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IMPACT OF THERMAL, ULTRAVIOLET AND ULTRASONIC TREATMENT ON MECHANICAL, PHYSICOCHEMICAL AND SENSORY CHARACTERISTICS OF PEAR JELLY

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Abstract: *The purpose of this study is to evaluate the influence of thermal, ultraviolet and ultrasonic processing by examining the mechanical, physicochemical and sensory characteristics of pear fruit jelly. Samples were processed using thermal pasteurization (TP), ultraviolet light (UV-C) and ultrasound (US) at 65°C/50 min for all methods. US increases the most mechanical performance values compared to TP and UV-C treatment which reduces them. TP does not statistically significantly alter most physicochemical characteristics except for sugars, where it exhibits a slight reducing effect. UV-C irradiation increases water activity and moisture content the most compared to other treatments and has the least reducing effect on sugars. The US treatment significantly reduces the glucose, fructose and sucrose in the highest amount and increases total solids and soluble solids contents. In terms of color characteristics, TP treatment makes the color of the samples darker, UV-C irradiation more saturated, and US preserves the original colour best. The strongest correlations between physicochemical and colour parameters have positive and statistically significant Pearson coefficients. Different processing methods had different effects on the sensory characteristics, with UV-C improving aroma, US taste and texture, and TP having no significant effect on these.*

Key words: *thermal, ultraviolet and ultrasonic treatment, jelly, pears.*

1. Introduction

Thermal pasteurization is a type of thermal process in which heat treatment below 100°C is applied and can be combined with other preservation methods such as low-temperature storage, acidity or low water activity [7]. Low-temperature pasteurization is one of the most commonly used heat preservation methods for low or high moisture content, but at the same time it leads to a reduction in the nutritional and sensory characteristics of foods [30].

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Thermal pasteurization is a widely used low-temperature preservation method that results in significant changes in the bioactive content (total polyphenols, carotenoids, and vitamin C) of fruit juices and fruit-milk beverages [20], as well as some fruit jellies [5, 12]. Thermal pasteurization is one of the most commonly used and inexpensive methods for destroying pathogenic microorganisms and inactivating enzymes in order to increase the shelf-life and safety level of foods during their technological processing.

Ultraviolet light with a wavelength of 200-280 nm (UV-C) has the highest germicidal effect [33]. The action of this bactericidal effect is based on the ability of UV-C to damage the DNA or RNA of fungi, viruses, and bacteria through interaction between UV light photons and the genetic material of microorganisms [34]. When treating foods with UV-C, the dose of UV irradiation should be carefully monitored and the physicochemical characteristics of the finished foods should be observed because UV-C can cause adverse reactions such as degradation of proteins and antioxidants, reduction of vitamins, discoloration and generation of unpleasant odor [8].

According to some authors, US processing can reduce color changes, minimize mass loss during storage, and reduce softening by improving firmness in fruits and vegetables [11]. Ultrasonic processing minimizes flavor loss, conserves energy, and improves food homogeneity by reducing the time and intensity of the heat treatment [3]. Ultrasound (US) treatment has an antimicrobial effect on fruits and vegetables due to cavitation and free radical formation [24]. US irradiation can significantly improve the retention rate of some important nutrients (carotenoids, phenolic components, anthocyanins and ascorbic acid) in fruit and vegetable products. The purpose of this study is to investigate the effects of thermal, ultraviolet and ultrasonic processing on mechanical, physicochemical and sensory characteristics of pear fruit jelly.

2. Materials and Methods

2.1. Preparation of Pear Jelly

In a 150 ml beaker, all the necessary chemical substances are added to make the fruit jelly from pears. The necessary ingredients to make the fruit jelly are: gelling agents (iota-carrageenan and sodium alginate with a total concentration of 2.2%, mixed in a ratio of 2.7:1), 1.0% sodium citrate, 0.22% calcium lactate, 0.1% aspartame, 0.2% vegetable fiber and 96.28% natural pear juice. The initial Brix of the mixture was 15.1% and was boiled down to a final Brix of 20% and a pH of 4.90-5.30%. Losses from water evaporation are 24.65%. The gelling mixture is molded and cooled at 3-5°C for 2 hours. The resulting jellies were then frozen at -25°C for 3 hours. Frozen samples are dried at 33-35°C for 30 hours. The resulting jellies were coated with a calcium-alginate film by immersion in a calcium bath for 2 minutes containing 5.6% calcium lactate. The samples were then re-immersed for 12 minutes in a solution containing 1.3% sodium alginate, 0.025% potassium sorbate and 1.3% glycerol. The resulting edible film on the fruit jellies is dried again at 33-35°C for 30 hours. The ready-made fruit jellies are processed by various preservation methods followed by a short cooling for 5 min./-25°C.

2.2. Technological Processing of Pear Jelly

The sample processing used thermal pasteurization (TP), UV light irradiation (UV-C) and ultrasonic treatment (US) at 65°C/50 min for all methods. Thermal pasteurization was done using an electric pasteurizer brand - Adler, model - AD 4496. The UV treatment of the product was carried out using UV light of 254 nm wavelength through an ultraviolet sterilizer - Towel Warmer model: JY-502 with power 200 W. Ultrasonic irradiation (US) was done in ultrasonic bath - Siel Gabrovo UST 5.7-150 with power 300W and sound frequency 36 kHz. During the technological processing of the fruit jellies colorless glass containers of 25 ml were used.

2.3. Mechanical Analysis of Pear Jelly

Various mechanical measurements such as force, strain, compressive stress, stiffness, modulus of elasticity, etc. are performed with the Stable Microsystems Texture Analyzer. The mechanical analysis of the samples was done by penetration test in uniaxial deformation mode along Y axis at maximum strain of 80% with test speed of 2 mm/s and post-test speed of 2 mm/s using an aluminum cylindrical probe of 5 mm diameter (P/5) and area of 19.634 mm^2. Rupture force and rupture deformation (distance) are defined as the maximum value of the first inflection point from the penetration curves obtained using the texture analyzer. The compressive stress is calculated by dividing the force by the cross-sectional area of the probe at the rupture point [16]. Stress is the change in the ratio of the length or volume of the material (sample) to its original size [29]. Stiffness is defined as the slope of the force-deformation curve reported in N/mm and reflects the apparent modulus of elasticity [22]. Young's modulus is defined by the slope of the compressive stress-strain curve in the linear elastic regime [35].

2.4. Physicochemical Analysis of Pear Jelly

Water activity (a_w) was measured at 25°C using a portable water activity analyser – HydroPalm – HP23-AW-A by Rotronic. Moisture content and total dry weight were determined using an XY-100W halogen hygrometer in automatic mode and at a constant temperature of 105°C. Solid soluble solids (°Brix) content was measured using an Abbe 325 refractometer. Active acidity (pH) was measured at 25°C using a digital pH - meter (Milwaukee MW 102). Glucose, fructose and sucrose contents were determined by liquid chromatograph - HPLC Elite Chrome Hitachi coupled with a Chromaster 5450 refractive index detector (*RID*) at a flow rate of 1 ml/min and an injection volume of 20 µl.

2.5. Measurement of the Colour of Pear Jelly

The colour analysis was carried out using a digital portable handheld colorimeter model - PCE-CSM5 v.1.2 with light source D65. The results were expressed as CIE (L^*, a^*, b^*) system which represents L^* - lightness of colour, a^* - redness and b^* - yellowness respectively. Colour intensity (C^*), colour hue (°*hue*), total colour difference (ΔE), browning index (*BI*) and yellowness index (*YI*) were analyzed according to Nistor et al. [25] and were calculated using Equations (1)-(5).

$$C^* = \left(a^{*2} + b^{*2}\right)^{1/2} \qquad (1)$$

$$°hue = \arctan\left(\frac{b^*}{a^*}\right) \qquad (2)$$

$$\Delta E = \left(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}\right)^{1/2} \qquad (3)$$

$$BI = \frac{100 \cdot \frac{a^* + 1.75 \cdot L^*}{5.645 \cdot L^* + a^* - 3.012 \cdot b^*} - 0.31}{0.17} \qquad (4)$$

$$YI = \frac{142.86 \cdot b^*}{L^*} \qquad (5)$$

2.6. Sensory Evaluation of Fruit Jellies

The sensory analysis of pear fruit jellies was performed by applying sensory descriptive analysis according to ISO 6658:2017. The sensory analysis was performed by 15 tasters (5 men and 10 women) aged from 33 to 56 years from the Department of Food Technology at the Institute of Food Preservation and Quality - Plovdiv, Bulgaria. The sensory characteristics of four samples of the fruit jellies preserved by TP, UV-C, US and the control were evaluated. Tasters evaluated the product on certain sensory characteristics: colour, aroma, taste and texture. Samples were evaluated using a 10-point scale (1-10) where 9-10 = excellent; 7-8 = very good; 5-6 = good; 3-4 = average; 1-2 = poor/not acceptable [15]. The more pronounced a sensory characteristic of the product, the higher the score.

2.7. Statistical Analysis

The results obtained for the mechanical, physicochemical and sensory characteristics were statistically processed by applying t-Test (t-Test: Paired Two Sample for Means) to test the hypotheses regarding the difference between the means of two dependent samples (control and experimental sample) at a statistical significance level of α=0.05 ($p<0.05$) using the M.S. Excel 2010 software.

2.8. Correlation Analysis

All Pearson's correlation coefficients between the mechanical characteristics were determined by the Pearson's sample correlation coefficient using M.S. Excel 2010. The statistical significance of the Pearson correlation coefficients (r) were determined by comparing each sample Pearson coefficient with the critical value of the Pearson coefficient (r_{cr}) at a significance level of α = 0.05 ($p<0.05$) and degrees of freedom - f = n-2, where n - is the number of measurements (number of samples) such as n = 4; f = 2; r_{cr} = 0.950. If the determined Pearson's coefficient by absolute value is equal or greater than the critical value (0.950) - the coefficient is statistically significant.

3. Results

3.1. Mechanical Analysis of Pear Jelly

Figures 1 and 2 show graphically the changes in mechanical characteristics – force-distance, compressive stress-strain and the determined stiffness and Young's modulus for the different processing methods compared to the control.

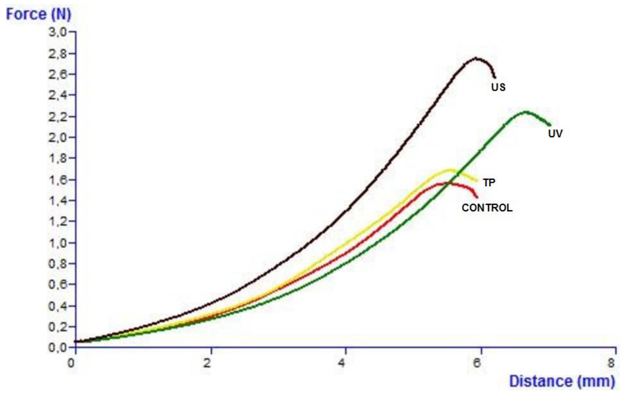

Fig. 1. *Typical force versus distance curves of fruit jellies treated by thermal pasteurization (TP), ultraviolet light (UV-C) and ultrasound (US)*

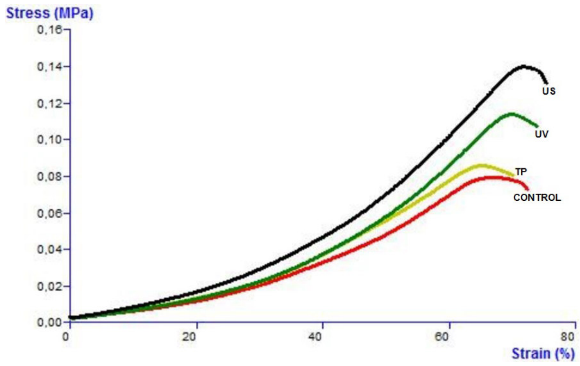

Fig. 2. *Stress - strain curves of fruit jellies processed by thermal pasteurization (TP), ultraviolet light (UV-C) and ultrasound (US)*

3.2. Physicochemical Analysis of Pear Jelly

The results of the physicochemical analysis of the samples under different treatments are reported in Table 1.

3.3. Colour Characteristics of Pear Jelly

Table 2 shows a summary of the results of the colour parameters obtained from the colour analysis of the samples under different treatments.

3.4. Pearson Correlation Analysis

Pearson's correlation coefficients and its statistical significance between physicochemical characteristics and colour parameters of fruit jellies are shown in Table 3.

3.5. Sensory Evaluation of Pear Jelly

Figure 3 shows the values of the scores from the sensory analysis performed on the fruit jellies treated by thermal pasteurization (TP), UV light (UV-C) and ultrasound (US) compared to the control.

Physicochemical characteristics of pear jelly Table 1

Physicochemical characteristics	Types of processing temperature [°C/time, min.]			
	Control	TP	UV-C	US
		65°C/50	65°C/50	65°C/50
pH	6.36* ± 0.03[a]	6.34* ± 0.02[a]	6.39* ± 0.01[b]	6.38* ± 0.04[a]
MC [%]	53.30 ± 1.03[a]	52.96 ± 1.76[a]	54.60 ± 2.23[a]	51.39 ± 1.29[a]
DM [%]	46.70 ± 1.03[a]	47.04 ± 1.76[a]	45.23 ± 2.31[a]	49.85 ± 0.94[b]
TSS [°Brix]	41.28 ± 2.88[a]	42.83 ± 1.48[a]	41.52 ± 4.09[a]	44.02 ± 1.99[a]
a_w	0.85 ± 0.01[a]	0.85 ± 0.06[a]	0.88 ± 0.01[b]	0.86 ± 0.01[c]
GC [%]	0.25 ± 0.03[a]	0.08 ± 0.03[b]	0.21 ± 0.08[a]	0.05 ± 0.02[c]
FC [%]	1.25 ± 0.14[a]	1.00 ± 0.08[b]	1.12 ± 0.11[c]	0.87 ± 0.05[d]
SC [%]	0.55 ± 0.05[a]	0.15 ± 0.04[b]	0.45 ± 0.05[a]	0.02 ± 0.01[c]

Note: TP – thermal pasteurization; UV-C – ultraviolet light; US – ultrasound; MC – moisture content; DM – dry matter; TSS – total soluble solids (°Brix); a_w – water activity; GC – glucose content; FC – fructose content; SC – sucrose content; * Mean value of seven measurements (n=7) ± standard deviation; Values followed by the same letters in each row are not statistically significant (p>0.05) compared to control according to the t-test

Colour parameters of pear jelly Table 2

Colour parameters	Types of processing temperature [°C/time, min.]			
	Control	TP	UV-C	US
		65°C/50	65°C/50	65°C/50
L*	35.04 ± 1.64[a]	34.55 ± 0.84[a]	36.12 ± 0.55[a]	34.44 ± 0.83[a]
a*	4.29 ± 0.17[a]	4.70 ± 0.38[b]	4.60 ± 0.55[a]	4.61 ± 0.15[c]
b*	12.44 ± 1.48[a]	12.63 ± 1.05[a]	13.22 ± 0.55[a]	12.29 ± 1.65[a]
C*	13.17 ± 1.44[a]	13.48 ± 1.02[a]	14.01 ± 0.58[a]	13.13 ± 1.60[a]
°hue	70.82 ± 1.75[a]	69.52 ± 1.79[a]	70.81 ± 2.23[a]	69.26 ± 1.96[b]
ΔE	-	2.80 ± 1.11[b]	2.34 ± 1.36[c]	2.06 ± 1.12[d]
YI	50.70 ± 5.33[a]	52.23 ± 4.45[a]	52.29 ± 2.43[a]	50.89 ± 5.83[a]
BI	12.24 ± 0.76[a]	13.29 ± 1.05[b]	12.69 ± 1.13[a]	13.03 ± 0.54[c]

Note: TP – thermal pasteurization; UV-C – ultraviolet light; US – ultrasound; L^* - lightness; a* – redness; b^* – yellowness; C^* – colour saturation/intensity; °hue – colour tone; ΔE – total colour difference; YI – yellowing index, and BI – browning index; *Mean value of seven measurements (n=7)±standard deviation; Values followed by the same letters in each row are not statistically significant (p>0.05) versus control according to the t-test

4. Discussion

4.1. Mechanical Analysis of Pear Jelly

The results plotted graphically in Figure 1 show the type and magnitude of the slope of the curves obtained from the penetration test by the texture analyser of the samples. Regardless of the processing method applied to the fruit jellies, each of the curves is characterized by the presence of a linear and the absence of a non-linear section. The slope of the linear section of each of the typical curves shown corresponds to the elastic deformation and firmness of the samples. The absence of a non-linear section near the inflection point of the curve indicates that the jellies do not exhibit plastic deformation, but only elastic deformation.

TP-treated samples have significantly lower force compared to UV-C and US irradiated gels. This fact is due to the difference in the slope and length of each individual curve. Figure 1 shows the force values that are significantly higher compared to the same mechanical parameter of heat-treated binary hydrocolloid gels [21].

Table 3

Pearson correlation coefficients between physicochemical characteristics of fruit jelly

TMP:	pH	MC	DM	TSS	a_w	GC	FC	SC	L*	a*	b*	C*	°hue	ΔE	YI	BI
pH	1															
MC	0.168	1														
DM	-0.024	-0.989*	1													
TSS	-0.035	-0.869	0.886	1												
a_w	0.850	0.525	-0.400	-0.199	1											
GC	0.197	0.753	-0.748	-0.961*	0.218	1										
FC	-0.074	0.716	-0.751	-0.967*	-0.014	0.963*	1									
SC	0.128	0.785	-0.790	-0.981*	0.189	0.996*	0.978*	1								
L*	0.593	0.893	-0.819	-0.730	0.814	0.709	0.556	0.704	1							
a*	-0.025	-0.142	0.161	0.599	0.276	-0.755	-0.764	-0.724	-0.135	1						
b*	0.385	0.886	-0.834	-0.552	0.792	0.424	0.321	0.449	0.896	0.267	1					
C*	0.365	0.824	-0.772	-0.442	0.795	0.299	0.199	0.327	0.836	0.394	0.991*	1				
°hue	0.290	0.830	-0.810	-0.962*	0.364	0.987*	0.923	0.983*	0.814	-0.649	0.559	0.442	1			
ΔE	0.017	-0.027	0.051	0.507	0.358	-0.673	-0.693	-0.640	-0,022	0.993*	0.378	0.499	-8.549	1		
YI	-0.069	0.585	-0.587	-0.147	0.458	-0.090	-0.078	-0.031	0.441	0.702	0.793	0.853	0.035	0.772	1	
BI	-0.294	-0.410	0.391	0.756	-0.078	-0.903	-0.840	-0.868	-0.475	0.933	-0.067	0.066	-0.849	0.889	0.499	1

Note: MC – moisture content; DM – dry matter; TSS – total soluble solids (°Brix); a_w – water activity; GC – glucose content; FC – fructose content; SC – sucrose content; *Pearson's coefficient is statistically significant at significance level α=0.05 ($p<0.05$) and $r_{cr.}$=0.950

From Figure 1, it can be seen that the deformation of the TP-treated jellies is statistically insignificantly smaller compared to the control. The UV-C and US treatment of the jellies showed significantly greater deformation compared to TP and control. This fact is due to the larger slopes and longer linear sections of the UV-C and US curves whereas no similar dependence was observed for TP compared to control. The present study results for the deformation of samples treated by TP, UV-C and US are numerically higher compared to composite alginate beads [27].

The line sections of the control and TP curves are almost identical, indicating that these samples have very similar mechanical characteristics whereas no similar trend is observed between the UV-

C and US curves. The UV-C curve has a longer linear section (greater deformation) and a smaller slope (less firmness and force) compared to the US curve. This means that the UV-C treated jellies are softer and more elastic compared to the US irradiated samples. Regardless of the type of treatment applied to the samples, their firmness is always greater compared to the control due to the greater slope (TP and US) or greater length (UV-C) of a given curve type.

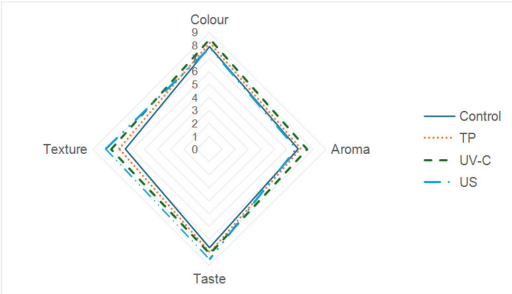

Fig. 3. *Sensory characteristics of pear jelly*

From the data shown in Figure 2, it can be seen that the compressive stress of the TP treated samples increased to the least extent compared to the control, while the opposite effect was observed for the UV-C and US irradiation. The significantly higher compressive stress of the gels in UV-C and US treatments is due to the greater slope of the curves. In Figure 2 it can be seen that TP increases the compressive stress the least and US treatment the most. The highest increase in compressive stress with US irradiation is probably due to the fact that the ultrasound creates cavitation, which in turn significantly changes the mechanical and physicochemical characteristics of the samples. The values for compressive stress of the samples shown (Figure 2) are many times higher compared to agar jelly with chickpea puree [23].

It can be seen from the curves in Figure 2 that the results for the stress between the control and TP on the one hand and UV-C and US on the other hand are very close in numerical value, indicating that they have similar force of jelly structure. From Figure 2, it can be seen that TP increases the least and US the most in tension as compared to the control sample. The strain curves shown in Figure 2 are similar to those of osmotically dried composite gels with maltodextrin added at 80% strain [14].

The Young's modulus, or modulus of elasticity, indicates the linear elasticity of deformation of the samples. The US curve in Figure 2 has the largest modulus of elasticity compared to the control and other processing methods. This fact is due to the fact that ultrasound changes the structure of the jellies making them harder and more ductile as a result of the increase in their strength and stiffness. Regardless of the type of treatment applied to the samples, their elastic modulus is higher compared to the control, which is untreated due to the greater slopes and lengths of the linear sections of the curves. A similar effect associated with an increase in the elastic modulus (Young's modulus) as a result of heat treatment has been reported for gel beads composed of sodium alginate and starch [37].

4.2. Physicochemical Analysis of Pear Jelly

The active acidity of fruit pulp is a very important physicochemical characteristic that significantly influences gel structure formation in jams and jellies. From the data in Table 1, it can be seen that the active acidity (pH) varies in a very narrow range, indicating that the applied preservation methods do not significantly alter this physicochemical parameter. Regardless of the treatment method used, the pH values obtained for the samples were similar to those of hydrogel with added *Eclipta alba* extract [17].

From the physicochemical analysis performed, it was found that the three treatment methods (TP, UV-C and US) resulted in negligible and statistically insignificant changes in moisture content. A similar insignificant effect of TP and UV-C was observed on dry matter. The US treatment showed a significant increase in dry matter, most likely due to the additional release and dispersion of polysaccharides from the plant cells into the finished product.

Regardless of the sample processing method applied, total soluble solids (TSS) changed over a very small and statistically insignificant ($p>0.05$) range. The soluble solids (°Brix) of fruit jellies were less compared to gelatin jelly with mint extract [1].

The variation in water activity (a_w) is determined by the equilibrium compared humidity (*ERH*), which in turn depends on the moisture content of the food product and compared water vapour pressure in the ambient air, which is in equilibrium with the material [18]. The a_w values of samples treated with UV-C and US were higher compared to the control, while no similar trend was observed for the TP treatment. This physicochemical effect is most likely due to the fact that prolonged irradiation of a food product with UV light or ultrasound may further increase its internal temperature [9, 31]. This, in turn, leads to an increase in the air temperature in a closed system and, respectively, the partial pressure of saturated water vapor over the system according to the Arden Buck equation [38], hence an increase in compared humidity and, respectively, the water activity of the samples. The results for Aw of fruit jellies are similar to those of velvet tamarind jelly [6].

Of the preservation methods applied, only the UV-C treatment changed the amounts of glucose and sucrose statistically insignificantly, while the other two methods (TP and US) did not show a similar effect. US irradiation reduced 5.0 times and TP treatment 3.1 times the amount of glucose compared to the control. Our results for glucose and fructose in fruit jellies are significantly lower than those reported by other authors [32].

The US treatment reduced to the greatest extent the amount of fructose monosaccharide, i.e. by 30.40%, as compared to the control, whereas this reduction was less pronounced for the other methods (TP and UV-C). This significant reduction in fructose content in TP, UV-C and US treatments may be due to induction of free radicals during UV-C irradiation, i.e. a photochemical reaction taking place and significant thermal heating in TP and US resulting in fructose being converted to furan [13].

TP and US treatment of the samples reduced sucrose content to a greater extent compared to UV-C irradiation. US reduced the most sucrose content (27.5 times), followed by TP (3.6 times) and UV-C (1.2 times) compared to the control. The amount of sucrose in the samples decreases during the technological processing by TP and US, which may be due to degradation or oxidation processes during the Maillard reaction [19]. In all processing methods, the sucrose content of fruit jellies was many times lower compared to the results reported for carrageenan jelly from soy milk [26].

4.3. Colour Characteristics of Pear Jelly

The *L** values shown in Table 2 of the samples change negligibly little and statistically insignificantly, indicating that the different preservation methods do not make the samples significantly lighter or darker. The determined lightness (*L**) of jellies treated by TP,UV-Cand US are very close to the value of the same colour parameter of thermally treated grapefruit jelly with reduced sugar content [2].

The TP and US treatments resulted in a significant increase in the reddishness (*a**) of the jellies compared to the control, whereas no undercutting effect was observed with the UV-C treatment. On the other hand, TP, UV-C and US treatments of fruit jellies did not change the *b** – values to a statistically significant extent compared to the control, indicating retention of the basic yellow colour. According to some authors, this colour protection is due to the calcium-alginate hydrogel coating on the fruit jellies, which protects β-carotene from oxidative degradation and fading [39].

From the results shown in Table 2, it can be seen that the colour intensity (*C**) does not change statistically significantly regardless of the processing method used, meaning that the jellies have similar colour intensity. The C* – value of the jellies processed by TP is very close in numerical value to the colour intensity reported for Jaboticaba jelly [28].

°Hue – the value of gels irradiated with UV-C was statistically indistinguishable from that of the control, whereas no similar trend was observed for the US treatment. The UV-C treatment imparted a slightly more greenish hue to the samples compared to TP and UV-C, which is most likely due to the greater degradation of the dye substances by UV-C, as confirmed by the higher colour hue (°hue) value. The jellies treated with TP and US have a more yellowish hue due to the better preservation of the yellow pigment substances (carotenoids).

The change in total colour difference is used to estimate the difference in colour between two samples [4]. The colour difference was statistically significant ($p<0.05$) for all preservation methods applied compared to the control. The highest value of *ΔE* was found in jellies treated with TP followed by UV-C and US treatments. On the other hand, a smaller overall colour difference (*ΔE*) means that the colour of the sample is more identical in colour parameters to that of the control, which means significantly better colour preservation and vice versa. TP changes the colour to the greatest extent due to the highest values of *a** and *BI* making the samples darker in colour. UV-C irradiation lowers *ΔE* to a greater extent compared to TP, and US changes the colour difference the least, preserving the original colour of the samples best as compared to the control. Fruit jellies treated with US have the lowest *ΔE* value because the colour characteristics (*L*, b** and *C**) are the lowest in numerical values as compared to the control and compared to the other two treatments (TP and UV-C).

Regardless of the processing methods applied, the yellowing index (YI) of the samples was higher compared to the control. According to the results in Table 2, the TP and UV-C treatments increased the YI slightly more compared to the control, while the US irradiation showed the opposite effect, which was due to the changes in the yellowness (*b**) values. Higher YI values mean that the fruit jellies have a lighter and deeper yellow colour and vice versa, which is confirmed by the changes in *L** and *a**. The increase in *YI* of the samples is due to longer UV-C irradiation, which in turn leads to a greater increase in *b** and *C** values. Another reason for the increase in YI is the stronger browning of the samples (increase in *BI*) at TP as a result of the Maillard reaction, which leads to a larger colour difference (*ΔE*). When the jellies are treated with US, the YI increases to the least extent due to the more sparing effect of the ultrasound on the pigment substances (carotenoids) and the Maillard reaction taking place to a lesser extent (lower *BI*).

The TP and US treatments made the jellies darker in colour, which was confirmed by the increase in *BI* to a greater and more significant extent with UV-C irradiation as compared to the control. The greater increase in BI under TP and US treatments may be due to the degradation of yellow pigments (carotenoids) and vitamin C (ascorbic acid) on the one hand and the progress of partial caramelization and the Maillard reaction on the other hand. UV-C irradiation had no significant effect on BI in contrast to the other two methods (TP and US). This is due to the fact that no significant amount of brown pigment substances (melanoidins) are formed under UV light and no degradation of the available pigment components occurs due to the protective action of the calcium alginate coating of the samples.

4.4. Pearson Correlation Analysis

Pearson coefficients are used to measure the strength and direction of the linear correlation between two or more pairs of variables (mechanical characteristics). According to the data shown in Table 3, the correlation coefficients between the sugars (glucose and sucrose) and the colour characteristics *a** and *ΔE* were the highest, positive and statistically significant (r = 0.996; r = 0.993).

From the correlation analysis performed, it was found that pH has only one very strong and positive correlation with water activity (r = 0.850), while no similar trend was observed for the other variables. The linear correlation between moisture content and total dry matter was very strong and statistically significant but negative (r = -0.989), indicating that as one variable increases, the other decreases. Another similar negative and very strong but statistically insignificant correlation was observed between moisture content and Brix (r = -0.869).

Pearson's coefficients for moisture content versus colour parameters (*L*, b*, C** and *°hue*) are positive and very high, but statistically insignificant. The correlation coefficients for total dry matter and the colour characteristics *L*,* *b** and *°hue* were high but statistically insignificant and negative (r = -0.819; r = -0.834; r = - 0.810). The Pearson's coefficients between moisture content and *b** and between total dry matter and Brix were positive and the same in numerical value (r = 0.886).

The correlation coefficients of Brix versus glucose, fructose and sucrose (r = -0.961; r = -0.967; r = - 0.981) on the one hand and colour hue (*°hue*) on the other hand (r = -0. 962) were high and statistically significant but negative in numerical value. Pearson's coefficients for glucose versus sugars (fructose and sucrose) and colour parameters (*°hue* and *BI*) are very high, positive and statistically significant. The strongest correlations with respect to fructose were observed with sucrose and colour hue (r = 0.978; r = 0.923). A similar but statistically significant correlation trend was found between sucrose and colour hue (r = 0.983).

The Pearson coefficients for *L** versus *b*, C** and *°hue* are positive but statistically insignificant. The correlations of *a** with respect to the other variables are very weak and statistically insignificant except for those with respect to *ΔE* and *BI*. The only statistically significant and strongest correlation with respect to *b** is that with respect to *C** (r = 0.991). According to the data in Table 3, with respect to the correlations of *YI,* there is only one very strong and positive correlation with respect to *C** (r = 0.853), with the remaining correlations being very weak or statistically insignificant. The *BI* coefficients showed very strong but negative correlations against sugars (glucose, fructose and sucrose) and colour nuance and only one very strong but positive correlation against *ΔE* (r = 0.889).

4.5. Sensory Evaluation of Pear Jelly

According to the sensory analysis performed, the UV-C irradiated jellies had the highest colour and aroma scores and those treated with US the lowest compared to the control. The colour changes may be due to the formation of brown pigments initiated by the Maillard reaction. Similar minimal and insignificant differences in colour and odour have been reported in the jam with hibiscus extract and in the mixed papaya and mango jam. The treatment of fruit jellies with US resulted in the best flavour and pasteurisation and in the worst taste compared to the control sample according to the ratings given by the tasters. This fact is probably due to the different physical effects of the preservation methods on the flavour and volatile components of the fruit jellies. The ratings given by tasters for the taste of pear jellies were significantly higher compared to those of carrot and apple jams [36]. In terms of the sensory parameter texture, fruit jellies treated with US had the highest and statistically significant tasting score as compared to the control. The higher texture score of the US-treated jellies compared to TP and UV-C was due to the different influence of the preservation methods on the strength of the gel structure. US irradiation increased the strength, respectively the rupture force of the fruit jellies to the greatest extent due to the cavitation created during the treatment and the subsequent compaction of the gel structure. The sensory texture evaluations of UV-C and US irradiated samples were identical to those of a mixed pumpkin and tomato vegetable jam [10].

5. Conclusions

Treatment with TP or UV-C has a stronger reducing effect on the mechanical characteristics as compared to US irradiation, which improves them. TP had no significant effect on most of the physicochemical characteristics except for sugars, while UV-C irradiation reduced sugars the least and US irradiation the most compared to the control. The TP treatment gives a reddish-brown hue to the samples, making the colour darker, the UV-C irradiation makes the colour more deep yellow and the US treatment preserves the original colour best. Correlation dependencies between physicochemical characteristics (glucose and sucrose) and between colour parameters ($a^*/\Delta E$ and b^*/C^*) were the strongest, statistically significant and positive. UV-C treatment resulted in improved aroma, US of taste and texture, while TP did not significantly affect sensory characteristics. The use of ultrasound is recommended as the best technological processing method due to the significant increase in the strength of the gelatinous structure, the reduction of the monosaccharide content, the preservation of the colour intensity and the improvement of the taste of the final product.

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