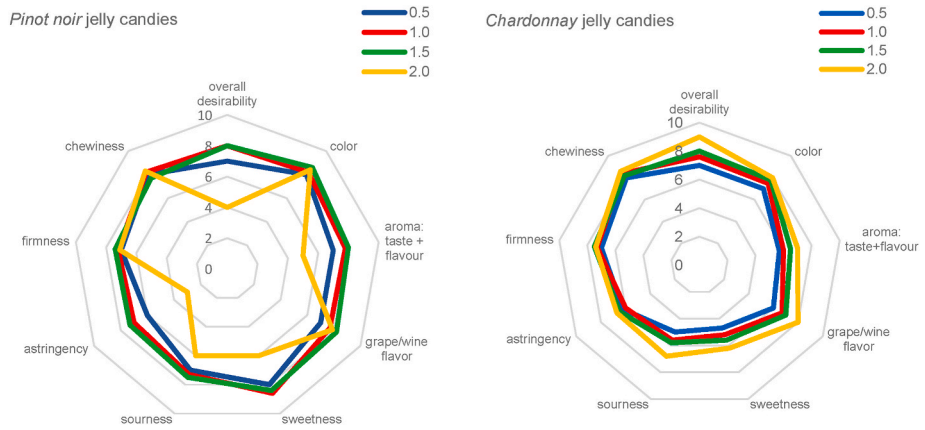

Fig. 4. Sensory profile of *Pinot noir* and *Chardonnay* jelly candies enriched with grape pomace extract at different concentrations (0.5–2.0 g/100 g).

acceptability without inducing excessive astringency. Tseng and Zhao (2013) observed that higher levels of red grape pomace in cookies enhanced antioxidant capacity but also increased bitterness and astringency, consistent with our results for *Pinot noir* jellies. Furthermore, González-Centeno et al. (2015) reported that incorporating red grape pomace into yogurts improved phenolic content but decreased sensory scores at higher concentrations, due to intensified astringency.

Our findings align with previous reports, confirming that sensory perception in grape pomace enriched products depends strongly on the type of pomace (red and white), its phenolic composition (tannins, anthocyanins, phenolic acids), and the concentration level used. At optimal supplementation, *Chardonnay* pomace contributed to a balanced and appealing sensory profile, whereas excessive addition of *Pinot noir* pomace resulted in over-astringency and decreased aroma perception. Comparative radar plots further demonstrated that *Pinot noir* extracts imparted a more pronounced wine-like character, stronger sweetness, and higher astringency, while *Chardonnay* extracts produced a milder and more harmonious profile with greater consumer appeal. These differences reflect the compositional variation between red and white grape pomace: *Pinot noir* provided higher levels of anthocyanins, tannins, and phenolic acids, whereas *Chardonnay* lacked anthocyanins and resveratrol, resulting in a softer and more balanced sensory character.

Comparable outcomes were also observed in similar studies focusing on confectionery systems. Kaynarca et al. (2023) demonstrated that the incorporation of winery-waste and pomegranate-peel extracts into fish-gelatin candies improved color stability, texture, and overall acceptability. Likewise, Gümüş et al. (2024) found that wine lees could be effectively used as a natural colorant and functional ingredient in jelly formulations, enhancing both color intensity and phenolic retention. These reports further support our findings, indicating that by-products of winemaking can enhance the sensory and functional qualities of confectionery products when used at optimal concentrations, while excessive enrichment may negatively affect sensory balance.

The differences observed between the present findings and those reported in other studies may stem from the distinct composition of grape pomace extracts and the use of a pectin–inulin gel system, which differs from the gelatin- or starch-based matrices commonly applied elsewhere (Gümüş et al., 2024; Kaynarca et al., 2023). These formulation differences can significantly influence phenolic compound retention, gel structure formation, and the perception of texture and astringency (Boff et al., 2022; Tolve et al., 2021). Moreover, variations in extraction temperature, solvent polarity, and ultrasound-assisted processing time may have contributed to the different phenolic profiles and bioactivity levels obtained (González-Centeno et al., 2015; Tseng & Zhao, 2013). Although the present work focused primarily on the functional and sensory evaluation of the developed products. Future investigations should address the technological characteristics of jelly systems — including texture parameters, gel strength, and water activity — to support formulation optimization and improve industrial applicability.

4. Conclusions

The present study demonstrated that alcohol-free wine-based jelly candies enriched with *Pinot noir* and *Chardonnay* grape pomace extracts represent a promising strategy for the upcycling of winemaking by-products into sustainable, functional confectionery. The developed products exhibited significant antioxidant activity, favorable phenolic profiles, and measurable α-glucosidase inhibition, confirming their potential as health-promoting snacks.

Beyond the demonstrated functionality, the findings open several future research directions.

Further investigations could concentrate on process optimization aimed at reducing the excessive astringency observed at higher levels of red grape pomace addition, as well as on the application of microencapsulation or controlled-release technologies to enhance the stability of phenolic compounds during processing and storage. Future research could also explore consumer perception, product shelf-life, and sensory evolution under real market conditions. Additionally, expanding this approach to include other grape varieties or mixed pomace formulations may provide a deeper understanding of varietal effects on the functional and sensory properties of confectionery products. From a sustainability perspective, the integration of grape pomace valorization with dealcoholised wine production presents a viable pathway toward a circular bioeconomy, reducing waste generation and enhancing resource efficiency within the wine industry. Overall, this work lays the foundation for future studies combining food innovation, health functionality, and sustainable technology development in the confectionery sector.

CRediT authorship contribution statement

Małgorzata Lasik-Kurdyś: Writing – original draft, Visualization, Supervision, Methodology, Investigation, Conceptualization. **Małgorzata Gumienna:** Writing – review & editing, Methodology, Formal analysis, Conceptualization. **Małgorzata Krzywonos:** Writing – review & editing, Visualization, Formal analysis, Conceptualization. **Noranizan Mohd Adzahan:** Writing – review & editing, Methodology, Formal analysis.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used Writefull software in order to grammatical correction. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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Corrigendum

Corrigendum to "Alcohol-free wine based jelly candies enriched with grape pomace extracts with antioxidant and antidiabetic properties: Implications for sustainable development and health benefits" [LWT-Food Science and Technology (2025) 239C 118952]

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