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Upcycling Blackberry Juice Pomace into Fruit Beer: Effects of High Pressure Processing on Polyphenols, Colour, Volatile Profile and Sensory Analysis

Luca Pretti [1], Manuela Sanna [1], Massimiliano Rinaldi [2], Antonio Valentoni [1], Margherita Rodolfi [2,*], Rohini Dhenge [2], Daniele Sanna [3], Maria Cristina Porcu [3], Tina Lino [2] and Tommaso Ganino [2,4,*]

[1] Porto Conte Ricerche Srl, Tramariglio, 07041 Alghero, SS, Italy; pretti@portocontericerche.it (L.P.); sanna@portocontericerche.it (M.S.)
[2] Department of Food and Drug, University of Parma, 43124 Parma, PR, Italy; massimiliano.rinaldi@unipr.it (M.R.); rohinivijay.dhenge@unipr.it (R.D.); tina.lino@unipr.it (T.L.)
[3] Institute of Biomolecular Chemistry (ICB), National Research Council—CNR, 07100 Sassari, SS, Italy; daniele.sanna@cnr.it (D.S.); mariacristinagiuseppina.porcu@cnr.it (M.C.P.)
[4] Institute of BioEconomy (IBE), National Research Council—CNR, 50019 Sesto Fiorentino, FI, Italy
* Correspondence: margherita.rodolfi@unipr.it (M.R.); tommaso.ganino@unipr.it (T.G.)

Abstract

The integration of fruit by-products into brewing represents a promising strategy to enhance sustainability within the beverage sector. This study evaluates the use of dried blackberry (*Rubus fruticosus* L.) juice pomace, either untreated or pre-treated by High-Pressure Processing (HPP), as an ingredient in fruit beer production. A portion of the blackberry pomace was dried at 50 °C and incorporated into a beer formulation named "control beer" (CB), while another portion of the blackberry pomace was subjected to HPP at 600 MPa for 3 min, dried at 50 °C and incorporated into a beer formulation named HPPB. The beers were analysed for their physicochemical parameters, colour properties, total phenolic content, antioxidant capacity (UV–Vis and EPR), and volatile composition (HS-SPME-GC-MS). A trained sensory panel (n = 8) assessed descriptive attributes. HPP significantly affected the colour of the dried pomace and resulted in beers with higher lightness (L*) but lower redness (a*) and total phenolics. CB exhibited higher antioxidant capacity, whereas HPPB showed increased levels of fruity esters. Sensory analysis confirmed that HPPB was perceived as significantly more fruity in both orthonasal odour and flavour ($p < 0.05$). No significant differences were detected in beer oxidative stability by EPR. These findings demonstrate that HPP-treated blackberry pomace can modulate the sensory profile of fruit beers despite reducing phenolic retention, and that upcycled by-products can support the development of sustainable, specialty beers.

Keywords: fruit beers; blackberry; by-products; high-pressure processing; sensory analysis; sustainability; oxidative stability

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1. Introduction

Beer, typically made with malt, water, and hops and fermented with yeasts, is the most popular alcoholic beverage worldwide and is in third place behind water and tea in terms of popularity [1,2]; its market is constantly growing, with its total volume expected to exceed 180 billion litres by 2024 [3]. There are around 150 identified styles of beer, giving consumers a wide range of options, according to the Beer Judge Certification Program [4]. Due to their focus on flavour and brewing processes, craft or speciality beers are currently a rising

market within the beverage sector, utilizing various ingredients or brewing techniques resulting in the creation of distinctive recipes.

The innovation of beer can be categorized into two primary trends: one is identified as functional beers, such as those without alcohol, fewer calories, and mostly created to satisfy people's desire for a healthy lifestyle; the other is beer with a distinct flavour or taste that is created using additional ingredients such as fruits, herbs, and spices [5,6]. Because of its accessibility and larger market, the latter trend is preferred by producers. Almost every kind of fruit, comprising drupes, kernel fruits, tropical fruits, and berries, can be added in the category of fruit beer [7]. Although the cost of making beer undoubtedly grows, adding fruits meets customer demand for unusual flavour, smell, and visual stimuli [8].

Depending on the amount and type of fruit added, beer can acquire a higher acidity as well as an odd colour and a fruity taste and flavour [9]. Three categories can be used to describe fruit beers: those with added fruit, those with added fruit extracts, and those with fruit-flavoured additions. The first kind is the most common due to its simplicity in preparation. The addition of fruit by-products falls within the first category as well [10,11].

The rise in the worldwide consumption of fruit juice also increases the volume of industry waste. It has been found that only Europe, from the drinks, fruits and vegetables industry, produces about 100 Mt of waste and by-products per year [12].

Blackberry (*Rubus fruticosus* L.) is a high-value fruit; the first step of blackberry juice production consists in an expression stage, from which a pomace (20–25% of the entire fruit), made of seeds, skins and stem, is formed. The blackberry pomace is a waste for the industry, but it is rich in various compounds with biological activities such as anthocyanins, important molecules for their antioxidant properties [13] and colouring properties [14]: its employ could therefore be a valuable and cheap alternative to the use of fresh fruits. Blackberry by-products need to be stabilized for storage and to overcome seasonality. Before stabilization, blackberry pomace can also be pre-treated with traditional or more innovative procedures for modifying its techno-functional properties. The use of High-Pressure Processing (HPP), a non-thermal treatment known to preserve the nutritional value of the treated foods [15–18], could be a feasible strategy to modify the blackberry pomace microstructure and make some compounds linked to colour or flavour more extractable [19–21].

This study provides the first comprehensive assessment of HPP-treated blackberry pomace as a brewing ingredient, integrating physicochemical analysis, volatile profiling, phenolic characterization, antioxidant capacity (UV–Vis and EPR), sensory descriptive analysis, and consumer acceptance. In this context, blackberry juice pomace was selected as a model fruit by-product based on both economic and technological considerations. Fresh blackberries are a high-value fruit characterised by a short shelf life, which limits their practical application in brewing and significantly increases production costs, especially for fruit beers requiring relatively high fruit additions. Conversely, the use of blackberry pomace derived from juice processing represents a cost-effective and sustainable alternative, allowing the valorisation of an underutilised residue while retaining a matrix rich in pigments and aroma precursors. Furthermore, the application of stabilisation treatments such as drying and High-Pressure Processing may enhance the handling and processability of the by-product and modulate the extractability of colour- and flavour-related compounds, potentially offering advantages for industrial implementation, even though shelf-life was not specifically addressed in the present study. In addition, blackberry pomace represents a technologically challenging matrix due to its high content of thermolabile pigments and phenolic compounds, making it a suitable model for investigating the impact of non-thermal pre-treatments on the extractability and functional contribution of fruit by-products in brewing. This approach is particularly relevant in the current market scenario,

where fruit beers are gaining popularity and red berry-derived ingredients are increasingly valued for their sensory and visual contribution. In this study, the reference beer was not conceived as a fruit-free control but as a formulation containing the same blackberry by-product stabilised through conventional drying. This design allowed a direct comparison between two stabilization approaches applied to the same raw material: drying alone versus High-Pressure Processing followed by drying. The aim was therefore not to evaluate the preservative efficacy of HPP, but to determine whether the non-thermal treatment could modify the techno-functional behaviour of the pomace during brewing—particularly in terms of the extractability of colour- and aroma-related compounds, as well as its contribution to the sensory profile of the final beer. No previous research has combined these analytical levels to investigate the influence of a non-thermal pre-treatment on the brewing suitability and functional impact of fruit-processing by-products.

2. Materials and Methods

2.1. Blackberry Pomace Production and Treatment

Blackberry pomace was obtained from the production of a blackberry cloudy juice by cold extraction FTE (CE-FTE, John Bean Technology, Chicago, IL, USA). A batch of 400 kg of wild blackberries was used for the extraction by means of a 0.4 mm sieve and rotor speed of 1500 rpm. After extraction, around 100 kg of blackberry by-product was obtained and different aliquots were then collected without any treatment (C) or subjected to a high -pressure process (HPP) at 600 MPa for 3 min by means of a 30 L Avure™ vertical machine (AVURE Technologies, Erlanger, KY, USA) after packaging in high-density polyethylene bags under 95% vacuum by using a packaging (Lavezzini Univac, Fiorenzuola d'Arda, PC, Italy) machine. C and HPP by-products were both stabilized by drying at 50 °C for around 24 h until a final moisture content of 12% was reached, and then stored under vacuum in high-density polyethylene bags until brewing.

2.2. Pomace Colour Analyses

The colorimetric parameters of dried blackberry samples were obtained by means of image analysis: samples were scanned by means of a desktop flatbed scanner (Hewlett Packard Scanjet 8200, Palo Alto, CA, USA) at 236 pixels per cm (600 dpi of resolution; true colour—24 bit), equipped with a cold cathode lamp for reflective scanning. Red (R), Green (G) and Blue (B) colour parameters were then obtained. In addition, the colour of a solution of dried blackberry pomace was measured after dissolution in distilled water, respecting the same concentration used in the beer recipe, as depicted below by using a Minolta Colorimeter (CM 36DG, Minolta Co., Osaka, Japan) equipped with a standard illuminant D65 using a 10-degree position of the standard observer. Twelve replicates from each sample were performed.

2.3. Beer Production

The beer was produced using the pilot plant of Porto Conte Ricerche Srl (Alghero, Italy) (Figure 1). The beer was produced in 100 L batches. Eighty percent Pale malt (Weyermann, Bamberg, Germany) and 20 percent Weizen malt (Weyermann, Bamberg, Germany) were used as grist.

The malts were milled in a two-roller mill (Marican, Langhirano, PR, Italy) with a spacing of 1 mm. The mash-in was carried out by adding 70 L water to 10 g $MgCl_2$ and 10 g $CaCl_2$ (Mr. Malt, Udine, Italy). The mash was heated to 64 °C and held for 60 min (saccharification rest), followed by heating to 72 °C for 10 min, and finally to 78 °C for 10 min for mash-out. The wort was then transferred to a kettle and the spent grains were washed with water at 78 °C. The wort was then brought to a final volume of 100 L. At this

stage, the wort was divided into two parts of 50 L aliquots and boiled for 60 min. East Kent Goldings hops (Mr. Malt, Udine, Italy) were added at the beginning of the boil to reach a final bitterness of 10 IBU (International Bitter Unit). After 50 min of boiling, 0.5 kg C was added for the production of control beer (CB) and 0.5 kg HPP for the production of HPP beer (HPPB). After the boil, the wort was clarified in a whirlpool, and then cooled at 18 °C.

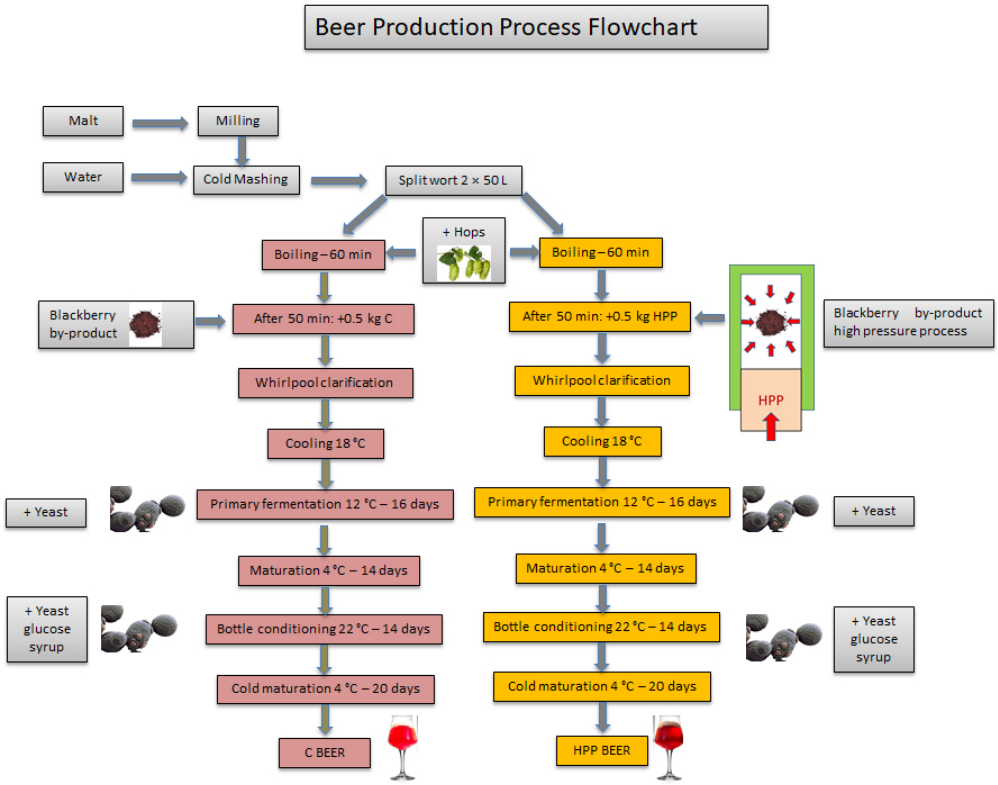


Figure 1. Flowchart of the brewing process: control beer (CB, left) and HPP Beer (HPP Beer, Right).

Fermentation of each wort was carried out at 12 °C for 16 days by adding 0.5 g L^{-1} of dry lager yeast W34-70 (Fermentis SafLager™, Marcq-en-Baroeul Cedex, France) directly into the fermenter. Beer maturation was performed at 4 °C for two weeks. After primary fermentation, the beers were cold matured at 4 °C for an additional 20 days. Prior to bottle conditioning, all matured beers were primed with 10 g L^{-1} glucose syrup (Uniglad Ingredients, Grinzane Cavour, Italy) and inoculated with 0.05 g L^{-1} of F2 yeast (Fermentis, Marcq-en-Baroeul Cedex, France). Bottle conditioning took place at 22 °C for 14 days, yielding the final conditioned beers (CB and HPPB). For each condition and batch (CB and HPPB), three independent beers were produced (Figure 1).

2.4. Standard Quality Attributes of Beers

The original extract (% *w*/*w*), real extract (% *w*/*w*), apparent extract (% *w*/*w*), real degree of fermentation (RDF %), alcohol (% *v*/*v*) and density (g/cm^3) were measured with a PBA-B generation M (Anton Paar, Graz, Austria) [22]. Foam stability was measured with a NIBEM-OPH foam stability tester (Pentair Haffmans, Zeist, The Netherlands), according to the European Brewery Convention method [23].

2.5. Beer Colour Analyses

Beer colour coordinates (CIE L* a* b*) were measured according to ASBC method Beer-10 [24], with a PerkinElmer Lambda 35 spectrophotometer (PerkinElmer, Shelton, CT,

USA) on filtered samples (cellulose acetate filters, pore size 0.45 µm). EBC colour units were determined according to the European Brewery Convention method [23].

2.6. EPR Spin Trapping Experiments

Electron paramagnetic resonance (EPR) analyses were performed using a Bruker EMX spectrometer (Bruker Instruments Inc., Billerica, MA, USA) operating in the X-band region (9.40 GHz), equipped with an HP 53150A frequency counter and an ER 4111 VT variable-temperature control unit. The experimental parameters were set as follows: modulation frequency 100 kHz, modulation amplitude 1.0 G, microwave power 20 mW, receiver gain 5×10^5, and a time constant and conversion time fixed at 163.84 ms.

Spin-trapping assays were conducted following the protocol reported by Valentoni et al. [25]. Briefly, 5 µL of a PBN solution (2.5 mM in absolute ethanol) was evaporated under a nitrogen stream and subsequently re-dissolved in 250 µL of decarbonated beer samples. An aliquot of 100 µL was then loaded into capillary tubes and placed inside the EPR resonator maintained at 60 °C. Spectral acquisition was performed at 5 min intervals for a minimum duration of 150 min [25]. Each sample was analysed in triplicate.

2.7. DPPH Antioxidant Activity Assay

The radical scavenging activity was evaluated by means of the DPPH (2,2-Diphenyl-1-picrylhydrazyl) assay, performed according to the method described by Porcu et al. [26]. Briefly, 100 µL of a 1 mM DPPH solution prepared in absolute ethanol was combined with 150 µL of beer samples at different dilution levels and with 1.75 mL of absolute ethanol. The reaction mixtures were incubated for 30 min at room temperature in the absence of light, after which the absorbance was recorded at 517 nm using a Perkin Elmer Lambda 35 spectrophotometer. Prior to spectrophotometric analysis, all samples were centrifuged at 3000 rpm for 5 min.

The percentage of DPPH radical inhibition was determined using the following equation:

$$\% \text{ of inhibition} = ((ABS_{blank} - ABS_{sample})/ABS_{blank}) \times 100$$

where ABS_blank corresponds to the absorbance measured for a control solution in which 150 µL of distilled water replaced the diluted beer sample. A dose–response curve was constructed by plotting the inhibition percentage against the logarithm of beer concentration, and the data were fitted using a linear regression model with GraphPad Prism 8 software (GraphPad Software, San Diego, CA, USA) [26].

In order to rule out potential interference due to beer colour, the radical scavenging activity was additionally assessed by electron paramagnetic resonance (EPR) spectroscopy, exploiting the intrinsic stability of the DPPH radical, following the approach reported by Sanna et al. [27]. The EC_{50} values were expressed as mL of beer per mg of DPPH. All determinations were performed in triplicate for each sample.

2.8. Total Phenol Content (TPC)

TPC was quantified by applying the Folin–Ciocalteu colorimetric assay, following the procedure reported by Sanna and Pretti [28]. Results were expressed as milligrams of gallic acid equivalents per litre of beer (mg GAE/L). Each sample was analysed in triplicate.

2.9. Volatiles Profile of Fermented Wort and Beer

Fermented wort and matured beer samples were subjected to volatile compound analysis to characterise their aroma profiles [10,29]. For each determination, 5 mL of previously degassed sample was placed into a 10 mL headspace vial, together with 1 g of sodium chloride and 0.05 mL of 1-butanol used as internal standard (5 g/L prepared in

ultrapure water containing 5% v/v absolute ethanol). The vials were immediately sealed using PTFE/silicone septa.

Volatile components were extracted and analysed by headspace solid-phase microextraction coupled with gas chromatography–mass spectrometry (HS-SPME-GC-MS, Thermo Scientific, Hudson, NY, USA), employing a Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB–CAR–PDMS) fibre (Supelco, Bellefonte, PA, USA). Prior to extraction, samples were equilibrated at 60 °C for 10 min; subsequently, the fibre was exposed to the headspace for 30 min. Both equilibration and extraction steps were carried out under continuous agitation. The thermal desorption of analytes was performed in the GC injector at 250 °C for 10 min, applying a split flow of 5 mL/min. The SPME fibre was conditioned daily in accordance with the supplier's recommendations.

Chromatographic separations were achieved using a TRACE GC system interfaced with an ISQ single-quadrupole mass spectrometer (Thermo Scientific, Hudson, NY, USA). A SLB-5 ms capillary column (60 m × 0.25 mm internal diameter × 0.25 µm film thickness; Supelco, Bellefonte, PA, USA) was employed, with helium used as the carrier gas at a constant flow rate of 1 mL/min. The oven temperature programme was initiated at 35 °C, maintained for 7 min, and followed by a ramp to 200 °C at 3 °C/min with a holding time of 7 min; subsequently, the temperature was increased to 250 °C at 5 °C/min and maintained for an additional 10 min. The transfer line and ion source temperatures were set at 250 °C and 270 °C, respectively. Mass spectra were recorded over a range of 30–250 amu using an electron impact ionisation energy of 70 eV.

Data acquisition and processing were conducted using TraceFinder software (version 5.1, Thermo Scientific, Hudson, NY, USA). Compound identification was based on a comparison of the acquired mass spectra with those contained in the NIST library (NIST 2005, Mass Spectral Search Program v.2.0d; Washington, DC, USA; version 2.2, June 2014). Only compounds exhibiting identity match factors greater than 850 according to the NISTMS Search 2.0 algorithm were considered reliably identified. Chromatographic peaks were manually integrated, and the relative abundance of each volatile was calculated by normalising the peak area of the analyte to that of the internal standard (A_s/A_IS), subsequently expressed as a percentage of the total A_s/A_IS area sum [30].

2.10. Sensory Analysis

Prior to inclusion in the study, all panellists provided written informed consent. Sensory characterisation of the beers was performed by applying a modified version of the Quantitative Descriptive Analysis (QDA) approach [31].

The sensory panel was composed of eight trained male assessors, aged between 45 and 60 years. Panel selection, training and performance monitoring were conducted in accordance with the ISO 8586 [32] and ISO 13299 [33] standards for descriptive sensory analysis. Preliminary training sessions were carried out to familiarise assessors with the product space, the selected descriptors, and the use of intensity rating scales. During training, sensory attributes were discussed and defined by consensus, and reference standards were used to anchor the intensity scale for each descriptor. Panel performance was monitored in terms of repeatability and discriminative ability, and only assessors able to consistently detect small sensory differences among samples were included in the final panel. Beer samples were presented in odour-neutral sensory booths, served in appropriate glassware at a temperature of 8 ± 2 °C and covered with a glass lid to prevent aroma loss. Assessors were provided with water for oral rinsing between consecutive samples. Samples were identified using random three-digit codes and were served according to a fully randomised presentation order across panellists and evaluation sessions.

Attribute intensity was rated using a seven-point horizontal scale, ranging from "absence of perception" to "very high intensity". The descriptors considered included "fruity" and "floral" for both orthonasal perception and flavour, while "yeast" was additionally evaluated for odour. Taste perception was described using the attributes "sweet", "sour", and "bitter". Reference standards for each descriptor were developed during dedicated training sessions and stored in labelled amber glass vials. All reference compounds were obtained from Aroxa (Cara Technology, Surrey, UK).

To reduce carry-over effects, panellists cleansed their palate during pauses using mineral water (Smeraldina, A.L.B. S.p.A., Sardinia, Italy) and plain, unsalted crackers (Mulino Bianco, Barilla, Italy). Sensory data were analysed by analysis of variance (ANOVA) followed by Tukey's multiple comparison test. Panel performance, including assessor repeatability and discriminative capacity, was evaluated using PanelCheck software [34]. This software provides statistical measures (e.g., mean squared error and F-values derived from ANOVA models) and graphical outputs (e.g., F plots) to assess both the consistency of individual assessors and the ability of the panel as a whole to detect small sensory differences among samples. These performance checks ensured that the trained panel produced reliable descriptive data, as commonly adopted in sensory analysis protocols. This sensory evaluation was conducted in accordance with ethical standards for research involving human participants. Ethical review and approval were waived for this study because it involved sensory evaluation of beer and did not include clinical tests, invasive procedures, or the collection of personal or sensitive data.

2.11. Statistical Analysis

All experimental data generated in this study were subjected to statistical analysis and are reported as mean values ± standard deviation.

Differences between the two beer samples (CB and HPPB) were evaluated by one-way analysis of variance (ANOVA) for physicochemical parameters, colour coordinates, total phenolic content, antioxidant activity indices (DPPH and EPR), and volatile compound relative abundances. When statistically significant effects were observed, Tukey's honestly significant difference (HSD) test was applied. The level of statistical significance was set at $p < 0.05$.

Sensory descriptive data were analysed by ANOVA followed by Tukey's multiple comparison test. Panel performance, including assessor repeatability and discriminative ability, was assessed using PanelCheck software.

All statistical analyses were performed using Statgraphics Centurion Version XIX (Statgraphics Technologies Inc., The Plains, VA, USA), XLSTAT Version 2024.1.1 (Addinsoft, Paris, France), PanelCheck software (version 1.4.2; Nofima, Ås, Norway), and GraphPad Prism 8 (GraphPad Software, USA).

3. Results and Discussion

3.1. Blackberry Juice By-Products Characterization

The colour of the dried blackberry juice by-product was significantly influenced by the HPP treatment: particularly, HPP-treated by-products presented a darker colour with significantly lower values for all colorimetric parameters (Table 1). HPP-treated by-product was significantly less red (lower R values); this result is in agreement with previous findings on blackberry puree treated with high pressure [35]. Yu et al. [36] obtained the same results in bayberry juice. The decrease in all colour parameters after high-pressure treatment seems to be species dependent; in fact, on tomato, ref. [37] found only a non-significant increase in the L-value after HPP treatment, whereas Ahmed et al. [38] observed no colour change on mangoes after HPP treatment.

Table 1. Colour parameters of dried C and HPP by-products and liquor obtained from both by-products. Values are averages of ten measurements ± the standard deviation. Asterisks indicate the significance: * $p < 0.05$, and ** $p < 0.01$.

Colour Parameter	C	HPP	Sig.
Dried pomace			
R	84.6 ± 1.7	78.7 ± 1.8	*
G	47.3 ± 0.3	44.3 ± 0.9	**
B	50.0 ± 0.2	46.9 ± 0.9	*
Liquor			
L*	48.2 ± 1.0	46.2 ± 1.7	*
a*	29.3 ± 3.8	30.6 ± 1.9	*
b*	15.2 ± 2.4	15.9 ± 1.5	*

The liquor colour of HPP-treated samples presented a significantly lower bright level, but significantly higher red and yellow levels resulted in a more orange/brick colour.

3.2. Quality Attributes of Beers

On the CB and HPPB conditioned beers, the technological parameters were measured (Table 2). No differences were observed except for foam stability and colour. The L*a*b* values observed for the beer samples showed an opposite trend if compared to the pomace liquor colour: CBs were less bright and more red than HPPBs (Table 2). The differences between the liquor colour and the beer colour could well be due to differences in their pH values; nonetheless, they suggest a higher disruption of anthocyanins during beer production in HPPB than in CB, confirmed by the lower TPC in the former and the higher antioxidant capacity of the latter. This difference could derive from the major heat exposure of the poly-phenols in HPP during the boiling step in beer production, because of the cell damage caused by high-pressure treatment [19,20]. Compared with the results previously obtained with six commercial beers (from 297 to 425 GAE mg/L) [26], the values of TPC were higher, confirming the addition of polyphenols deriving from the blackberry pomace.

Table 2. Quality parameters of CB and HPPB conditioned beers. Values are averages of two measurements ± the standard deviation. Asterisks indicate the significance ($p < 0.05$).

Parameter	CB	HPPB	Sig.
Alcohol (% *v*/*v*)	6.600 ± 0.100	6.500 ± 0.050	
Density (g/cm^3)	1.010 ± 0.005	1.009 ± 0.003	
Re (Real extract) (% *w*/*w*)	5.385 ± 0.120	5.210 ± 0.215	
Ae (App. extract) (% *w*/*w*)	3.050 ± 0.118	2.900 ± 0.082	
p (Original extract) (% *w*/*w*)	15.205 ± 0.200	15.000 ± 0.310	
RDF (Real Deg. of Ferm.)	66.440 ± 0.432	66.980 ± 0.641	
CO_2 (g/L)	3.893 ± 0.020	4.220 ± 0.040	
O_2 (g/L)	0.282 ± 0.100	0.213 ± 0.010	
Foam stability (s/3 cm)	254.000 ± 7.000	236.000 ± 2.000	*
pH	4.100 ± 0.001	4.100 ± 0.001	
TCP (GAE mg/L)	493.000 ± 20.000	451.000 ± 15.000	*
Colour			
EBC unit	22.000 ± 0.012	17.000 ± 1.000	*
L*	78.700 ± 0.400	88.400 ± 2.300	*
a*	16.000 ± 0.600	6.100 ± 1.700	*
b*	39.600 ± 0.800	33.000 ± 2.000	*

3.3. DPPH Antioxidant Activity

The EC_{50} values obtained for the two samples in the spectrophotometric assay are 0.2841 mL beer/mg DPPH for CB (CI 95% 0.2549–0.3100) and 0.5428 mL beer/mg DPPH for HPPB (CI 95% 0.4444–0.6213). Measurements carried out in EPR confirm these findings, being 0.2744 mL beer/mg DPPH for CB (CI 95% 0.2239–0.3153) and 0.4859 mL beer/mg DPPH (CI 95% 0.4253–0.5356) for HPPB samples. In the two assays, the EC_{50} values for the CB sample are significantly lower than those obtained for HPPB, indicating the larger antioxidant capacity of CB. This finding is in agreement with the polyphenol content of the two beers (Table 2). The EC_{50} values obtained for CB and HPPB in the spectrophotometric assay are much smaller in comparison with the values measured for six commercial beers produced with different styles (from 0.718 to 1.763 mL beer/mg DPPH) [26], showing that the addition of blackberry pomace increases the antioxidant activity of the beers. The lower antioxidant capacity observed in HPPB compared to CB should not be interpreted as the result of a direct degradation of antioxidant compounds induced by High-Pressure Processing. Previous studies have shown that High-Pressure Processing generally preserves phenolic compounds, while changes in antioxidant-related parameters are more frequently associated with indirect effects, such as modifications in compound extractability and availability, interactions with the food matrix, or oxidation phenomena occurring during subsequent processing steps rather than during the pressure treatment itself [39,40]. Accordingly, the reduced antioxidant performance of HPPB is more likely attributable to process-induced alterations in the availability or reactivity of phenolic compounds within the complex beer matrix, rather than to their chemical degradation.

3.4. EPR Analysis

The production of radicals in CB and HPPB samples during a forced aging treatment at 60 °C was monitored, recording the EPR spectra of the PBN-1-hydroxyethyl radical adduct at 5 min intervals. Various parameters that correlate EPR measurements with beer oxidative stability have been proposed and, among these, the area under the intensity vs. time curve (AUC) is considered particularly useful [41]. No significant differences in the intensity of the adduct vs. time curves, nor in the AUC values, are observed in our samples. After 150 min, the intensity reaches values of 5825 ± 904 arbitrary units (a. u.) in CB and 5080 ± 315 a. u. in HPPB, while the AUC values are 525,515 ± 57,888 a. u. for CB and 447,071 ± 34,094 a. u. for HPPB, so the two beers cannot be distinguished according to their resistance to oxidation (Figure 2). This can be explained supposing that above certain antioxidant concentrations, their effect on the AUC and intensity of the radical adduct do not further increase. It is interesting to observe that the values of AUC and adduct intensity after 150 min at 60 °C, measured for both CB and HPPB, are significantly lower than the ones observed in previous works [26], by using the same methods, for six commercial beers styles (AUC values observed were comprised between 6.19×10^5 and 5.94×10^6 and the intensity between 7.80×10^3 and 6.07×10^4). All these results confirm that the effect of the addition of fruit by-products to the beer recipe can have, as one of the consequences, an increase in the overall content of antioxidant compounds, even when such by-products underwent treatments potentially impacting their stability [42].

3.5. Volatiles Profile of Beers

The total concentration of each compound family was calculated as the sum of the individual compounds reported in Figure 3 and Table 3. Figure 3 shows the relative abundance of the main chemical classes of volatile compounds detected in CB and in HPPB. Overall, the two beers exhibited a similar qualitative distribution of volatile families:

esters represented the predominant class in both samples, followed by carboxylic acids, and alcohols.

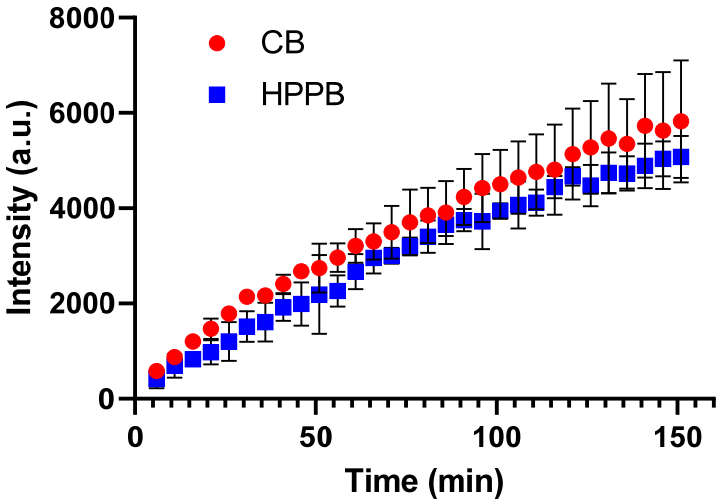


Figure 2. Intensity (arbitrary units a. u.) of the PBN-1-hydroxyethyl radical adduct vs. time recorded at 60 °C on CB and HPPB samples. Three replicates were examined for each sample.

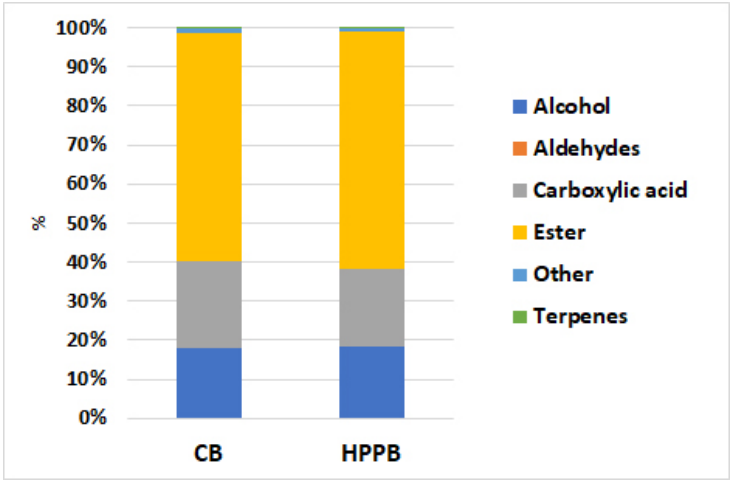


Figure 3. Relative abundance (%) of chemical classes in conditioned beers CB and HPPB.

A closer inspection, however, reveals minor variations between the two beers. In HPPB, esters appeared slightly more abundant than in CB, whereas CB showed a marginally higher proportion of carboxylic acids and aldehydes. Small differences were also observed in the fraction of alcohols. Terpenes and the group classified as "Others" remained negligible in both samples, with only minimal shifts between conditions.

Although these changes are limited in magnitude, they indicate that the addition of HPP may have caused subtle adjustments in the relative proportions of certain volatile classes, without altering the overall compositional profile of the beer. In the conditioned beers, 17 volatile compounds were identified and the main differences were observed in the ester fraction: HPPB showed a slightly higher relative amount (61% vs. 58%) and significant differences in ethyl decanoate (caprylic, fruity, apple), ethyl 9-decenoate (fruity) and ethyl (11E)-11-hexadecenoate (sweet). CB showed a significantly higher percentage of ethyl octanoate (apple, sweet, fruity, sour apple), ethyl hexanoate (sour apple, aniseed, fruity, sweet, solvent, apple, fatty acids), and 3-methylbutyl ethanoate (fruity, banana) (Table 3). Several authors report different results when HPP treatment was applied to fruits

or processed fruits. Perez-Cacho and Rouseff [43] reported that, from the point of view of flavour profile, high pressures do not make significant differences in orange juice, as also confirmed by Baxter et al. [44]. Mastello et al. [45] identified significant differences when these are stabilised using HHP on orange juices. In our work, the HPP treatment of the raw material (blackberry by-products) resulted in a significant difference between the two beers produced (CB vs. HPPB).

Table 3. Relative abundance of volatile compounds in CB and HPPB conditioned beers. Values are averages of three measurements ± the standard deviation; compounds with relative abundance < 0.09% are not listed. Asterisks indicate the statistical significance of differences between samples ($p < 0.05$).

Family	Compound	CB	HPPB	Sig.
Alcohols	2-Phenylethan-1-ol	6.32 ± 0.39	6.86 ± 0.50	
	3-Methylbutan-1-ol	12.86 ± 0.38	12.99 ± 0.73	
	2-Methylbutan-1-ol	3.64 ± 0.03	3.62 ± 0.20	
	2-Methylpropan-1-ol	0.75 ± 0.06	0.70 ± 0.05	
Carboxylic acids	Octanoic acid	12.59 ± 0.87	12.15 ± 0.44	
	Decanoic acid	8.13 ± 0.05	6.62 ± 0.69	
	Dodecanoic acid	1.19 ± 0.05	0.60 ± 0.40	
Esters	Ethyl octanoate	21.37 ± 0.20	18.93 ± 0.57	*
	Ethyl hexanoate	6.23 ± 0.76	3.88 ± 0.56	*
	Ethyl decanoate	5.77 ± 0.95	9.76 ± 1.02	*
	3-Methylbutyl ethanoate	5.39 ± 0.38	4.20 ± 0.18	*
	Ethyl acetate	3.25 ± 0.11	2.83 ± 0.22	
	Ethyl dodecanoate	3.01 ± 0.40	3.08 ± 0.85	
	Ethyl 9-decenoate	2.98 ± 0.13	6.08 ± 1.04	*
	2-Phenethyl acetate	2.24 ± 0.72	2.23 ± 0.16	
	Ethyl (11E)-11-hexadecenoate	0.26 ± 0.10	1.08 ± 0.21	*
Terpenes	Linalool	0.12 ± 0.02	0.09 ± 0.01	

3.6. Sensory Analysis

The sensory profile obtained through quantitative descriptive analysis showed that the HPPB beer received significantly higher intensity scores for the "fruity" descriptor, both in orthonasal perception (O-) and in flavour (F-), compared to the control beer (CB) ($p < 0.05$). No statistically significant differences were observed between the two samples for the other sensory attributes evaluated (Figure 4). The higher fruity perception associated with HPPB can be directly related to differences observed in the volatile profile, particularly to the higher relative abundance of selected ester compounds known to contribute to fruity aroma notes. This correspondence between chemical composition and sensory perception supports the role of aroma-active compounds derived from the treated pomace in shaping the sensory profile of the beer.

Comparable sensory–chemical approaches integrating descriptive analysis and volatile profiling have been previously applied to the sensory characterisation of craft fruit beers produced with fruit-based adjuncts [10].

The lack of significant differences in taste-related attributes and yeast-associated notes indicates that the application of High-Pressure Processing to the blackberry by-product primarily affected aroma expression without altering the overall sensory balance of the beer. Within the sensory characterisation of craft and fruit beers, the "fruity" descriptor represents a central attribute when fruit-derived ingredients are used; in this context, the significant increase in fruity perception observed in HPPB highlights the specific contribution of the treated blackberry pomace to the aromatic profile of the beer).

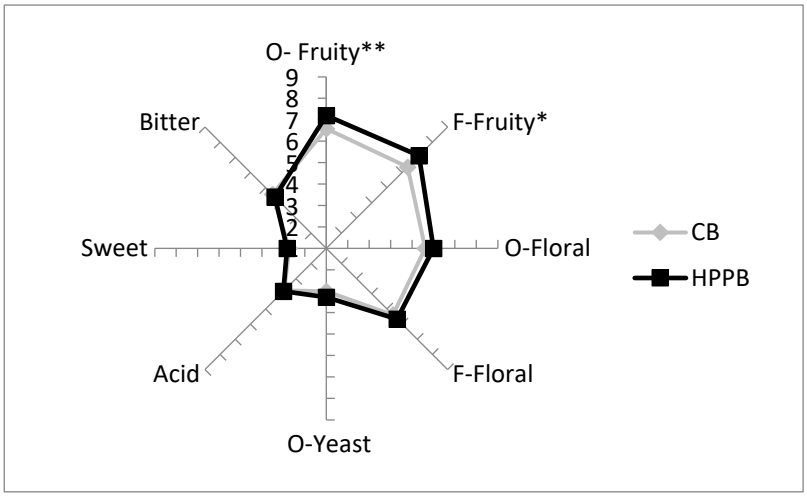


Figure 4. Radar/spider plot of the mean intensity scores for CB and HPPB beers. Significant differences between samples were observed for the "fruity" descriptor in odour (** $p < 0.01$) and flavour (* $p < 0.05$).

4. Conclusions

This study demonstrates the feasibility of upcycling blackberry juice pomace as an ingredient for fruit beer production, supporting sustainable brewing strategies aligned with circular economy principles. The comparison between conventional drying and High-Pressure Processing (HPP) as pre-treatments highlighted that HPP does not primarily act as a preservation strategy, but rather as a technological tool capable of modulating the functional behavior of the by-product during brewing.

While HPP treatment resulted in lower phenolic retention and antioxidant capacity, it positively influenced the aromatic profile of the beers, enhancing fruity esters and sensory perception without compromising technological quality or oxidative stability. These findings indicate a trade-off between phenolic preservation and aroma modulation, which may be strategically exploited depending on the targeted beer style and sensory profile.

Overall, the integration of HPP-treated fruit by-products offers brewers a flexible approach to tailoring sensory attributes while valorizing agro-industrial residues. This work provides a basis for the further optimisation of non-thermal pre-treatments to balance functional and sensory properties in innovative fruit beers.

5. Limitations

This study has some limitations that should be acknowledged. Sensory evaluation was performed using a trained panel, which is appropriate for descriptive analysis but does not directly reflect consumer acceptance; therefore, future studies should include consumer testing to assess overall liking and market relevance. In addition, although the sensory panel included a higher proportion of male assessors, this aspect is not expected to have significantly influenced the results, as gender-related differences are generally not considered critical in trained panels; nevertheless, a more balanced gender distribution could be considered in future work. Furthermore, the brewing trials were conducted at pilot scale and using a single High-Pressure Processing condition, and the potential effects of scale-up and alternative pressure–time combinations were not explored. Finally, a detailed compositional characterisation of blackberry pomace before and after High-Pressure Processing was not included in the experimental design and therefore represents a limitation of the present study; future research should address this aspect to better elucidate the mechanisms underlying the observed effects. In addition, future studies

should specifically address the long-term stability of the treated by-product in order to support its practical storage, handling, and industrial application.

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Institutional Review Board Statement: The sensory evaluation was conducted by trained professional panelists as part of routine product quality assessment activities. The study did not involve any medical or clinical procedures, did not include vulnerable subjects, and did not collect personal or sensitive data. According to Italian regulations governing ethics committee oversight (Law No. 3/2018 and subsequent decrees, applicable to clinical and medical research only), as well as European and national data protection legislation (EU Regulation 2016/679—GDPR; Italian Legislative Decree 196/2003, as amended), approval by an ethics committee was not required.

Informed Consent Statement: Informed consent was obtained from all participants involved in the sensory evaluation. Participation was voluntary, and all panelists were professional trained assessors. No personal or sensitive data were collected, and all data were processed in anonymized form, in accordance with European and Italian data protection regulations.

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed at the corresponding author.

Conflicts of Interest: Author Luca Pretti, Manueia Sanna and Antonio Valentoni was employed by the company Porto Conte Ricerche Srl. They participated in 2024 in the study. Porto Conte Ricerche conducts research and development in food technology and applied biotechnology, focusing particularly on the environment, industry and healthcare. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that couid be construed as a potential conflict of interest.

References

1. Panda, S.; Swain, M.; Ray, R. Anthocyanin-Rich Sweet Potato (*Ipomoea batatas* L.) Beer: Technology, Biochemical and Sensory Evaluation. *J. Food Process. Preserv.* **2015**, *39*, 3040–3049. [CrossRef]
2. Martínez, A.; Vegara, S.; Herranz-López, M.; Martí, N.; Valero, M.; Micol, V.; Saura, D. Kinetic changes of polyphenols, anthocyanins and antioxidant capacity in forced aged hibiscus ale beer. *J. Inst. Brew.* **2017**, *123*, 58–65. [CrossRef]
3. Statista.com. Beer—Worldwide. 2024. Available online: https://www.statista.com/outlook/cmo/alcoholic-drinks/beer/worldwide?currency=eur (accessed on 4 November 2024).
4. Strong, G.E. Kristen Beer Judge Certification Program Style Guidelines. 2021. Available online: https://www.bjcp.org/style/2021/beer/ (accessed on 3 December 2024).
5. Kawa-Rygielska, J.; Adamenko, K.; Kucharska, A.Z.; Prorok, P.; Piorecki, N. Physicochemical and antioxidative properties of Cornelian cherry beer. *Food Chem.* **2019**, *281*, 147–153. [CrossRef]
6. Paiva, R.A.M.; Mutz, Y.S.; Conte-Junior, C.A. A Review on the Obtaining of Functional Beers by Addition of Non-Cereal Adjuncts Rich in Antioxidant Compounds. *Antioxidants* **2021**, *10*, 1332. [CrossRef] [PubMed]
7. Castro Marin, A.; Baris, F.; Romanini, E.; Lambri, M.; Montevecchi, G.; Chinnici, F. Physico-Chemical and Sensory Characterization of a Fruit Beer Obtained with the Addition of Cv. Lambrusco Grapes Must. *Beverages* **2021**, *7*, 34. [CrossRef]
8. Yang, Q.; Tu, J.; Chen, M.; Gong, X. Discrimination of Fruit Beer Based on Fingerprints by Static Headspace-Gas Chromatography-Ion Mobility Spectrometry. *J. Am. Soc. Brew. Chem.* **2022**, *80*, 298–304. [CrossRef]

9. Martínez, A.; Vegara, S.; Martí, N.; Valero, M.; Saura, D. Physicochemical characterization of special persimmon fruit beers using bohemian pilsner malt as a base. *J. Inst. Brew.* **2017**, *123*, 319–327. [CrossRef]
10. Fanari, M.; Forteschi, M.; Sanna, M.; Piu, P.P.; Porcu, M.C.; D'hallewin, G.; Secchi, N.; Zinellu, M.; Pretti, L. Pilot plant production of craft fruit beer using Ohmic-treated fruit puree. *J. Food Process. Preserv.* **2019**, *44*, e14339. [CrossRef]
11. Pereira, I.M.C.; Matos Neto, J.D.; Figueiredo, R.W.; Carvalho, J.D.G.; Figueiredo, E.A.T.d.; Menezes, N.V.S.d.; Gaban, S.V.F. Physicochemical characterization, antioxidant activity, and sensory analysis of beers brewed with cashew peduncle (*Anacardium occidentale*) and orange peel (*Citrus sinensis*). *Food Sci. Technol.* **2020**, *40*, 749–755. [CrossRef]
12. Fierascu, R.C.; Sieniawska, E.; Ortan, A.; Fierascu, I.; Xiao, J. Fruits By-Products—A Source of Valuable Active Principles. A Short Review. *Front. Bioeng. Biotechnol.* **2020**, *8*, 319. [CrossRef]
13. Kaume, L.; Howard, L.R.; Devareddy, L. The Blackberry Fruit: A Review on Its Composition and Chemistry, Metabolism and Bioavailability, and Health Benefits. *J. Agric. Food. Chem.* **2012**, *60*, 5716–5727. [CrossRef]
14. Zhao, X.; Yin, Y.; Fang, W.; Yang, Z. What happens when fruit married with beer? *Int. J. Gastron. Food Sci.* **2023**, *32*, 100716. [CrossRef]
15. Houška, M.; Silva, F.V.M.; Evelyn; Buckow, R.; Terefe, N.S.; Tonello, C. High Pressure Processing Applications in Plant Foods. *Foods* **2022**, *11*, 223. [CrossRef]
16. Barbhuiya, R.I.; Singha, P.; Singh, S.K. A comprehensive review on impact of non-thermal processing on the structural changes of food components. *Food Res. Int.* **2021**, *149*, 110647. [CrossRef]
17. Song, Q.; Li, R.; Song, X.; Clausen, M.P.; Orlien, V.; Giacalone, D. The effect of high-pressure processing on sensory quality and consumer acceptability of fruit juices and smoothies: A review. *Food Res. Int.* **2022**, *157*, 111250. [CrossRef] [PubMed]
18. Hurtado, A.; Guàrdia, M.D.; Picouet, P.; Jofré, A.; Ros, J.M.; Bañón, S. Stabilisation of red fruit-based smoothies by high-pressure processing. Part II: Effects on sensory quality and selected nutrients. *J. Sci. Food Agric.* **2017**, *97*, 777–783. [CrossRef] [PubMed]
19. Paciulli, M.; Medina Meza, I.G.; Rinaldi, M.; Ganino, T.; Pugliese, A.; Rodolfi, M.; Barbanti, D.; Morbarigazzi, M.; Chiavaro, E. Improved Physicochemical and Structural Properties of Blueberries by High Hydrostatic Pressure Processing. *Foods* **2019**, *8*, 272. [CrossRef]
20. Vázquez-Gutiérrez, J.L.; Plaza, L.; Hernando, I.; Sánchez-Moreno, C.; Quiles, A.; de Ancos, B.; Cano, M.P. Changes in the structure and antioxidant properties of onions by high pressure treatment. *Food Funct.* **2013**, *4*, 586–591. [CrossRef]
21. del Carmen Razola-Díaz, M.; Volpe, S.; Gómez-Caravaca, A.M.; Torrieri, E.; Verardo, V. Impact of blanching and high hydrostatic pressure combined treatments on the physico-chemical and microbiological properties and bioactive-compound profile of an industrial strawberry smoothie. *LWT—Food Sci. Technol.* **2024**, *206*, 116612. [CrossRef]
22. Valentoni, A.; Melis, R.; Sanna, M.; Porcu, M.C.; Rodolfi, M.; Braca, A.; Bianco, A.; Zara, G.; Budroni, M.; Anedda, R.; et al. Fruit Beer with the *Bisucciu* Sardinian Apricot Cultivar (*Prunus armeniaca* L.): A Technological and Analytical Approach. *Fermentation* **2023**, *9*, 305. [CrossRef]
23. EBC. *Analytica-EBC*; Fachverlag Hans Carl: Nürnberg, Germany, 2007.
24. ASBC. Method Beer-10. Color. In *ASBC Methods of Analysis*; ASBC, Ed.; ASBC: St. Paul, MN, USA.
25. Valentoni, A.; Santoru, A.; Sanna, M.; Fanari, M.; Porcu, M.C.; Fadda, A.; Sanna, D.; Pretti, L. Evolution of sensory analysis attributes and volatile aging markers in bottle fermented craft beers during storage at different temperatures. *Food Chem. Adv.* **2022**, *1*, 100151. [CrossRef]
26. Porcu, M.C.; Fadda, A.; Sanna, D. Relationship among EPR oxidative stability and spectrophotometric parameters connected to antioxidant activity in beer samples. *Eur. Food Res. Technol.* **2024**, *250*, 2123–2132. [CrossRef]
27. Sanna, D.; Delogu, G.; Mulas, M.; Schirra, M.; Fadda, A. Determination of Free Radical Scavenging Activity of Plant Extracts Through DPPH Assay: An EPR and UV–Vis Study. *Food Anal. Methods* **2012**, *5*, 759–766. [CrossRef]
28. Sanna, V.; Pretti, L. Effect of wine barrel ageing or sapa addition on total polyphenol content and antioxidant activities of some Italian craft beers. *Int. J. Food Sci. Technol.* **2014**, *50*, 700–707. [CrossRef]
29. Braga, C.M.; Zielinski, A.A.; Silva, K.M.; de Souza, F.K.; Pietrowski Gde, A.; Couto, M.; Granato, D.; Wosiacki, G.; Nogueira, A. Classification of juices and fermented beverages made from unripe, ripe and senescent apples based on the aromatic profile using chemometrics. *Food Chem.* **2013**, *141*, 967–974. [CrossRef] [PubMed]
30. Kleinová, J.; Klejdus, B. Determination of volatiles in beer using solid-phase microextraction in combination with gas chromatography/mass spektrometry. *Czech J. Food Sci.* **2014**, *32*, 241–247. [CrossRef]
31. Stone, H.; Sidel, J.L. 1—Introduction to Sensory Evaluation. In *Sensory Evaluation Practices*, 3rd ed.; Academic Press: San Diego, CA, USA, 2004; pp. 1–19.
32. *ISO 8586*; Sensory Analysis—Selection and Training of Sensory Assessors. International Organization for Standardization: Geneva, Switzerland, 2023.
33. *ISO 13299*; Sensory Analysis—Methodology—General Guide to Defining a Sensory Profile. International Organization for Standardization: Geneva, Switzerland, 2016.

34. Tomic, O.; Nilsen, A.; Martens, M.; Næs, T. Visualization of sensory profiling data for performance monitoring. *LWT—Food Sci. Technol.* **2007**, *40*, 262–269. [CrossRef]
35. Patras, A.; Brunton, N.P.; Da Pieve, S.; Butler, F. Impact of high pressure processing on total antioxidant activity, phenolic, ascorbic acid, anthocyanin content and colour of strawberry and blackberry purées. *Innov. Food Sci. Emerg. Technol.* **2009**, *10*, 308–313. [CrossRef]
36. Yu, Y.; Lin, Y.; Zhan, Y.; He, J.; Zhu, S. Effect of high pressure processing on the stability of anthocyanin, ascorbic acid and color of Chinese bayberry juice during storage. *J. Food Eng.* **2013**, *119*, 701–706. [CrossRef]
37. Sánchez-Moreno, C.; Plaza, L.; de Ancos, B.; Cano, M.P. Impact of high-pressure and traditional thermal processing of tomato purée on carotenoids, vitamin C and antioxidant activity. *J. Sci. Food Agric.* **2006**, *86*, 171–179. [CrossRef]
38. Ahmed, J.; Ramaswamy, H.S.; Hiremath, N. The effect of high pressure treatment on rheological characteristics and colour of mango pulp. *Int. J. Food Sci. Technol.* **2005**, *40*, 885–895. [CrossRef]
39. Oey, I.; Van der Plancken, I.; Van Loey, A.; Hendrickx, M. Does high pressure processing influence nutritional aspects of plant based food systems? *Trends Food Sci. Technol.* **2008**, *19*, 300–308. [CrossRef]
40. Barba, F.J.; Terefe, N.S.; Buckow, R.; Knorr, D.; Orlien, V. New opportunities and perspectives of high pressure treatment to improve health and safety attributes of foods. A review. *Food Res. Int.* **2015**, *77*, 725–742. [CrossRef]
41. Marques, L.; Espinosa, M.H.; Andrews, W.; Foster, R.T. Advancing Flavor Stability Improvements in Different Beer Types Using Novel Electron Paramagnetic Resonance Area and Forced Beer Aging Methods. *J. Am. Soc. Brew. Chem.* **2017**, *75*, 35–40. [CrossRef]
42. Zhang, L.; Zhang, C.; Wei, Z.; Huang, W.; Yan, Z.; Luo, Z.; Beta, T.; Xu, X. Effects of four drying methods on the quality, antioxidant activity and anthocyanin components of blueberry pomace. *Food Prod. Process. Nutr.* **2023**, *5*, 35. [CrossRef]
43. Perez-Cacho, P.R.; Rouseff, R. Processing and Storage Effects on Orange Juice Aroma: A Review. *J. Agric. Food. Chem.* **2008**, *56*, 9785–9796. [CrossRef] [PubMed]
44. Baxter, I.A.; Easton, K.; Schneebeli, K.; Whitfield, F.B. High pressure processing of Australian navel orange juices: Sensory analysis and volatile flavor profiling. *Innov. Food Sci. Emerg. Technol.* **2005**, *6*, 372–387. [CrossRef]
45. Mastello, R.B.; Janzantti, N.S.; Bisconsin-Júnior, A.; Monteiro, M. Impact of HHP processing on volatile profile and sensory acceptance of Pêra-Rio orange juice. *Innov. Food Sci. Emerg. Technol.* **2018**, *45*, 106–114. [CrossRef]

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