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Preparation of Gazpacho Assisted by Pulsed Electric Fields: A Preliminary Study

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Abstract: Pulsed Electric Fields (PEFs) are a technology increasingly used in the food industry for various purposes. However, their potential benefits as a pretreatment prior to the culinary preparation of a product have rarely been investigated. No previous study has investigated the use of PEFs in obtaining gazpacho, a typical Spanish dish. We aimed to evaluate the possibility of applying this technology in pretreating the vegetables used in gazpacho; furthermore, we evaluated its impact on the final product by comparing results with control samples. Applied at several different intensities (0.5–1.5 kV/cm and 4–40 kJ/kg), PEFs softened and decreased the vegetables' water-holding capacity. In addition, this technique beneficially affected the organoleptic characteristics of gazpacho, increasing its consistency, improving its color (which became more reddish and intense), and enhancing its flavor. Moreover, the use of PEFs allowed us to reduce the amount of water in the mix, thus saving natural resources, concentrating nutrients, and decreasing energy consumption. Although further studies are required, PEFs can be considered a technology of interest in this productive sector.

Keywords: gazpacho; pulsed electric fields; tomato; pretreatment



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1. Introduction

Gazpacho

According to the Royal Spanish Academy (RAE), “gazpacho” is a cold soup typical of Andalusia (southern Spain), with tomato, pepper, oil, vinegar, garlic, and salt as basic ingredients. Currently, there is no specific legislation on the use of the term “gazpacho”. However, according to Spanish legislation RD 2452/1998, gazpacho cannot be officially classified as a “cold soup” since it does not contain dehydrated ingredients (as indicated in the legal definition of soups), nor has it undergone a rehydration process by cooking in water. Instead, the composition of gazpacho is a whipped mixture of fresh vegetable products, namely tomato, onion, garlic, pepper, cucumber, oil, and vinegar and/or lemon, with the optional addition of bread [1].

According to the Spanish Ministry of Agriculture, Fisheries, and Food (MAPA, 2023), the average consumption per inhabitant of gazpacho and “salmorejo” (a soup similar to gazpacho, but without adding water or any vegetables except tomato) between January and May 2023 was 1.8 L. This was 10.1% more than in 2022, representing a turnover of EUR 178.96 million for the gazpacho production sector. This increase in consumption may be due to rising temperatures. Zumos y Gazpachos de España (“Spanish Juices and

Gazpachos”), an association representing 90% of the juice and gazpacho producers in the country, has found that 93% of Spaniards consume either “gazpacho” or “salmorejo”; more specifically, 54% prefer “gazpacho” [2]. The Spanish regions with the highest consumption of gazpacho and salmorejo are all located on the Mediterranean coast: Catalonia, Valencian Community, Murcia, and Andalusia. Consumption of these two products increases during spring and summer, accounting for 70.6% of annual sales. The total export volume of “gazpacho” and “salmorejo” has recently increased: these drinks are now being marketed in France, the United Kingdom, Belgium, and Germany [2].

The preparation of gazpacho begins with the cultivation and collection of the vegetables that form part of the recipe. At the moment of preparation, those vegetables must be at an optimum stage of ripeness to ensure satisfactory organoleptic characteristics in the final product. Vegetables are subsequently washed, cut, and ground to make a vegetable puree. To remove the remains of skin and seeds, the puree is usually strained. Bread is often added and mixed with salt, oil, and vinegar. In the last step, water is added to achieve the desired thickness [3].

Prior to packaging, gazpacho is usually pasteurized; in some cases, it can even be sterilized. However, high temperatures and heat significantly affect the organoleptic profile of the vegetable ingredients. For this reason, to guarantee health safety with a minimum impact on the product’s quality, non-thermal preservation technologies are currently being evaluated: two of these are High Hydrostatic Pressure (HHP) and Pulsed Electric Fields (PEFs) [4–6]. Such treatments ensure that products maintain organoleptic and nutritional properties similar to those of the fresh product. Thanks to the application of such non-thermal technologies, the product is processed at temperatures lower than conventional heat pasteurization, reducing thermal damage (although tending to reduce shelf life) [7]. Under refrigeration (2–7 °C), pasteurization extends a product’s shelf life by 1 to 4 additional months, compared to 10–12 days of shelf life for a fresh product [3].

Increasingly used in the food industry, PEFs are a non-thermal technology that applies electric field strengths between 0.1 and 30 kV/cm (in the form of short pulses in the order of microseconds) to a product placed between two electrodes at room temperature [8]. As a result, the product’s temperature barely increases, and the food’s thermosensitive components remain unaffected, thus only modifying its nutritional composition or sensory characteristics to a negligible extent [8]. The underlying mechanism is electroporation, a phenomenon that arises when PEFs are applied to live cells. Pores appear in the cytoplasmic membrane, causing cytoplasmic compounds to “leak” outside the cell [9]. As a technology, Pulsed Electric Fields are currently applied to pasteurize liquid foods at temperatures lower than those used with heat, improve the extraction of intracellular compounds of interest, optimize traditional treatments (such as the production of French fries), or even cook food. However, PEF as a pretreatment before the culinary preparation of a product has hardly been investigated; to date, no study has explored its potential in obtaining gazpacho. Our study aimed to evaluate the effect of PEF as a pretreatment applied to vegetables used in the preparation of gazpacho, studying how this technology affects the final product compared to gazpacho produced without PEF. We also aimed to evaluate PEF’s potential in improving the overall gazpacho production process’s technological efficiency, specifically regarding aspects of tomato peeling on the one hand, and the final mix’s texture and sensory quality (viscosity, color, aroma, taste, etc.) on the other.

2. Materials and Methods

2.1. Preparation of Gazpacho

At local supermarkets, we purchased the following ingredients: Genio cherry tomatoes (Grupo La Caña, Motril, Granada, Spain), short cucumber, California red pepper,

Pedroñeras purple garlic (IGP) (Grupo Lomar, Almería, Spain), white bread without the crust (Alcampo, Guadalajara, Spain), extra virgin olive oil (Ybarra, Dos Hermanas, Sevilla, Spain), Jerez vinegar (DOP) (Coosur, Vilches, Jaen, Spain), and fine iodized sea salt (Hacendado, Valencia, Spain).

Raúl Ruiz-Comeras, a professional chef, established the gazpacho recipe for our experiment: 1 kg cherry tomatoes, 150 g red peppers, 80 g cucumber, 40 g bread, 5 g garlic, 150 g olive oil, 250/125 g water, 30 g Jerez vinegar, and 5 g salt. We cut and blended the ingredients with a 5-speed Cecotec Power Titanium 1800 Max Inox blender (Valencia, Spain). Ingredients were mixed for 1 min at maximum blender speed, as we had previously established that these blending conditions yielded a homogeneous product consistency independently of blending speed and time.

Based on the same list of ingredients (Table 1), we prepared twelve different gazpachos (formulations). The differences among them depended on whether the cucumber was peeled or not, whether the prepared gazpacho was sieved (or not) through a stainless-steel sieve with a mesh size of 1 mm (Fackelmann, Jaén, Spain), and according to the amount of added water (250 g or 125 g). Based on those parameters, we prepared six control gazpachos and six PEF-treated gazpachos. In this paper, the term “PEF-treated gazpacho” refers to a mixture of tomatoes, red pepper, and cucumber treated with PEF, not to the finished product with the remaining ingredients. In order to compare results, for each study, the total number of tomatoes, cucumbers, and peppers purchased at the same time of ripening was divided into two batches, one for the controls and the other for the pulse-treated tomatoes.

Table 1. Formulations used in the preparation of gazpacho.

Formulation Name	1C	1P	2C	2P	3C	3P	4C	4P	5C	5P	6C	6P
PEF treatment	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
Sieving	No		No		No		Yes		Yes		Yes	
% water	100		100		50		100		100		50	
Cucumber peel	Yes		No		Yes		Yes		No		Yes	

2.2. PEF Pretreatment of Vegetables

A pulse generator capable of applying square wave pulses of variable width (from 1 to 200 μ s) with a frequency of up to 200 Hz (EPULSUS-PM-10, 2 kW, Energy Pulse System, Lisbon, Portugal) was used. Maximum output voltage and current were 10 kV and 180 A, respectively. Processing system parameters (load voltage, pulse width, number of pulses, and frequency) were controlled by a touch screen provided with the equipment and monitored with an oscilloscope (Tektronix, TDS 220, Wilsonville, OR, USA). To measure applied voltage, amperage, and pulse duration, a high-voltage probe (Tektronix, P6015A, Wilsonville, OR, USA) and a current probe (Stangenes Industries Inc., Palo Alto, CA, USA), respectively, each connected to the oscilloscope, were used. The investigated PEF conditions ranged from 0.5 to 1.5 kV/cm and 4 to 40 kJ/kg, applying pulses lasting 20 μ s. These ranges of conditions are within the PEF intensities described in the literature applied in different vegetables to evaluate distinct effects as discussed later on [8–10].

To apply the PEF treatments, the vegetables were introduced in separate batches (as indicated below) into the treatment chamber and covered with tap water (0.40 ± 0.05 mS/cm). The treatment chamber consisted of 2 square parallel electrodes measuring 5 cm $\times$ 5 cm, with a 5 cm gap. Per batch treatment, we inserted either 7–8 cherry tomatoes, or 10 slices of cucumber with skin of 0.5 cm thickness, or 5–6 square pieces of red pepper measuring 2 cm $\times$ 3 cm.

2.3. Evaluation of Vegetable and Gazpacho Parameters After PEF Treatments

2.3.1. Vegetable Firmness

To evaluate the vegetables' firmness before and after applying a PEF treatment, an AGROSTA 100Field non-destructive digital durometer (AgroTechnology, Forges Les Eaux, France) was used. The system was connected to a computer loaded with the corresponding "Agrosta 100" version 10 software to read the data. The durometer's measurements are based on quantification of the force required to retract a plunger of a certain length placed manually against the fruit's surface, estimating its firmness by measuring the fruit's deformation without penetrating the product. Results are expressed in Durofel units ranging from 0 to 100, where zero corresponds to the sensor being completely outside the vegetable's surface and 100 to the sensor being fully inserted. Among the available sensors, Sensor A100-25, the one most suitable for the vegetables featured in this study, was used. For each determination, 3 to 5 measurements per vegetable were conducted.

2.3.2. Water Holding Capacity (WHC) of Vegetables

Samples of 11 ± 1 g were wrapped in gauze and placed in a 50 mL Falcon tube with five glass beads. The tubes were centrifuged at $500 \times g$ for 2 min (Gyrozen 1736R, Gimpo, South Korea), and samples were weighed after centrifugation. WHC was determined based on the following equation:

$$\text{WHC} = 100 - \left(\frac{P_i - P_f}{P_i} \times 100 \right) \quad (1)$$

where P_i and P_f corresponded to the sample's weight (in grams) before and after centrifugation, respectively. Two to Four samples per vegetable were used for each determination.

2.3.3. Consistency of Tomato Juice and Gazpacho

A Bostwick consistometer (ZXCON-CON2 COLE PARMER Endecotts, London, UK) was used to obtain objective measurements (cm) of gazpacho and tomato juice fluidity. All measurements were performed in triplicate.

2.3.4. Color Measurement

A colorimeter (Minolta CM-2002 series, Osaka, Japan) was used to determine color parameters. Results were expressed using the L^* , a^* , b^* CIELAB color space. Based on these values, we estimated total color change (ΔE^*) using the following equation:

$$\Delta E^* = \sqrt{L_0 - L^* + (a_0 - a^*)^2 + (b_0 - b^*)^2} \quad (2)$$

where L_0 , a_0 , and b_0 represent the initial values of color for control gazpachos, and L^* , a^* , and b^* are the values of gazpachos obtained from PEF-treated vegetables. Three measurements were made of each sample.

2.3.5. Sensory Analysis

To elicit consumer opinion regarding PEF-treated gazpacho, we held a preference tasting session featuring 27 untrained panelists. They evaluated two samples of gazpacho, prepared with Formulation 1C (control) and Formulation 1P (prepared with vegetables treated with PEF at 1 kV/cm, 10 kJ/kg, and 20 μ s pulse width), where we added 100% water and peeled cucumber and sieved the resulting gazpacho. Participants expressed their preference for one of the two gazpachos based on the following parameters: general appearance, color, aroma, texture, and flavor.

2.4. Statistical Analysis

To obtain a meaningful data matrix, all tests were performed at least in triplicate. To know whether there were statistically significant differences between the parameters obtained in separate tests, the GraphPadPRISM[®] program version 8.0 (GraphPad Software) was used to apply Student's *t*-test and one-way ANOVA for an analysis of data derived from 2 samples or multiple samples, respectively. In the data graphs shown below, the error bars correspond to the standard deviation of the measurement; the existence of statistically significant differences ($p = 0.05$) is signaled by different letters of the alphabet.

3. Results and Discussion

To evaluate the effect of PEF as a pretreatment on the vegetables used in the preparation of gazpacho, two research stages were necessary. In the first one, we determined the effect of the main PEF parameters on the vegetables used in preparing tomato juice and gazpacho; in the second phase, we evaluated the effect of PEF on the resulting product quality.

3.1. Influence of PEF Treatments on Cherry Tomato Juice Consistency

Figure 1 shows the effect on tomato juice consistency of applying electric field strength (at a constant energy of 10 kJ/kg) and specific energy (at a constant field strength of 1 kV/cm) to tomatoes before peeling and blending. As a reference, we include a tomato juice consistency measurement obtained from untreated tomatoes (data from Value 0). As observed, juice consistency increased by raising the two parameters to a maximum beyond which fluidity no longer increased. A maximum fluidity value was obtained by applying 1 kV/cm (Figure 1a) at 10 kJ/kg (Figure 1b). This increased the consistency parameter from 3 ± 0.1 cm to 9.6 ± 0.7 cm.

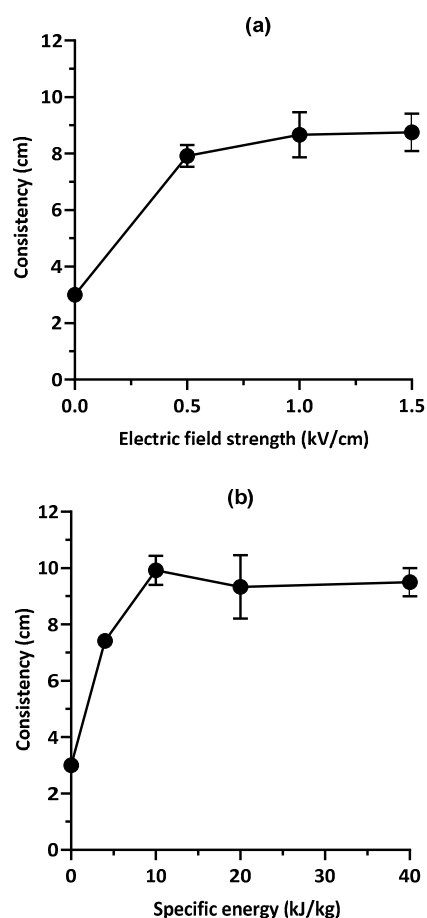


Figure 1. Effect on tomato juice consistency of (a) electric field strength (10 kJ/kg) and (b) specific energy (1 kV/cm) applied to tomatoes.

3.2. Influence of PEF Treatments on Cherry Tomatoes

To determine the origin of the greater consistency of tomato juice resulting from PEF treatments, we extended our inquiry to study the effect of PEF on two tomato characteristics: firmness and Water Holding Capacity (WHC).

We determined the firmness of cherry tomatoes before and after applying various PEF treatments. Figure 2a,b show the tomatoes' firmness expressed in Durofel units after subjecting them to different electric field strengths (at a constant specific energy of 10 kJ/kg) and different specific energies (at a constant field strength of 1 kV/cm), respectively. Independently of the type of treatment, PEF-treated tomatoes were softer than untreated ones. The decrease in firmness was around $27.8 \pm 8.5\%$ in PEF-treated tomatoes compared to control ones.

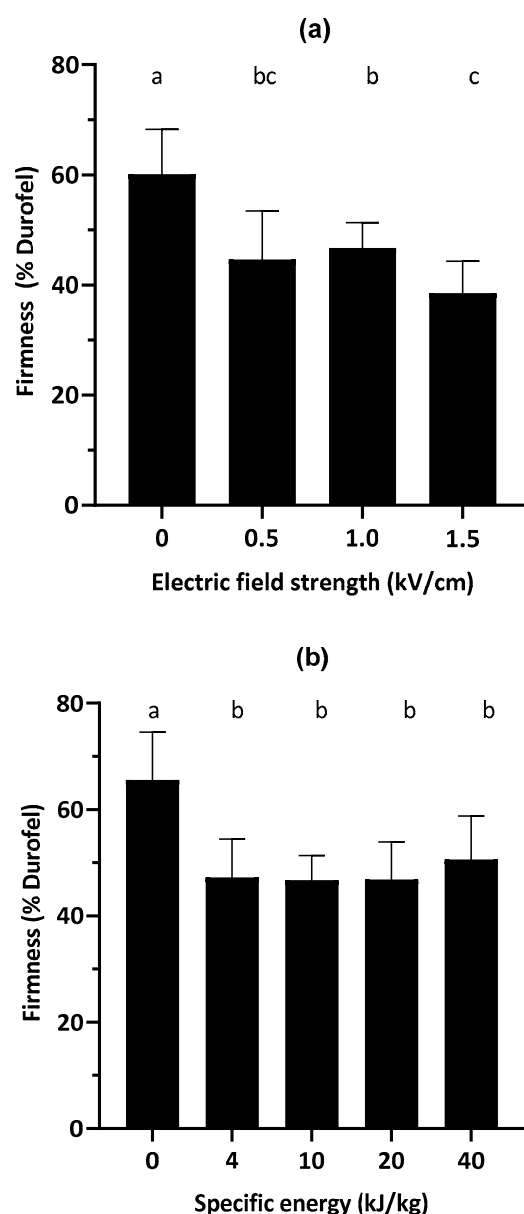


Figure 2. Effect of (a) electric field strength (at 10 kJ/kg) and (b) specific energy (at 1 kV/cm) on tomato firmness measured in Durofel units.

Thus, the application of PEF softened the tomatoes. We surmise that PEF pretreatment made the blending phase more effective by causing a greater release of tomato components, including water. This, in turn, would make the obtained juice more fluid, thereby explaining

the results shown in Figure 1. This vegetable softening effect achieved through PEF has already been described in the treatment of potatoes as well as tomatoes [10,11]. Further research teams have found that applying PEF to fruit increases fruit juice yield (which is in line with our results) [12–16]. The reduced firmness we observed affected the electric consumption (measured in watts with a wattmeter) of the mixer we set at maximum power when we prepared gazpacho with either PEF-treated vegetables (1 kV/cm and 10 kJ/kg) or non-treated ones. In terms of electric consumption, the blender that prepared gazpacho with PEF-treated vegetables significantly consumed less energy, 3.7%, compared to control samples: the consumption was reduced from 354 ± 2.2 to 340.8 ± 2.1 W for control and PEF-treated samples.

As indicated, another way to estimate the potential effect of PEF on the consistency of the tomato juice obtained was to evaluate the tomatoes' WHC. Figure 3 shows the percentage of water released after centrifugation of control and PEF-treated tomatoes (1 kV/cm, 10 kJ/kg). Tomatoes treated with PEF lost more water than control tomatoes, probably due to the electroporation of their cells triggered by the PEF treatment. These results, associated with the decreased hardness of the PEF-treated tomatoes, justify the difference in fluidity observed in Figure 1 between control tomato juices and those elaborated from PEF-treated tomatoes. These data are also in line with the more pronounced increase in yield in other types of extracted juices observed by several research teams after applying PEF treatments to fruits and/or vegetables [12,14,16].

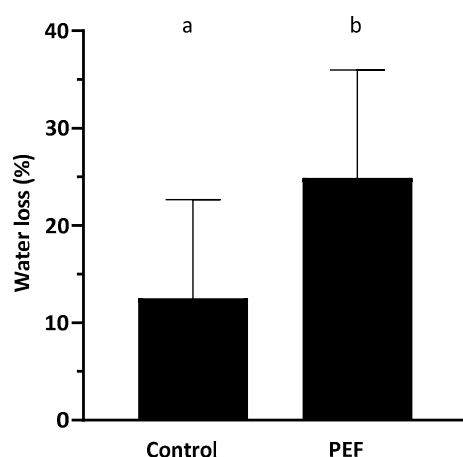


Figure 3. Influence of PEF treatment (1 kV/cm, 10 kJ/kg) on water loss from control and PEF-treated tomatoes.

3.3. Effect of PEF on the Firmness of Red Pepper and Cucumber

In the same way that the effect of PEF treatments on tomato firmness was evaluated, we extended our observations further to vegetables included in the gazpacho recipe: red pepper and cucumber. Figure 4 shows the effect of 1 kV/cm electric field strength and 10 kJ/kg specific energy on the firmness of red pepper (Figure 4a) and cucumber (Figure 4b). In terms of firmness, both types of vegetables responded to the two parameters in a manner similar to the tomato results. Regardless of PEF intensity, we found no statistically significant differences in firmness. Firmness decreased by around $18.8 \pm 5\%$ and $23.1 \pm 9.6\%$ for the pepper and cucumber, respectively, compared to the non-PEF-treated product.

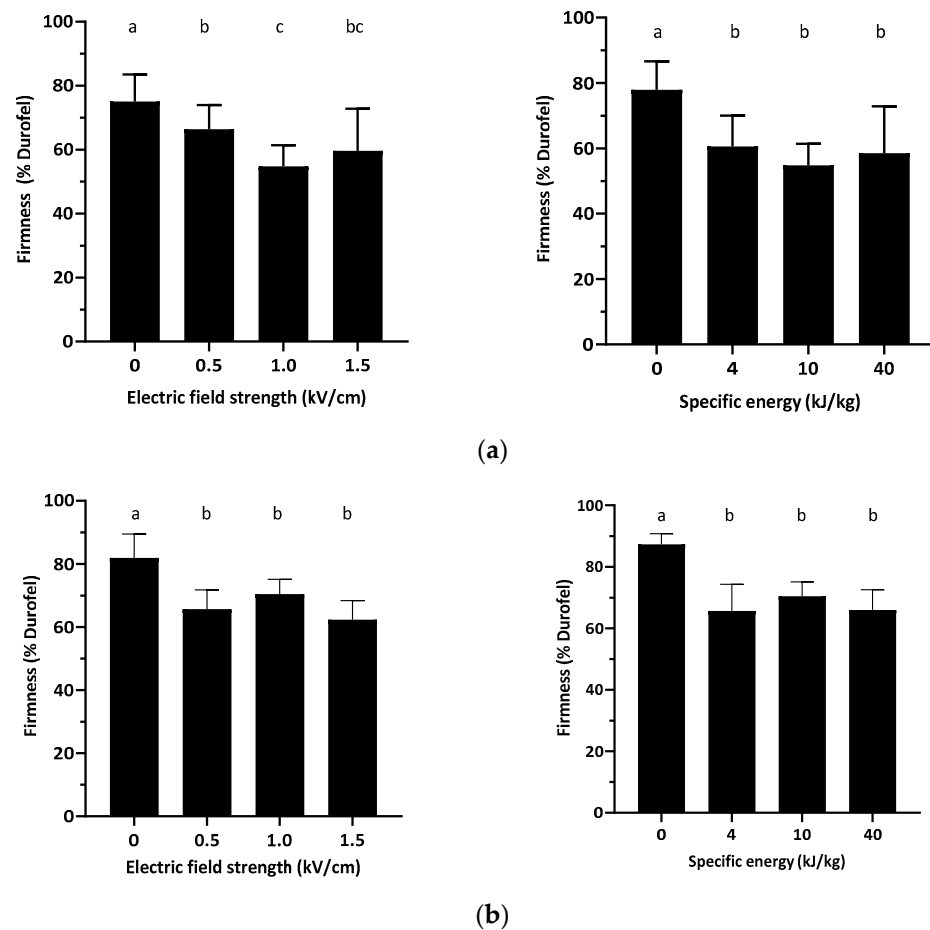


Figure 4. Effect of electric field strength (at 10 kJ/kg) and specific energy (at 1 kV/cm) applied to red pepper (a) and cucumber (b) on their firmness, measured in Durofel units.

3.4. Effect of PEF Gazpacho Characteristics

Once we evaluated the effect of PEF on separate gazpacho ingredients, we proceeded to determine how PEF might affect gazpacho elaboration. Based on our results, we prepared several gazpachos, subjecting the vegetables to a PEF treatment of 1 kV/cm and 10 kJ/kg, applying pulses of 20 μ s, and then grinding them at maximum mixer speed for 1 min, following the indications derived from Table 1. To characterize the effect of PEF on gazpacho, the parameters of consistency, color, and sensory analysis were evaluated.

3.4.1. Consistency

Similar to the process we applied to obtain tomato juice (see Section 3.1), gazpachos were prepared from non-treated and PEF-treated vegetables to determine the resulting product's consistency. The control gazpacho had a consistency of 6.6 ± 1.93 cm, while the one obtained from PEF-treated vegetables was more fluid, with a consistency of 8.75 ± 3.21 cm. However, these differences were not statistically significant, possibly due to variability in the results. In any case, the greater fluidity of the gazpacho obtained from PEF-treated vegetables could be due to more pronounced water release: they probably became softer once their cells had been electroporated, as described above (Figures 2–4).

The variability observed in results might have an explanation: despite intense shaking, certain remaining solid components might still affect the gazpachos' degree of emulsification. To study this effect, several gazpachos were prepared (according to the formulation in Table 1) to reduce eventual solids in suspension by sieving the gazpacho and by eliminating the cucumber skin, a common practice in the preparation of Spanish gazpacho. Finally,

since a more substantial release of water from the PEF-treated tomatoes was observed (Figure 3), we found that it would be of interest to prepare gazpachos with less added water. This would also reduce the dilution of nutrients. Thus, we tested two formulations: one with 100% added water and the other with 50% added water, following the recipe in Table 1. Figure 5 indicates the consistency of the twelve different prepared gazpachos using either non-PEF-treated vegetables (marked with a “C”) or vegetables subjected to a PEF treatment of 1 kV/cm and 10 kJ/Kg (square bars marked with the letter “P”). Independently of the followed recipe, the fluidity of gazpachos prepared with PEF-treated vegetables (squared bars) was more pronounced than gazpachos prepared with control vegetables. This effect was more statistically significant (indicated with *) when the gazpacho was sifted (Preparations 4, 5, and 6).

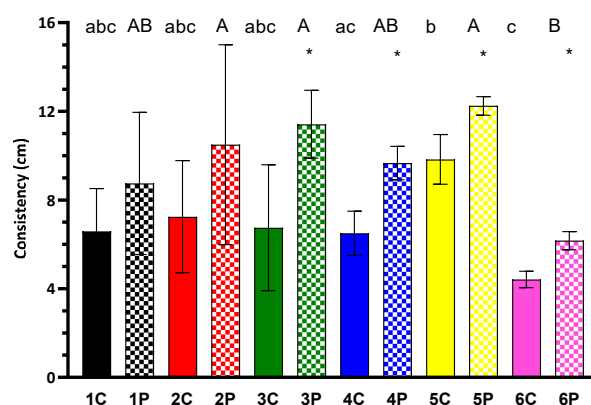


Figure 5. Consistency of various prepared gazpachos: control preparations (letter “C”) and gazpachos prepared with PEF-treated vegetables (letter “P”) based on Table 1: (1) with unpeeled cucumber, unsifted, and 100% added water; (2) with peeled cucumber, unsifted, and 100% added water; (3) with unpeeled cucumber, unsifted, and 50% added water; (4) with unpeeled cucumber, sifted, and 100% added water; (5) peeled cucumber, sifted, and 100% added water; (6) with unpeeled cucumber, sifted, and 50% added water. The * symbol indicates statistically significant differences between control and pulsed samples for the same type of preparation. Alphabet letters indicate significant differences between types of preparation (lowercase letters indicate that the comparison is among control samples; capital letters indicate that the comparison is among PEF samples). PEF treatment applied to vegetables: 1 kV/cm; 10 kJ/kg.

Apart from adding water, the additional steps of removing the cucumber skin and sifting the prepared gazpacho allowed us to obtain a control gazpacho (Preparation 5C) that was significantly more fluid than the other preparations, something that would be logical when reducing dry extract of the product. Indeed, that same preparation, but using PEF-treated vegetables, resulted in the most fluid gazpacho (Preparation 5P).

The effect of applying various types of preparations was less evident in PEF-treated samples. This could be due to several factors: apart from releasing more water, PEF-treated vegetables would also release enzymes and other compounds that might interfere with the emulsion (when preparing the gazpacho) or the amount of incorporated air (when mixing). It would be interesting to evaluate the emulsions in more detail, for example, by visualizing each one under a microscope or characterizing the size of the fat globules formed, as has been described in other food matrices [17–19].

At any rate, our results show that it would be interesting for a gazpacho producer to work with vegetables previously treated with PEF since that step could reduce the amount of added water required to obtain a product with a certain fluidity while increasing the amount of gazpacho obtained from the same amount of vegetables. On the whole, PEF pretreatment would result in products richer in nutrients, featuring enhanced bioavailability. This has been observed in studies of tomatoes and other vegetables subjected to PEF pretreatments [20–23].

3.4.2. Color

Figure 6 shows the different CIELAB coordinates of the distinct prepared gazpachos. The same parameters and codes were followed as those indicated for the case of consistency (Figure 5). The L^* parameter (Figure 6a), related to the luminosity or clarity of the product, decreased when the vegetables in the gazpacho had been treated with PEF. This might indicate that they were darker than control, regardless of the type of preparation. In all cases, coordinate a^* (Figure 6b) was higher in gazpachos prepared with PEF-treated vegetables, with a greater or lesser degree of statistical significance. This indicates that those gazpachos were more reddish than control samples. These results are coherent, given that three previous studies have noted a more elevated extraction of lycopene in tomatoes treated with PEF [24–26]. On the other hand, none of the changes in coordinates seemed to have a clear relationship with the type of preparation. There was no clear effect of PEF pretreatment on coordinate b^* (Figure 6c), which indicates a color varying between blue and yellow, except in gazpachos prepared from cucumber with skin, sifted, and with 50% added water (Preparation 6). In this case, as in the others, the type of preparation did not seem to exert a clear effect on the b^* coordinate.

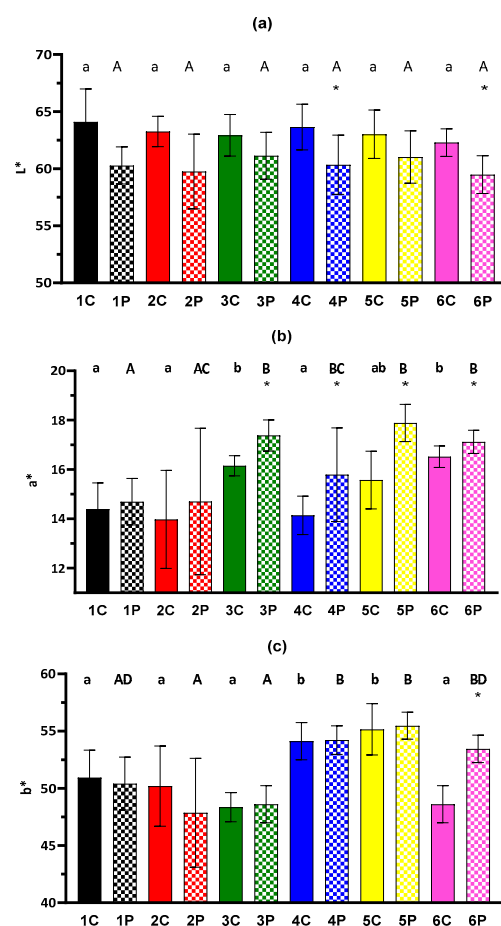


Figure 6. Coordinates (a) L^* , (b) a^* , and (c) b^* of various prepared gazpachos. Control preparations (letter “C”) and gazpachos prepared with PEF-treated vegetables (letter “P”) based on Table 1: (1) with unpeeled cucumber, unsifted, and 100% added water; (2) with peeled cucumber, unsifted, and 100% added water; (3) with unpeeled cucumber, unsifted, and 50% added water; (4) with unpeeled cucumber, sifted, and 100% added water; (5) with peeled cucumber, sifted, and 100% added water; (6) with unpeeled cucumber, sifted, and 50% added water. The * symbol indicates statistically significant differences between control and pulsed samples for the same type of preparation. Letters indicate significant differences between types of preparation (lowercase letters indicate that the comparison is among control samples; capital letters indicate that the comparison is among PEF samples). PEF treatment: 1 kV/cm; 10 kJ/kg.

Finally, based on the data shown in Figure 6, the ΔE values of the different gazpacho preparations were calculated. Figure 7 shows the values obtained for each preparation by comparing a control sample with the corresponding gazpacho obtained with PEF-treated vegetables. The gazpacho prepared with unpeeled cucumber, without sifting, and with 50% water (Preparation 3) was the one with the least amount of differences. In general, gazpachos obtained from PEF-treated vegetables showed ΔE values greater than 3, indicating that clear differences would be visible between them and the others to the naked eye. As an example, Figure 8 is a photograph of two gazpachos: one (left) obtained with and the other (right) without the assistance of PEF. One can observe a slightly darker and more reddish color in the sample on the left, obtained with PEF-treated vegetables, still including cucumber skin, unsifted, and with 100% added water (Recipe 1).

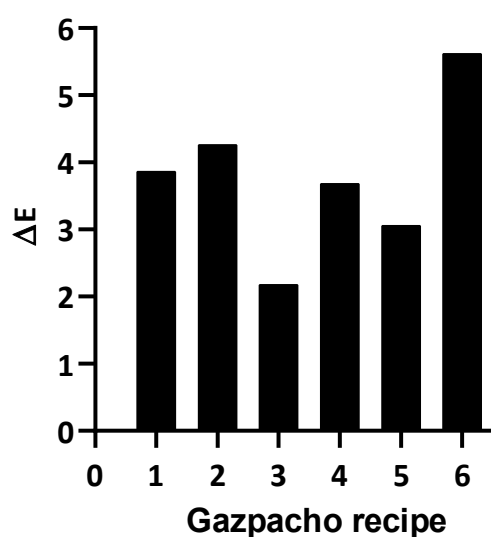


Figure 7. ΔE values of various prepared gazpachos. Values obtained by comparing a control preparation with the respective PEF-assisted one: (1) with unpeeled cucumber, unsifted, and 100% added water; (2) with peeled cucumber, unsifted, and 100% added water; (3) with unpeeled cucumber, unsifted, and 50% added water; (4) with unpeeled cucumber, sifted, and 100% added water; (5) with peeled cucumber, sifted, and 100% added water; (6) with unpeeled cucumber, sifted, and 50% added water.



Figure 8. Images of PEF (left) and control (right) gazpachos obtained according to Preparation 1: containing unpeeled cucumber, unsifted, and with 100% water added.

3.4.3. Sensory Analysis

From all the above, we concluded that a PEF pretreatment exerted certain observable effects on gazpachos thereby obtained, including an increase in fluidity, a more intense color, etc. This may or may not be a desired goal, depending on consumer preferences. To explore this aspect, a hedonic or affective sensory analysis was conducted resorting to potential consumers, i.e., untrained tasters. To simplify the evaluation process, we organized a preference test comparing two gazpachos: one prepared by treating the vegetables with PEF (1 kV/cm, 10 kJ/kg, and 20 μ s) and another without the assistance of PEF. In both cases, we used unpeeled cucumber, the prepared gazpacho was not sifted, and we added 100% water. Figure 9 shows the preferences ascribed to each gazpacho according to hedonic sensory analysis. Control samples are in blue, and PEF-treated samples are in red. In most cases, the results of the tasting session favor the gazpacho prepared with PEF-treated vegetables. The values of those preparations obtained in the categories “overall appearance”, “color”, “texture”, and “flavor” were 48.2, 70.4, 55.6, and 66.7%, respectively. Aroma was the sole parameter where consumers preferred the control sample (66.7%), perhaps due to its greater intensity, given that we used extra virgin olive oil. This point merits further investigation by, i.e., analyzing aroma profile by Gas Chromatography; moreover, it has recently been described that intensity of positive attributes (fruity, bitter, and pungent attributes) of extra virgin olive oil was generally higher when assisting its extraction with PEF [27].

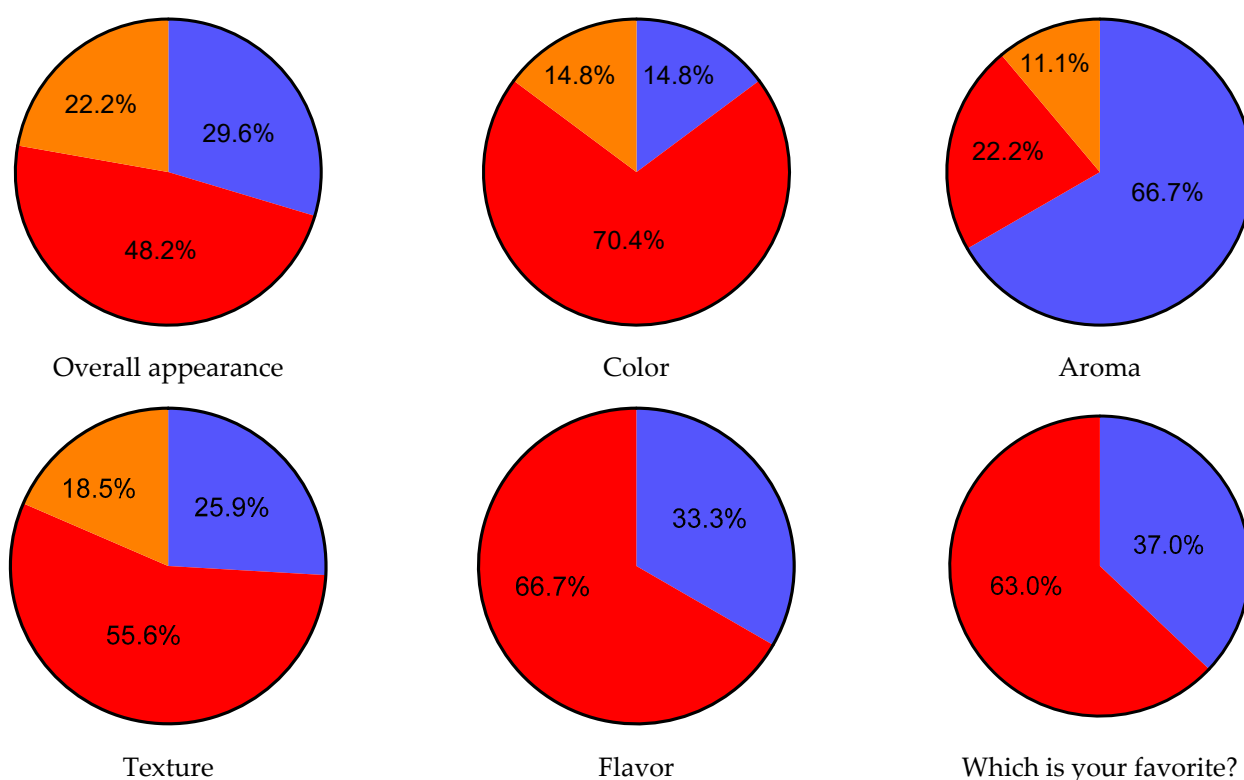


Figure 9. Preference percentages for control gazpachos (in blue) or PEF gazpachos (in red) according to hedonic sensory analysis. The “indifferent” option is indicated in orange.

In the texture category, tasters preferred the PEF-treated gazpacho preparation (55.6%), perhaps because the control gazpacho was thicker, whereas the PEF-treated gazpacho preparation was more liquid and easier to drink. That fluidity, combined with color and, particularly, taste (which was significantly more intense, possibly due to a more elevated extraction of sapid compounds), led 63.0% of our panelists to prefer the gazpacho preparation featuring vegetables pretreated with PEF. Overall, this experiment seems to

indicate that the application of PEF in preparing gazpacho would have a beneficial effect on this type of product's organoleptic characteristics.

4. Conclusions

In this study, for the first time in the literature, the application of a PEF pretreatment to the vegetables traditionally used in preparing Spanish gazpacho (i.e., tomato soup with vegetables, bread, and oil) was evaluated. After studying the application of several varying PEF parameters to the vegetables included in gazpacho, we concluded that PEF affected the vegetables (tomato, red pepper, and cucumber) and the final product (gazpacho) in several aspects. On the one hand, all the PEF treatments we investigated softened the vegetables and decreased their WHC. This, in turn, made subsequent blending more energy-efficient due to lower blender consumption (3% fewer watts required).

A PEF pretreatment also increased gazpacho consistency, regardless of the type of preparation. This was most likely due to a greater release of water from the vegetables' cells. Color differences were also evident: PEF pretreatment resulted in gazpachos with a more intense, reddish color. Improved scores in the sensory categories of color, texture, and flavor were probably due to a presumably higher extraction of sapid compounds. In any case, further research is required to characterize the effect of preparing gazpacho with PEF-treated vegetables on several aspects, including aroma and emulsion attributes, as stated above.

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