



Influence of postharvest ultrasounds treatments on tomato (*Solanum lycopersicum*, cv. Zinac) quality and microbial load during storage



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ABSTRACT

Whole tomato fruits were treated at ultrasonic power levels from 10% to 100%, and at a constant frequency of 45 kHz, for different times (1–19 min). A central composite rotatable design (CCRD) was applied to optimise ultrasonic treatments for tomato quality (colour, texture and total phenolic content (TPC)) maintenance. According to response surface analysis, the optimal treatment parameters were 55%_10 min, 80%_15 min and 100%_19 min. At these conditions, and especially at higher power levels, a maximum retention of colour and texture, as well as an increase of TPC and microbial reduction were obtained in comparison with untreated fruits during 15 storage days at 10 °C. The ultrasounds treatment was found to be effective in delaying colour development and texture losses, preserving sensorial quality of whole tomato, with increase of TPC and microbial load reduction. Moreover, this postharvest treatment can be used as an alternative for extending fresh fruits shelf-life.

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1. Introduction

Ultrasonic (US) fields consist of waves at high amplitude, in frequency generally above 20 kHz, and is a propagation process of mechanical vibration in the medium. US when propagated through a biological structure, induces compressions and depressions of the medium particles and a high amount of energy can be imparted. Depending on the frequency used and the applied sound wave amplitude a number of physical, chemical and biochemical effects can be observed, which enable a variety of applications. In the food industry, the combined mechanical, heating and cavitation effects are used as a cleaning action on surfaces to kill some bacteria, inactivate virus or even damage cell wall of some smaller microbial [1]. The mechanism of microbial inactivation by US is mainly due to thinning of cell membranes, localised heating, production of free radicals (e.g., $\cdot\text{OH}$, $\text{HOO}\cdot$, and $\text{O}\cdot$) [2,3] and formation of hydrogen peroxide [4].

The use of US in fresh produce decontamination is relatively recent. Seymour et al. [5], Scouten and Beuchat [6], Huang et al. [7], and Ajlouni et al. [8] used single-frequency ultrasound to decontaminate different fruits and vegetables. Mixed results have been reported, with some authors concluding that one log of additional reduction was achieved, while others reporting no additional

reduction. Moreover, the power ultrasound has been reported to enhance certain quality parameters, such as on orange fruit [9], apple cider, milk [10], peanuts [11] and more recently on strawberry fruit postharvest [12].

The efficacy of US treatments can be affected by power level (%), treatment time (min) and temperature (°C) [13,14]. In this case, where several variables may influence the treatment impact, response surface methodology (RSM) can be an effective technique for optimising the process [15]. RSM is a powerful statistical and mathematical tool with the advantage of determining the effects of operational factors and their interactions.

The aim of this study was to optimise the ultrasounds treatments at 45 kHz of constant frequency by response surface methodology on tomato quality (colour, texture and total phenolic content). The impact of three optimal conditions (55%_10 min, 80%_15 min; 100%_19 min) on tomato colour, texture, total phenolic content, sensorial analysis (colour and global acceptability) and microbial load, during 15 days storage at 10 °C, was also evaluated.

2. Materials and methods

2.1. Plant material

Tomato (*Solanum lycopersicum*, cv. Zinac) fruits harvested at mature-green maturity stage, with uniform colour (by USDA

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Table 1
Initial tomato quality attributes.

Quality attributes	
<i>Colour parameters</i>	
L^*	45.78 ± 1.00
a^*	−8.81 ± 1.06
b^*	22.05 ± 1.78
$^{\circ}h$	111.76 ± 1.92
<i>Texture</i>	
Firmness (maximum force, N)	11.42 ± 2.11
<i>Total phenolic content</i>	
TPC (mg GAE 100 g ^{−1})	21.37 ± 0.66
<i>Microbial load</i>	
Mesophilic count (Log ₁₀ cfu g ^{−1})	3.76 ± 0.20
Yeasts and moulds (Log ₁₀ cfu g ^{−1})	2.22 ± 0.10

standard tomato colour classification [16]), size, round shape and without bruises or signs of infection, were obtained from a commercial greenhouse Carmo & Silvério in centre west of Portugal. On arrival to laboratory, fruits were stored overnight in a cooling chamber (at 10 °C) until ultrasounds treatment. Table 1 summarises the initial values of tomato quality attributes.

2.2. Ultrasound treatment

For each ultrasounds treatment conditions and storage day *ca.* 1500 g of tomato fruits were sonicated in an ultrasonic bath at 10 °C ± 0.5 °C (Elma Transsonic Cleaning baths – multiple-frequency units) with 45 L nominal capacity, a constant ultrasound frequency of 45 kHz, and varying the treatment power level and time conditions according to the experimental design presented in Table 2. After treatment, tomato fruits were dried (absorbent paper) and stored at 10 °C, as previously optimised by [17], during 15 days.

2.3. Experimental design

A central composite rotatable design (CCRD) was used to optimise and evaluate the main, interaction, and quadratic effects of sonication conditions (power level: *PL*, and treatment time: *t*) and storage period (*Sp*) on tomato quality. The complete design consisted of three sets of experimental points: (i) a traditional factorial design with 2^k points, k being the number of independent

Table 2
Coded and uncoded matrix of independent variables.

Coded independent variables			Uncoded independent variables		
X_1	X_2	X_3	Power level (%) (<i>PL</i>)	US time (min) (<i>t</i>)	Storage period (days) (<i>Sp</i>)
1	1	1	82	15	12
1	1	−1	82	15	4
α	0	0	100	10	8
0	0	α	55	10	15
−1	−1	1	28	5	12
0	0	− α	55	10	1
− α	0	0	10	10	8
−1	−1	−1	28	5	4
1	−1	−1	82	5	4
−1	1	1	28	15	12
1	−1	1	82	5	12
0	0	0	55	10	8
−1	1	−1	28	15	4
0	− α	0	55	1	8
0	0	0	55	10	8
0	α	0	55	19	8

variables (factors) with coded levels +1 and −1; (ii) to account for non-linearity, a star of 2^k points, coded as $+\alpha$ and $-\alpha$ on the axis of the system at a distance of $\alpha = [2^k]^{1/4}$ from the origin; and (iii) two central points to provide an estimate of the lack of fit of the obtained linear statistical model as well as of the pure error of the experiments [18]. The ranges of interest of each independent variable were: power level (*PL*): 10–100%; treatment time (*t*): 1–19 min; and storage period (*Sp*): 1–15 days. Table 2 shows the coded and uncoded matrix of independent variables.

The evaluated quality parameters (dependent variables) were: colour, texture and total phenolic content (TPC).

2.4. Quality attributes evaluation

2.4.1. Colour

The colour of tomato fruits was evaluated using a tristimulus colorimeter (Minolta chroma Meter, CR-300, Osaka, Japan), measuring the CIEL*a*b* parameters. The instrument was calibrated using a white standard tile ($L^* = 97.10$, $a^* = 0.19$, $b^* = 1.95$), and the illuminant C (10° observer). L^* values represent the luminosity of samples (0-black to 100-white), a^* and b^* values indicate the variation of greenness to redness (−60 to +60) and blueness to yellowness (−60 to +60), respectively. From the CIELab coordinates the hue angle ($^{\circ}h = \arctg(b^*/a^*)$) was calculated. Four determinations for each fruit were performed in equatorial zone. Sixteen measurements were determined for each treatment condition.

2.4.2. Texture

Texture was determined by a penetration test with a Texture Analyzer (TA.HDi, Stable Microsystem Ltd, Godalming, UK), using a 50 N load cell and a stainless steel cylinder probe with a 2 mm diameter. The penetration test was performed at 3 mm s^{−1} of speed and at 7.5 mm of penetration distance in the equatorial zone of the fruits. Force–distance curves were recorded and firmness (maximum peak force (N)) was used as indicator of texture. Sixteen measurements were taken for each treatment condition.

2.4.3. Total phenolic content

Total phenolic content (TPC) was determined using the Folin–Ciocalteu reagent [19]. Samples (10 g) were homogenised in 70% aqueous methanol (10 ml), using a Yellow line DI 25 basic polytron (IKA-Labortechnik, Stauten, Germany), centrifuged (Sorvall RC-5, rotor SS34, DuPont, Wilmington, United States) at 19,000 rpm for 20 min at 4 °C, and the supernatant collected. One hundred microlitre of supernatant was mixed with 5 ml of Folin–Ciocalteu (1/10, v/v) and 4 ml of Na₂CO₃ (7.5%, w/v). The mixture was placed in a water-bath (45 °C for 15 min) and the absorbance measured at 765 nm in an ATI Unicam UV/VIS UV4 spectrophotometer (Unicom Limited, Cambridge, United Kingdom), using gallic acid as a standard. Results (six replicates) were expressed as milligram gallic acid equivalents (mg GAE 100 g^{−1}) of fresh weight.

2.4.4. Sensorial analysis

Analytical-descriptive tests were used to discriminate the sensory quality attributes of untreated (Ctr) and US-treated samples during storage. A panel of 8/10 trained-panellists (members of our Department), who met the basic requirements of sensory sensitivity according to [20] in adequate conditions compliant to [21], identified and distinguished the sensory attributes: colour and global acceptability of samples, using numeric rating scales as follows:

Colour rating system: 1 = green (0% red); 2 = breaker (<10% red); 3 = turning (10% < red < 30%); 4 = pink (30% < red < 60%); 5 = red (60% < red < 90%) and 6 = red (>90% red).

Global acceptability rating system: 1 = highly acceptable; 2 = moderately acceptable; 3 = medium acceptable (consumer limit); 4 = moderately unacceptable; 5 = unacceptable.

Global acceptability was related to quality attributes like colour and texture, evaluated visually and by the touch, respectively.

Panellists were asked to evaluate samples along storage, scoring the level of difference between US-treated and untreated samples in each attribute perceived intensity.

2.4.5. Microbial analysis

Total mesophilic count was performed according to [22]. Ten g of sample (a mix of skin/surface and pericarp, to have a homogeneous and representative sample of tomato fruits) was mixed with 90 ml peptone saline solution in a sterile stomacher bag and homogenised for 1 min using a Stomacher. Dilutions were made in peptone water, as needed for plating. Plate Count Agar was used as the media for total mesophilic counts pour plate, incubated at 30 °C for 3 days.

Yeast and mould were determined according to [23], using Rose Bengal Chloramphenicol Agar, surface inoculation and incubated at 25 °C during 5 days.

2.5. Model fitting and statistical analysis

Data were fitted to second-order polynomial Eq. (1), for each dependent Y variable (colour, texture and TPC) as a function of independent variables X_j (PL, t and Sp), through a stepwise multiple regression analysis using Statistic version 7.0 software [24]:

$$Y = b_0 + \sum_{j=1}^3 b_j X_j + \sum_{i < j} b_{ij} X_i X_j + \sum_{j=1}^3 b_{jj} X_j^2 \quad (1)$$

Y – predicted response; X_j – independent variables; b_0 – intercept coefficient; b_j – linear terms; b_{jj} – squared terms; b_{ij} – interaction terms.

The stepwise regression procedure was performed using the backward elimination method in order to remove non-significant interaction terms from the initial response surface model, step by step. In each subsequent step, the least significant variable in the model was removed until all remaining variables had individual *P*-values smaller than 0.05 [25]. So, the criteria for eliminating a variable from the full regression equation was based on R^2 values, standard error (SE) estimate, and significance F-test and the derived *P*-values. Models three dimensional response surface plots were generated [24], as a function of two variables, while keeping the third variable at central level. Statistically significant differences ($P < 0.05$) between samples were determined according to Tukey Honestly Significant Difference (HSD) Test.

To verify the accuracy of the predictive equations for the colour, texture and TPC, a total of 5 randomly selected US treatment experiments, within the range of experimental conditions, were replicated.

2.6. Optimisation of US postharvest conditions

Optimal conditions for the postharvest US treatment on whole tomato were obtained using the second-order polynomial models of RSM. A series of conditions were generated and the selection was based on maximum retention of colour and texture parameters and increase of total phenolic content, in comparison with untreated fruits.

In order to assess the effects of optimised US conditions on tomato quality and storability, fruits subjected to identified optimal conditions and fruits not subjected to any treatment (Ctr samples) were also evaluated at 0, 8 and 15 storage days at 10 °C, using the same analytical protocol considered for the experimental

design and sensory analysis (colour and global acceptability) and microbial load evaluation.

3. Results and discussion

3.1. Model fitting

Mathematical models for all studied attributes were developed by response surface methodology (RSM) and its adequacy was tested by analysis of variance technique (ANOVA). Three tests were required to evaluate the adequacy of the model: Student's *t*-test that indicated the significance of the factors, Fisher's variance ratio test, and *R*-square test [26]. Table 3 shows the ANOVA analysis of a^* colour parameters, texture, and total phenolic content, and all models were significant ($P < 0.05$). The predictive model equations developed for these parameters of whole tomato (Eqs. (2)–(4)) are presented in Table 4. The variability of experimental data was explained by correlation coefficients (R^2 and R^2_{adj}), that were satisfactory, despite the low values for texture ($R^2 = 0.48$, $R^2_{adj} = 0.41$).

Table 5 presents predicted vs. experimental results for five US treatment conditions randomly selected. It can be concluded that experimental results were very close to the predicted. This implies that there was a high fitting degree between experimental and regression model predicted data. Hence, the response surface modelling could be applied effectively to predict US treated tomato quality attributes during storage at 10 °C.

3.2. Colour

The analysis of the response surface showed that storage period (Sp, days) had a significant effect ($P < 0.05$) on colour changes of tomato fruits, mainly on a^* colour parameter.

The response surfaces representing ultrasounds effect on whole tomato colour (a^*) are shown in Fig. 1 and described by Eq. (2) (Table 4). The range of power levels lower than 40% and higher than 70% conducted to green colour stability and fruits ripening delay. The lower a^* values observed in all US treated samples during the first 8 days of storage at 10 °C, demonstrate that tomato fruits treated with ultrasounds present better storage stability. The US-treated samples with a period of time lower than 6 min

Table 3

Analysis of variance of the second order polynomial models for a^* colour parameter, texture and total phenolic content (TPC) of sonicated tomato.

Effect	Source	SS	df	MS	F-ratio (model significance)	P
a^*	Regression	711.07	9	79.01	26.74 ^a	0.00036
	Residual	17.73	6	2.95		
	Lack-of-fit	14.84	5	2.97	1.03 ^b	0.63
	Pure error	2.89	1	2.89		
	Total	728.8	15			
Texture	Regression	5.16	2	2.58	6.11 ^a	0.013
	Residual	5.48	13	0.42		
	Lack-of-fit	5.21	12	0.43	1.59 ^b	0.56
	Pure error	0.27	1	0.27		
	Total	10.64	15			
TPC	Regression	41.14	4	10.29	9.48 ^a	0.0014
	Residual	11.94	11	1.09		
	Lack-of-fit	11.91	10	1.19	49.12 ^b	0.11
	Pure error	0.024	1	0.024		
	Total	53.08	15			

SS – sums of squares; df – degrees of freedom; MS – mean square; F test significant at $P < 0.05$.

^a $F (MS_{\text{regression}}/MS_{\text{residuals}})$.

^b $F (MS_{\text{lack-of-fit}}/MS_{\text{pure error}})$.

Table 4Model equations for a^* , texture and total phenolic content (TPC) with corresponding regression coefficients.

Eqs.	Parameter	Model equations	R^2	R^2_{adj}
(2)	a^*	$-9.03 + 0.27 * PL - 0.0014 * PL^2 - 1.37 * t + 0.064 * t^2 + 0.85 * Sp + 0.035 * Sp^2 - 0.0084 * PL * t - 0.00082 * PL * Sp + 0.024 * t * Sp$	0.98	0.94
(3)	Texture	$10.68 - 0.078 * t^2 - 0.11 * Sp$	0.48	0.41
(4)	TPC	$25.83 - 0.00084 * PL^2 - 0.015 * t^2 + 0.0058 * PL * t + 0.0061 * PL * Sp$	0.78	0.69

Table 5Experimental (average \pm standard deviation) and predicted values of a^* colour parameters, texture and total phenolic content (TPC) obtained by the RSM models.

US conditions			a^*		Texture		TPC	
Power level (%) (PL)	US time (min) (t)	Storage period (days) (Sp)	Experimental	Predicted	Experimental	Predicted	Experimental	Predicted
10	1	1	-6.76 ± 0.63	-6.95	10.66 ± 1.86	10.23	24.82 ± 0.61	25.85
28	5	5	-3.81 ± 0.85	-3.39	9.18 ± 1.47	9.68	25.54 ± 0.40	26.47
55	10	6	-1.23 ± 0.75	-2.84	8.53 ± 1.52	9.29	28.48 ± 0.93	27.01
80	15	9	0.30 ± 0.66	0.41	7.67 ± 1.32	8.50	28.65 ± 0.84	28.48
100	19	15	10.44 ± 1.24	11.10	7.67 ± 1.83	1.32	30.84 ± 0.63	31.28

revealed significant ($P < 0.05$) colour changes, reaching values of 10 units.

A similar study developed by [27] found that blackberry juice exhibits a high degree of anthocyanins stability after sonication treatment, since a decrease of only 5% was observed at the maximum treatment conditions of 100% amplitude for 10 min.

Colour degradation may be due to the extreme physical conditions which occur at micro-scale during sonication (temperatures and pressure up to 5000 K and 500 MPa, respectively). Moreover, various sonochemical reactions, including generation of free radicals, enhancement of polymerisation/depolymerisation reactions

and other reactions [28], may be responsible for the observed colour degradation.

3.3. Texture

The effect of the studied independent variables (PL, t and Sp) on firmness of fresh whole tomato is shown in Fig. 2 and described by Eq. (3) (Table 4), where it can be seen that only the treatment time and storage period have significant effects on firmness. The storage period had the most significant effect and is responsible for the highest changes in tomato firmness. Moreover, its negative effect

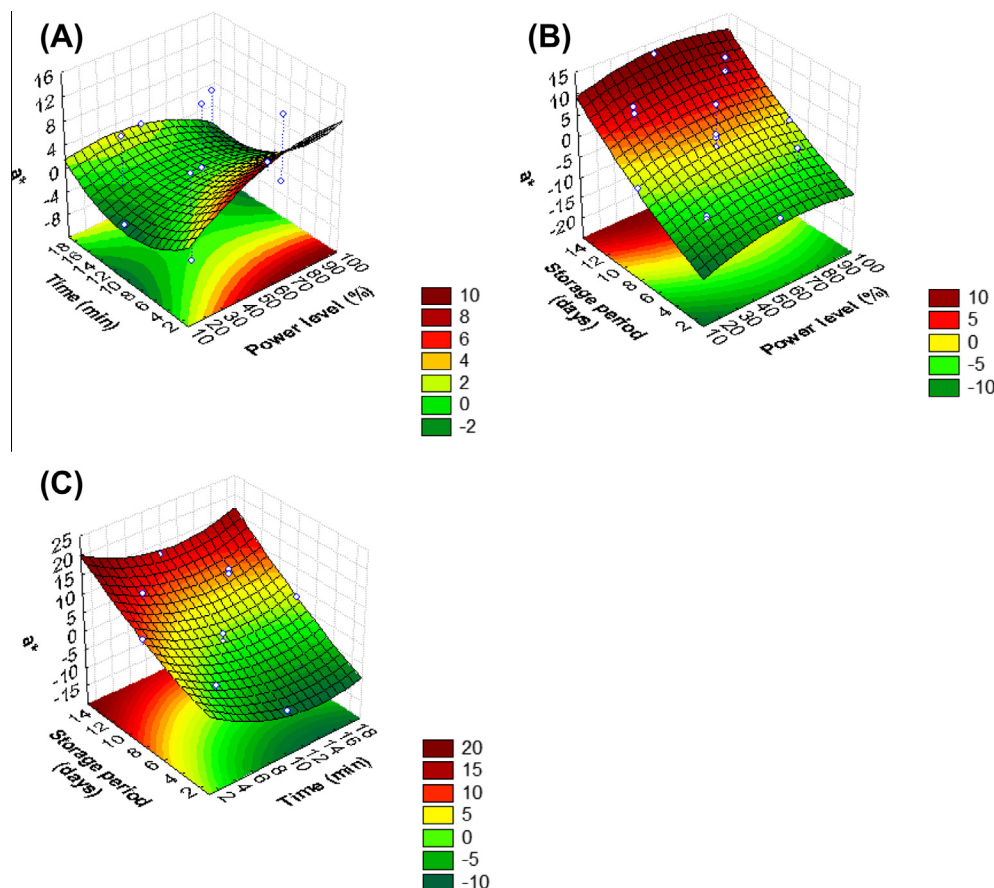


Fig. 1. a^* colour parameter projected at the central point (55%, 10 min, 8 days): (A) PL vs. t ; (B) PL vs. Sp ; (C) t vs. Sp . (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

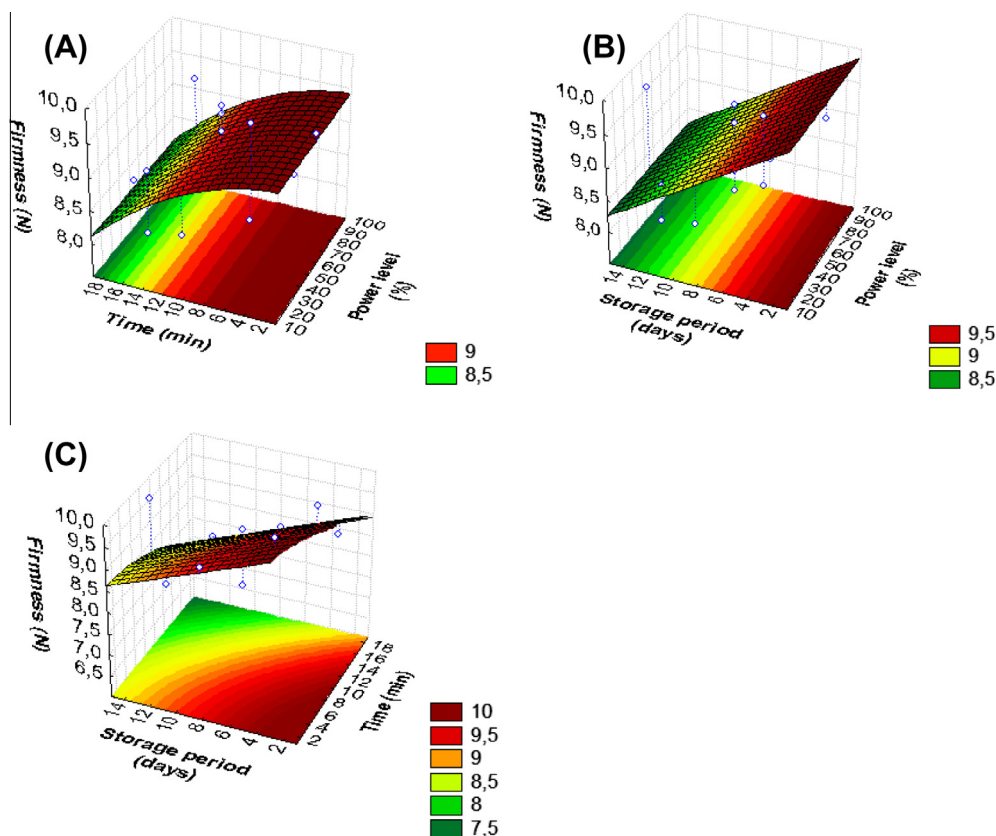


Fig. 2. Texture (maximum force, N) projected at the central point (55%, 10 min, 8 days): (A) PL vs. t ; (B) PL vs. Sp; (C) t vs. Sp.

(-0.11 Sp) shows that losses of firmness increase with storage period.

The initial firmness of fresh whole tomato was 11.42 ± 2.11 N (Table 1). The range of power levels selected for this study (10–100%) did not contribute to a significant change ($P < 0.05$) on tomato maximum force. During the first 2 storage days at 10°C , the maintenance on US-treated samples firmness was achieved, for all US treatment conditions. After 6 days at 10°C , all US-treated samples evidenced an accelerated loss on maximum force.

A study developed by Cao et al. [12,29] on strawberry fruits reported the significant effect of power level and treatment time on fruits firmness, mainly on strawberries treated with lower power that revealed the highest fruits firmness.

Tomato fruits softening has been studied [30,31] and correlated with the action of polygalacturonase (PG) and pectin methylesterase (PME), responsible for solubilisation and depolymerization of cell wall constituents. It is possible that the different effects of US treatment in our work are related to these enzyme activities and cell wall degradation.

3.4. Total phenolic content

The response surfaces representing ultrasounds effect on total phenolic content (TPC) of whole tomato are shown in Fig. 3 and described by Eq. (4) (Table 4). Ultrasounds treatment power level (PL) and time (t), as well as storage period (Sp) have a significant effect ($P < 0.05$) on whole fresh tomato TPC.

From the data plot analysis, it can be stated that ultrasounds performed at the range of 40–100% and for more than 4 min promote higher content of phenolic compounds (>28 mg GAE 100 g^{-1}) (Fig. 3A). Treatments with higher power level and shorted period of time revealed a drastic reduction of phenolic compounds (14%). Lower power level for long periods of time treatments

presented similar results. Outside the treatment time mentioned previously, ultrasounds induced higher levels in TPC during storage at 10°C . By calculation of model equation at power level of 80%–30 min and at day 15, higher value of TPC ($30\text{ mg GAE } 100\text{ g}^{-1}$) was obtained, compared to untreated fruit. Comparing with Ctr sample, all the US-treated samples showed highest TPC.

Tiwari et al. [9] reported a reduction on anthocyanin and ascorbic acid contents of 3.2% and 11%, respectively, on strawberry juice sonicated at 100%_10 min. Degradation of phenolic compounds during ultrasounds treatment may be related to oxidation reactions, promoted by the interaction with free radicals formed during sonication [14,27]. Nevertheless, Sales & Resurreccion [11] reported the enhancement of phenolic and antioxidants on peanuts treated with US and UV-treatments.

3.5. Evaluation of optimised US conditions on quality, sensorial and microbial load of tomato fruits

The US conditions for tomato fruit could be considered optimum if decay incidence reached minimum values and fruit quality parameters, like colour, texture and TPC, attained minimal changes during storage. Based on these criteria, three optimum US conditions were determined: 55%_10 min, 80%_15 min and 100%_19 min.

As shown in Fig. 4(A) only the treatment at 100%_19 min led to a significant change ($P < 0.05$) on a^* colour parameter, compared to Ctr samples. After 8 days at 10°C , the effect of US on delay of red colour development was detected for all US-treated samples (low a^* value). However, this difference was not noticeable at the end of storage. This behaviour/development was detected by the panellists (Fig. 4B and C). Comparing the objective value of a^* colour parameter and the sensorial assessments of tomato fruits, a significant correlation was established:

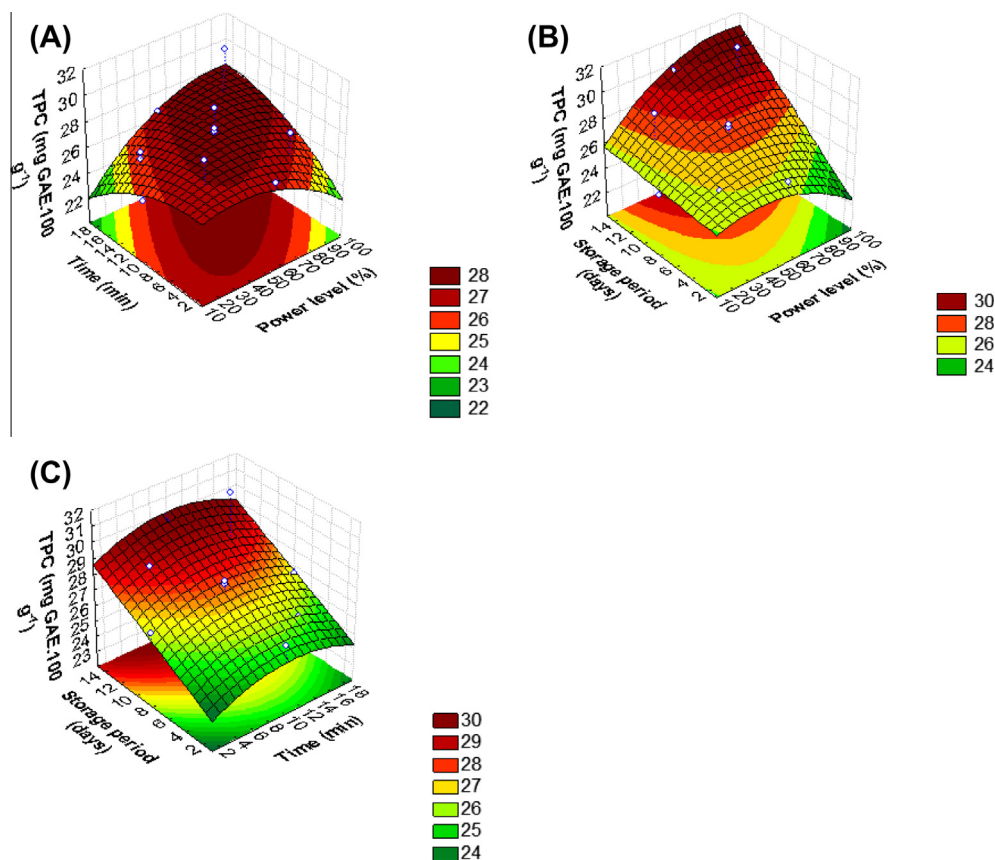


Fig. 3. Total phenolic content (TPC, mg GAE 100 g⁻¹) projected at the central point (55%, 10 min, 8 days): (A) PL vs. t; (B) PL vs. Sp; (C) t vs. Sp.

$R^2 = 0.97$, $P < 0.00$ and $R^2 = 0.60$, $P < 0.05$ for colour and global acceptability, respectively.

The firmness of tomato after US treatment remained similar with Ctr samples (11.42 N), with exception on US-treated with 55%_10 min, where a reduction of 17% was observed (Fig. 4D). During storage, losses on all studied samples (untreated and US-treated) was observed, being the US conditions of 80%_15 min the best treatment for retarding the inevitable fruits firmness losses due to postharvest.

In terms of TPC (Fig. 4E), after US treatment at 80%_15 min an initial and significant increment ($P < 0.05$) was revealed (10%). Furthermore, during storage an increase on TPC was observed in all US-treated tomato, but only significantly different ($P < 0.05$) at 80%_15 min.

Mesophilic count and yeasts and moulds (Y&M) of untreated and US-treated samples are presented on Fig. 4(F) and (G), respectively. Ultrasonic treatment significantly ($P < 0.05$) reduced the initial mesophilic load, reaching values of 2.55 Log₁₀ and 2.95 Log₁₀ immediately after sonication at power level of 80%_15 min and 100%_19 min, respectively. In terms of Y&M, no significant changes ($P > 0.05$) were denoted between the three treatments, reaching values lower than 1 Log₁₀. A microbial development on all samples (Ctr and US-treated) was observed along storage, were the Ctr sample presented the highest mesophilic count and Y&M at the end of storage (ca. 6 Log₁₀ and 3.5 Log₁₀, respectively). After 15 days at 10 °C, the US-treated at 80% presents the lowest mesophilic count, less than 2.76 Log₁₀, when compared with untreated sample. The microbial load found in all samples (Ctr and US-treated) did not reach the maximum value recommended (aerobic mesophilic flora $< 5 \times 10^6$ cfu g⁻¹) by the International Commission on Microbiological Specifications for Foods [32].

One of the most relevant effects of ultrasound is on microbial populations. Still, the microorganisms do not respond in the same way to sonication treatment. Amplitude of ultrasounds waves, exposure or treatment time, food composition, food processed volume or temperature are some of the factors affecting the efficacy of microbial inactivation by ultrasounds [33]. Also, the performance of ultrasound treatment is affected by the form, type or diameter of the microorganisms [34]. On a study reported by Cao et al. [12], the microbial population of sonicated strawberry declined as the treatment was prolonged, reaching the lowest value at 10 min. José and Vanetti [35] evaluated the efficiency of different sanitization treatments (sodium dichloroisocyanurate, hydrogen peroxide, peracetic acid, chlorine dioxide and ultrasounds) on cherry tomatoes and observed a reduction above 1.0 Log₁₀ on aerobic mesophilic count after ultrasounds treatment at frequency of 45 kHz.

4. Conclusions

In this study, response surface methodology (RSM) was used for optimising ultrasounds conditions (power level and treatment time) during storage at 10 °C for maintaining tomato quality during postharvest period. The RSM can be employed to model quality parameters of sonicated whole tomato fruits, while minimising the number of required experiments.

The sonication postharvest treatment conditions for tomato fruit could be considered optimum if decay incidence, development of red colour and microbial populations reached minimum values, while responses for phenolic compounds content reached maximum values simultaneously. As predicted by RSM, the optimum sonication treatment conditions at constant frequency of 45 kHz,

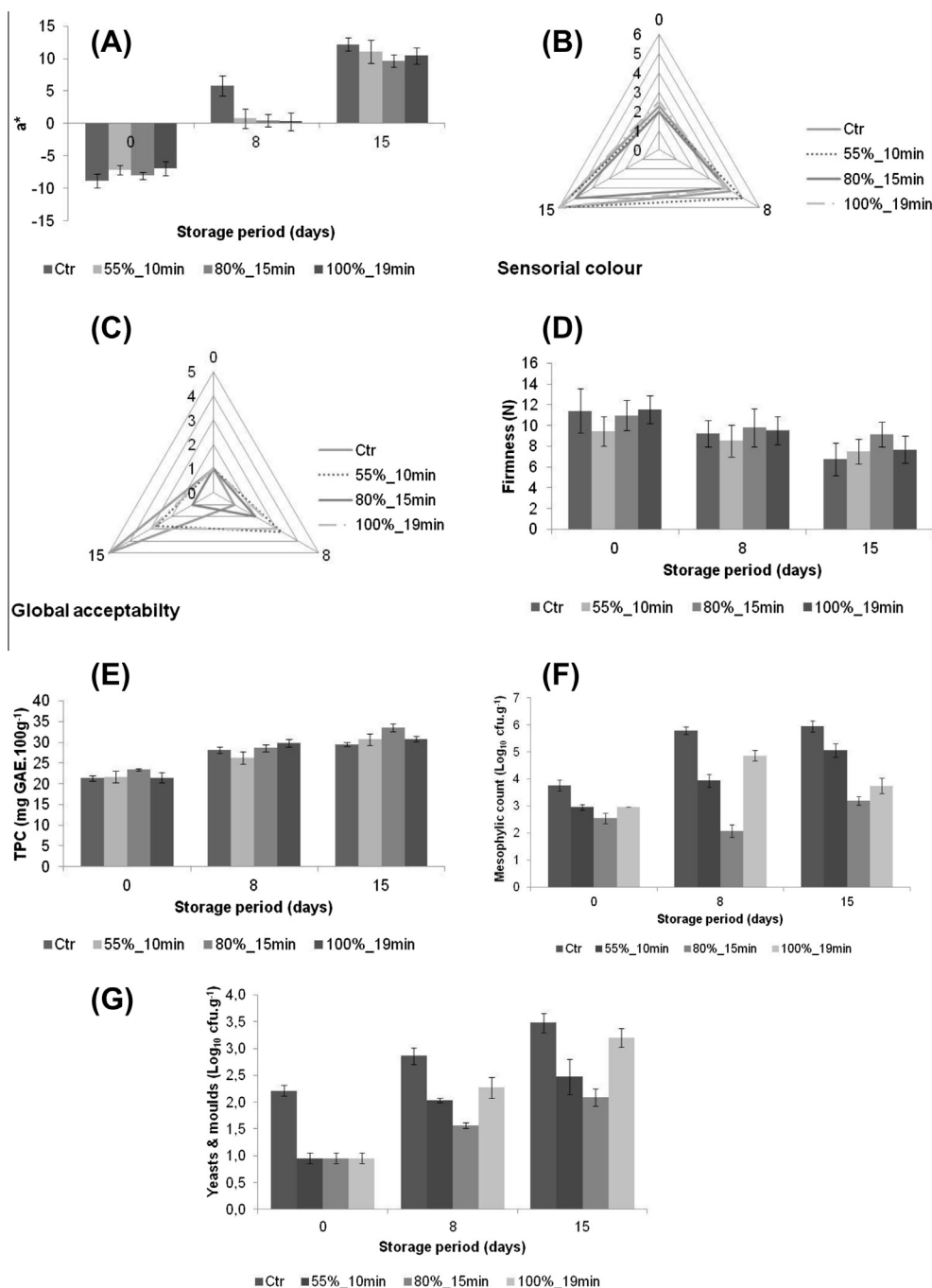


Fig. 4. Effect of optimal US treatment conditions on quality (a^* , firmness and TPC), sensorial (colour and global acceptability) and microbial load (mesophilic and yeasts and moulds), compared to untreated sample, during 15 days of storage at 10 °C. Vertical bars represents standard deviation.

and for tomato storage at 10 °C, was between the power level of 80% and 100% with treatment time around or less than 30 min.

The application of sonication treatment may provide a useful mean for extending the postharvest life of fresh whole tomato fruits. This treatment might be of interest from a technological perspective, since it can increase nutrition value and maintain quality, while reducing losses from harvest/storage to consumption, and increase tomato feasibility for posterior industrial applications.

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