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First Investigation on Ultrasound-Assisted Preparation of Food Products: Sensory and Physicochemical Characteristics

Daniella Pingret, Anne-Sylvie Fabiano-Tixier, Emmanuel Petitcolas, Jean-Paul Canselier, and Farid Chemat

Abstract: This paper presents a comparison between manufactured food products using conventional and ultrasound-assisted procedures. Three different foam-type products, chocolate *Genoise*, basic sponge cake, and chocolate mousse were prepared using both methods with subsequent evaluation of the samples using both sensory and physicochemical methods. Ultrasound-assisted preparations were considered superior according to the sensory analysis, and physicochemical data confirmed this finding. This approach of applying an emerging piece of equipment, with potential industrial application to assist food preparation, consists of a new technique that could be of great interest for the development of not only other food products created by molecular gastronomy but also for practical work carried out by students.

Keywords: food preparation, molecular cooking, sensory analysis, ultrasound

Introduction

The global food market is increasing continuously with the emergence of developing countries, which brings the urge to increase productivity and reduce manufacturing duration among food manufacturers. As a result of this demand, innovations in processing techniques, packaging, flavors, nutritive components, and also quality and safety are increasing. Indeed, manufacturers need to use faster and more productive technologies in order to satisfy consumer requirements for a safe final product that retains all nutritional aspects. The use of ultrasound (US) has been of great importance to achieve some of these purposes.

Power US produces cavitation in liquid media, generating mechanical effects (intense pressure, shear forces) and temperature gradients within the material, which can disrupt its structure physically or promote chemical reactions (Mason and others 1996). In industrial processes, US application requirements are a mostly liquid medium and a source of high-energy vibrations (the transducer) in contact with the processing medium (Patist and Bates 2008). In particular, US provides energy well adapted to the formulation of dispersed systems: emulsions (L/L), suspensions (S/L), aerosols (L/G or S/G), and foams (Abismaïl and others 1999). Although foaming is usually reduced during US emulsification with mechanical stirring process (Ultra-Turrax rotor-stator), one cannot conclude that US exerts a systematic antifoaming action, since US-assisted foam generation has been reported several times (Abismaïl and others 1999; Lim and Barigou 2005). In fact, the interactions caused by power US in dispersed (or colloidal) systems have been a subject of historical interest for physical chemists: emulsification and aerosol formation appear among the first applications of power

US (Richards and Loomis 1927) and has been extensively studied since then (Abismaïl and others 1999; Gaikwad and Pandit 2008).

Applications of high-intensity US in the food industry include cleaning of equipment, homogenization, sterilization, heat and mass transfer, emulsification, dispersion, aerosol formation, defoaming, extraction (for example, proteins), crystallization, freezing, degassing, filtration, drying, oxidation/reduction reactions, meat tenderization, recombined meat products, enzyme reactions or inhibition, cell disruption, and living cell stimulation (McClements 1995; Mason and others 1996; Mason and Paniwnyk 1996; Povey and Mason 1998; Knorr and others 2004; Dolatowski and others 2007; Torley and Bhandari 2007; Vilkuh and others 2008). Since many food products exist as dispersions (especially emulsions or foams) (Dagleish 1996; Dickinson and Patino 1999; Xu and others 2003; Friberg and others 2004), there are numerous possibilities for applying this technology to the agro-food industry in order to meet demands for increasing production efficiency. Although US is currently used in a number of different sectors of the agro-food industry, a search in the literature did not yield any reference to earlier reports of US use to assist the preparation of foam-type foods.

The optimized extraction of date syrup and the antimicrobial effects on the fruit has been studied (Entezari and others 2004), as also the homogenization and fermentation of yogurt (Wu and others 2000). Regarding edible foams, a recent study shows that US improves the foaming properties of egg white, and it results in crispier meringues from lighter and stiffer foam (Knorr and others 2004). Although food viscosity can either increase or decrease, depending on the US intensity (Soria and Villamiel 2010), the better homogenization achieved by the use of ultrasounds has already been described in the processing of milk, where the size of the fat globules was reduced as their membranes were disrupted (Bermudez-Aguirre and others 2008). In food systems with high fat content, the cavitation phenomena might provoke chemical reactions that originate discrepancies in product quality (Schneider and others 2006). The oxidation process in sonicated fats and oils might result in the breakup of preexisting lipo(hydro)peroxides; therefore, the number of unsaturated bonds can possibly determine

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the oil susceptibility to off-flavors and studies have shown degradation of sunflower oil exposed to ultrasounds are more significant than that of palm oil (Patrick and others 2004).

US technique has proved to be a significant food processing technology with large commercial scale-up potential and low maintenance costs. Laboratory and industrial sonoreactors exist from 1 to 1000 L coupled to homogenizing pump systems in order to fill the ultrasonic bath, to stir the mixture, and empty the system at the end of the experiment. The machines have 25% of supplementary costs when compared to a conventional (CV) reactor and this amount corresponds to the implantation of the entire system, and payback (of less than 1 y) on capital investments is competitive (Patist and Bates 2008).

The objective of this work was to compare sensory and physicochemical properties of 3 foam-type products prepared conventionally and with ultrasonic methods. Evaluations of texture, water activity, and color together with sensory analyses were performed for 3 types of food preparations, namely, chocolate *Genoise*, sponge cake, and chocolate mousse (viscosity was only determined for the chocolate mousse). These products were chosen for their semiliquid state during preparation and for certain similarities in the processing steps. The effects of sonication on the different aspects of physicochemical parameters and sensory analysis are discussed. A gas chromatography-mass spectrometry (GC-MS) analysis of volatile compounds was performed. A literature search did not yield any reference to earlier reports on US-assisted preparation of food. This work was the first attempt to use an US device to assist food preparation, being a great contribution to molecular gastronomy with a potential industrial application, as also a great potential practical work for students.

Materials and Methods

Materials and equipment

US-assisted preparations were performed in an inox PEX1 ultrasonic bath (R.E.U.S., Contes, France) with 14 × 10 cm internal dimensions and maximal capacity of 1 L operating at a frequency of 25 kHz with maximum power of 150 W. The double-layered mantle (with water circulation) allowed for control of the temperature of the medium by cooling/heating systems such as a US “*bain marie*.” US power dissipating into the medium was determined by calorimetry (Kimura and others 1996). For the system under study, the initial temperature rise (T) was recorded against time (t) for 15 min. The total ultrasonic power in a time unit was calculated by substituting the value of dT/dt at time zero into the following equation: power = $(dT/dt) \cdot C_p \cdot M$, where C_p is the heat capacity of water (4.2 J/g · K) and M is the mass of water used (g). For mixing/blending the products inside the bowl, a whisk (at constant speed) was used. For texture assessment, a TA3 probe of a QTS25 Texture Analyzer (Stevens Advanced Weighing Systems, Leonard Farnell and Co., Ltd., U.K.) was used. For water activity assessment, a Hygrolab 3 (ROTRONIC AG, Bassersdorf, Switzerland) was used. Viscosity assessment was made using a rotary HAAKE VT550 viscometer and a SV-DIN sensor (Bohlin Reologi AB, Lund, Sweden). Color assessment was made using a spectrophotometer Minolta CM 3500d (Minolta, Osaka, Japan). A Hewlett Packard HP 5890 GC-MS (Hewlett Packard, Milano, Italy) system was used for chromatographic separation.

Food preparation

Three food products were prepared using CV and US-assisted techniques, namely, chocolate *Genoise*, basic sponge cake, and

chocolate mousse. The products prepared without US are referred to as CV, while those prepared with US are referred to as US. To better evaluate the influence of US in food processing, all preparations were carried out under the same conditions, and the sonication during the mixing step of the process was the only difference between US and CV samples. The temperature was kept at 25 °C during preparations as suggested by culinary procedures.

Chocolate *Genoise*. Cocoa powder (35 g), sugar (20 g), 2 fresh eggs, and a small amount of leavening agent were mixed with 20 g water and 200 mL cream and placed into the US bowl. Both mixtures were blended for 5 min to homogenize the ingredients and then for 5 more minutes (the US, in the case of the US samples, was applied in these 5 last minutes). The mixture was transferred to an aluminum dish and placed in an oven at 180 °C for 30 min. Finally, the CV and US products were cooled to room temperature before further analysis.

Sponge cake. Sugar (120 g) and 4 fresh eggs were put into the US bowl. The mixtures were blended for 5 min until homogenization and again for 5 min (the US, in the case of the US samples, was applied in these 5 last minutes, as for the chocolate *Genoise*). Both products were then cooled to room temperature. Next, 120 g flour was put into the bowl and mixed slowly with a spatula before being transferred to an aluminum dish and placed in the oven at 180 °C for 30 min. Finally, the samples were cooled to room temperature before further analysis.

Chocolate mousse. Cocoa powder (100 g), oil (30 g), sugar (30 g), and a small amount of gelatin powder were poured into 200 mL pasteurized milk inside the US bowl. The CV mixture was blended for 5 min while the US mixture was blended for 3 min and sonicated for 2 min with US. The products were poured into small glass bowls and cooled to 4 °C for 4 h before further analysis.

Analysis methodology

The principal characteristics of the products were determined by physicochemical tests (texture, water activity, and color) and sensory evaluation. The assays were applied to all samples, except for viscosity, that was determined for the chocolate mousse only. The results of the physicochemical analyses reported below are the averages of 3 measurements.

Texture. Since texture is one of the most important sensory characteristics determining consumer preferences, this parameter was measured by a reliable and practical technique based on the multiparameter determination of texture characteristics to accurately predict sensory texture attributes (Montero-Calderón and others 2008). The texture of the samples was determined by a typical texture profile analysis (TPA), the principle of which is the simulation of the chewing action (Figure 1A) and consequent evaluation of derived parameters (Bourne 2002; Kim and others 2009). The textural parameters considered were *hardness*, which measures the peak force of the 1st compression cycle and expresses the maximum force necessary to compress the sample and is expressed in Newton (N); *cohesiveness*, which expresses how well the product withstands a 2nd deformation relative to how it behaved under the 1st deformation, measured as area of work during the 2nd compression divided by the area of work during the 1st compression (dimensionless); *springiness*, which represents how well a product physically springs back after it has been deformed during the 1st compression, measured at the downstroke of the 2nd compression by the distance of the detected height of the sample on the 2nd compression (in mm); and *adhesiveness*, which corresponds to the work required to overcome attractive forces between the

sample and the other surface, expressed in Newton (N) (Bourne 2002; Montero-Calderón and others 2008; Chiabrando and others 2009; Kim and others 2009). All samples were placed in a 50-mL beaker and compressed as follows. First, the instrument height was checked to determine the initial height of the sample, followed by 2 consecutive compressions performed automatically at a test speed of 30 mm/min. Next, a compression distance of 10 mm was chosen, ensuring that the sample did not fracture before the 2nd compression. Finally, the testing was carried out after the samples had been equilibrated to a standard temperature of 25 °C for the initial taste panel training assessments.

Water activity. The a_w value (water activity) of a given medium is correlated with the deterioration of food stability due to the growth of microorganisms. The a_w of food preparations was determined using an electronic water activity meter calibrated before testing, and the variability of this meter was about $\pm 0.0015 a_w$ and ± 0.1 °C.

Viscosity. Viscosity in the samples was estimated at 25 °C, and the equipment was calibrated at different temperatures and the sensor parameters were the shear stress and the shear rate.

Color assessment. The color of the products was measured using the CIE $L^*a^*b^*$ system (CIE 1986), which is a simplified mathematical approximation to a uniform color space composed of perceived color differences. The lightness L^* (from 0 to 100) perceived by a standard observer is assumed to follow the intensity of a color stimulus according to a cubic root law. The colors of lightness L^* are arranged between the opponent colors green–red axis (a^* , from -128 to $+128$) and blue–yellow axis (b^* , from -128 to $+128$) along the rectangular coordinates a^* and b^* , as shown in Figure 1B. Any color represented in the rectangular coordinate system of axes L^* , a^* , b^* can alternatively be expressed in terms of polar coordinates with the perceived lightness L^* and the psychometric correlate of chroma (C^*) as shown in Eq. (3) (Hill and others 1997).

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

The color assessment of the samples was made using a colorimeter calibrated with distilled water. The samples were placed

on 50 mm dia. sterile plastic Petri dishes. Three measurements were made for each food preparation and the mean value was reported. The results were expressed in C^* .

Volatile compounds analysis. Volatiles compounds were analyzed by GC–MS after a solid phase microextraction (SPME fiber, 75 μm carboxan/polydimethylsiloxane coating) procedure. After trapping, desorption of volatiles takes place in a GC–MS injector at 250 °C. A Hewlett Packard HP 5890 GC–MS system was used for chromatographic separation. The injector mode was splitless and the ionization mode was an electron impact at 70 eV. Separation of compounds was achieved on a polar column (Supelcowax 10 TM, 60 m length, 0.2 mm i.d., 0.2 μm film thickness fused silica). The oven temperature was held at 40 °C for 5 min and ballistically increased to 60 °C and programmed to 220 °C at 4 °C/min. The program was then held at isotherm for 30 min. The flow of helium (carrier gas) was 1 mL/min. For the identification of eluted compounds, retention indices of the compounds were calculated from the injection of an n-alkane (C10 to C26) and compared to the indices reported in the literature. The identification was also confirmed by comparing their mass spectra to those in the data bank (Wiley/NBS library).

Sensory analysis. The influence of US on the sensory characteristics of the products was evaluated. Sensory analyses (Yantis 1992) were conducted by a panel consisting of 18 graduate students from the Univ. of Avignon, France. The subjects were seated in sensory booths with appropriate ventilation and lighting. The samples were presented to each panelist on white polystyrene plates. Subjects were instructed to place the stimuli on the tongue and rub the tongue against the palate. Tap water was supplied to the panelists for rinsing between samples. The following attributes were evaluated for the 3 products: creaminess, lingering taste, granularity, sweetness, egg taste, dryness, crumbliness, crunchiness, mellowness, cocoa flavor, and melting property. For overall quality, the scale range was from -3 to $+3$. On this scale, a score of 0 corresponded to an ideal perception, a score of -3 represented the weakest attribute and a score of $+3$ represented the strongest attribute. For each sample, the panelists gave their preferences on a hedonic scale (1 to 6). The sum of the points was calculated for each sample. The flavor was correlated by the ranges of each

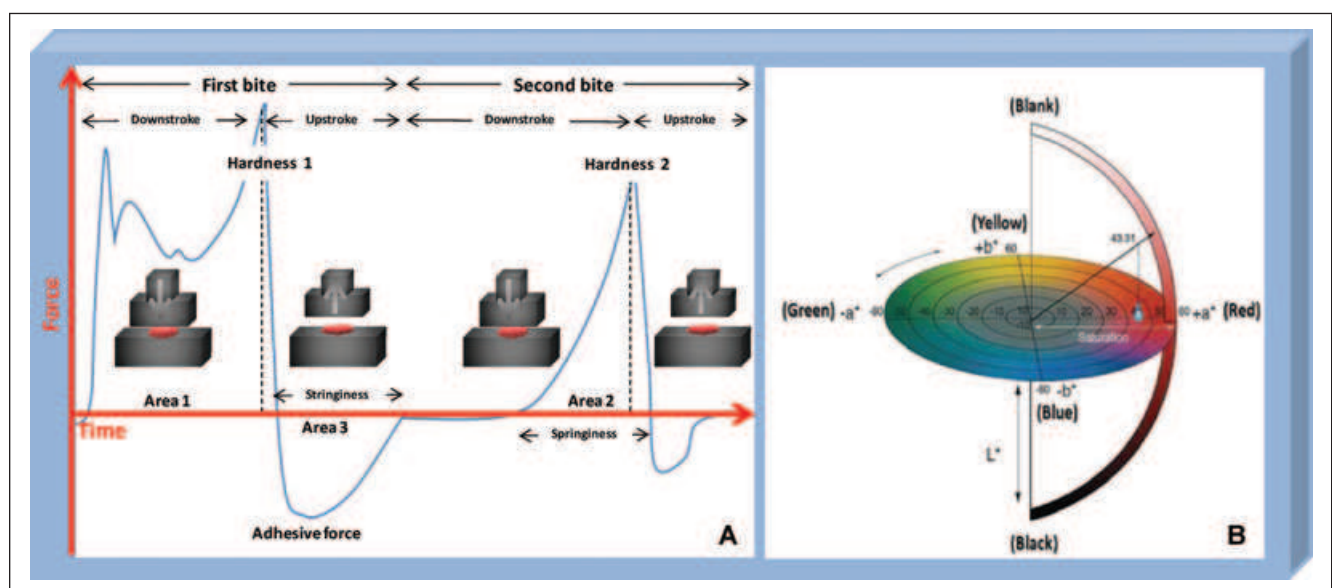


Figure 1—General texture profile analysis (TPA) curve (A) and CIE $L^*a^*b^*$ color assessment parameters (B).

sample from which the number one was the least appreciated and the number 6 was the most appreciated. A differentiation test was made as follows. Two samples of the product had to be recognized out of 6 by the panelists. The objective was to know if samples prepared with and without US were significantly recognized or not. The percentage of identification (PI) of samples was calculated. This value represented the number of times that the samples were recognized out of 100 identifications.

Results and Discussion

Chocolate Genoise

The preparation steps are represented in Figure 2. The CV sample presented more hardness, less springiness, more cohesiveness, and less adhesiveness than the sonicated one. Also, a_w was slightly increased by US (Table 1). There was a significant color differ-

ence between CV and US products, attributed to the fact that the US products were more aerated, since the US promotes a better homogenization regarding bubble distribution and size (Figure 2 and 3). Changes in color have been observed also in mayonnaise by the reflex of decreased size and better distribution of particles, creating an excellent white color (Patist and Bates 2008). Neither the CV nor the US samples was recognized by the examiners, but the sensory profile was better for the US product with a better appreciation of the attributes of sweetness, mellowness, crunchiness, and cocoa flavor (Figure 4 and Table 1). The US samples were preferred by a majority of panelists.

Sponge cake

The CV sample was harder, less springy, less cohesive, and less adhesive than the US sample. Also, a_w was slightly increased by the

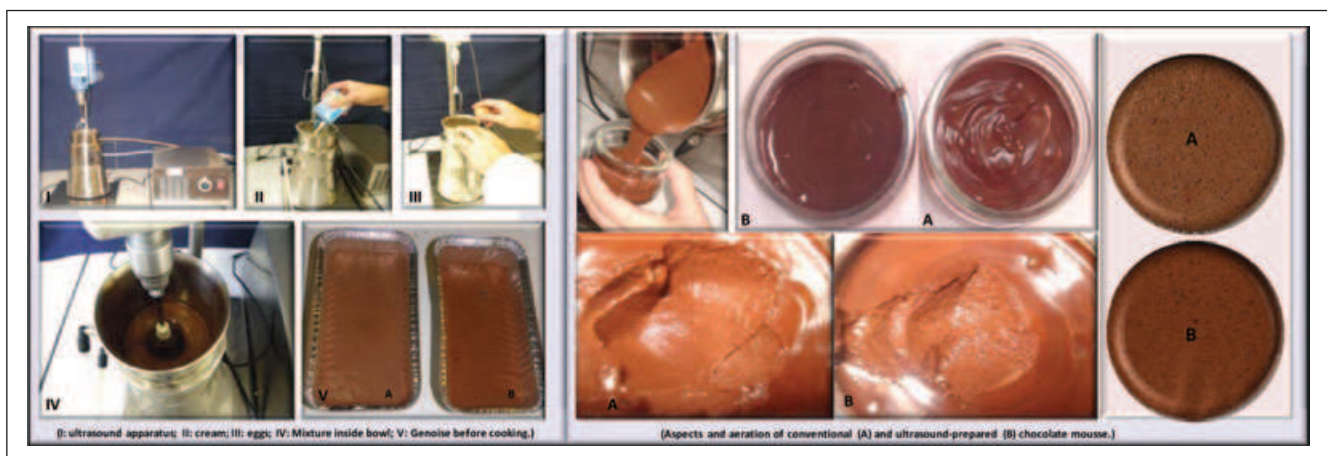


Figure 2—Materials and steps for conventional (A) and ultrasound-assisted preparation (B) of food and aspects of chocolate mousse.

Table 1—Physicochemical and sensory analysis of conventional (CV) and ultrasound-prepared (US) food samples.

Food samples		Texture				Physicochemical analysis			Sensory analysis	
		Hardness (N)	Springiness (mm)	Cohesiveness	Adhesiveness (N)	a_w	Coloration (C^*)	Viscosity (Pa.s)	PI (%)	Values attributed by panelists
Chocolate Genoise	CV	817	14.70	0.394	1284	0.713	3.40	-	0	26.5
	US	630	17.45	0.347	2961	0.723	5.27	-	0	56.0
Sponge cake	CV	1551	18.06	0.376	597	0.812	3.02	-	50.00	40.5
	US	286	26.34	0.465	735	0.870	5.36	-	50.00	43.5
Chocolate mousse	CV	85	4.50	0.299	192	0.956	4.82	157.15	71.43	47.0
	US	42	4.95	0.313	53	0.924	5.20	113.25	50.00	41.0

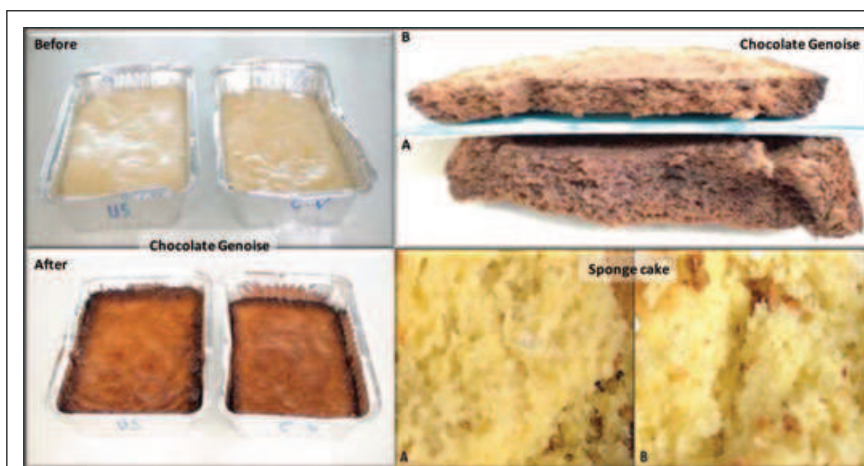


Figure 3—Visual and internal aspects of conventional (A) and ultrasound-prepared (B) chocolate Genoise and sponge cake.

US (Table 1). There was a large difference of coloration between the 2 samples. As for the other products, the color was affected by the aeration/homogenization effect of the US (Figure 3). In the sensory analysis, the PI was the same for both samples, so these values were not exploitable, but some attributes were more

appreciated for the US samples such as sweetness and egg taste (Figure 4). The US product was slightly preferred by the panelists (Table 1).

Chocolate mousse

The CV sample was harder, less springy, less cohesive, and more adhesive than the US sample. Also, a_w was slightly reduced by US (Table 1). The coloration was different for CV and US samples (Table 1 and Figure 2). We observed that the chocolate mousse obtained by US was shinier, smoother, more aerated, and presented a darker color. This color change may be assigned to the texture of the US sample, more specifically the size and the distribution of air bubbles producing different reflection properties. The viscosity was decreased by the effect of US. In fact, the samples prepared with US were more homogeneous and less denser than the CV samples (Figure 2) because of the compression–rarefaction phenomenon occurring on the air bubbles in the product during sonication. According to the sensory analysis, some attributes of the chocolate mousse were slightly changed by the US (Figure 4). The CV samples were found to be more cocoa-flavored, melting, creamy, and with more lingering tastiness and sweetness than the US samples. The identification percentage was larger for the CV samples, which is consistent with the larger preference for those samples, due to the more pleasant taste attributed to them (Table 1). Sensory experiments revealed that a short ultrasonic treatment of chocolate mousse is sufficient to generate a remarkable off-flavor. The panelists described the untreated chocolate mousse as typical, but the sample treated with US is described by different terms, mainly “metallic,” followed by “fishy,” “rancid,” and “tallowy.” The apparition of off-flavors due to the use of ultrasonic systems has been raised by different investigators (Chemat and others 2004a, 2004b; Patrick and others 2004; Schneider and others 2006), which corroborates our findings. Due to off-flavor observation, some compounds were extracted by SPME method and then analyzed by GC-MS. Hexanal, (Z)-hept-2-enal, and (2E,4E)-deca-2,4-dienal have been identified. These volatiles contribute to the following off-flavors (respectively): grassy and pungent, fishy and sweet, deep-fried and oxidized notes, and result from the degradation of fat and oils contained in chocolate mousse (Chemat and others 2004; Jahouach-Rabai and others 2008). Off-flavors and oil degradation were observed due to the high intensity of the probe and the horn systems. In fact, these 2 systems are very powerful because US is delivered on a very small surface, thus the intensity of US at the tip of the probe is very high (about 50 to 200 W/cm²). The power dissipated in the medium, measured by calorimetry, was about 70 W. The new device developed by R.E.U.S. does not consist of a probe system, but the power is delivered on the whole base of the system that corresponds to a power of about 1 W/cm². Even though the system used presents at least 10 times less power than the probe system, the same degradation results were observed.

The physicochemical and organoleptic parameters of the 3 food products were changed when they were prepared with US (Table 2). All products presented less hardness, while most presented more springiness (except for the mousse), more cohesiveness (except for the *Genoise*), and adhesiveness (except for the chocolate mousse). US was also found to change the water activity of the products but not in a consistent way (generally it was increased, except for the chocolate mousse), making it difficult to draw a firm conclusion on those aspects. The color was changed in all samples, and the viscosity of the chocolate mousse was decreased (Table 1).

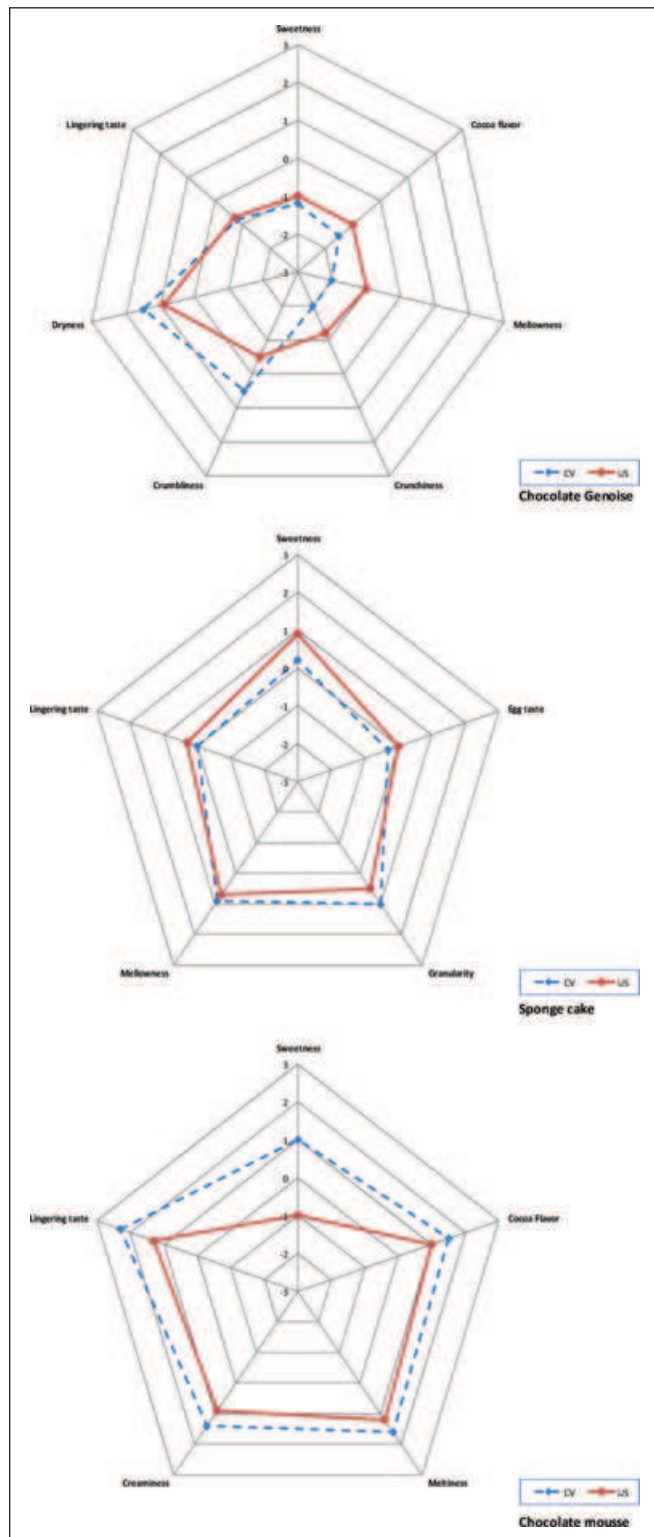


Figure 4—Sensory profile of conventional and ultrasound-prepared food samples.

Table 2—Summary of trends observed after US treatment.

Parameter	Genoise	Sponge cake	Mousse
Hardness	↓	↓	↓
Springiness	↑	↑	↓
Cohesiveness	↓	↑	↑
Adhesiveness	↑	↑	↓
Water activity	↑	↑	↓
Viscosity	—	—	↓
Coloration	↑	↑	↑
PI (%)	=	=	↑
Preference	↑	↑	↓

US is known to provide a more homogeneous mixing, so the distribution and size of particles are also more uniform, which can explain the viscosity decrease in US samples as well as the color difference, since different air bubble distribution and size might result in different reflective properties. Sensory analysis showed that sonication modified some attributes such as sweetness, meltiness, dryness, crunchiness, mellowness, and granularity and hence it was concluded that US application during preparation changed the flavor of the products. The formation of free radicals by US due to the breakage of molecular bonds would explain the physicochemical and organoleptic modifications on samples. Moreover, the variation in equilibrium points of the molecules and the formation of microjets could also be the origin of the greater color homogenization in the US-assisted prepared products. This homogenization might also likely result in better mass transfer between the different phases of the food. Furthermore, US generates energy due to the cavitation phenomenon, resulting in higher local temperature gradients. This energy can accelerate chemical reactions that might originate increased sweetness or other attributes perceived by the panelists.

The treated materials present a high complexity with presumably relatively high acoustic impedance that would result in a low penetration depth of US waves, so the liquid circulation variation due to acoustic streaming in the sonochemical bath should be taken into account. Generally it is believed that streaming generates liquid currents in a direction away from the transducer toward the free liquid surface and undergoes reflections at the reactor wall generating a mixed recirculation pattern. The variation in velocity is related to the power dissipation. A deeper physical investigation would be important for an industrial scale-up application.

Conclusions

This study shows that US used to assist foam-type food preparations (in this case a sponge cake, a chocolate *Genoise*, and a chocolate mousse) result in more homogeneous products that were not only well accepted by the panelists but even preferred to conventionally prepared ones as some organoleptic characteristics were improved. We showed that some physicochemical characteristics of the products were changed and since the chocolate mousse presented some important changes that led to less acceptance of

the product, and although some volatile compounds were identified by GC-MS that are responsible for the off-flavor observed, further studies should be conducted. This study might also be interesting for practical work for students, since a simple odor/flavor observation is sufficient for identifying degradation.

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