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STUDY THE INFLUENCE OF THERMAL PASTEURIZATION, ULTRAVIOLET AND ULTRASOUND IRRADIATION ON THE MECHANICAL PROPERTIES, ANTIOXIDANT ACTIVITY AND BIOACTIVE SUBSTANCES OF PEAR JELLY

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ABSTRACT

The aim of this research was to investigate the impact of thermal pasteurization (TP), ultraviolet light (UV-C) and ultrasound irradiation (US) on the mechanical characteristics, antioxidant activity and bioactive content of fruit jelly. The preservation methods used were thermal pasteurization (TP), short-wave ultraviolet light (UV-C) and ultrasound (US) at 65°C/50 min for all methods. Nine types of mechanical properties of the jellies were determined by a penetration test using a texture analyzer. The influence of different low-temperature preservation methods on the antioxidant potential of the samples was investigated by three methods (DPPH, ABTS and FRAP) based on different mechanisms. The changes in bioactive components (total phenols, flavonoids, carotenoids and chlorophyll) during the technological treatment with different methods were determined. TP and UV-C did not significantly affect the mechanical properties of the samples, while US treatment made the gels firmer and more elastic. In TP, the antioxidant activity measured by FRAP assay was decreased by 50.64% and the total phenolic content was reduced by 46.66% compared to the control. Under UV-C irradiation, the antioxidant capacity according to the ABTS method reduced by 35.51%, while the content of total carotenoids was reduced 116 times compared to the control. US irradiation leads to a reduce in the radical scavenging ability of the jellies (DPPH method) by 35.15% and increases by 180.8% the content of total chlorophyll in the samples compared to the control sample.

Keywords: pasteurization (TP), ultraviolet light (UV-C), ultrasound (US) treatment, mechanical characteristics, antioxidants, bioactive substances, jellies

INTRODUCTION

Pasteurization is a process that uses heat treatment below 100°C in combination with other preservation agents such as low water activity, acidity and low temperature storage (**Chiozzi *et al.*, 2022**). The various food compounds found in many types of food are an excellent substrate for the development of most types of bacteria and their inactivation is an essential stage of food safety. Thermal pasteurization is a technological method for inactivating enzymes and destroying the vegetative cells of most pathogenic microorganisms in food products with high and low moisture content, but at the same time it leads to a reduction of the nutritional and sensory characteristics of foods (**Roobab *et al.*, 2018**). Thermal pasteurization is the most commonly used method to increase the shelf life of fruit juices and milk by inactivating pathogenic microorganisms and enzymes, but on the other hand it reduces their sensory and nutritional qualities.
Treatment with ultraviolet light is a good technology for improving food safety and reducing the risk of foodborne illnesses in the food industry. Short-wave ultraviolet light (UV-C) finds application as a technological method for the preservation of liquid, fresh or minimally processed foods, due to the significant inactivation of bacteria, the absence of toxic residues, low exploitation costs and low energy consumption (**Meléndez-Pizarro *et al.*, 2020**). UV-C light has the ability to improve or preserve the nutritional properties of fruits and vegetables. According to some authors, when certain chemical substances in food are exposed to UV-C irradiation, they are activated or transformed into bioactive components that can have health benefits for humans (**Tchonkouang *et al.*, 2023**).
Ultrasonic treatment leads to the generation of acoustic waves, as a result of which the gas bubbles in a given liquid medium are compressed and expanded very quickly, which causes a local accumulation of energy leading to a short and rapid heating up to 5500 °C and an increase in pressure up to 50 MPa (**Zhang *et al.*, 2019**).
Combining ultrasound with moderate heat treatment (above 50 °C) is called thermosonification, as this technological treatment effectively destroys various types of microorganisms and enzymes in foods and preserves their nutritional and sensory characteristics (**Abdulstar *et al.*, 2023**). The application of ultrasound facilitates the speed of reactions, saves time and costs and improves the quality of food items (**Ngo & Ngo, 2017**). The use of ultrasound has been found to accelerate food sterilization by reducing the time and intensity of heat treatment, thereby reducing flavor loss and saving energy (**Bhargava *et al.*, 2021**). Different processing methods on fruits can significantly affect their phytochemical bioavailability and antioxidant activity (**Mihaylova *et al.*, 2021**). The application of ultrasound in HPV is used as a green technology that has the ability to restore or increase the availability of bioactive compounds in different food matrices (**Cisneros-Yupanqui *et al.*, 2021; Urango *et al.*, 2021**).
The purpose of this scientific work is to investigate the influence of thermal pasteurization, ultraviolet and ultrasonic processing on the mechanical properties, antioxidant activity and bioactive substances of the samples studied.

MATERIAL AND METHODS

In a 150 ml beaker all the necessary components for the preparation of the fruit jelly are placed, which are weighed on an electronic scale with accuracy to the third place after the decimal point. The necessary ingredients for making the fruit jelly are: 1.6 g iota-carrageenan, 0.6 g sodium alginate, 1.0 g sodium citrate (buffer), 0.22 g calcium lactate pentahydrate, 0.1 g aspartame, 0.2 g cellulose fiber and 96.28 g. natural pear juice (with Brix - 12% and pH = 4.02) The initial brix of the mixture is 15.07%, and it is boiled down to a final Brix of 20% and pH 4.90-5.30. Losses from water evaporation are 24.65%. The resulting gelling mixture is poured hot into a silicone mold, which is placed in a refrigerator for 1 h/3 °C to cool and gel. The resulting jellies are then transferred to a freezer for 2 h/-21 °C to freeze completely and make them easier to remove. Frozen fruit jellies are placed in glass petri dishes and dried for 30 h at 33-35 °C. The jellies were then covered with an alginate film by immersion in 5.6% calcium lactate pentahydrate for 2 min and in a solution containing 1.3% sodium alginate, 0.025% potassium sorbate and 1.3% glycerol (plasticizer) for 12 min. The resulting jellies are dried again on glass petri dishes for 30 h at 33-35 °C. Finally, the fruit jellies are preserved by various low-temperature methods, followed by a short cooling for 10 min./-21 °C.

Technological processing of fruit jellies

The time, temperature and type of preservation methods were selected on the basis of preliminary microbiological studies in our previous unpublished study, according to which no mold growth was detected for up to 3 months. Preservation of the samples was done by applying application of different types of treatment such as heat pasteurization (TP), ultraviolet light irradiation (UV-C) and ultrasound treatment (US) at 65 °C /50 minutes in all methods used. Thermal pasteurization was done using an electric pasteurizer brand - Adler, model - AD 4496.

Ultraviolet irradiation of the sample was done by shortwave ultraviolet light (UV-C) with the help of ultraviolet device (Warmer model: JY-502). The applied ultrasound on the samples was at a frequency and power of 36 kHz and 300W respectively.

During the technological processing of the obtained fruit jelly, colorless glass packaging (glass jars).

Determination of mechanical properties

The Stable Micro Systems Texture Analyzer (SMS TA) performs various mechanical measurements such as tear strength, tear strain, compressive strength, firmness, modulus of elasticity, etc. The mechanical measurements of the fruit jellies were performed with the texture analyzer described above by a penetration test in the Y-axis uniaxial deformation mode at a compressive stress of 80% with a test speed of 2 mm/s and a post-test speed of 2 mm/s using an aluminum cylindrical probe with a diameter 5 mm (P/5) and area 19.634 mm^2. To improve statistical accuracy, seven samples were measured. The mechanical parameters force and strain are determined as the largest value at the rupture point of the resulting graph by SMS TA. The compressive stress is calculated as the ratio between the rupture force and the area of the cylindrical piston at the breaking point (**Kohyama *et al.*, 2019**). Stiffness is defined as the slope of the force-deformation curve, reported in N/mm and reflects the apparent modulus of elasticity (**Liu *et al.*, 2019**). Rupture force (Energy of penetration) represents the work done to deform the product and is calculated from the area under the force-strain curve to the rupture point (**Mirzaei *et al.*, 2021**). The toughness is a basic mechanical parameter and represents the amount of energy (J) that is absorbed by 1 m^3 of material (sample) before rupture (**Manev and Petkova, 2021**). Young's modulus is defined as the slope from the linear region of the compressive stress-strain graph (**Triawan *et al.*, 2020**). Stiffness is defined as the tearing force divided by the deformation (**Shirmohammadi & Fielke, 2017**). Adhesion is the area of the negative peak under the force-time graph (**Guiné, 2020**).

Analysis of antioxidant activity

The antioxidant potential was measured on fruit jellies pretreated by TP, UV-C and US by three different methods (DPPH, FRAP and ABTS). The DPPH method was performed as described by **Abbasi & Shah (2018)** with some modifications. To 0.15 ml of the obtained extract, 2.85 ml of a previously prepared solution of DPPH (1,1-diphenyl-2-picrylhydrazyl) (0.1 mM in methyl alcohol) was added. The chemical reaction proceeds in the dark for 15 min at 37 °C. The color change (absorbance) was measured relative to a blank sample at 517 nm. ABTS and FRAP analyses were performed according to the procedures described by **Petkova *et al.* (2017)** and **Pedro *et al.* (2021)**, respectively. The results obtained from DPPH, ABTS and FRAP assay were expressed as mol^{-3} Trolox equivalent (TE) per g^{-1} sample.

Extraction of bioactive compounds

The retrieve of the bioactive substances from the samples was performed by 70% ethanol and ultrasonic treatment. The extracts were obtained by repetition three times at 45ºC and ultrasonic treatment with a frequency of 45 kHz and a power of 30W (**Petkova *et al.*, 2017**).

Analysis of total phenols

According to the method described by **Stintzing *et al.*, (2005),** the amount of total phenols in the obtained extracts was determined using the Folin–Ciocalteu reagent. The values for the content of total phenols are presented as milligrams of gallic acid equivalents per gram of sample (mg GAE/g) according to the standard straight line (**Ivanov *et al.*, 2018**).

Analysis of total flavonoids content

Total flavonoid content was determined according to the method described by **Kivrak *et al.*, (2009)**. A 0.5 ml aliquot of the sample was added to 0.1 ml 10% $Al(NO_3)_3$, 0.1 ml 1M CH3COOK and 3.8 ml ethanol (C_2H_5OH). After incubation at room temperature for 40 minutes, absorbance was measured at 415 nm. Quercetin is used as a standard and the results were presented as mg quercetin equivalents (QE) per g dw (mg QE/g dw).

Determination of total carotenoids and total chlorophyll

The content of pigment substances (total carotenoids and total chlorophyll) in fruit jellies was determined according to the method described by **Minchev *et al.*, (2020)**.

Statistical analysis

The obtained data on the arithmetic mean values for the mechanical characteristics and the content of bioactive components were processed statistically by applying the t-Test (t-Test: Paired Two Sample for Means) to test the hypotheses regarding the difference between the mean values of two dependent samples (control and experimental sample) at a statistical significance level $\alpha = 0.05$ ($p<0.05$) using MS Excel 2010 software.

Correlation analysis

The correlation relationships between the mechanical characteristics were determined by the linear correlation coefficient (Pearson's - r) using MS Excel 2013. The statistical significance ($\alpha = 0.05$; $p<0.05$) of Pearson's coefficients (r) was determined by comparing each value of the resulting coefficient (r) with a critical value of Pearson's coefficient ($r_{cr.} = 0.950$), which was determined depending on the number of measurements (n = 4) and degrees of freedom (f = n-2 = 2). If $r \geq r_{cr}$, therefore, the correlation coefficient is statistically significant.

RESULTS AND DISCUSSION

Mechanical properties

The data obtained from the mechanical analysis performed on the fruit jellies (samples) are summarized in Table 1

Table 1 Mechanical characteristics of the samples

Types of mechanical properties	Type of treatment temperature, °C /time, min			
	Control	TP 65/50	UV-C 65/50	US 65/50
Rupture force^a (N)	1.61*±0.64^a	1.80*±0.57^a	1.82*±0.88^a	2.75*±0.57^b
Rupture deformation^a (mm)	5.62±0.36^a	5.51±0.65^a	5.25±0.81^a	5.93±0.30^a
Stress^a (kPa)	81.92±32.48^a	91.49±29.00^a	92.55±44.92^a	140.17±28.93^b
Firmness^a (N/mm)	0.27±0.11^a	0.31±0.09^a	0.34±0.18^a	0.45±0.08^b
Rupture energy^a (mJ)	3.21±1.01^a	3.65±1.34^a	3.39±1.34^a	5.42±1.11^b
Toughness^a (mJ/cm^3)	28.91±8.10^a	33.07±8.86^a	32.55±10.21^a	46.36±8.05^b
Young modulus^a (kPa)	115.81±41.99^a	134.14±34.86^a	136.51±52.46^a	192.35±32.83^b
Stiffness^a (N/mm)	0.28±0.11^a	0.32±0.09^a	0.35±0.18^a	0.46±0.08^b
Adhesiveness^a (N.s)	- 0.28±0.05^a	-0.30±0.11^a	-0.32±0.09^a	-0.27±0.09^a

Legend: *Arithmetic mean of seven measurements (n = 7) ± standard deviation. Different letter values in each row are statistically significant (p<0.05) versus control by T-test.

From the data shown in Table 1, it can be seen that the tearing force increases insignificantly when the jellies is treated with TP and UV-C relative to the control, whereas the opposite effect is observed for the US treatment. The mean values for the rupture force of the jellies treated by TP and UV-C, respectively, were similar to the rupture force of strawberry jam (**Korus *et al.*, 2017**). Preserving the samples with US resulted in a 70.8% increase in tear rupture force compared to the control. This effect is most likely due to ultrasound removing air bubbles from the jellies, resulting in a denser and firmer jelly-like structure. Regardless of the preservation method used, the tearing rupture force of the samples was many times higher compared to coconut jam with added papaya, mango and pineapple fruit pulp (**Shahanas *et al.*, 2019**).

According to the mechanical analysis, the rupture deformation of the samples treated with TP and UV-C is decreased, and of those treated with US it increases to a minimal and statistically insignificant degree compared to the control. This shows that the preservation method has no significant effect on the rupture deformation. Similar small and non-significant changes in rupture deformation were observed in apple jelly with added fiber (**Figueroa and Genovese, 2020**).

From the measurements carried out and the results obtained, it was found that the compressive strength of the samples treated by TP and UV-C increased to a minimal extent by 11.68% and 12.97%, respectively, compared to the control sample. The compressive strength of fruit jellies treated with US increased the most by 71.10% compared to the control. This effect can be attributed to the cavitation created by the ultrasound, which in turn modifies the structure and physicochemical properties by breaking the side chains of the branched polysaccharides, resulting in an increase in their flexibility (**Cui & Zhu, 2021**), and hence the tension of pressure. The compressive strength results of the samples were much lower compared to kappa-carrageenan hydrogel and sodium alginate (**Yu *et al.*, 2019**).

From the mechanical analysis, it was found that the firmness of the TP-treated increased by 14.81% and by 66.66% when treated with US, while irradiation with UV-C resulted in an increase of 25.92% over the control. This positive effect of UV-C rays on the firmness of fruit jellies is due to the fact that UV light has the ability to delay fruit softening, resulting in a firmer texture of the final product (**Lavilla *et al.*, 2019**). Regardless of the preservation method used on the samples, their firmness was always greater than the control. This fact is most likely due to the physical impact of the different preservation methods on the physicochemical properties and structure (increase of the Young's modulus and stiffness) of the jellies. The firmness of the jellies was many times higher compared to the same textural parameter of acid gel of soy protein and tare gum (**Ingrassia *et al.*, 2019**).

From the results presented in Table 1, it can be seen that the rupture energy of the jellies irradiated with UV-C increased by 5.60%, and that of the samples treated with TP and US increased by 13.70% and 68.84%, respectively, compared to the control. The significant increase in the rupture energy of the fruit jellies was due to the fact that the different preservation methods improve the mechanical parameters - toughness and modulus of elasticity relative to the control sample. The measured values for penetration energy of fruit jellies are many times lower compared to jamun and apple jam (**Garg *et al.*, 2019**).

From the measurements carried out, it was found that the toughness of the fruit jellies increased from 14.38% to 60.35% depending on the preservation method used compared to the control. A similar increase in toughness with different treatment methods was found for polyvinyl hydrogel (**Chen *et al.*, 2022**). The greatest increase in toughness was observed when the samples were treated with US, and the least with TP. This fact is most likely due to the cavitation created by the ultrasound, which leads to the rupture of the chemical bonds of the main chains of polysaccharides and the formation of new ones, which causes the formation of a denser jelly-like network (**Beikzadeh *et al.*, 2020**). The toughness is an important mechanical parameter and indicates how much energy is adsorbed per unit volume of the sample, and its value (toughness) depends largely on the rupture force, compressive strength and Young's modulus.

Regardless of the conservation methods applied, the modulus of elasticity of all samples was greater than the control. The Young's modulus is a basic mechanical parameter that indicates the linear elasticity of the samples and is used to determine the firmness of the material. The US treatment increased to the greatest and statistically significant extent the Young's modulus by 66.09%, while in the samples treated with TP and UV-C no similar significant effect was observed compared to the control. This is due to the fact that ultrasound makes the samples firmer and tougher due to a significant increase in their stiffness and rupture force. A similar significant increase in elastic modulus was found in pectin hydrogel with added starch (**Souza Almeida *et al.*, 2021**).

According to the data shown in Table 1 it is seen that the stiffness of the jellies treated with TP and UV-C increased by 14.28% and 25.00%, respectively, but in the US treatment, a significantly greater increase of 64.28% was observed compared to the control. This improvement in stiffness is most likely due to the formation of a stronger double-crosslinked structure of the alginate-carrageenan fruit jellies as a result of the applied preservation methods compared to the control. The stiffness value of the samples depends mostly on the firmness, which in turn is determined by the rupture force. The stiffness of fruit jellies is about 10 times lower compared to beagels composed of monoglyceride oleogel and kappa-carrageenan hydrogel (**Zheng *et al.*, 2020**).

Adhesion indicates the strength of attraction between the surface of a food product and other materials in contact with it (**Hamedi *et al.*, 2018**), which also indicates the connectivity with the molecular structure of the product. From the data in Table 1, it can be seen that TP and UV-C treatment of the samples resulted to a statistically insignificant increase and US treatment to a decrease in adhesiveness compared to the control. The adhesiveness results of the TP and UV-C treated samples were similar to those of beetroot juice and spinach added jelly candies (**Algarni, 2020**), and the US treated jellies were similar to those of pectin gel (**Rungraeng & Kraithong, 2020**).

Pearson correlation analysis

Pearson's correlation coefficients and its statistical significance between the mechanical parameters of fruit jellies are shown in Tables 2.

Table 2 Correlation relationships expressed by Pearson coefficients between mechanical properties

TMP:	RF	RD	CS	FI	RE	TO	MY	ST	AD
RF	**1**								
RD	0.740	**1**							
ST	1.000*	0.740	**1**						
FI	0.981*	0.597	0.981*	**1**					
RE	0.992*	0.802	0.992*	0.952*	**1**				
TO	0.997*	0.722	0.997*	0.981*	0.992*	**1**			
MY	0.995*	0.677	0.995*	0.992*	0.982*	0.998*	**1**		
ST	0.982*	0.598	0.982*	1.000*	0.953*	0.982*	0.993*	1	
AD	0.592	0.979*	0.592	0.427	0.666	0.568	0.516	0.428	**1**

Legend: TMP - types of mechanical properties, RF - rupture force, RD - rupture deformation, CS- compressive stress, FI - firmness, RE - rupture energy, TO - toughness, MY - Young's modulus, ST - stiffness and AD - adhesiveness. *Pearson's coefficient is statistically significant at a significance level of $\alpha = 0.05$ ($p<0.05$) and a critical correlation coefficient value of $r_{cr.} = 0.950$

Correlation coefficients are used to measure the strength and direction of interdependence between two or more pairs of variables (mechanical properties). From the correlation analysis carried out, it was found that the highest, statistically significant and positive correlation relationship with maximum correlation coefficient (r = 1.000*) existed between rupture force and compressive strength on the one hand and stiffness and rigidity on the other hand. The correlation coefficients between rupture force and other mechanical parameters are very high, positive and statistically significant except for rupture deformation and adhesiveness versus rupture force where moderate to high correlation is observed (r = 0.740; r = 0.592). The Pearson's coefficients for the rupture deformation versus the other mechanical parameters were positive but statistically insignificant except for the adhesiveness versus rupture deformation, where a very strong, positive and statistically significant correlation was observed (r = 0.979*). The correlation coefficients for rupture force, compressive strength, and toughness versus rupture energy are very high, positive, statistically significant, and equal in numerical value (r = 0.992*). A similar effect was observed in the linear correlation coefficients between rupture force on the one hand and compressive strength on the other hand versus toughness (r = 0.997*). Pearson's coefficients for rupture force and compressive strength versus rupture deformation are positive, statistically insignificant, and the same numerically value (r = 0.740). A similar effect was observed between the correlation coefficients for rupture force and compressive strength versus adhesiveness (r = 0.592). The correlations between compressive strength on the one hand and stiffness on the other hand versus other mechanical properties are high in numerical value, statistically significant and positive except for adhesiveness and rupture deformation where lower, positive and statistically insignificant Pearson coefficients are observed. The same correlation effects were observed for rupture energy, toughness, Young's modulus, and stiffness with respect to the other mechanical properties except for adhesiveness and rupture deformation.

Antioxidant activity of fruit jellies

Figure 1 shows the antioxidant activity results of the samples.

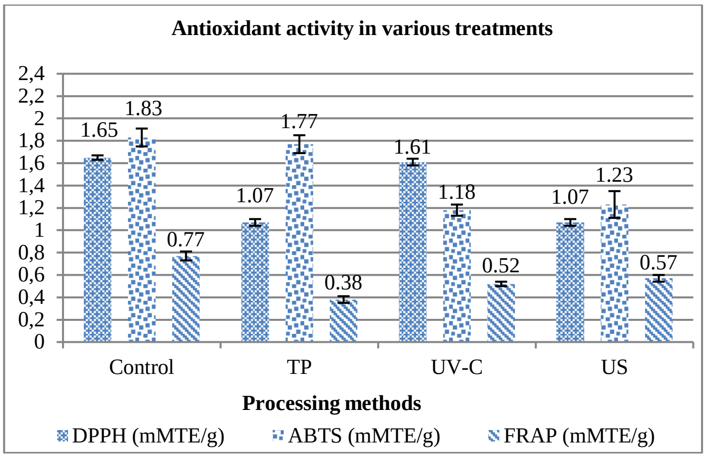

Figure 1 Values of antioxidant activity of fruit jellies under different processing methods

According to the DPPH test, the antioxidant potential of the jellies is always lower than the control sample irrespective of the preservation method used. The reduction of antioxidant activity by the DPPH method may be due to the degradation of total phenols and total carotenoids during processing. The TP and US treatments equally decreased the antioxidant potential by the DPPH method by 35.15% compared to the control.

A similar effect of TP associated with a reduction of radical scavenging capacity has been found in orange juice (**Vieira *et al.*, 2018**). UV-C treatment preserves to a greater extent compared to US and TP the antioxidant activity (by DPPH method) compared to the control. Similar effects related to more efficient preservation of antioxidant potential (by the DPPH method) with UV-C treatment compared to TP have been reported for longan juice (**Kijpatanasilp *et al.*, 2023**).

The data of the ABTS assay showed a decrease in the antioxidant activity in all samples relative to the control regardless of the preservation method used. The decrease in antioxidant capacity measured by the ABTS method is most likely due to the destructive effect of UV light on total phenols and carotenoids, which are major contributors to antioxidant properties. TP reduced the least and UV-C the most, the antioxidant potential determined by the ABTS method by 3.27% and 35.51%, respectively. ABTS analysis values of fruit jellies were many times higher relative to than Guabiroba jam - *Campomanesia xanthocarpa O. Berg* (**Prestes *et al.*, 2022**).

The iron reducing ability (FRAP) of the jellies was significantly lower compared to the control regardless of the preservation method applied. According to the FRAP test performed, the data showed that TP reduced the antioxidant potential (FRAP) by 50.64%, while UV-C and US decreased by 32.46% and 25.97% respectively. The difference in reducing effects between TP and US with respect to antioxidant activity (by FRAP method) was due to thermal pasteurization having a more pronounced destroying effect on antioxidant organic components (total phenols and flavonoids) relative to US. The results of FRAP method showed that the values were many times higher compared to the antioxidant activity (by FRAP method) of water-ethanol extract of blackberry jam (**Loizzo *et al.*, 2021**).

Bioactive components

Table 3 shows the summary results of the bioactive content using different preservation methods

Table 3 Bioactive substances of fruit jellies

Bioactive components	Type of treatment temperature, °C /time, min			
	Control	TP 65/50	UV-C 65/50	US 65/50
Total phenolics (mg GAE[1]/g)	0.15±0.03[a]	0.08±0.02[b]	0.10±0.02[c]	0.11±0.01[d]
Total flavonoids (mg QE[2]/g)	0.04±0.01[a]	0.03±0.01[b]	0.04±0.01[a]	0.04±0.01[a]
Total carotenoids (µg/g)	3.48±0.4[a]	0.12±0.02[b]	0.03±0.01[c]	0.38±0.02[d]
Total chlorophyll (µg/g)	0.47±0.05[a]	0.60±0.05[b]	0.81±0.03[c]	1.32±0.02[d]

Legend: [1]GAE – gallic acid equivalents; [2]QE – quercetin equivalents. Arithmetic mean of three measurements (n=3) ± standard deviation. Different letter values in each row are statistically significant ($p<0.05$) versus control by T-test.

From the data shown in Table 3, it can be seen that TP reduced the total phenolic content the most by 46.6%, followed by the US (26.6%) and UV-C (33.3%) treatments relative to the control. The reduction in total phenolics may be due to the additional thermal heating during sample preservation resulting in phenolic compounds being degraded, oxidized and polymerized with proteins (**Hind Saad Abu-shama *et al.*, 2022**). Significantly lower values of total phenolics compared to our results were found in apple jelly (**Hasani & Yazdanpanah, 2020**).

No statistically significant changes in total flavonoid content were observed in the UV-C and US treated samples compared to the control, whereas the opposite effect was observed in TP. Flavonoids reduction is most likely due to their thermal or chemical degradation during the process treatment (**Chalchisa *et al.*, 2022**). According to the reported data by **Grigio *et al*.** (**2022**), the contents of total flavonoids in camu-camu (*Myrciaria dubia*) and passion fruit jelly were significantly higher compared to our obtained results.

In all applied preservation methods, the content of total carotenoids was significantly reduced ($p<0.05$) compared to the control. UV-C irradiation reduced the carotenoid content 116 fold, followed by TP 29 fold and US 9 fold. This strong reducing effect by preservation methods can be explained by the isomerization or oxidation of carotenoids, which is related to the destruction of the nutrient matrix and the low stability of their polyene chain (**Vieira *et al.*, 2018**). The results for total carotenoid content in the samples were many times lower compared to the values reported by **Oliveira *et al.* (2020)** for monkey nut (*Anacardium humile*) fruit jelly.

The total chlorophyll content of the samples increased statistically significantly ($p<0.05$) relative to the control depending on the preservation methods used. According to the analysis performed, US treatment increased the amount of total chlorophyll by 180.8%, followed by UV-C and TP by 72.3% and 27.6%, respectively, relative to the control. This effect, according to some authors (**Ahmed *et al.*, 2019; Faisal *et al.*, 2021**), might be due to the fact that ultrasound enhances chlorophyll extraction as a result of pore dilation in plant cell walls and due to the lack of destructive effect on photosystem II of chlorophyll-protein complexes.

The increase in total chlorophyll during TP and UV-C treatments is due on the one hand to the formation of chlorophyll derivatives as a result of the heat treatment, which removes the magnesium atom from the porphine ring of chlorophyll, and on the other hand UV-C irradiation inhibits the enzymes chlorophyllase and Mg-dechelatase, which are responsible for the degradation of chlorophyll molecules (**Ebrahimi *et al.*, 2023**).

CONCLUSION

Treatment of jellies with TP and UV-C results in minimal changes in mechanical properties. Irradiation with US significantly improves the mechanical properties of the jellies by making them firmer and more elastic due to its strong physical effect on their jelly-like structure. In the TP treatment, the antioxidant activity determined by the ABTS method was preserved to the greatest extent, and the content of total phenols reduced the most compared to the control. The different preservation methods did not have a significant effect on changes in total flavonoids. UV-C irradiation reduced least the antioxidant activity according to the DPPH method the least and the amount of total carotenoids reduced to the most. US had the least reducing effect on iron reducing ability (FRAP) and heighten the total chlorophyll content of the samples the most.

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