Received: 16 January 2021 | Revised: 13 April 2021 | Accepted: 28 April 2021

DOI: 10.1111/jfpp.15598

ORIGINAL ARTICLE

Journal of Food Processing and Preservation | Institute of Food Science + Technology | ifst | WILEY

High-pressure processing of shalgam with respect to quality characteristics, microbial inactivation, and shelflife extension

Ceren Ates[1] | Gulsun Akdemir Evrendilek[1,2] | Sibel Uzuner[1]

[1]Department of Food Engineering, Faculty of Engineering, Bolu Abant Izzet Baysal University, Bolu, Turkey

[2]Department of Food Engineering, Faculty of Engineering, Ardahan University, Ardahan, Turkey

Correspondence
Gulsun Akdemir Evrendilek, Department of Food Engineering, Faculty of Engineering, Bolu Abant Izzet Baysal University, Bolu, Turkey.
Email: gevrendilek@yahoo.com

Funding information
Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Agricultural Research and Policies, Grant/Award Number: TAGEM/16/AR-GE/35; Republic of Turkey Ministry of Development Government Planning Agency, Grant/Award Number: 2009 DPT K 120140

Abstract

High hydrostatic pressure (HHP) processing of traditional fermented turnip juice (shalgam) was studied with respect to quality attributes, microbial inactivation, and shelflife extension. According to Box–Behnken design, shalgam samples were processed using 3–15 min, 4–40°C, and 200–500 MPa. The optimum processing conditions involved 34.23°C, 15 min, and 500 MPa for the color intensity and tone of 3.43 and 0.69 and the numbers of viable total mold and yeast, *Lactococcus lactis* subsp. *cremoris*, and *Lactobacillus paracasei* of 3.09, 2.51, and 2.68 log cfu/ml, respectively. Shalgam samples processed under the optimum conditions were stored at 4 and 22°C for 90 days. The control samples at 4 and 22°C were spoiled at 60 and 45th days, respectively. The storage time rather than the HHP processing affected physical properties, organic acids, phenolic compounds, and anthocyanins of shalgam. The treatment samples had significantly lower microbial growth during the storage time.

Practical applications

Due to the deteriorated color, bioactive, and sensory properties, the traditional heat processing of shalgam with the addition of antimicrobial agents (such as sodium benzoate) to extend its shelflife is not desirable by consumers. Alternative processing technologies are needed to extend its shelflife with no significant changes in its important properties. Its HHP treatment appeared as a practical option that preserved its quality parameters and extended its shelflife.

1 | INTRODUCTION

Fermented turnip juice (shalgam) produced by lactic acid fermentation of black carrot, sourdough, salt, bulgur flour, turnip, and water is one of the most popular traditional drinks in Turkey (Tanguler et al., 2017). Even though shalgam has a high salt concentration and is produced by lactic acid fermentation (Karaoglan et al., 2017), its preservation and shelflife extension still remains a challenge. Since its spoilage is caused mainly by yeast growth during its storage, the current practices aim to prevent yeast growth with the addition of antimicrobial agents such as sodium benzoate or heat treatment (Karaoglan et al., 2017). In order to avoid the addition of the chemical additives, the heat treatment is practiced but adversely changes its physicochemical, sensory, and bioactive compound properties.

High hydrostatic pressure (HHP) is an alternative that applies high isostatic pressures at the range of 100–1,000 MPa, provides microbial inactivation, enhances the safety and shelflife of perishable foods, and preserves nutritional, functional, and sensory qualities (Inada et al., 2018; Rodríguez-Roque et al., 2015). The U.S. Food and Drug Administration and the U.S. Department of Agriculture approved HHP as the reliable food processing technology alternative to conventional heat pasteurization (Guerrero-Beltrán et al., 2005; Inada et al., 2018).

The previous studies reported pulsed ultraviolet light (PUV) processing of shalgam with respect to inactivation of *Candida inconspicua* (Karaoglan et al., 2017), the degradation kinetics of anthocyanins (Karaoglan et al., 2019), UV processing with microbial inactivation, the estimation of changes in bioactive properties, and shelflife extension (Dogan, 2017), and ultrasonication (US) processing relative

to the heat treatment (Irkilmez, 2017). Thus far, the HHP processing of shalgam has not been explored with respect to the quantification of changes in physical, and bioactive properties, microbial inactivation, and shelflife extension. The objectives of this study were to: (1) process shalgam juice using Box-Benhken design-estimated HHP parameters; (2) determine their effects on its physical, and bioactive properties; (3) inactivate endogenous microflora and spoilage bacteria; (4) optimize and validate the HHP parameters for shelflife, and (5) extent its shelflife at 4 and 22°C.

2 | MATERIALS AND METHODS

2.1 | Shalgam samples

Shalgam samples produced by the traditional method (Incedayi et al., 2008) were kindly provided by Kemal Kükrer Gıda ve İhtiyac Maddeleri Pazarlama San. ve Tic. A.Ş. (Adana, Turkey). The samples were transferred at refrigeration temperature on the same day and processed immediately upon their receipt.

2.2 | Lactic acid bacteria

Lactobacillus paracasei and *Lactococcus lactis* subsp. *cremoris* cultures isolated from shalgam samples were obtained from Çukurova University Food Engineering Department (Adana, Turkey) in MRS (Fluka, Seelze, Germany) and M17 (Fluka, Seelze, Germany) slants, respectively. Cultures were activated transferring them into MRS (Fluka, Seelze, Germany) and M17 (Fluka, Seelze, Germany) broth, following the anaerobic incubation at 30 ± 2°C for 2 days. Cultures were harvested collecting pellets after centrifugation at 400× *g* for 5 min. The cell pellets were washed multiple times and inoculated into the control samples at the level of 10^5–10^6 cfu/ml (Yan et al., 2008).

2.3 | High hydrostatic pressure

A pilot-scale HHP equipment with a 2-L capacity (Avure, Middletown, OH, USA) at the Innovative Food Technologies Development Research and Application Center (YENIGIDAM) of Bolu Abant Izzet Baysal University, (Turkey) was used to process the control samples. The samples were placed into flexible pouches made from a multilayer polymer/aluminum/polymer film (polyethylene–aluminum–polypropylene) (APACK Packaging Technologies, Istanbul, Turkey) and vacuum packaged before processing. The average temperature increase was 0.4°C/100 MPa. The average pressure rise and fall rate were 100MPa/0.5 min and 100 MPa/0.2 min, respectively. Water was used as the pressure medium. The temperature of the pressure vessel was adjusted considering the temperature rise so that the temperature after achieving the set pressure was the same given in Table 1. Due to the lack of a previous study about the HHP treatment of shalgam, preliminary studies were performed to determine the HHP treatment parameters. Pressures from 200 to 500 MPa, treatment time (time after achieving the set pressure) from 3 to 15 min, and treatment temperature from 4 to 22°C according to Box Behnken design were applied (Table 1).

TABLE 1 (Un)coded variables of Box–Behnken design for physical, bioactive, sensory properties and microbial inactivation of shalgam processed by HHP

Process number	Pressure (MPa) X_1	Treatment time (min) X_2	Temperature (°C) X_3
Control	–	–	–
1	350 (0)	3 (−1)	40 (+1)
2	200 (−1)	3 (−1)	22 (0)
3	350 (0)	15 (+1)	40 (+1)
4[a]	350 (0)	9 (0)	22 (0)
5	200 (−1)	15 (+1)	22 (0)
6	350 (0)	3 (−1)	4 (−1)
7	500 (+1)	3 (−1)	22 (0)
8	350 (0)	15 (+1)	4 (−1)
9	500 (+1)	9 (0)	4 (−1)
10[a]	350 (0)	9 (0)	22 (0)
11	500 (+1)	15 (+1)	22 (0)
12	200 (−1)	9 (0)	40 (+1)
13	200 (−1)	9 (0)	4 (−1)
14	500 (+1)	9 (0)	40 (+1)
15[a]	350 (0)	9 (0)	22 (0)

[a]Mid-point.

2.4 | Physicochemical properties

pH, total soluble solids (TSS, °Brix), conductivity (mS/cm), and turbidity (NTU) were measured. Salt concentration was determined according to the Mohr method (Nielsen, 2010). Titratable acidity was determined as lactic acid equivalent based on the titrimetric method (AOAC, 1990).

Color L^*, a^*, and b^* values were measured using a Hunter Color Flex spectrophotometer (Hunter Associates Laboratory Inc., Reston VA, USA). Chroma (C^*), hue (h^o), and total color difference (ΔE) were calculated from the L^*, a^*, and b^* values. Color density (IC), color tone (CT), and percent color components of yellow, blue, and red were calculated reading the absorbance values of the centrifuged shalgam samples at yellow color tone (YCT, OD_{420}), blue color tone, (BCT, OD_{520}), and red color tone (RCT, OD_{620}) (PG Instruments T80+UV/VIS model spectrophotometer) against distilled water (Ribereau-Gayon et al., 2006). Color intensity was measured by determining absorbance at 540 nm (Sengupta et al., 2000). Reducing sugar content was determined with 3,5-dinitrosalicylic acid (DNS) (Sigma Aldrich, Steinheim, Germany) reagent. Glucose (Sigma Aldrich, Steinheim, Germany) was used as the substrate, while the calibration curve was

prepared using 0.1, 0.2, 0.4, 0.6, and 0.8 g/L stock solutions. Volatile acidity as acetic acid (g/L) was determined through distillation, while collected distillate was titrated with 0.1 M NaOH (Sigma Aldrich, Steinheim, Germany) (Fidan, 1975).

The 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) free radical method described by Moon and Terao (1998) was modified to estimate the total antioxidant capacity (TAC, %). The Folin-Ciocalteu spectrophotometric method at 720 nm was used to determine the total phenolic substance content (TPSC, mg/ml) (Abdullakasim et al., 2007). The total monomeric anthocyanin content (TMAC) was quantified according to the pH-differential method based on cyanidin-3-glucoside (mg/100 ml) (Evrendilek, 2017).

2.5 | High-performance liquid chromatography analyses

Organic acids (lactic and acetic acid) and phenolics (gallic acid, vanillic acid, *p*-coumaric acid, chlorogenic acid, caffeic acid, and myricetin) were determined using a high-performance liquid chromatography (HPLC, Shimadzu, LC-20AT, Kyoto, Japan) equipped with XTerra column (5 μm particle size, 4.6 mm diameter, 250 mm length, Waters, Ireland) and photodiode array (PDA, Shimadzu, Kyoto, Japan) detector at 50°C. The HPLC system was degassed before the analyses. Five milliliters of the samples were centrifuged (6,500 *g*, 4°C, 10 min), mixed with 20 ml of 5 mM H_2SO_4 acid, and 10 μl of the filtrated supernatants were injected into the column. Isocratic elution with 0.5 ml/min flow rate for 30 min with 5 mM H_2SO_4 was used. Concentrations of lactic and acetic acids were quantified comparing their peak areas at 210 and 244 nm (Sturm et al., 2003). Concentrations of gallic and vanillic acids were quantified at 280 nm, while concentrations of myricetin and *p*-coumaric, chlorogenic, and caffeic acids were quantified at 320 nm (Justesen et al., 1998).

HPLC equipped with XTerra column and a PDA detector was used to determine phenolic compounds. Ten milliliter sample and 20 ml methanol (80%, v/v) mixture were filtrated after the centrifugation at 1,800× *g* for 10 min. Twenty microliters of the filtrated samples (PTFE, 0.45 μm) were injected into the column. Oven temperature was set at 30°C. Gradient flow with the rate of 1.0 ml/min was formed by the mixture of 5% formic acid (A) and 80% acetonitrile (B). A PDA detector was used at 520 nm to detect concentrations of delphinidin-3-o glucoside chloride, petunidin 3-o glucoside chloride, cyanidin chloride, malvidin 3,5-di-o glucoside chloride, and peonidin 3-o glucoside chloride. All the available compounds were quantified comparing their peak areas against the standard curves obtained specifically for the reference solutions.

2.6 | Microbial inactivation

Inactivation of endogenous microflora was estimated based on the total mesophilic aerobic bacteria (TMAB), total mold and yeast (TMY), and total enterobactericeae (TE) counts. Samples diluted with 0.1% peptone water and appropriate dilutions were surface-plated on plate count agar (PCA, Fluka, Germany) for TMAB, potato dextrose agar (PDA, Fluka, Germany) acidified with 10% (w/v) tartaric acid (Sigma Chemical Co., Stockholm, Sweden) for TMY, and violet red bile agar (VRBA) for the total enterobactericeae (TE) count. PCA and VRBA plates were incubated at 35 ± 2°C for 24–48 hr. The PDA plates were incubated at 22 ± 2°C for 3–5 days, respectively. Appropriate dilutions were surface-plated on MRS (Fluka, Seelze, Germany) and M17 (Fluka, Seelze, Germany) agars in order to determine *L. paracasei* and *L. lactis* subsp. *cremoris* numbers, respectively. The plates were anaerobically incubated at 30 ± 2°C for 48 hr, with results being expressed in log cfu/ml (Ulucan, 2019).

2.7 | Shelflife studies

Both control and treatment groups (200 ml) under the optimum HHP parameters of 500 MPa, 15 min, and 34.23°C were stored at 4 and 22°C with daylight to mimic the commercial storage conditions. Sampling was made on days 0, 15, 30, 45, 60, 75, and 90 of the storage. pH, TSS, conductivity, salt concentration, TA, L^*, a^*, b^*, C^*, h^o, ΔT, IC, color tone, YCT, BCT, RCT, TMAB, TMY, phenolic compounds, organic acids, and anthocyanin compounds were performed for the shelflife studies.

2.8 | Box–Behnken design and optimization

Twenty-five responses of shalgam as pH, TSS, conductivity, turbidity, salt concentration, color (L^*, a^*, b^*, h^o, C^* and ΔE), color tone, IC, YCT, RCT, BCT, reducing sugar, volatile acidity, TAC, TMAC, TPSC, TMAB, TMY, *L. paracasei*, and *L. lactis* subsp. *cremoris* were optimized as a function of pressure (*P*, 200 to 500 MPa), treatment time (*t*, 3 to 15 min), and treatment temperature (*T*, 4 to 22°C) using the Box–Behnken design (BBD) with a quadratic model. The levels of these settings were determined by conducting the preliminary experiments and process parameters given in Table 1. MINITAB 17.0 (Minitab Inc. State College, PA, USA) was used for all the statistical analyses.

For the best-fit to the experimental data, the following quadratic regression model was used:

$$Y_n = b_0 + b_1X_1 + b_2X_2 + b_3X_3 + \cdots + b_{35}X_{35}^2$$

where Y_n is the 35 response variables; b_0 to b_{35} is the slope coefficients; and X_1, X_2, and X_3 are the predictors of *P*, *t*, and *T*, respectively. To validate the models, additional experiments were carried out in triplicate under the optimal conditions determined. To define the significant terms of the predictive model, analysis of variance (ANOVA), and regression models were performed at a 95% confidence interval ($p < .05$). Multiple comparisons were made using Tukey's test. The coefficient of variation (CV, %) was computed to verify the predicted model as follows:

$$CV = \frac{\sigma}{\bar{X}}100$$

where σ is sample standard deviation, and $\overline{X}$ is sample mean.

The numerical and graphical optimization and point prediction were carried out to establish the optimum level of five independent variables, *P*, *t*, and *T* to achieve desirable responses such as minimum TMY, *L. paracasei*, *L. lactis* subsp. *cremoris*, target color tone, and IC. The optimum value of multiple responses was determined by using MINITAB optimizer tool.

3 | RESULTS AND DISCUSSIONS

3.1 | Effect of high-pressure processing on shalgam properties and microbial inactivation

The applied HHP parameters did not change the mean pH of 3.45 ± 0.01 and volatile acidity of 0.24 ± 0.00 g/L acetic acid ($p > .05$) but TSS (3.13 ± 0.12), conductivity (12.94 ± 0.06 mS/cm), salt concentration (7.80 ± 0.00 ppm), turbidity (343.53 ± 4.55 NTU), titratable acidity (0.41 ± 0.00 g/L), and reducing sugar (0.50 ± 0.02 g/L) ($p \leq .05$) (Table 2). The mean color values of the control samples were 8.56 ± 0.04, 32.70 ± 0.17, 11.71 ± 0.02, 34.66 ± 0.045, 0.35 ± 0.01, 0.00 ± 0.00, 3.43 ± 0.00, 0.665 ± 0.00, 35.45 ± 0.02%, 11.35 ± 0.00% and 53.58 ± 0.01% for color L^*, a^*, b^*, C^*, $h°$, ΔE, IC, color tone, YCT, BCT and RCT, respectively. The significant differences were observed between the control and treatments groups in the color parameters. The mean TMAC, TPSC and TAC of the control samples were 1.38 ± 0.02 mg/ml, 254.43 ± 0.55 mg GAE/ml, and 71.74 ± 0.05%, respectively. A significant increase occurred in TMAC and TPSC with HHP ($p \leq .05$).

The mean TMAB, TMY, *L. paracasei* and *L. lactis* subsp. *cremoris* of the control samples were 3.99 ± 0.04, 3.96 ± 0.08, 4.27 ± 0.18, and 4.22 ± 0.14 log cfu/ml, respectively. Regardless of the HHP parameters, all the treatments decreased the mean TAMB, TMY, *L. paracasei* and *L. lactis* subsp. *cremoris* counts. No colonies were detected for the control and treatment groups in terms of the TE count.

Black carrot used in shalgam provides the intense purplish-red color. Moreover, black carrot also provides a high amount of anthocyanins to shalgam. Color, spicy taste, and aroma are the most distinguished properties of shalgam which make it popular. Any processing applied to shalgam should not adversely affect the physical properties, in particular, color and sensory properties as they are easily degraded by the applied processing parameters. In order to increase its shelflife, pasteurization at different temperatures are on demand. Currently, the heat processing at 65°C for 30 min or 90°C for 3 min to extent its shelflife to 3 months at 4°C are on trials, but the deterioration of color, the degradation of anthocyanins, and the adverse changes in physical properties limited the heat process applications (Coskun, 2017).

Low pH of shalgam corresponds to a high degree of acidity and has a significant impact on pigment stability (Cabriata et al., 2000; Cevallos & Cisneros-Zevallos, 2004) and sensory properties. Total acidity (TA) is one of the significant properties used as the quality and stability indicators of shalgam due to the generation of organic acids throughout the fermentation of black carrots. TA is also associated with sensory characteristics (color, taste, aroma, etc.) of the end products (Tanguler et al., 2014). Thus, pH and TA of shalgam need to be monitored after its fermentation and during its storage.

Color is one of the important quality parameters for fruits, vegetables, and their products such as shalgam (Keskin et al., 2017). The purplish-red color of shalgam comes from anthocyanins present in black carrot. Anthocyanins are the most abundant group of pigments and are responsible for the red, blue, and purple colors (Turker et al., 2004). Its color changes could be attributed to the extraction, isomerization, oxidation, and enzymatic co-oxidation of anthocyanins (Tanriseven et al., 2020).

HHP was successfully applied to pomegranate juice with dark red color similar to shalgam with the preservation of its physicochemical properties and bioactive compounds and the shelflife extension (Varela-Santos et al., 2012). pH and acidities of red wines and fermented pomegranate juices were not significantly affected by the pressures below 600 MPa (Rios-Corripio et al., 2020). No significant difference in the physical properties of ΔE, TSS, pH, and TA of fermented pomegranate juice was observed with HHP (Ma et al., 2019). ΔE values indicate the magnitude of color difference of a material (Pathare et al., 2013; Patras et al., 2011). The color differences can be perceived by the naked eye if the value of ΔE is >5. Despite of changes in chromatic characteristics treated with HHP, these changes could not be perceived by the naked eye (Szczepańska et al., 2020). In fact, shalgam juices treated by HHP15 had the highest ΔE of 29.78 ± 0.42, but this difference was not observed visually.

The mean TMAC, TPSC and TAAC of the control samples were 1.38 ± 0.02 mg/ml, 254.43 ± 0.55 mg GAE/ml, and 71.74 ± 0.05%, respectively. A significant increase occurred in TMAC and TPSC with HHP. A significant increase in TAAC was observed only with HHP6 and HHP13 (Table 3).

The increase in the bioactive properties and individual bioactive compounds were in close agreement with the related literature (Inada et al., 2018; Vázquez-Gutiérrez et al., 2011, 2013). The significant increase is most likely related to the enhanced extractability of these compounds. The HHP processing changed the persimmon microstructure and the integrity of cell walls and membranes, thus releasing tannins to the intercellular space (Vázquez-Gutiérrez et al., 2011). The significant increases in the total phenolic compound content and the antioxidant activity were consistent with the hypothesis that HHP increased the bioactive compound extractability. Similarly, this was also reported for HHP-treated onion samples (Vázquez-Gutiérrez et al., 2013). HHP-treated fruit-juice-based beverage at 400 MPa for 5 min revealed a 35% increase in the content of phenolic compounds (Rodríguez-Roque et al., 2015). TAC of apple juice significantly increased when treated by 250 MPa for 3 min (Queiroz et al., 2010); and 91.18, 97.52, 95.69, and 95.89% retentions of total flavonoids, TPSC, TMAC, and TAC of pomegranate juice were reported at 600 MPa for 3 min (Ma et al., 2019). The retention of flavonoids and phenols occurred with up to 600 MPa for 4 min with a 10% increase in TAC of fermented pomegranate juice (Rios-Corripio

TABLE 2 Changes in the physical properties of shalgam processed by high hydrostatic pressure processing according to Box–Behnken design ($n = 3$)

Process number	pH	TSS (°Brix)	Conductivity (mS/cm)	Salt concentration (ppm)	Turbidity (NTU)	Titratable acidity (g/L)	Volatile acidity (g/L acetic acid)	Reducing sugar (g/L)
C	3.45 ± 0.01^{ab}	3.13 ± 0.12^{c}	12.94 ± 0.06^{hı}	7.80 ± 0.00^{ef}	343.53 ± 4.55^{ab}	0.41 ± 0.00^{ab}	0.24 ± 0.00^{a}	0.50 ± 0.02^{def}
1	3.44 ± 0.00^{b}	3.07 ± 0.12^{c}	14.14 ± 0.03^{b}	8.63 ± 0.06^{b}	336.93 ± 2.61^{b}	0.40 ± 0.00^{bc}	0.24 ± 0.00^{a}	0.57 ± 0.00^{a}
2	3.45 ± 0.01^{ab}	3.20 ± 0.00^{bc}	13.65 ± 0.00^{d}	8.30 ± 0.00^{c}	351.03 ± 1.35^{a}	0.43 ± 0.01^{a}	0.24 ± 0.00^{a}	0.51 ± 0.02^{efg}
3	3.45 ± 0.01^{ab}	3.07 ± 0.12^{c}	14.62 ± 0.03^{a}	9.03 ± 0.06^{a}	193.40 ± 3.68^{h}	0.43 ± 0.03^{a}	0.24 ± 0.00^{a}	0.48 ± 0.01^{h}
4	3.45 ± 0.01^{ab}	3.93 ± 0.12^{a}	13.16 ± 0.02^{g}	7.93 ± 0.15^{de}	279.37 ± 1.42^{c}	0.39 ± 0.02^{bc}	0.24 ± 0.00^{a}	0.52 ± 0.01^{efg}
5	3.45 ± 0.00^{ab}	3.47 ± 0.12^{b}	13.14 ± 0.01^{g}	8.00 ± 0.10^{d}	263.67 ± 3.95^{d}	0.40 ± 0.00^{bc}	0.24 ± 0.00^{a}	0.52 ± 0.01^{def}
6	3.45 ± 0.01^{ab}	3.33 ± 0.12^{bc}	12.84 ± 0.02^{j}	8.03 ± 0.06^{d}	165.93 ± 0.98^{j}	0.37 ± 0.01^{cd}	0.24 ± 0.00^{a}	0.52 ± 0.01^{efg}
7	3.46 ± 0.01^{a}	3.80 ± 0.00^{a}	12.99 ± 0.01^{h}	7.77 ± 0.06^{f}	247.10 ± 1.31^{e}	0.41 ± 0.00^{ab}	0.24 ± 0.00^{a}	0.52 ± 0.01^{efg}
8	3.45 ± 0.01^{ab}	3.47 ± 0.12^{b}	13.89 ± 0.01^{c}	8.60 ± 0.00^{b}	151.50 ± 0.20^{k}	0.34 ± 0.00^{e}	0.24 ± 0.00^{a}	0.56 ± 0.01^{ab}
9	3.45 ± 0.01^{ab}	3.47 ± 0.12^{b}	13.47 ± 0.00^{e}	8.30 ± 0.00^{c}	221.57 ± 4.05^{g}	0.38 ± 0.00^{bcd}	0.24 ± 0.00^{a}	0.55 ± 0.01^{abc}
10	3.45 ± 0.01^{ab}	4.00 ± 0.12^{a}	12.90 ± 0.01^{ij}	7.80 ± 0.00^{ef}	279.43 ± 3.78^{c}	0.39 ± 0.01^{bcd}	0.24 ± 0.00^{a}	0.54 ± 0.01^{bcde}
11	3.46 ± 0.01^{a}	3.93 ± 0.12^{a}	12.70 ± 0.03^{k}	7.80 ± 0.00^{ef}	245.27 ± 0.06^{e}	0.41 ± 0.01^{ab}	0.24 ± 0.00^{a}	0.52 ± 0.02^{def}
12	3.45 ± 0.01^{ab}	3.20 ± 0.00^{bc}	13.83 ± 0.00^{c}	8.60 ± 0.00^{b}	173.03 ± 1.19^{j}	0.36 ± 0.00^{de}	0.24 ± 0.00^{a}	0.53 ± 0.01^{cdef}
13	3.45 ± 0.01^{ab}	3.27 ± 0.12^{bc}	13.53 ± 0.00^{e}	8.40 ± 0.00^{c}	184.83 ± 3.20^{i}	0.40 ± 0.00^{bc}	0.24 ± 0.00^{a}	0.51 ± 0.00^{fg}
14	3.45 ± 0.01^{ab}	3.27 ± 0.12^{bc}	14.10 ± 0.01^{b}	8.70 ± 0.00^{b}	235.20 ± 2.71^{f}	0.36 ± 0.00^{de}	0.24 ± 0.00^{a}	0.55 ± 0.01^{abcd}
15	3.45 ± 0.01^{ab}	3.93 ± 0.12^{a}	13.26 ± 0.04^{f}	8.00 ± 0.06^{d}	256.50 ± 1.21^{d}	0.41 ± 0.01^{ab}	0.24 ± 0.00^{a}	0.53 ± 0.03^{def}

Note: Data in the same column with different superscript letters are significantly different ($p \leq .05$).

TABLE 3 Changes in bioactive properties of shalgam processed by high hydrostatic pressure ($n = 3$)

Processes number	TMAC (mg/ml)	TPSC (mg GAE/ml)	TAC (%)
C	1.38 ± 0.02^{l}	254.43 ± 0.55^{1}	71.74 ± 0.05^{b}
1	2.58 ± 0.02^{j}	386.07 ± 6.54^{ab}	70.35 ± 0.16^{ghı}
2	4.65 ± 0.05^{b}	321.90 ± 5.23^{g}	71.61 ± 0.01^{bc}
3	4.79 ± 0.06^{b}	288.64 ± 4.69^{h}	69.99 ± 0.34^{ı}
4	3.37 ± 0.02^{efg}	346.84 ± 3.32^{def}	70.97 ± 0.03^{ef}
5	2.24 ± 0.07^{k}	371.31 ± 1.10^{abc}	71.05 ± 0.08^{def}
6	2.80 ± 0.03^{ij}	340.90 ± 3.96^{efg}	72.71 ± 0.06^{a}
7	2.96 ± 0.05^{hı}	286.14 ± 9.41^{h}	71.18 ± 0.20^{cde}
8	3.16 ± 0.16^{fgh}	367.74 ± 6.79^{bcd}	70.17 ± 0.03^{hı}
9	3.03 ± 0.01^{hı}	288.96 ± 6.65^{h}	70.75 ± 0.03^{efg}
10	3.42 ± 0.04^{ef}	367.67 ± 8.96^{bcd}	71.56 ± 0.07^{bcd}
11	5.50 ± 0.25^{a}	360.12 ± 5.03^{cde}	70.63 ± 0.07^{efgh}
12	3.16 ± 0.04^{gh}	326.97 ± 7.60^{fg}	70.56 ± 0.05^{fgh}
13	3.93 ± 0.06^{c}	258.73 ± 8.83^{1}	72.43 ± 0.26^{a}
14	3.77 ± 0.03^{cd}	391.13 ± 12.70^{a}	68.84 ± 0.08^{j}
15	3.60 ± 0.09^{de}	366.56 ± 14.52^{bcd}	71.57 ± 0.49^{bcd}

Note: Data in the same column with different superscript letters are significantly different ($p \leq .05$).

et al., 2020). According to Varela-Santos et al. (2012) and Chen et al. (2013), TPSC and TAC of the phenols did not decrease with the HHP treatment of pomegranate juice and fermented pomegranate juice, respectively. Because HHP treatment does not affect the free-radical scavenging activity, no significant changes in bioactive properties of HHP-treated beverages and juices were observed. An increase or a decrease in antioxidant activity could be due to a combined effect of different compounds, which act synergistically or antagonistically. Factors such as the oxidation system, the degree of glycosylation, the partition coefficient, and the concentration of other antioxidant compounds that the fruit had could be correlated with the antioxidant activity (Hassimotto et al., 2005; Tsikrika & Rai, 2019).

More specifically, the effect of HHP on bioactive compounds depends on the applied pressure and treatment time. The HHP treatment of 200, 350, and 500 MPa for 5, 7.5, and 10 min increased the total phenolic compound content (up to 38%) and the antioxidant activity of jabuticaba juice by FRAP assay (up to 46%) (Inada et al., 2018). TPSC, TMAC, and TAC also rose in onion with HHP that also increased the bioactive compound extractability (Vázquez-Gutiérrez et al., 2013). Liu et al. (2016) reported increased TMAC for blue honeysuckle berry with HHP during its storage.

The inhibitory effect of HHP on microbial flora was presented in different juices and fermented beverages. The HHP treatment at 300 MPa for 2.5 min resulted in 3.17 log cycles reduction in the total aerobic bacteria (TAB) count and 1.85 log cycles reduction in the TMY count in cloudy pomegranate juice (Chen et al., 2013). 350 MPa for 2.5 min was sufficient to decrease microorganisms in clear pomegranate juice (Varela-Santos et al., 2012). Applied pressures of 300, 400, and 500 MPa up to 10 min at 20°C provided 3.8, 4.1, and 4.5 log cfu/ml reductions in the total count of spoilage microorganisms in beetroot juice (Sokołowska et al., 2017).

3.2 | Modeling studies

According to ANOVA results, the insignificant terms were excluded from the models of the color tone, IC, TMY, *L. paracasei* and *L. lactis* subsp. *cremoris* (Table 4). The significant quadratic terms found were the pressure ($p = .000$), treatment temperature ($p = .000$), and time ($p = .021$) with a positive effect on color tone and IC ($p < .05$), respectively. Temperature ($p = .0001$) had a negative effect on TMY. Both treatment time ($p = .0001$) and pressure ($p = .0001$) had a negative effect on *L. paracasei*. Treatment temperature ($p = .0001$) and pressure ($p = .0001$) had a negative effect on *L. lactis* subsp. *cremoris*. There was a significant interaction between treatment time and temperature with a negative effect on color tone, IC, and TMY. A significant interaction between pressure and treatment temperature ($p = .023$) with a negative effect on IC was detected. The degree of influence of the operational conditions on the color tone, IC, TMY, and *L. lactis* subsp. *cremoris* was inferred from the relative magnitudes of the coefficients of the quadratic regression models. Pressure was the most important factor for both *L. paracasei* (0.427) and *L. lactis* subsp. *cremoris* (0.316). Treatment temperature was the most important factor for color tone (0.281), IC (0.469) and TMY (0.522). The goodness-of-fit (R^2_{adj}) of the models showed that 0.79, 0.92, 0.71 and 0.86% of variations in color tone, IC, TMY, and *L. lactis* subsp. *cremoris* were explained, respectively. The insignificant lack-of-fit values for the five models also indicated that the model fitted the experimental data well (Table 4).

TABLE 4 Revised ANOVA results and estimated regression coefficients for the transformed coded color tone, color intensity, total mold, and yeast count, *Lactobacillus paracasei* and *Lactococcus lactis* subsp. *cremoris* model for shalgam processed by high hydrostatic pressure

	Color tone		Color intensity		Total mold and yeast count		*Lactobacillus paracasei*		*Lactococcus lactis* subsp. *cremoris*	
Terms	Coeff	*p* value	Coeff	*p* value	Coeff	*p* value	Coeff	*p* value	Coeff	*p* value
Linear										
X_1 (P)	−0.248	.007	–	–	–	–	−0.427	.000	−0.316	.000
X_2 (t)	−0.189	.037	−0.131	.018	–	–	−0.323	.000	–	–
X_3 (T)	0.281	.003	0.469	.000	−0.522	.000	–	–	−0.235	.000
Square										
$X_1 * X_1$	–	–	0.529	.000	–		–	–	−0.135	.001
$X_2 * X_2$	–	–	0.188	.021	−1.388	.000	–	–	–	–
$X_3 * X_3$	1.454	.000	1.349	.000	–	–	–	–	–	–
Interaction										
$X_1 * X_2$	–	–	–	–	–	–	–	–	–	–
$X_1 * X_3$	–	–	−0.178	.023	–	–	–	–	–	–
$X_2 * X_3$	−0.582	.000	−0.157	.044	−0.693	.000	–	–	–	–
Lack-of-fit	–	.374	–	.615	–	.176	–	.478	–	.322
Constant	−0.730	.000	−1.089	.000	0.707	.000	3.267	.000	3.336	.000
R^2	.82		.94		.73		.83		.87	
R^2 (adj)	.79		.92		.71		.82		.86	
R^2 (pred)	.77		.92		.68		.80		.84	

Table 4 shows the regression equations for color tone, IC, TMY, *L. paracasei*, and *L. lactis* subsp. *cremoris*. The selection of the most accurate model involved the consideration of several criteria such as R^2, lack-of-fit value, and *p*-value. The best-fit quadratic models belonged to color tone, IC, TMY, and *L. lactis* subsp. *cremoris*, while the best-fit first-order model belonged to *L. paracasei*.

The effects of the HHP treatments on the multiple responses were illustrated using the surface plots (Figures 1–3). Color tone was affected by both pressure and treatment time and fell with the increased pressure and treatment time at 22°C (Figure 1a). The interaction between the treatment time and the pressure showed a negative correlation with the color tone (Figure 1a). The highest treatment time at the lower temperature (15°C) maximized the color tone. The color tone increased with the increased temperature (45°C) at the lowest treatment time (5 min) and the lowest temperature and the highest treatment time at 350 MPa (Figure 1b). The color tone increased with the increased pressure at above and below 15°C (Figure 1c). The IC value increased with the increased temperature under the lowest treatment time at an increasing rate (Figure 2a). The IC values peaked with the lowest pressure at the lowest treatment time (15 min) (Figure 2b). IC increased and decreased with the increases in pressure and temperature above and below 30°C, respectively (Figure 2c). The TMY count plunged with the highest temperature at the highest treatment time (15 min) (Figure 3a) with the negative relationship between the temperature and the treatment time (Figure 3a). The mean initial numbers of *L. paracasei* fell the most at the highest pressure (500 MPa) and the longest treatment time (15 min) (Figure 3b). The mean initial numbers of *L. paracasei* dropped with the increased treatment time and pressure linearly (Figure 3b). The initial numbers of *L. lactis* subsp. *cremoris* declined with the increased treatment time and pressure (Figure 3c). The highest treatment time (15 min) minimized the initial number of *L. lactis* subsp. *cremoris* at the highest pressure (500 MPa) (Figure 3c).

3.3 | Joint optimization and model validations

The operational settings were optimized to minimize the mean initial numbers of *L. lactis* subsp. *cremoris*, *L. paracasei* and TMY and target the IC and color tone of the shalgam quality properties. The numerical values of the color properties of the control samples were taken as target. The multiple response optimization was based on the composite desirability function (D) that ranges from zero to one (ideal), a geometric mean of individual desirabilities (d). The optimum operational conditions were achieved with 500 MPa, 15 min, and 34.23°C. The minimum values of TMY (3.08 log cfu/ml), *L. paracasei* (2.52 log cfu/ml), *L. lactis* subsp. *cremoris* (2.65 log cfu/ml), target color tone (3.43), and target IC (0.67) were obtained with the optimum operational conditions. These conditions were experimentally tested to validate the predictive power of the models. The resultant color tone, IC, TMY, *L. paracasei*, and *L. lactis* subsp. *cremoris* values indicated no significant difference between the measured and

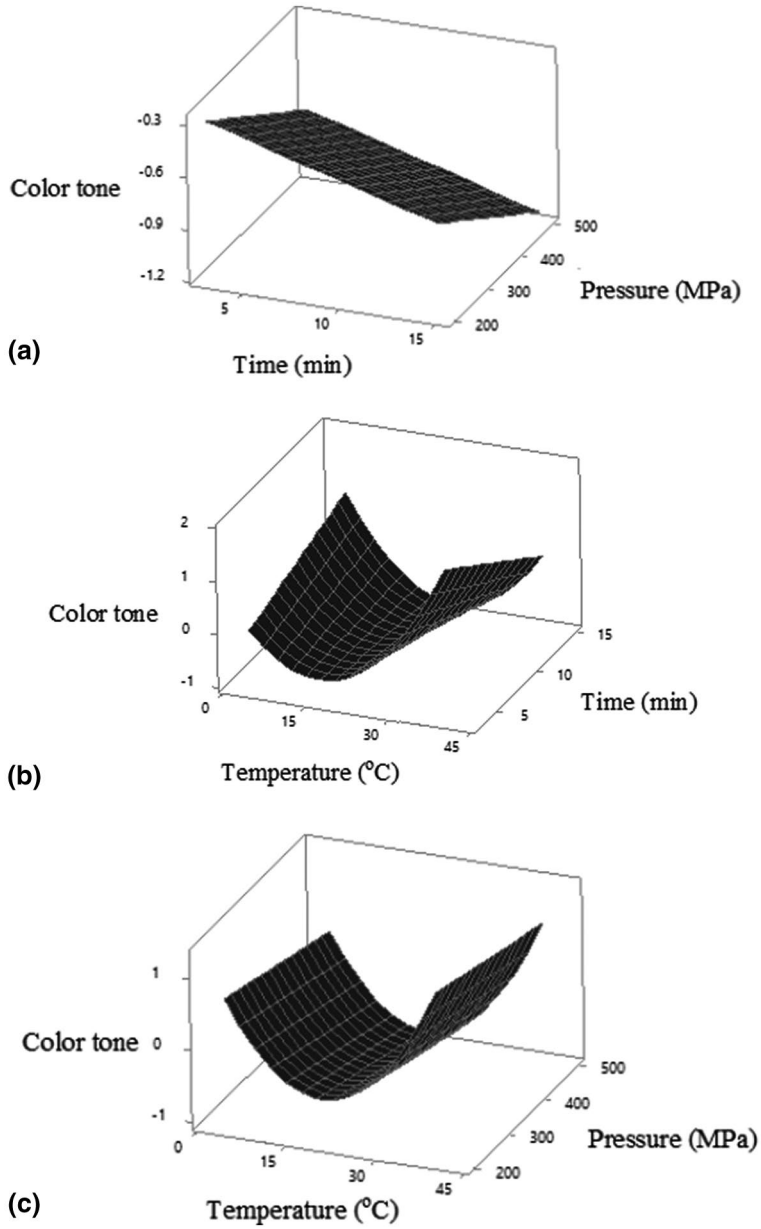

FIGURE 1 Effects of (a) pressure versus treatment time, (b) temperature versus treatment time, and (c) temperature versus pressure on color tone of spicy shalgam treated by high hydrostatic pressure

predicted values (Table 4). The smaller CV values (Table 5) showed the better reproducibility of the model.

3.4 | Shelflife studies

Both control and treatment groups were stored at 4 and 22°C for 90 days. The control samples were spoiled at 60 and 45th days at 4 and 22°C, respectively. Their pH significantly rose with the storage time. The pH of the control samples at 22°C was significantly higher than that of the control samples at 4°C and the treatment samples at 4 and 22°C ($p \leq .05$) (Table 6). Regardless of the temperature and HHP processing, TSS significantly increased with the storage time ($p \leq .05$). No significant change occurred in the conductivity between the control and treatment samples at 4 and 22°C with the storage time ($p > .05$). Salt concentration did not significantly change with the storage time, the HHP treatment, and the storage temperature ($p > .05$). TA increased significantly only with the storage time ($p \leq .05$). Neither the HHP treatment nor the storage time significantly affected TA ($p > .05$). All the samples had a decreased L^* value by the end of the storage time. HHP-treated samples at 22°C had significantly lower L^* values than that of the other samples ($p \leq .05$). Both control and treatment samples at 22°C had lower L^* values than did the control samples stored at 4°C. A significant decrease in the a^* value of all the samples occurred with the storage time. The a^* value was affected by the storage time rather than the storage temperature and the HHP treatment. The b^* values of the samples decreased during the shelflife studies. Overall, the treatment samples had higher b^* values than did the control samples at the corresponding storage temperatures. Chroma, $h°$ and ΔE of the samples were significantly affected by the storage time ($p \leq .05$) rather than the HHP treatment or the storage temperature. Color

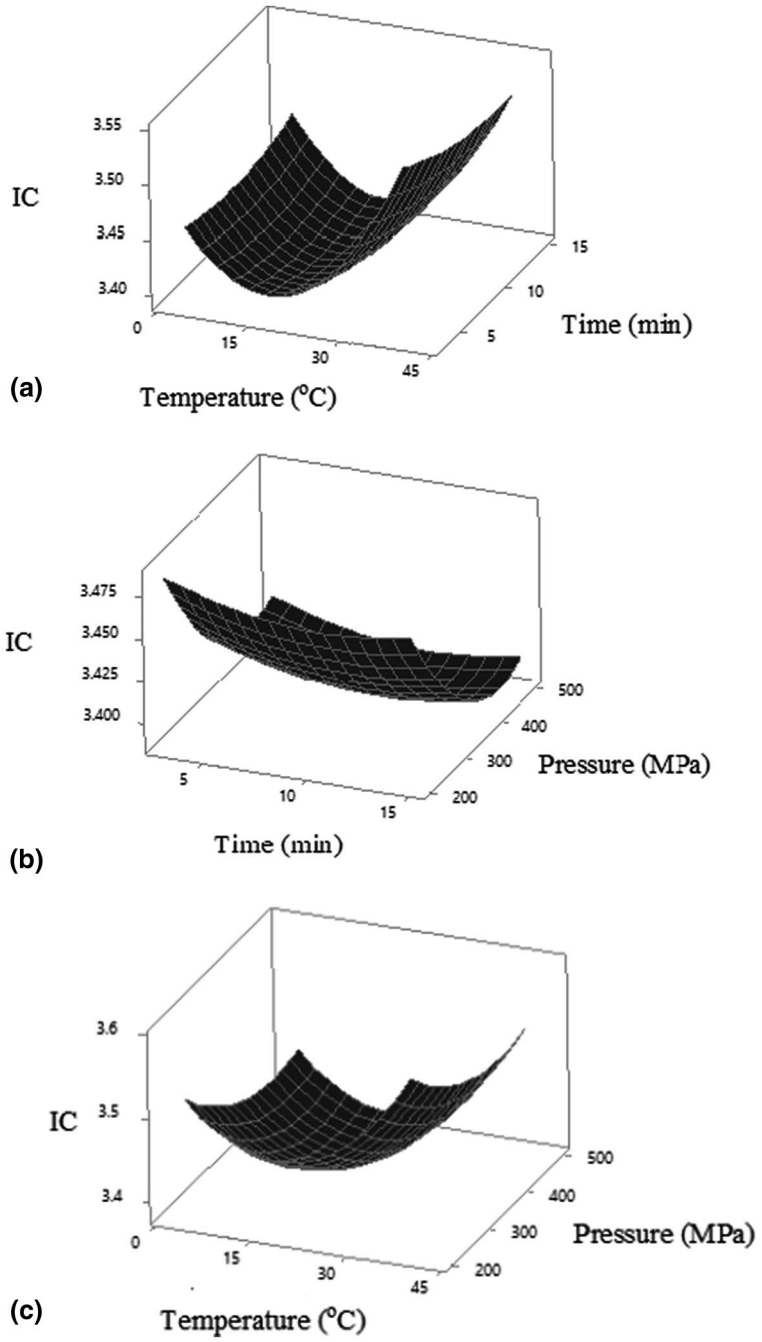

FIGURE 2 Effects of (a) temperature versus treatment time, (b) treatment time versus pressure, and (c) temperature versus pressure on color intensity of spicy shalgam treated by high hydrostatic pressure

intensity, color tone, YCT, BCT, and RCT of all the samples did not significantly change with the HHP treatment, the storage time, and the storage temperature ($p > .05$) (Table 6).

No significant difference was observed between the control and treatment samples at 4 and 22°C during the shelflife studies in the lactic and acetic acid concentrations ($p > .05$). The concentrations of gallic acid and myricetin did not significantly change with the storage time, the HHP treatment, and the storage temperature ($p > .05$). Except for the control samples at 22°C with a significantly lower *p*-coumaric acid, the initial *p*-coumaric acid of the samples did not significantly change with the storage temperature, the storage time, and the HHP treatment. The initial concentration of chlorogenic acid did not significantly fall with the storage time or HHP treatment. The treatment samples at 22°C had significantly higher chlorogenic acid concentration than did the other samples. The initial concentration of vanillic acid did not significantly change with the storage time and the storage temperature. Only the treatment samples at 4°C had a lower vanillic acid concentration than did the other samples ($p \leq .05$). The mean caffeic acid concentrations of the control samples significantly fell with the storage time. The initial caffeic acid concentrations of the treatment samples went up with the storage time ($p \leq .05$). The control samples at 22°C had a lower caffeic acid concentration than did the other samples ($p \leq .05$) (Table 7).

The treatment samples stored at both 4 and 22°C had higher initial concentrations of delphinidin 3-o-glucoside, petunidin 3-o-glucoside, malvidin-3,5-diglucoside, and peonidin-3,5-diglucoside than did the

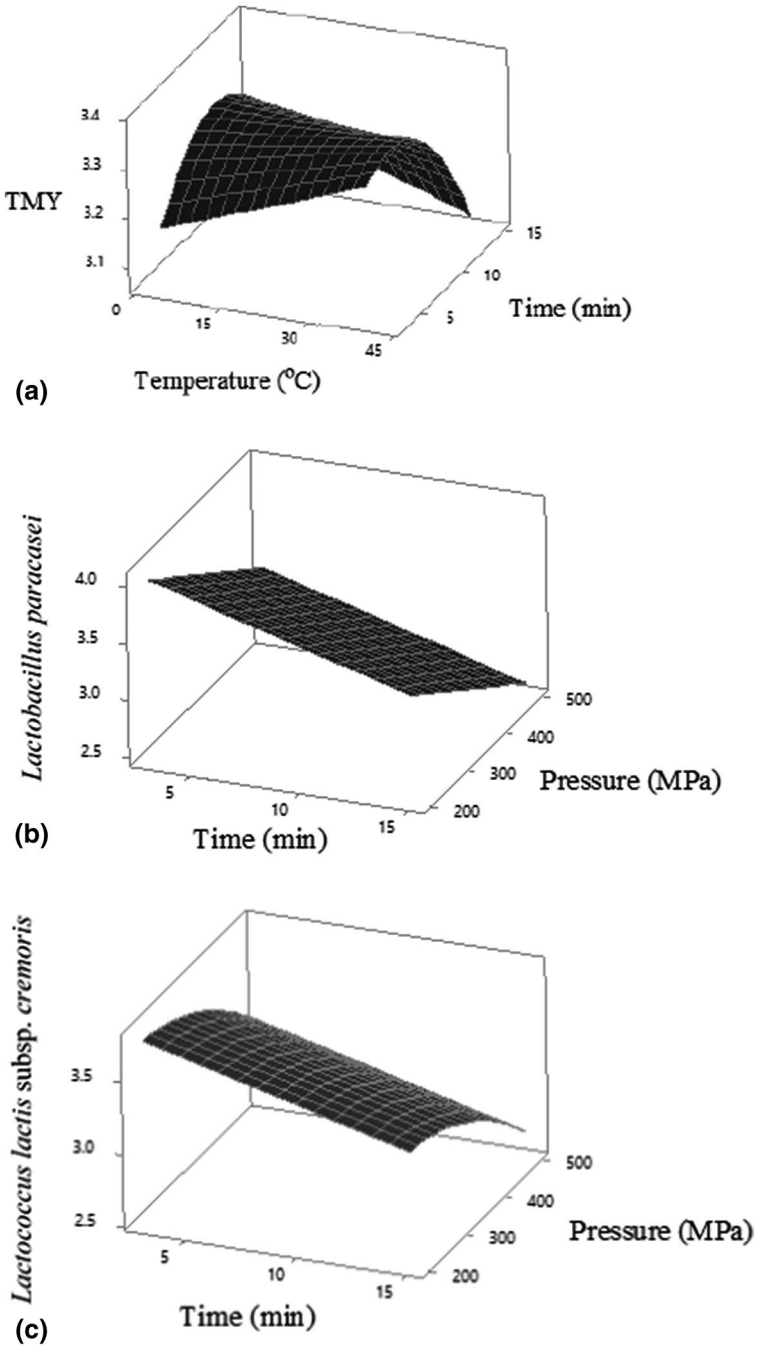

FIGURE 3 Effects of (a) temperature versus treatment time on total mold and yeast, (b) pressure versus treatment time on *Lactobacillus paracasei* and *Lactococcus lactis. paracasei*, and (c) pressure versus treatment time on *Lactococcus lactis* subs. *cremoris* of spicy shalgam treated by high hydrostatic pressure

TABLE 5 Regression equations for the coded color tone, color intensity, total mold and yeast, *Lactobacillus paracasei*, and *Lactococcus lactis* subsp. *cremoris* models for shalgam samples processed by high hydrostatic pressure

Response	Models	Equation	Experimental	Predicted	CV (%)
Color tone	Quadratic	$Y_1 = -0.730 - 0.248 * X_1 - 0.189 * X_2 + 0.281 * X_3 + 1.454 * X_3^2 - 0.582 * X_2 * X_3$	3.43 ± 0.00	3.43	0.02
Color intensity	Quadratic	$Y_2 = -1.089 - 0.131 * X_2 + 0.469 * X_3 + 0.529 * X_1^2 + 0.188 * X_2^2 + 1.349 * X_3^2 - 0.178 * X_1 * X_3 - 0.157 * X_2 * X_3$	0.69 ± 0.00	0.67	2.70
Total mold and yeast	Quadratic	$Y_3 = 0.707 - 0.522 * X_3 - 1.388 * X_2^2 - 0.693 * X_2 * X_3$	3.09 ± 0.03	3.08	0.18
Lactobacillus paracasei	Linear	$Y_4 = 3.267 - 0.427 * X_1 - 0.323 * X_2$	2.51 ± 0.09	2.52	0.38
Lactococcus lactis subsp. *cremoris*	Quadratic	$Y_5 = 3.336 - 0.316 * X_1 - 0.235 * X_3 - 0.135 * X_1^2$	2.68 ± 0.01	2.65	0.71

control samples during the shelflife study ($p \leq .05$). Regardless of the storage temperature and the treatment, the mean concentration of anthocyanin compounds significantly reduced in all the samples with the storage time. The anthocyanin compounds were affected more adversely by the storage time than the storage temperature and the HHP treatment (Table 8).

The mean initial counts of TAMB and TMY increased during the shelflife studies ($p \leq .05$). The increased TAMB and TMY counts of the treatment samples at 4 and 22°C were insignificant ($p > .05$). TAMB and TMY counts increased with the HHP treatment, the storage temperature, and the storage time. The control samples had significantly higher TMAB and TMY counts at 22°C than 4°C and did the treatment samples at 4 and 22°C.

Shalgam pH was affected by the storage temperature and time, its production type, and the presence of antimicrobial agents. A slight change in its pH in 90-day-storage was reported by Turker et al. (2004). Its TA changed during its storage according to Tanriseven et al. (2020).

Color changes occurred depending on the storage time, the temperature, the heat processing, and the addition of sorbate. A significant increase in the polymeric color of shalgam stored at 40°C relative to 4 and 25°C; and a decrease in its color density stored at 4, 25, and 40°C after 90 days were previously stated for the control, pasteurized, and sorbate-treated samples, respectively (Turker et al., 2004). Although a decrease in the color values with the storage time was evidenced in the present study, the maximum ΔE was 6.50 ± 0.66 at the end of the shelflife studies which was slightly higher than that of the distinct ΔE value given by Ohta and Roberstson (2007). No significant changes in color tone, color intensity, YCT, BCT, and RCT indicated no significant degradation or oxidation in anthocyanin compounds. No significant decrease in the bioactive properties and individual bioactive compounds during the shelflife studies was consistent with the spectrophotometric color measurement. The monomeric anthocyanin content and color density of the control, pasteurized, and sorbate-added shalgam samples stored at 4, 25, and 40°C for 90 days decreased over time as a function of storage temperature, whereas their percent polymeric color and browning increased. While 4 and 25°C revealed no significant difference, 40°C storage temperature had a significant impact on the monomeric anthocyanin content, polymeric color, color density, and browning. The anthocyanin profile of shalgam changed during the storage with the highest degradation rates for the samples stored at 40°C (Turker et al., 2004).

Unlike HHP, the pulsed UV (PUV) light treatment of shalgam caused a significant change in pH, TA (% lactic acid), TMAC, color density, h^o, brightness, and percent color components (yellow, red and blue) at each level. PUV-light caused a 63% degradation of anthocyanin, increased yellow and blue color (%), and decreased red color (%) with a longer treatment time and a shorter distance (Karaoglan et al., 2019). UV-processed shalgam showed comparable results to heat processing in terms of the microbiological and bioactive properties and higher sensory scores for the six-month storage. The UV processing provided 3 log cfu/ml inactivation in the initial TMAB count (Dogan, 2017). Its ultrasonication (US) processing at different temperatures and flow rates showed no adverse effect on its physicochemical properties during the six-month storage. The microbial inactivation with US was close to that with the heat treatment (72°C at 20 s). US processed shalgam had better sensory scores than did the heat-treated samples (Irkilmez, 2017). Our results were similar to the UV and US processing in that the applied process parameters did not significantly change most of the properties with the microbial inactivation and shelflife extension.

The treatment samples had an extended shelflife with better preserved physical, bioactive properties and a lower microbial growth. The treatment at 600 MPa for 5 min ensured microbiological safety of grapefruit juice stored at 4°C for 21 days and preserved antioxidants and antioxidant capacity (Wang et al., 2018). The pressurization process (300–500 MPa) extended the microbiological shelflife of beetroot juice from 1 to 7–14 days, respectively, with refrigerated storage (Sokołowska et al., 2014). No significant change occurred in pH, TSS, TA, TAC, and color of cloudy ginger juice with 3 log cfu/ml reduction in microbial load with the HHP processing. An increase in TPSC but color darkening during storage at 4 and 22°C were observed. The quality changes in cloudy ginger juice were more noticeable at 22°C than 4°C during its storage (Chen et al., 2016).

The microbial stability of the HHP-treated beverages is vital as it determines the shelflife. The HHP-treated shalgam had significantly lower TAMB and TMY counts which did not significantly increase during the shelflife studies. For example, the microbial safety of HHP-treated papaya beverage stored at 4°C for 40 days met the national hygienic standard for fruit and vegetable juice. The studies about cloudy purple sweat potato nectar and cloudy pomegranate juice showed that their microbial safety was ensured during their storage owing to their HHP treatment (Chen et al., 2013; Wang et al., 2012).

4 | CONCLUSIONS

This study provides the first results about both the HHP processing of shalgam and the optimum processing conditions determined for the 25 responses. The optimum HHP processing conditions for color intensity, color tone, TMY, viable *L. lactis* subsp. *cremoris*, and *L. paracasei* were 34.23°C, 15 min, and 500 MPa. The shelflife studies at 4 and 22°C were performed for 90 days for the treatment samples under the optimum processing conditions. Relative to the control samples spoiled at 4 and 22°C by 45 and 60th days, respectively, the treatment samples remained acceptable for over 90 days. The reason for the shelflife studies to last for 90 days was the shalgam

(Continues)

TABLE 6 Effect of high hydrostatic pressure, storage time, and storage temperature on the selected physical properties of the control

TABLE 6 (Continued)

and the high hydrostatic pressure processed shalgam samples ($n = 3$)

		Temperature			
		4°C		22°C	
	Days of storage	Control	High hydrostatic pressure processed	Control	High hydrostatic pressure processed
pH	0	3.71 ± 0.00^{bA}	3.71 ± 0.01^{cA}	3.71 ± 0.00^{cA}	3.71 ± 0.01^{eA}
	15	3.60 ± 0.01^{cA}	3.60 ± 0.00^{dA}	3.60 ± 0.02^{dA}	3.56 ± 0.01^{fB}
	30	3.71 ± 0.01^{bB}	3.70 ± 0.02^{cB}	4.71 ± 0.02^{bA}	3.71 ± 0.01^{eB}
	45	4.21 ± 0.04^{aB}	4.02 ± 0.01^{bC}	5.22 ± 0.01^{aA}	3.81 ± 0.02^{dD}
	60	4.21 ± 0.03^{aA}	4.02 ± 0.01^{aC}		4.14 ± 0.02^{cB}
	75		4.00 ± 0.01^{bB}		4.26 ± 0.03^{bA}
	90		4.02 ± 0.01^{bB}		4.33 ± 0.03^{aA}
Total Soluble Solids (°Brix)	0	8.75 ± 0.07^{bB}	8.85 ± 0.07^{deB}	8.85 ± 0.21^{bcAB}	8.90 ± 0.00^{cA}
	15	8.90 ± 0.14^{bA}	8.60 ± 0.00^{eB}	8.90 ± 0.14^{bcA}	8.80 ± 0.28^{cAB}
	30	9.00 ± 0.30^{bA}	9.15 ± 0.07^{cA}	9.10 ± 0.14^{bA}	9.00 ± 0.00^{bcA}
	45	9.70 ± 0.14^{aA}	9.00 ± 0.00^{cdB}	9.86 ± 0.03^{aA}	9.00 ± 0.00^{bcB}
	60	9.85 ± 0.07^{aA}	9.50 ± 0.14^{bB}		9.30 ± 0.42^{abcAB}
	75		9.70 ± 0.00^{bA}		9.75 ± 0.07^{abA}
	90		10.00 ± 0.00^{aA}		10.00 ± 0.00^{aA}
Conductivity (mS/cm)	0	12.79 ± 0.01^{aA}	12.68 ± 0.03^{aB}	12.82 ± 0.03^{aA}	12.69 ± 0.09^{aB}
	15	12.58 ± 0.02^{aA}	12.54 ± 0.09^{aA}	12.60 ± 0.02^{aA}	12.61 ± 0.10^{aA}
	30	12.53 ± 0.35^{aB}	12.74 ± 0.04^{aA}	12.82 ± 0.08^{aA}	12.82 ± 0.04^{aA}
	45	12.64 ± 0.03^{aA}	12.64 ± 0.03^{aA}	12.68 ± 0.02^{aA}	12.68 ± 0.08^{aA}
	60	12.58 ± 0.03^{aA}	12.62 ± 0.02^{aA}		12.67 ± 0.08^{aA}
	75		12.54 ± 0.09^{aB}		12.78 ± 0.04^{aA}
	90		12.42 ± 0.03^{aB}		12.81 ± 0.04^{aA}
Salt concentration (mg/kg)	0	7.45 ± 0.27^{aA}	7.40 ± 0.20^{aA}	7.50 ± 0.32^{aA}	7.30 ± 0.30^{aA}
	15	7.20 ± 0.14^{aA}	7.15 ± 0.27^{aA}	7.20 ± 0.34^{aA}	7.20 ± 0.42^{aA}
	30	7.45 ± 0.27^{aA}	7.40 ± 0.32^{aA}	7.45 ± 0.27^{aA}	7.50 ± 0.30^{aA}
	45	7.70 ± 0.20^{aA}	7.40 ± 0.26^{aA}	7.70 ± 0.36^{aA}	7.45 ± 0.36^{aA}
	60	7.75 ± 0.37^{aA}	7.65 ± 0.27^{aA}		7.70 ± 0.42^{aA}
	75		7.50 ± 0.70^{aA}		8.10 ± 0.46^{aA}
	90		7.85 ± 0.27^{aA}		8.05 ± 0.48^{aA}
Titratable acidity (g/L)	0	0.29 ± 0.01^{aA}	0.30 ± 0.01^{bA}	0.28 ± 0.02^{aA}	0.29 ± 0.02^{bA}
	15	0.29 ± 0.01^{aa}	0.29 ± 0.02^{bcA}	0.30 ± 0.01^{aA}	0.30 ± 0.01^{bA}
	30	0.29 ± 0.00^{aB}	0.28 ± 0.00^{cC}	0.29 ± 0.00^{aB}	0.31 ± 0.01^{bA}
	45	0.30 ± 0.01^{aA}	0.29 ± 0.01^{bcA}	0.31 ± 0.01^{aA}	0.31 ± 0.01^{bcA}
	60	0.31 ± 0.03^{aA}	0.31 ± 0.01^{bA}		0.32 ± 0.02^{bA}
	75		0.32 ± 0.02^{abA}		0.28 ± 0.02^{bA}
	90		0.37 ± 0.03^{aA}		0.38 ± 0.01^{aA}

(Continues)

TABLE 6 (Continued)

		Temperature			
		4°C		22°C	
	Days of storage	Control	High hydrostatic pressure processed	Control	High hydrostatic pressure processed
L^*	0	11.57 ± 3.34^{aAB}	12.32 ± 2.13^{aAB}	12.28 ± 1.92^{aA}	9.95 ± 0.03^{bB}
	15	9.60 ± 1.17^{aB}	11.57 ± 0.29^{aA}	9.10 ± 0.16^{bB}	9.75 ± 0.48^{abB}
	30	9.07 ± 1.37^{aA}	9.41 ± 0.04^{bA}	7.64 ± 0.05^{cC}	8.20 ± 0.04^{cB}
	45	9.11 ± 0.31^{aC}	11.64 ± 0.38^{aA}	8.82 ± 0.13^{bD}	10.06 ± 0.05^{aB}
	60	9.31 ± 0.43^{aB}	11.22 ± 0.33^{aA}		7.40 ± 0.42^{dC}
	75		8.98 ± 0.93^{bcA}		7.10 ± 0.16^{deB}
	90		8.63 ± 0.09^{cA}		6.89 ± 0.07^{eB}
a^*	0	38.12 ± 4.92^{abcdA}	40.05 ± 3.42^{abdA}	38.78 ± 1.47^{aA}	37.54 ± 0.01^{aA}
	15	34.20 ± 0.35^{dA}	34.26 ± 0.30^{bA}	33.85 ± 0.16^{cA}	33.98 ± 0.57^{bcA}
	30	39.39 ± 1.33^{aA}	36.22 ± 0.09^{cB}	32.15 ± 0.05^{dD}	34.18 ± 0.11^{bC}
	45	35.42 ± 0.10^{cB}	38.12 ± 0.17^{bA}	34.73 ± 0.38^{bC}	34.11 ± 0.19^{bD}
	60	36.91 ± 0.33^{bB}	39.70 ± 0.28^{aA}		32.99 ± 0.40^{cdC}
	75		35.07 ± 1.37^{dA}		31.79 ± 0.76^{dB}
	90		33.98 ± 1.74^{dA}		30.22 ± 0.13^{eB}
b^*	0	18.63 ± 3.02^{abA}	20.02 ± 4.26^{abA}	19.31 ± 2.76^{aA}	19.30 ± 0.23^{aA}
	15	12.99 ± 1.22^{bA}	14.34 ± 1.26^{bA}	12.74 ± 1.38^{bA}	14.18 ± 2.05^{bA}
	30	12.59 ± 2.30^{baA}	14.59 ± 0.20^{bA}	10.59 ± 0.23^{cB}	14.12 ± 0.01^{bA}
	45	11.41 ± 0.21^{bB}	14.88 ± 0.11^{bA}	10.14 ± 0.64^{cC}	14.50 ± 0.25^{bA}
	60	10.48 ± 0.50^{cC}	14.42 ± 0.51^{bA}		12.72 ± 0.44^{cB}
	75		13.63 ± 1.97^{bcA}		11.39 ± 0.45^{dA}
	90		12.91 ± 0.72^{cA}		9.69 ± 0.39^{eB}
Chroma	0	42.49 ± 7.05^{abA}	44.80 ± 4.96^{abA}	43.34 ± 2.54^{aA}	40.92 ± 0.08^{aA}
	15	44.00 ± 2.23^{aA}	37.13 ± 0.38^{cB}	36.17 ± 0.28^{bC}	36.45 ± 0.55^{bcC}
	30	37.19 ± 0.08^{bB}	39.05 ± 0.01^{bA}	33.84 ± 0.03^{cD}	36.50 ± 0.09^{cC}
	45	38.24 ± 0.01^{bB}	42.10 ± 0.11^{bA}	37.24 ± 0.37^{bC}	37.06 ± 0.27^{bC}
	60	36.03 ± 0.49^{cB}	44.64 ± 0.48^{aA}		35.01 ± 0.53^{cdC}
	75		37.63 ± 1.98^{bcA}		33.45 ± 0.87^{deB}
	90		36.35 ± 1.88^{bcA}		31.74 ± 0.24^{eB}
Hue	0	0.45 ± 0.08^{aA}	0.46 ± 0.05^{abA}	0.46 ± 0.04^{aA}	0.41 ± 0.01^{aA}
	15	0.36 ± 0.03^{aB}	0.40 ± 0.00^{abcA}	0.36 ± 0.01^{bcB}	0.37 ± 0.01^{bB}
	30	0.46 ± 0.03^{aA}	0.38 ± 0.01^{abcB}	0.32 ± 0.02^{cC}	0.36 ± 0.02^{bcB}
	45	0.38 ± 0.01^{aC}	0.44 ± 0.00^{abcA}	0.37 ± 0.01^{bcC}	0.40 ± 0.00^{aB}
	60	0.40 ± 0.01^{aB}	0.48 ± 0.01^{aA}		0.34 ± 0.01^{cC}
	75		0.37 ± 0.04^{bcA}		0.32 ± 0.01^{dB}
	90		0.36 ± 0.00^{cA}		0.31 ± 0.01^{dB}
Total color difference	0	0.00 ± 0.0^{aB}	4.22 ± 1.35^{bA}	0.00 ± 0.0^{aB}	4.00 ± 0.15^{bA}
	15	0.00 ± 0.0^{aC}	4.41 ± 0.08^{bA}	0.00 ± 0.0^{aC}	3.94 ± 0.23^{cB}
	30	0.00 ± 0.0^{aC}	6.49 ± 0.13^{aA}	0.00 ± 0.0^{aC}	3.96 ± 0.04^{cB}
	45	0.00 ± 0.0^{aC}	6.08 ± 0.13^{aA}	0.00 ± 0.0^{aC}	4.41 ± 0.27^{aB}
	60	0.00 ± 0.0^{aB}	6.50 ± 0.66^{aA}		

(Continues)

TABLE 6 (Continued)

		Temperature			
		4°C		22°C	
	Days of storage	Control	High hydrostatic pressure processed	Control	High hydrostatic pressure processed
Color intensity	0	3.37 ± 0.04^{aA}	3.39 ± 0.04^{aA}	3.38 ± 0.04^{aA}	3.36 ± 0.04^{aA}
	15	3.38 ± 0.04^{aA}	3.35 ± 0.05^{aA}	3.36 ± 0.04^{aA}	3.37 ± 0.04^{aA}
	30	3.39 ± 0.04^{aA}	3.36 ± 0.04^{aA}	3.35 ± 0.03^{aA}	3.37 ± 0.04^{aA}
	45	3.38 ± 0.03^{aA}	3.36 ± 0.04^{aA}	3.30 ± 0.04^{aA}	3.34 ± 0.05^{aA}
	60	3.37 ± 0.04^{aA}	3.36 ± 0.04^{aA}		3.31 ± 0.05^{aA}
	75		3.37 ± 0.03^{aA}		3.30 ± 0.05^{aA}
	90		3.35 ± 0.04^{aA}		3.30 ± 0.05^{aA}
Color tone	0	0.64 ± 0.03^{aA}	0.65 ± 0.03^{aA}	0.64 ± 0.03^{aA}	0.64 ± 0.03^{aA}
	15	0.64 ± 0.03^{aA}	0.64 ± 0.03^{aA}	0.63 ± 0.03^{aA}	0.63 ± 0.03^{aA}
	30	0.64 ± 0.03^{aA}	0.63 ± 0.04^{aA}	0.63 ± 0.04^{aA}	0.64 ± 0.03^{aA}
	45	0.64 ± 0.04^{aA}	0.64 ± 0.04^{aA}	0.63 ± 0.04^{aA}	0.63 ± 0.03^{aA}
	60	0.63 ± 0.03^{aA}	0.64 ± 0.03^{aA}		0.63 ± 0.03^{aA}
	75		0.64 ± 0.04^{aA}		0.61 ± 0.03^{aA}
	90		0.63 ± 0.03^{aA}		0.63 ± 0.04^{aA}
Yellow color tone (%)	0	35.77 ± 1.15^{aA}	35.81 ± 1.03^{aA}	35.87 ± 1.02^{aA}	35.67 ± 1.15^{aA}
	15	35.63 ± 1.11^{aA}	35.67 ± 1.03^{aA}	35.34 ± 1.02^{aA}	35.34 ± 1.06^{aA}
	30	35.46 ± 1.12^{aA}	35.45 ± 1.02^{aA}	35.27 ± 1.01^{aA}	35.43 ± 1.02^{aA}
	45	35.81 ± 1.07^{aA}	35.63 ± 1.02^{aA}	35.46 ± 1.01^{aA}	35.30 ± 1.00^{aA}
	60	35.79 ± 1.11^{aA}	35.67 ± 1.15^{aA}		35.23 ± 1.02^{aA}
	75		35.20 ± 1.04^{aA}		34.15 ± 1.02^{aA}
	90		35.16 ± 1.14^{aA}		35.17 ± 1.02^{aA}
Blue color tone (%)	0	8.51 ± 0.29^{aA}	8.79 ± 0.23^{aA}	8.44 ± 0.28^{aA}	8.49 ± 0.21^{aA}
	15	8.57 ± 0.64^{aA}	8.20 ± 0.28^{aA}	8.64 ± 0.21^{aA}	8.85 ± 0.27^{aA}
	30	8.93 ± 0.26^{aA}	8.46 ± 0.31^{aA}	8.64 ± 0.22^{aA}	8.77 ± 0.22^{aA}
	45	8.54 ± 0.12^{aA}	8.34 ± 0.21^{aA}	8.85 ± 0.25^{aA}	8.72 ± 0.27^{aA}
	60	8.76 ± 0.21^{aA}	8.27 ± 0.31^{aA}		8.46 ± 0.21^{aA}
	75		8.43 ± 0.20^{aA}		8.46 ± 0.36^{aA}
	90		8.42 ± 0.33^{aA}		8.43 ± 0.38^{aA}
Red color tone (%)	0	55.72 ± 0.36^{aA}	55.40 ± 0.36^{aA}	55.69 ± 0.27^{aA}	55.84 ± 0.26^{aA}
	15	55.80 ± 0.53^{aA}	56.13 ± 0.25^{aA}	56.03 ± 0.21^{aA}	55.81 ± 0.22^{aA}
	30	55.60 ± 0.38^{aA}	56.09 ± 0.32^{aA}	56.09 ± 0.33^{aA}	55.80 ± 0.34^{Aa}
	45	55.65 ± 0.29^{aA}	56.04 ± 0.21^{aA}	56.28 ± 0.32^{aA}	55.98 ± 0.26^{aA}
	60	55.46 ± 0.30^{aA}	56.06 ± 0.46^{aA}		56.30 ± 0.52^{aA}
	75		55.37 ± 0.46^{aA}		56.39 ± 0.54^{aA}
	90		55.62 ± 0.59^{aA}		56.39 ± 0.56^{aA}

Note: Data in the same column with different lowercase superscript letter and data in the same row with different uppercase superscripts letters are significantly different ($p \leq .05$).

producers' requirement to extent its shelflife and preserve its quality and physical properties since the heat-treated shalgam lost its quality and started to spoil after 60th day at 4°C. The study also revealed how its physical, and bioactive properties and its microbial inactivation changed with HHP during its shelflife. It was observed that the storage time rather than the HHP processing and storage temperature affected properties of shalgam. For example, the mean initial concentrations of TSS, TA, L^*, a^*, b^*, chroma, $h°$, ΔE, caffeic acid, and all anthocyanin compounds were significantly changed by storage time, whereas no significant change was detected for conductivity, salt color intensity, color tone, YCT, BCT, RCT, the lactic acid, acetic acid, gallic acid, myricetin, *p*- coumaric acid, vanillic acid,

TABLE 7 Effect of high hydrostatic pressure, storage time, and storage temperature on the organic acids and phenolic compounds (mg/kg) of the control and the high hydrostatic pressure processed shalgam samples ($n = 3$)

		Temperature			
		4°C		22°C	
	Days of storage	Control	High hydrostatic pressure processed	Control	High hydrostatic pressure processed
Lactic acid	0	2,562.0 ± 387.0^{aA}	2,549.0 ± 299.0^{aA}	2,562.0 ± 387.0^{aA}	2,549.0 ± 299.0^{aA}
	15	2,534.7 ± 116.7^{aA}	2,856.1 ± 197.9^{a}	2,534.7 ± 116.7^{aA}	2,856.1 ± 197.9^{a}
	30	2,650.0 ± 111.9^{aA}	2,997.9 ± 183.8^{aA}	2,650.0 ± 111.9^{aA}	2,997.9 ± 183.8^{aA}
	45	2,799.0 ± 185.0^{aA}	2,772.5 ± 195.5^{aA}	2,799.0 ± 185.0^{aA}	2,772.5 ± 195.5^{aA}
	60	2,794.8 ± 136.6^{abA}	2,333.0 ± 221.0^{aAB}	2,794.8 ± 136.6^{abA}	2,333.0 ± 221.0^{aAB}
	75		2,498.0 ± 220.0^{aB}		2,498.0 ± 220.0^{aB}
	90		2,358.0 ± 187.0^{aA}		2,358.0 ± 187.0^{aA}
Acetic acid	0	139.80 ± 19.90^{aA}	137.90 ± 58.8^{aA}	127.70 ± 22.60^{aA}	148.60 ± 26.50^{aA}
	15	144.02 ± 11.85^{aA}	145.78 ± 20.54^{aA}	124.63 ± 15.18^{aA}	119.50 ± 29.90^{aA}
	30	153.29 ± 13.72^{aA}	147.21 ± 12.41^{aA}	120.20 ± 16.30^{aA}	129.10 ± 12.44^{aA}
	45	155.12 ± 15.10^{aA}	133.49 ± 13.59^{abA}	115.50 ± 26.50^{aA}	138.09 ± 13.68^{aA}
	60	158.09 ± 11.10^{aA}	137.94 ± 15.73^{aA}		126.02 ± 10.01^{bA}
	75		135.00 ± 24.9^{aA}		118.60 ± 21.9^{aA}
	90		140.53 ± 18.10^{aA}		119.80 ± 19.9^{aA}
Gallic acid	0	89.80 ± 11.3^{aA}	90.00 ± 6.80^{aA}	81.90 ± 5.70^{aA}	94.31 ± 12.26^{aA}
	15	82.64 ± 5.06^{aA}	90.79 ± 4.51^{aA}	68.66 ± 2.83^{bB}	83.80 ± 22.80^{aA}
	30	88.12 ± 6.82^{aA}	94.70 ± 10.19^{aA}	66.71 ± 3.55^{bcB}	71.90 ± 14.70^{aA}
	45	79.22 ± 9.74^{abA}	88.80 ± 9.50^{abA}	57.09 ± 7.29^{bcB}	72.04 ± 6.54^{aA}
	60	73.24 ± 7.52^{bA}	81.72 ± 6.78^{abA}		74.66 ± 4.06^{bA}
	75		81.60 ± 4.80^{abA}		70.40 ± 5.20^{bA}
	90		77.90 ± 4.20^{bA}		60.90 ± 7.00^{bA}
p-coumaric acid	0	4.86 ± 0.83^{aA}	4.01 ± 0.79^{aA}	4.08 ± 0.29^{aA}	4.52 ± 0.48^{aA}
	15	4.45 ± 0.42^{aA}	4.40 ± 0.25^{aA}	3.97 ± 0.07^{aB}	4.23 ± 0.94^{aA}
	30	4.56 ± 0.43^{aA}	4.59 ± 0.28^{aA}	3.71 ± 0.08^{aB}	4.43 ± 0.37^{aA}
	45	4.47 ± 0.40^{aA}	4.37 ± 0.38^{aA}	3.66 ± 0.22^{aB}	4.19 ± 0.23^{aA}
	60	4.58 ± 0.45^{aA}	4.29 ± 0.27^{aA}		4.99 ± 0.59^{aA}
	75		4.71 ± 0.68^{aA}		4.81 ± 0.66^{aA}
	90		4.84 ± 0.46^{aA}		4.80 ± 0.62^{aA}
Chlorogenic acid	0	18.80 ± 6.54^{aB}	18.70 ± 4.36^{aB}	17.44 ± 7.55^{aB}	34.43 ± 3.64^{aA}
	15	19.04 ± 2.41^{aB}	18.27 ± 1.33^{aB}	16.02 ± 5.20^{aB}	34.64 ± 5.21^{aA}
	30	19.27 ± 3.11^{aB}	18.61 ± 2.27^{aB}	16.83 ± 5.59^{aB}	33.22 ± 5.14^{aA}
	45	18.40 ± 2.22^{aB}	18.14 ± 3.98^{aB}	13.62 ± 5.15^{aB}	33.69 ± 3.32^{aA}
	60	17.27 ± 1.86^{aB}	18.28 ± 2.22^{aB}		34.24 ± 2.81^{aA}
	75		18.94 ± 2.00^{aB}		33.50 ± 8.50^{aB}
	90		17.53 ± 3.20^{aB}		33.55 ± 4.56^{aA}

(Continues)

TABLE 7 (Continued)

		Temperature			
		4°C		22°C	
	Days of storage	Control	High hydrostatic pressure processed	Control	High hydrostatic pressure processed
Vanillic acid	0	0.60 ± 0.05^{aA}	0.23 ± 0.07^{dB}	0.54 ± 0.03^{aA}	0.53 ± 0.07^{aA}
	15	0.59 ± 0.06^{aA}	0.39 ± 0.02^{dB}	0.49 ± 0.04^{aA}	0.53 ± 0.04^{aA}
	30	0.53 ± 0.04^{aB}	0.31 ± 0.07^{cC}	0.47 ± 0.03^{aB}	0.60 ± 0.02^{aA}
	45	0.52 ± 0.06^{aA}	0.34 ± 0.03^{aB}	0.36 ± 0.01^{dB}	0.62 ± 0.05^{aA}
	60	0.50 ± 0.07^{aA}	0.32 ± 0.06^{bB}		0.60 ± 0.33^{aA}
	75		0.31 ± 0.03^{dB}		0.61 ± 0.90^{aA}
	90		0.26 ± 0.06^{aB}		0.64 ± 0.09^{aA}
Caffeic acid	0	6.72 ± 1.44^{aA}	3.14 ± 0.64^{cB}	3.71 ± 0.59^{aB}	4.72 ± 0.51^{cA}
	15	4.20 ± 0.37^{bA}	4.57 ± 0.11^{bA}	3.08 ± 0.01^{bB}	4.48 ± 1.05^{cA}
	30	4.60 ± 0.07^{bA}	4.59 ± 0.22^{bA}	3.13 ± 0.14^{bB}	4.97 ± 0.08^{cA}
	45	4.30 ± 0.48^{bA}	4.68 ± 0.50^{bA}	2.04 ± 0.09^{cB}	5.09 ± 0.52^{cA}
	60	2.39 ± 0.87^{cC}	4.37 ± 0.36^{bB}		6.29 ± 0.18^{bA}
	75		5.25 ± 1.03^{abA}		7.13 ± 1.74^{abA}
	90		5.84 ± 0.09^{aB}		7.84 ± 0.09^{aA}
Myricetin	0	0.58 ± 0.14^{aA}	0.57 ± 0.13^{aA}	0.57 ± 0.03^{aA}	0.59 ± 0.05^{aA}
	15	0.56 ± 0.02^{aA}	0.58 ± 0.02^{aA}	0.55 ± 0.03^{aA}	0.54 ± 0.05^{aA}
	30	0.54 ± 0.03^{aA}	0.51 ± 0.02^{aA}	0.52 ± 0.04^{aA}	0.54 ± 0.14^{aA}
	45	0.55 ± 0.03^{aA}	0.56 ± 0.03^{aA}	0.50 ± 0.04^{aA}	0.52 ± 0.04^{aA}
	60	0.53 ± 0.03^{aA}	0.56 ± 0.03^{aA}		0.53 ± 0.04^{aA}
	75		0.56 ± 0.03^{aA}		0.52 ± 0.05^{aA}
	90		0.53 ± 0.03^{aA}		0.50 ± 0.05^{aA}

Note: Data in the same column with different lowercase superscript letter and data in the same row with different uppercase superscripts letters are significantly different ($p \leq .05$).

and chlorogenic acid. The treatment samples had significantly lower microbial growth during the storage time.

The HHP processing appeared as a viable option for processing shalgam. The benefits of the HHP-processed shalgam appeared to outweigh the initial high capital cost of HPP as it provides higher quality shalgam and an extended shelflife without the addition of antimicrobial agents. Further studies need to be performed with its full cost-benefit analyses in order to address its scale-up issues.

ACKNOWLEDGEMENTS

The authors would like to thank Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Agricultural Research and Policies (project no: TAGEM/16/AR-GE/35) and Republic of Turkey Ministry of Development Government Planning Agency (Project no: 2009 DPT K 120140) for financial support and Innovative Food Technologies Development Application and Research Center (YENIGIDAM) for HPLC analyses.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Ceren Ates: Data curation; Formal analysis. **Gulsun Akdemir Evrendilek:** Conceptualization; Data curation; Funding acquisition; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing-original draft; Writing-review & editing. **Sibel Uzuner:** Data curation; Validation; Visualization.

DATA AVAILABILITY STATEMENT

Data will be available upon request.

ORCID

Gulsun Akdemir Evrendilek https://orcid.org/0000-0001-5064-4195

Sibel Uzuner https://orcid.org/0000-0003-1050-8206

REFERENCES

Abdullakasim, P., Songchitsomboon, S., Techagumpuch, M., Balee, N., Swatsitang, P., & Sungpuag, P. (2007). Antioxidant capacity, total phenolics and sugar content of selected Thai health beverages. *International Journal of Food Sciences and Nutrition*, *58*(1), 77–85. https://doi.org/10.1080/09637480601140946

TABLE 8 Effect of high hydrostatic pressure, storage time, and storage temperature on the concentrations of anthocyanin compounds (mg/kg) of the control and the high hydrostatic pressure processed shalgam samples ($n = 3$)

		Temperature			
		4°C		22°C	
	Days of storage	Control	High hydrostatic pressure processed	Control	High hydrostatic pressure processed
Delphinidin 3-o-glucoside	0	1.11 ± 0.07^{aB}	2.24 ± 0.06^{aA}	1.11 ± 0.04^{aB}	2.18 ± 0.04^{aA}
	15	1.00 ± 0.05^{aB}	2.19 ± 0.03^{aA}	0.92 ± 0.06^{bB}	2.20 ± 0.06^{aA}
	30	0.80 ± 0.03^{bB}	2.14 ± 0.04^{abA}	0.65 ± 0.04^{cC}	2.12 ± 0.07^{aA}
	45	0.74 ± 0.01^{cB}	2.06 ± 0.04^{bA}	0.60 ± 0.02^{cC}	2.04 ± 0.08^{aA}
	60	0.65 ± 0.00^{dB}	1.86 ± 0.03^{cA}		1.83 ± 0.05^{bA}
	75		1.42 ± 0.04^{dA}		1.43 ± 0.03^{cA}
	90		1.18 ± 0.04^{eA}		1.16 ± 0.04^{dA}
Petunidin 3-o-glucoside	0	21.22 ± 3.04^{aA}	22.50 ± 2.32^{aA}	22.02 ± 2.57^{aA}	21.95 ± 2.20^{Aa}
	15	16.78 ± 1.51^{aA}	19.03 ± 1.18^{aA}	16.81 ± 1.36^{aA}	18.53 ± 1.33^{Aa}
	30	11.86 ± 1.04^{bB}	18.70 ± 1.13^{aA}	11.04 ± 0.53^{bB}	18.45 ± 0.72^{abA}
	45	8.06 ± 0.86^{cB}	17.45 ± 1.07^{abA}	6.98 ± 0.89^{cB}	17.71 ± 0.62^{bA}
	60	7.22 ± 0.62^{cB}	17.06 ± 0.81^{bA}		16.72 ± 0.76^{bA}
	75		17.25 ± 0.76^{bA}		16.24 ± 0.89^{bA}
	90		17.03 ± 0.58^{bA}		16.23 ± 0.81^{bA}
Malvidin-3,5-diglucoside	0	0.48 ± 0.07^{aA}	0.49 ± 0.08^{aA}	0.42 ± 0.07^{aA}	0.44 ± 0.07^{aA}
	15	0.39 ± 0.07^{aA}	0.41 ± 0.02^{aA}	0.33 ± 0.05^{aA}	0.37 ± 0.04^{abA}
	30	0.14 ± 0.04^{bB}	0.37 ± 0.06^{abA}	0.12 ± 0.05^{bB}	0.34 ± 0.06^{bA}
	45	0.04 ± 0.03^{cB}	0.34 ± 0.03^{bA}	0.02 ± 0.03^{cB}	0.29 ± 0.04^{bA}
	60	0.00 ± 0.00^{dB}	0.27 ± 0.04^{bA}		0.24 ± 0.05^{bA}
	75		0.21 ± 0.03^{cA}		0.19 ± 0.03^{cA}
	90		0.17 ± 0.03^{cA}		0.15 ± 0.04^{cA}
Peonidin-3,5-diglucoside	0	0.06 ± 0.01^{aB}	0.09 ± 0.01^{aA}	0.06 ± 0.02^{aB}	0.09 ± 0.02^{aA}
	15	0.03 ± 0.01^{bB}	0.08 ± 0.01^{abA}	0.02 ± 0.01^{bB}	0.08 ± 0.02^{aA}
	30	0.01 ± 0.00^{cB}	0.06 ± 0.01^{bA}	0.00 ± 0.01^{cB}	0.06 ± 0.01^{aA}
	45	0.00 ± 0.00^{dB}	0.04 ± 0.01^{cA}	0.00 ± 0.00^{cB}	0.03 ± 0.01^{bA}
	60	0.00 ± 0.00^{dB}	0.03 ± 0.00^{dA}		0.02 ± 0.01^{bA}
	75		0.02 ± 0.01^{eA}		0.01 ± 0.00^{cA}
	90		0.02 ± 0.01^{eA}		0.01 ± 0.00^{cA}

Note: Data in the same column with different lowercase superscript letter and data in the same row with different uppercase superscripts letters are significantly different ($p \leq .05$).

AOAC. (1990). *Official methods of analysis* (15th ed.). Association of Official Analytical Chemists.

Cabriata, L., Fossen, T., & Andersen, O. M. (2000). Colour and stability of the six common anthocyanidin 3-glucosides in aqueous solutions. *Food Chemistry*, *68*, 101–107. https://doi.org/10.1016/S0308-8146(99)00170-3

Cevallos, B. A., & Cisneros-Zevallos, L. (2004). Stability of anthocyanin based aqueous extracts of Andean purple corn and red-fleshed sweet potato compared to synthetic and natural colorants. *Food Chemistry*, *86*, 69–77. https://doi.org/10.1016/j.foodchem.2003.08.011

Chen, D., Pan, S., Chen, J., Pang, X., Guo, X., Gao, L., Liao, X., & Wu, J. (2016). Comparing the effects of high hydrostatic pressure and ultrahigh temperature on quality and shelf life of cloudy ginger juice. *Food and Bioprocess Technology*, *9*(10), 1779–1793. https://doi.org/10.1007/s11947-016-1759-1

Chen, D., Xi, H., Guo, X., Qin, Z., Pang, X., Hu, X., Liao, X., & Wu, J. (2013). Comparative study of quality of cloudy pomegranate juice treated by high hydrostatic pressure and high temperature short time. *Innovative Food Science & Emerging Technologies*, *19*, 85–94. https://doi.org/10.1016/j.ifset.2013.03.003

Coskun, F. (2017). A traditional Turkish fermented non-alcoholic beverage, "Shalgam". *Beverages*, *3*(4), 49–62. https://doi.org/10.3390/beverages3040049

Dogan, K. (2017). *Optimization of ultraviolet pasteurization conditions of shalgam (şalgam) juice and determination of its shelf life*. MSc thesis. Yildiz Teknik University.

Evrendilek, G. A. (2017). Impacts of pulsed electric field and heat treatment on quality and sensory properties and microbial inactivation of pomegranate juice. *Food Science and Technology International*, *23*(8), 668–680. https://doi.org/10.1177/1082013217715369

Fidan, I. (1975). Sarap Analiz Yöntemleri. Tekel Enstitüleri Yayınları Seri A No:11, Istanbul.

Guerrero-Beltrán, J. A., Barbosa-Cánovas, G. V., & Swanson, B. G. (2005). High hydrostatic pressure processing of fruit and vegetable products. *Food Reviews International*, *21*, 411–425. https://doi.org/10.1080/87559120500224827

Hassimotto, N. M. A., Genovese, M. I., & Lajolo, F. M. (2005). Antioxidant activity of dietary fruits, vegetables, and commercial frozen fruit pulps. *Journal of Agricultural and Food Chemistry*, *53*(8), 2928–2935. https://doi.org/10.1021/jf047894h

Inada, K. O., Torres, A. G., Perrone, D., & Monteiro, M. (2018). High hydrostatic pressure processing affects the phenolic profile, preserves sensory attributes and ensures microbial quality of jabuticaba (*Myrciaria jaboticaba*) juice. *Journal of the Science of Food and Agriculture*, *98*(1), 231–239. https://doi.org/10.1002/jsfa.8461

Incedayi, B., Uylaşer, V., & Çopur, Ö. U. (2008). Traditional Turkish beverage shalgam: Manufacturing technique and nutritional value. *Journal of Food, Agriculture and Environment*, *6*(3–4), 31–34.

Irkilmez, U. (2017). *Effect of ultrasound application on shelf life and quality properties of salgam juice in continuous systems*. MSc thesis. Yildiz Teknik University.

Justesen, U., Kunthsen, P., & Leth, T. (1998). Quantitative analysis of flavonols, flavones, and flavanones in fruits, vegetables and beverages by high-performance liquid chromatography with photo-diode array and mass spectrometric detection. *Journal of Chromatography A*, *799*(1–2), 101–110. https://doi.org/10.1016/S0021-9673(97)01061-3

Karaoglan, H. A., Keklik, N. M., & Işikli, N. D. (2017). Modeling inactivation of *Candida inconspicua* isolated from turnip juice using pulsed UV light. *Journal of Food Process Engineering*, *40*(2), 12418. https://doi.org/10.1111/jfpe.12418

Karaoglan, H. A., Keklik, N. M., & Isıklı, N. D. (2019). Degradation kinetics of anthocyanin and physicochemical changes in fermented turnip juice exposed to pulsed UV light. *Journal of Food Science and Technology*, *56*(1), 30–39. https://doi.org/10.1007/s13197-018-3434-1

Keskin, M., Setlek, P., & Demir, S. (2017). Use of color measurement systems in food science and agriculture. In *International advanced researches & engineering congress*. 16–18 November (pp. 2350–2359).

Liu, S., Xu, Q., Li, X., Wang, Y., Zhu, J., Ning, C., Chang, X., & Meng, X. (2016). Effects of high hydrostatic pressure on physicochemical properties, enzymes activity, and antioxidant capacities of anthocyanins extracts of wild *Lonicera caerulea* berry. *Innovative Food Science & Emerging Technologies*, *36*, 48–58. https://doi.org/10.1016/j.ifset.2016.06.001

Ma, Y., Yin, X., Bi, X., Su, F., Liang, Z., Luo, M., Fu, D., Xing, Y., & Che, Z. (2019). Physicochemical properties and bioactive compounds of fermented pomegranate juice as affected by high-pressure processing and thermal treatment. *International Journal of Food Properties*, *22*(1), 1250–1269. https://doi.org/10.1080/10942912.2019.1640737

Moon, J.-H., & Terao, J. (1998). Antioxidant activity of caffeic acid and dihydrocaffeic acid in lard and human low-density lipoprotein. *Journal of Agricultural and Food Chemistry*, *46*(12), 5062–5065. https://doi.org/10.1021/jf9805799

Nielsen, S. S. (2010). Sodium determination using ion selective electrodes, Mohr titration and test strips. In S. S. Nielsen (Ed.), *Food analysis laboratory manual* (pp. 75–85). Springer.

Ohta, N., & Robertson, A. (2007). *Colorimetry: Fundamentals and applications* (pp. 25–37). John Wiley & Sons.

Pathare, P. B., Opara, U. L., & Al-Said, F. A. J. (2013). Colour measurement and analysis in fresh and processed foods: A review. *Food and Bioprocess Technology*, *6*(1), 36–60. https://doi.org/10.1007/s11947-012-0867-9

Patras, A., Brunton, N. P., Tiwari, B. K., & Butler, F. (2011). Stability and degradation kinetics of bioactive compounds and colour in strawberry jam during storage. *Food and Bioprocess Technology*, *4*(7), 1245–1252. https://doi.org/10.1007/s11947-009-0226-7

Queiroz, C., Moreira, C. F. F., Lavinas, F. C., Lopes, M. L. M., Fialho, E., & Valente-Mesquita, V. L. (2010). Effect of high hydrostatic pressure on phenolic compounds, ascorbic acid and antioxidant activity in cashew apple juice. *High Pressure Research*, *30*(4), 507–513. https://doi.org/10.1080/08957959.2010.530598

Ribereau-Gayon, P., D. Dubourdieu, B. Doneche, & A. Lonvaud (Eds.). (2006). *Handbook of enology, the microbiology of wine and vinifications* (Vol. *1*). Wiley.

Rios-Corripio, G., Welti-Chanes, J., Rodríguez-Martínez, V., & Guerrero-Beltrán, J. Á. (2020). Influence of high hydrostatic pressure processing on physicochemical characteristics of a fermented pomegranate (*Punica granatum* L.) beverage. *Innovative Food Science & Emerging Technologies*, *59*, 102249. https://doi.org/10.1016/j.ifset.2019.102249

Rodríguez-Roque, M. J., de Ancos, B., Sánchez-Moreno, C., Cano, M. P., Elez-Martínez, P., & Martín-Belloso, O. (2015). Impact of food matrix and processing on the in vitro bioaccessibility of vitamin C, phenolic compounds, and hydrophilic antioxidant activity from fruit juice-based beverages. *Journal of Functional Foods*, *14*, 33–43. https://doi.org/10.1016/j.jff.2015.01.020

Sengupta, S., Jana, M. L., Sengupta, D., & Naskar, A. K. (2000). A note on the estimation of microbial glycosidase activities by dinitrosalicylic acid reagent. *Applied Microbiology and Biotechnology*, *53*(6), 732–735. https://doi.org/10.1007/s002530000327

Sokołowska, B., Skąpska, S., Fonberg-Broczek, M., Niezgoda, J., Chotkiewicz, M., Dekowska, A., & Rzoska Niezgoda, S. (2014). Inactivation and sublethal injury of *Escherichia coli* and *Listeria innocua* by high hydrostatic pressure in model suspensions and beetroot juice. *High Pressure Research*, *34*(1), 147–155. https://doi.org/10.1080/08957959.2012.664642

Sokołowska, B., Woźniak, Ł., Skąpska, S., Porębska, I., Nasiłowska, J., & Rzoska, S. J. (2017). Evaluation of quality changes of beetroot juice after high hydrostatic pressure processing. *High Pressure Research*, *37*(2), 214–222. https://doi.org/10.1080/08957959.2017.1302443

Sturm, K., Koron, D., & Stampar, F. (2003). The composition of fruit of different strawberry varieties depending on maturity stage. *Food Chemistry*, *83*, 417–422. https://doi.org/10.1016/S0308-8146(03)00124-9

Szczepańska, J., Barba, F. J., Skąpska, S., & Marszałeka, K. (2020). High pressure processing of carrot juice: Effect of static and multi-pulsed pressure on the polyphenolic profile, oxidoreductases activity and colour. *Food Chemistry*, *307*, 125549. https://doi.org/10.1016/j.foodchem.2019.125549

Tanguler, H., Gunes, G., & Erten, H. (2014). Influence of addition of different amounts of black carrot (*Daucus carota*) on shalgam quality. *Journal of Food, Agriculture and Environment*, *12*, 60–65.

Tanguler, H., Selli, S., Sen, K., Cabaroglu, T., & Erten, H. (2017). Aroma composition of shalgam: A traditional Turkish lactic acid fermented beverage. *Journal of Food Science and Technology*, *54*(7), 2011–2019. https://doi.org/10.1007/s13197-017-2637-1

Tanriseven, D., Kadiroglu, P., Selli, S., & Kelebek, H. (2020). LC-DAD-ESI-MS/MS-assisted elucidation of the phenolic compounds in shalgams: Comparison of traditional and direct methods. *Food Chemistry*, *305*, 125505. https://doi.org/10.1016/j.foodchem.2019.125505

Tsikrika, K., & Rai, K. (2019). The effect of high pressure processing on antioxidant activity of Irish potato cultivars. *Proceedings*, *11*(1), 9–13. https://doi.org/10.3390/proceedings2019011009

Turker, N., Aksay, S., & Ekiz, H. İ. (2004). Effect of storage temperature on the stability of anthocyanins of a fermented black carrot (*Daucus carota* var. *L.*) beverage: Shalgam. *Journal of Agricultural and Food Chemistry*, *52*(12), 3807–3813. https://doi.org/10.1021/jf049863s

Ulucan, E. (2019). *Effects of some physicochemical and microbiological properties of ultrasonic application on shalgam juice after fermentation*. MSc thesis. Selcuk University.

Varela-Santos, E., Ochoa-Martinez, A., Tabilo-Munizaga, G., Reyes, J. E., Pérez-Won, M., Briones-Labarca, V., & Morales-Castro, J. (2012). Effect of high hydrostatic pressure (HHP) processing on physicochemical properties, bioactive compounds and shelf-life of pomegranate juice. *Innovative Food Science & Emerging Technologies*, *13*, 13–22. https://doi.org/10.1016/j.ifset.2011.10.009

Vázquez-Gutiérrez, J. L., Plaza, L., Hernando, I., Sánchez-Moreno, C., Quiles, A., de Ancos, B., & Pilar Cano, M. (2013). Changes in the structure and antioxidant properties of onions by high pressure treatment. *Food and Function*, *4*, 586–591. https://doi.org/10.1039/C3FO30253A

Vázquez-Gutiérrez, J. L., Quiles, A., Hernando, I., & Pérez-Munuera, I. (2011). Changes in the microstructure and location of some bioactive compounds in persimmons treated by high hydrostatic pressure. *Postharvest Biology and Biotechnology*, *61*, 137–144. https://doi.org/10.1016/j.postharvbio.2011.03.008

Wang, C. Y., Wang, Y. T., Wu, S. J., & Shyu, Y. T. (2018). Quality changes in high hydrostatic pressure and thermal pasteurized grapefruit juice during cold storage. *Journal of Food Science and Technology*, *55*(12), 5115–5122. https://doi.org/10.1007/s13197-018-3452-z

Wang, Y., Liu, F., Cao, X., Chen, F., Hu, X., & Liao, X. (2012). Comparison of high hydrostatic pressure and high temperature short time processing on quality of purple sweet potato nectar. *Innovative Food Science & Emerging Technologies*, *16*, 326–334. https://doi.org/10.1016/j.ifset.2012.07.006

Yan, P. M., Xue, W. T., Tan, S. S., Zhang, H., & Chang, X. H. (2008). Effect of inoculating lactic acid bacteria starter cultures on the nitrite concentration of fermenting Chinese paocai. *Food Control*, *19*(1), 50–55. https://doi.org/10.1016/j.foodcont.2007.02.008

How to cite this article: Ates C, Akdemir Evrendilek G, Uzuner S. High-pressure processing of shalgam with respect to quality characteristics, microbial inactivation, and shelflife extension. *J Food Process Preserv*. 2021;45:e15598. https://doi.org/10.1111/jfpp.15598