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The effects of ultrasound waves on yield, texture and some qualitative characteristics of cheese

Seyed Mahdi Hosseini Bahri[1], RezaEsmaeilzadeh Kenari[2*]

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Abstract

In this study, the effects of bath and probe ultrasound treatments were investigated on yield, texture (hardness, adhesion, cohesion, springiness and chewiness), pH and moisture content of fresh white cheese. The times 2, 4, 6 minutes and 5, 10, 15 minutes were used in probe treatment (frequency 20 kHz) and bath treatment (frequency 37 kHz), respectively, at temperatures of 40, 50 and 60°C in two stages (raw cow milk and cheese matrix). The results showed that applying ultrasound treatment significantly (P<0.05) increases cheese making yield and moisture content and decreases pH compared with the control sample, so that the highest moisture content and efficiency were related to probe ultrasound treatment in 2 minutes at 30°C. Results of the texture analysis showed that the cheese sample hardness significantly (P<0.05) reduced with the increasing time and temperature of ultrasound treatment compared to control samples. Also parameters of the adhesiveness and chewiness decreased as a result of ultrasound treatment compared to the control samples, but parameters of cohesiveness and springiness did not have discernable change trends.

Keywords: ultrasound bath and probe, yield, quality characteristics, texture characteristics, cheese

Introduction

The processes of thermal pasteurization and sterilization are the most common methods used in processing of dairy products in order to eliminate and inactivate microorganisms. However, heat may result in drop of sensory properties and nutritional value of dairy products. One of the most important components of milk that can be altered by heat is protein. It can be said that protein is the most valuable compartment of milk due to its high nutritional value and unique physical and chemical properties. These unique properties of protein play a key role in the production of dairy products, such as cheese or yogurt (Cameron *et al*., 2009). Coincided with an increase of consumer's information, the demand for the use of novel methods of food processing with minimal impact on reducing nutritional value and overall quality of food has been increased. Among the new technologies that have been proposed to improve the dairy products shelf life, ultrasound alone or in combination with heat (thermosonication) or with pressure (manosonication) can efficiently disable many bacterial species and improve quality of the products (Marchesini et al., 2012). Low frequency ultrasound technology (18-100 kHz) has many potential applications in the dairy industry, such as homogenization, crystallization, and anti-foam properties; facilitating the isolation of milk fat with high frequency equal to or higher than 400 kHz). The sound range in ultrasound is divided to ultrasound with high frequency, low intensity (respectively higher than 1 MHz and less than 1Wcm^{-2}) and with low frequency and high intensity (respectively 20-100 kHz and 10-1000 Wcm^{-2}) which both are applied in food technology. However, high-intensity, low-frequency is usually used in the food industry. The first type is non-destructive and can be used to

1. PhD student, Department of Food Science and Technology, Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Sari, Iran- Greenhouse Cultivation Research Department,Tehran Agricultural and Natural Resources Research and Education Center, AREEO,Varamin, Iran .
2. Associated professor, Department of Food Science and Technology, Faculty of Agricultural Engineering, Sari Agricultural Sciences and Natural Resources University, Sari, Iran.
(Corresponding Author Email: reza_kenari@yahoo.com)
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analyze and characterize the compounds, while the latter can be used to modify cellular structures and a number of other processes such as foam inhibitors, emulsification, inhabitation or activation of the enzyme and crystallization. The ultrasound frequency is directly effective on the number of bubbles created in the system so that the higher frequency will lead to smaller number and size of bubbles. As a result, the power generated by cavitation will reduce (Alarcon-Rojo *et al*., 2015).

During the ultrasound treatment, mechanical power and high temperature caused by cavitation lead to great structural changes in milk. Some of these structural changes can be noted as reduction in the size of fat globules, cracking cell membrane of milk fat and breaking down milk casein micelles into smaller components (the components which are connected with triacylglycerol). Free radicals and other reactive species may be formed during ultrasound treatment. These chemicals can lead to oxidation reactions and production of volatile compounds in the environment which plays an important role in compromising the quality of milk. The production of these series of destructive compounds caused by ultrasound treatment highly depends on treatment conditions (frequency, intensity, range and temperature). It is important to determine the optimum process conditions. All of these structural changes caused by ultrasound treatment can lead to positive or negative qualitative and technological impaction dairy products (Marchesini *et al*., 2012). The use of ultrasound has found many applications in the dairy industry. Low-frequency waves between 100-18 KHz are used in operations such as homogenization, crystallization and de-foaming and the waves with higher frequencies up to 400 kHz are used to accelerate the separation of milk fat. Many food components are sensitive to thermal process and are vulnerable against biological and chemical changes and reducing these food components and long processing time and energy consumption in conventional processing methods are among the disadvantages of these methods. Using innovative technology methods such as ultrasound can largely reduce energy consumption and process time and costs and also prevent the vulnerability and sensitivity of nutrient products (Chemat and Khan, 2011). Among the new technologies used to improve the health and durability of milk, ultrasound technique causes the inactivation of many bacterial species more efficiently, better performance of starter bacteria in cheese making, further release of starter enzymes before and after the addition of the starter and also increases efficiency and improve quality of cheese (Piyasena *et al*., 2003). So far, relatively few studies have been conducted on the application of ultrasound in cheese making and in this context doing more research should be considered. Marchesini *et al* (2012) showed that the use of ultrasound significant increases the amount of free fatty acids, reduces the pH of the raw milk by increasing lipolysis reactions, decreases the number of somatic cells and improves the quality of milk, as well as decreasesthe formation process of clots in the cheese-making stage. So far, no study has been provided that attempted to evaluate the ultrasound treatment changing the texture of cheese. In this study, the effects of ultrasound bath (at a frequency of 37 kHz) and probes (20 kHz) are investigated on yield of cheese, textural properties (hardness, cohesiveness, adhesiveness, springiness and chewiness) and qualitative characteristics of the cheese (pH and moisture content) in two step process: 1) applying ultrasound on raw milk before adding starter and 2) applying ultrasound to the matrix cheese (after the formation of cheese clots) at 40, 50 60°C for 2, 4 and 6 minutes in probe technique and 5, 10 and 15 minutes in the bath technique.

Materials and methods

Supplying raw milk

In order to conduct the cheese-making

process, 20 kg of raw cow milk was prepared at the local market in Sari immediately after milking and was maintained at 4°C until the testing time (24 hours). Enough rennet tablets were purchased (IIEC, Iran Industrial Enzymes Company).

Applying ultrasound process to the raw cow milk used in cheese making

500 ml of raw milk was pasteurized in a non-continuous way at 62°C for 10 minutes to produce each ultrasound, before applying ultrasound and then, was affected by ultrasound in two methods of probes (at 40, 50 and 60°C for 2, 4 and 6 minutes) and bath (at 40, 50 and 60°C for 5, 10 and 10 minutes). In the probe method, ultrasound cell disruptor (Model KS-250F, China, Ningbo Zhejiang) was used with a frequency of 20 kHz and range of 45% and power of 250 watts and in the bath method Elma Ultrasonic cleaning device (model S 30 H, Germany) with a frequency of 37 kHz and power of 280 watts. Then, after applying the ultrasound process the temperature of milk was brought to 42°C and the amount of 0.1 grams rennet per liter was added to the milk. After the clot formation (about 20 minutes), the cheese matrix was cut and dehydrated. And after all these the compression operation was performed for 2 hours. And finally fresh white cheese was packed in plastic packages containing salt water solution 4%. All tests were performed three days after the production and brining (Villamiel and de Jong, 2000).

Applying ultrasound process to the cheese matrix

After the pasteurization of milk, as described above, the temperature of the milk was brought to 42 °C and the amount of 0.1 grams rennet per liter was added to the milk. Cheese matrix was affected by ultrasound in two methods of probes (at 40, 50 and 60°C for 2, 4 and 6 minutes) and bath (at 40, 50 and 60°C for 5, 10 and 10 minutes) after the clot formation (20 minutes). And operations like drainage, compressing, packaging and brining were donerespectively. Milk control samples were prepared from pasteurized milk without an ultrasound process (Villamiel and de Jong, 2000).

Measuring moisture content

25 grams of cheese was weighed and the moisture content of the samples was measured using an electric oven according to the following formula (Benedito *et al.*, 2000):

Moisture content= (intial sample weight- dried sample weight)/ intial sample weight (1)

Measuring pH

The pH value of the samples was measured using a digital electrode pH meter PB 11 (Sartorius, Germany).

Determining the yield of cheese

Based on the amount of milk and cheese production, cheese yield is calculated as follows:

$$\text{Cheese yield}=\frac{\text{consumed milk}}{\text{produced cheese}} \quad (2)$$

Texture Profile Analysis

Analysis of tissue (TPA) by Brookfield CT3 Texture Analyzer (Brookfield Engineering Laboratories, USA) was pressed in order to study the changes resulting from the ultrasound process on the textural characteristics of the cheese samples, during the two-cycle compression using cylinder probe (50 mm diameter) up to 20% of the original thickness. Pre-test, test and returning speed were 1, 1 and 60 mm per minute, respectively. In the following we are going to evaluate the qualitative characteristics of the texture including; Hardness (the highest amount of force required for the first compression stage (N)); Cohesiveness (ratio of the force curve area during the second compression cycle to the ratio of the force curve area during the first compression cycle); Adhesiveness (negative force area for unloading in the first compression cycle); Springiness(ratio of the distance that the sample restores after the first compression (mm)); Chewiness (multiplication of hardness in cohesiveness and springiness (Nmm)) (O'Callaghan and Guinee, 2004).

Statistical analysis

All experiments were performed at least in three replications. Statistical analysis included one-way analysis of variance (ANVOA) and the significance mean (*post hoc* Duncan test) carried out at the significance level of $P<0.05$ using version 9 of SAS software. Stochastic statistical design was used in this work.

Results and discussion

The effects of ultrasound treatment on cheese pH

The pH is one of the most important cheese quality parameters of the texture which directly affects many chemical, structural and functional characteristics of cheese compounds. Reduction of pH leads to an increase in soluble calcium content and consequently increases the vulnerability of milk and helps to facilitate the process for cheese making. Decrease in pH causes the contraction of the protein matrix and helps the withdrawal of the whey (Pastorino *et al.*, 2003).

Tables 1 and 2 respectively show probe and bath ultrasound treatment effect on the cheese pH (applying ultrasound on raw milk for the cheese making and cheese matrix). Ultrasound treatment significantly reduces the pH of the cheese samples compared to control samples ($p<0.05$). In general, with increasing ultrasound treatment time, a significant decrease in cheese pH ($p<0.05$) was observed. It was also found that cheese samples prepared by applying ultrasound to the raw milk has less pH than the cheese samples prepared by applying treatment to the cheese matrix. In fact, applying ultrasound treatment on raw milk cheese is leading to a further reduction in pH. As can be seen in Tables 1 and 2, in general, samples treated with ultrasound probe have less pH than the ones treated with ultrasound bath this could be due to the more intense effect of ultrasound probe than the ultrasound bath on the milk composition structure. Increasing temperature of the ultrasound treatment initially leads to an increase in pH but ultrasound treatment reduced the pH of cheese at higher temperatures. The same behavior was noticed by Marchesini et al. (2012). They stated that temperature rise initially leads to an increase in the pH, due to the acceleration of CO_2 emissions from the milk but as the temperature increases, pH decreases due to the intensification of the Maillard reaction.

Ultrasound treatment can cause fat globule membrane damage caused by cavitation and release of free fatty acids, triglycerides, phospholipids and cholesterol from the center of the fat globules. The release of triglycerides in milk leads to an increase in lipolysis reaction and consequently an increase in free fatty acids of milk and ultimately reducing the pH due to an increase in lipolysis enzyme effect. Intensification of lipolysis reactions results in improved flavor in cheese ripening as well. The lower the pH, the faster the cheese ripening happens (Bermúdez-Aguirre *et al.*, 2008).

The effects of ultrasound treatment on moisture content of the cheese:

Moisture content is a very important parameter in the process of cheese making is directly related to cheese making yield. The higher the moisture content, the faster the ripening process happens and also the cheese yield would be higher. Higher moisture content leads to an increase in the amount of lactose in the cheese and therefore it produces more lactic acid in the ripening stage and the cheese becomes more acidic (Britz and Robinson, 2008, Walstra *et al.*, 2005).

The results of the ultrasound bath and probe treatment on the content of the cheese (ultrasound applied on raw milk and cheese matrix), are presented in Tables 1 and 2. Moisture content of the sample was 54.20%. As can be seen in Tables 1 and 2, applying ultrasound treatment significantly increases moisture content compared to the control sample ($p<0.05$). Moisture content of the samples treated with ultrasound was in the range of 58.60-54.26 %. In general, an increase in ultrasound treatment time and temperature significantly decreases the moisture content of the cheese ($p<0.05$). The moisture content of the cheese samples produced by ultrasound treatment on raw milk was more than the samples produced by ultrasound treatment on the cheese matrix (after inoculation).

Table 1- The effect of bath ultrasound on the pH and moisture content of raw milk and cheese matrix

ultrasound treatment type		pH	Moisture (%)
Raw milk	*5 min, 30 °C*	5.04±1.22^{gh}	57.84±1.42^{b}
	5 min, 40°C	5.16±2.35^{cde}	57.15±2.20^{c}
	5 min, 50°C	5.10±2.17^{efg}	56.15±1.42^{g}
	10 min, 30 °C	4.96±2.11^{i}	56.94±2.16^{d}
	10 min, 40°C	5.08±1.24^{fg}	56.45±2.15^{f}
	10 min, 50°C	4.99±1.31^{hi}	56.12±1.33^{g}
	15 min, 30 °C	4.85±1.33^{j}	56.55±1.21^{e}
	15 min, 40°C	4.98±0.62^{i}	56.13±1.16^{g}
	15 min, 50°C	4.88±1.40^{j}	55.60±0.51^{j}
Cheese matrix	*5 min, 30 °C*	5.20±1.42^{bcd}	57.94±2.12^{a}
	5 min, 40°C	5.24±0.60^{ab}	55.94±1.62^{h}
	5 min, 50°C	5.21±1.23^{abc}	55.15±0.13^{l}
	10 min, 30 °C	5.13±1.31^{ef}	56.48±0.71^{f}
	10 min, 40°C	5.15±0.22^{de}	55.34±0.46^{k}
	10 min, 50°C	5.13±0.85^{ef}	54.78±0.33^{n}
	15 min, 30 °C	5.04±0.52^{gh}	55.72±1.23^{i}
	15 min, 40°C	5.10±1.40^{fg}	54.92±1.34^{m}
	15 min, 50°C	5.05±1.50^{g}	54.54±0.50^{o}
Ultrasound treatment		5.26±0.28^{a}	54.20±1.52^{p}

Mean (*n=3*) values with different letters represents the significant case at P<0.05.

Table 2- The effect of probe ultrasound on the pH and moisture content of raw milk and cheese matrix

Ultrasound treatment type		pH	Moisture (%)
Raw milk	*2 min, 30 °C*	4.88±0.22^{j}	58.60±1.42^{a}
	2 min, 40°C	5.02±0.35^{fg}	55.95±2.20^{e}
	2 min, 50°C	4.94±2.17^{hi}	54.94±1.42^{j}
	4 min, 30 °C	4.78±2.11^{l}	57.88±2.16^{b}
	4 min, 40°C	4.90±1.24^{ij}	55.38±2.15^{h}
	4 min, 50°C	4.83±1.31^{k}	54.55±1.33^{m}
	6 min, 30 °C	4.65±1.33^{mn}	56.92±1.21^{c}
	6 min, 40°C	4.69±0.62^{m}	54.85±1.16^{k}
	6 min, 50°C	4.61±1.40^{n}	54.26±0.51^{p}
Cheese matrix	*2 min, 30 °C*	5.16±1.42^{bc}	56.80±2.12^{d}
	2 min, 40°C	5.18±0.60^{b}	55.32±1.62^{i}
	2 min, 50°C	5.14±1.23^{bc}	54.45±0.13^{n}
	4 min, 30 °C	5.08±1.31^{de}	55.58±0.71^{f}
	4 min, 40°C	5.13±0.22^{bcd}	54.64±0.46^{l}
	4 min, 50°C	5.12±0.85^{cd}	54.44±0.33^{n}
	6 min, 30 °C	4.98±0.52^{gh}	55.53±1.23^{g}
	6 min, 40°C	5.04±1.40^{ef}	54.31±1.34^{o}
	6 min, 50°C	5.01±1.50^{fg}	54.42±0.50^{n}
Ultrasound treatment		5.26±0.28^{a}	54.20±1.52^{p}

Mean (*n=3*) values with different letters represents the significant case at P<0.05.

It is recognized that ultrasound treatment reduces the size of casein micelles that in this regard, the exact ultrasound mechanism is not clear. It is also observed that after the ultrasound treatment, the serum protein of the solution increases and the reason for this has been attributed to the breakdown of the connection between serum casein and protein (kappa-casein and beta-lactoglobulin connection), which is the result of pasteurization heat. Breaking down serum protein-casein connection facilitates the effect of renin enzyme on the kappa-casein and contributes to the formation of cheese clots (Chandrapala *et al*., 2012). Increasing the moisture content of cheese samples after ultrasound treatment may be attributed to the casein micelles' break down and reduction in the size and thus increasing the active surface and absorbing more water. Also reduction in the moisture content of the cheese by increasing the treatment time and temperature can be due to possible denaturation of serum protein and caseins. In fact increase in ultrasound treatment temperature and time results in denaturation of milk proteins and surface exposure of hydrophobic groups. This can decrease the moisture content of cheese samples compared to less ultrasound treatment temperature and time.

The effect of ultrasound treatment on the yield of cheese making:

Figure 1 shows the effect of bath and probe ultrasound treatment on the yield of cheese making (ultrasound applied on raw milk and cheese matrix). As can be seen in Figure 1, generally ultrasound treatment resulted in a significant increase in cheese making yield ($p<0.05$). In general we can say that with increasing ultrasound treatment time and temperature there was a significant reduction in cheese making yield ($p<0.05$). It was also found that applying ultrasound treatment on raw milk leads to more cheese making yield compared to applying ultrasound treatment on cheese matrix. These results showed overlap with the moisture content data (Tables 1 and 2). Since the content of moisture is one of the most important parameters that directly affect cheese yield. The highest yield of cheese (0.25%) was for the ultrasound treatment applied to the raw milk for 2 minutes at 30°C (Figure 1 c). It is recognized that due to mechanical stresses caused by cavitation, the fat globules of the milk are crushed and the sizes are increased and the numbers increased so that the size of fat globules are the same size as casein micelles. In such circumstances the globule membrane no longer will be able to cover all fat globules. And the fat globules with the hydrophobic part will be coated with casein particles. It results in the creation of a new membrane with different combinations and connection of casein micelle to the fat globules (Meyer et al., 2006). These series of protein-fat binding helps clustering and accumulating casein and serum proteins and therefore provides an ideal structure for cheese making. Smaller fat globules provide a suitable substrate for the rennet enzyme activity due to their physical properties and reduce coagulation time and also increase the time for the clot to become stiff (Villamiel et al., 1999). Increasing cheese making yield through ultrasound treatment can be attributed to several reasons: (1) increasing the moisture content of the samples after applying ultrasound; (2) Casein micelles downsizing which increases the instability of milk and increases the rennet enzyme effects; (3) Creating a complex between hydrophobic parts of serum proteins and casein with fat globules that as well as increasing the serum proteins in cheese it also increases the yield and the nutritional value of cheese.

The effects of ultrasound treatment on the cheese textural features:

Rheological properties of cheese are evaluated by determining its response to stressor strain applied during processes such as compression, shear or cut. Rheological properties such as elasticity, viscosity and viscoelastic properties of cheese are primarily related to the structure, composition and strength of attraction between structural elements. Rheological properties of cheese are usually assessed by measuring rheological parameters in experimental tests. Cheese rheology is a function of the composition, microstructure (e.g. structural composition), physical and chemical state of the components and macro molecular characteristics of (Composite structure consisting of casein clots gaps). Physical and chemical properties include parameters such as the ratio of solid to liquid fat, hydrolysis degree and matrix para-casein hydration and the amount of intermolecular attractions between molecules of para-casein. Texture profile analysis (TPA) is a simulated test and a very important indicator for determining changes in the cheese texture) (O'Callaghan and Guinee, 2004). TPA parameters can be observed in Tables 3 and 4 as well as (hardness, adhesiveness, cohesiveness, springiness and chewiness) control samples and samples of cheese produced by ultrasound treatment on raw milk and cheese matrix.

Hardness parameter is the amount of force required to achieve the desired change in the shape of the sample (O'Callaghan and Guinee, 2004). The amount of hardness in control samples was N35.04 and in samples treated with baths and probes ultrasound treatment it was ranged 24.02-15.22 and 19.86-14.94 N, respectively (Tables 3 and 4). In general it can be said that the hardness of the cheese after ultrasound treatment significantly reduced compared to control ($p<0.05$).

Reducing the hardness of the cheese in the ultrasound treatment can be attributed to several reasons. Ultrasound treatment leads to an increase in the moisture content of the samples. On the other hand, water can act as a plasticizer in the texture and reduce hardness; because water can be placed between bigger components and reduce friction (Hennelly *et al*., 2006). Another reason of reducing the cheese hardness in the ultrasound can be attributed to a decrease in pH.Pastorino et al (Pastorino *et al*., 2003) reported that lower pH leads to a decrease in Cheddar hardness parameter. They stated that pH 5 is due to the increased solubility of calcium and consequently electrostatic force between proteins reduced and smaller protein masses have been formed in the cheese and reduced hardness.

In Tables 3 and 4 it can be observed that samples treated with probe ultrasound have less hardness than the samples treated with bath ultrasound. The reason for this can be related to the more intense damaging effect of ultrasound probe on milk components. It was also found that ultrasound treatment applied to cheese matrix compared with its application to raw milk has led to a further reduction of cheese hardness. Ultrasound treatment time and temperature rise resulted in a significant decrease of the cheese hardness ($p<0.05$). This can be due to more severe destruction of the protein network.

Adhesiveness parameters are used to describe a state of the food sticking to the teeth when chewing (Hennelly *et al*., 2006). The amount of the control sample adhesiveness was 1.30 mJ and in samples treated with baths and probes ultrasound it was in the range of0.2-1.1 mJ and 0.2-1.1 mJ, respectively (Tables 3 and 4). In fact, ultrasound treatment resulted in a significant reduction of sample adhesiveness compared to control samples ($p<0.05$). The reason for this can probably be due to the moisture content in the samples followed by ultrasound treatment. Cohesiveness parameter helps to achieve a comprehensive understanding of the viscoelastic properties such as tensile stability of the materials (Hennelly *et al*., 2006). The control sample cohesiveness was in the range of 0.56 and for the samples treated with bath and probe ultrasound it was range 0.60-0.76 and 0.62-0.78 (Tables 3 and 4). We can say that cohesiveness of cheese samples significantly increased after ultrasound treatment compared to control samples ($p<0.05$). Also with changes in temperature, time and type of treatment ultrasound no specific changes were observed. Springiness indicates the characteristics of elasticity and the ability to recover the structure of the samples. As can be seen in Tables 3 and 4, no certain changes took place for ultrasound treatment compared with the control sample.

Chewiness is a combination parameter and it is obtained by multiplying hardness, cohesiveness and springiness. There is an inverse relationship between tenderness, fragility, and chewiness parameter (Hennelly *et al*., 2006). According to Tables 3 and 4, the amount of the control sample chewiness was 118.32 mJand in samples treated with baths and probes ultrasound it was in the range of 70.42-123.74 mJ and 58.54-101.42 mJ, respectively (Tables 3 and 4).

It can be said that the ultrasound

treatment significantly reduced chewiness and actually increases the cheese tenderness (p<0.05). Results related to the cheese samples chewiness completely overlaps with the data related to hardness. And generally harder samples have higher chewiness.

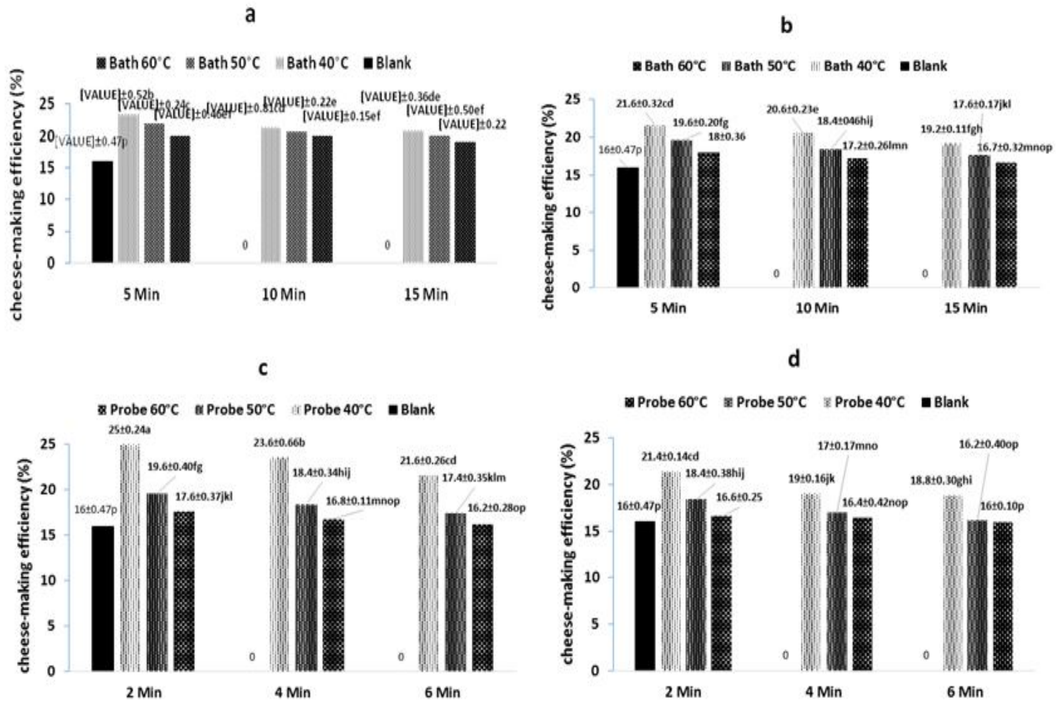

Fig. 1. The effect of ultrasound on the cheese-making efficiency of: raw milk treated by bath US (a), cheese matrix treated by bath US (b), raw milk treated by probe US (c), cheese matrix treated by probe US (d).
Mean (*n=3*) values with different letters represents the significant case at P<0.05.

Table 3- The effect of bath ultrasound on the texture parameters of raw milk and cheese matrix

Type of ultrasound treatment		Hardness (N)	Adhesiveness(mJ)	Cohesiveness	Springiness (mm)	Chewiness (mJ)
	5 min, 30 °C	24.02 ± 1.22^{b}	0.60 ± 0.21^{f}	0.65 ± 0.23^{d}	7.58 ± 0.42^{c}	118.34 ± 1.94^{c}
	5 min, 40°C	21.92 ± 1.55^{d}	0.20 ± 0.19^{b}	0.72 ± 0.25^{bc}	7.75 ± 0.26^{b}	122.32 ± 2.16^{b}
	5 min, 50°C	19.68 ± 2.04^{h}	0.85 ± 0.12^{cd}	0.64 ± 0.18^{d}	7.38 ± 0.18^{d}	92.95 ± 3.12^{i}
	10 min, 30 °C	20.85 ± 1.88^{f}	0.50 ± 0.32^{g}	0.74 ± 0.10^{b}	8.02 ± 0.32^{a}	123.74 ± 2.17^{a}
Raw milk	*10 min, 40°C*	19.23 ± 2.11^{i}	0.80 ± 0.02^{cd}	0.69 ± 0.19^{cd}	7.10 ± 0.20^{g}	94.21 ± 2.55^{a}
	10 min, 50°C	17.76 ± 1.34^{j}	0.21 ± 0.10^{fg}	0.65 ± 0.05^{d}	7.45 ± 0.21^{d}	86.01 ± 1.46^{h}
	15 min, 30 °C	17.96 ± 2.15^{j}	0.60 ± 0.12^{f}	0.60 ± 0.05^{c}	6.28 ± 0.27^{j}	92.98 ± 3.05^{j}
	15 min, 40°C	16.74 ± 2.22^{k}	1.10 ± 0.25^{b}	0.67 ± 0.24^{d}	6.34 ± 0.18^{j}	70.44 ± 3.18^{i}
	15 min, 50°C	15.32 ± 1.64^{l}	0.50 ± 0.15^{g}	0.64 ± 0.15^{d}	6.66 ± 0.22^{i}	65.30 ± 2.11^{o}
	5 min, 30 °C	23.55 ± 2.44^{c}	0.90 ± 0.31^{c}	0.65 ± 0.12^{d}	7.43 ± 0.21^{d}	113.74 ± 2.74^{d}
	5 min, 40°C	21.46 ± 2.13^{e}	1.10 ± 0.25^{b}	0.76 ± 0.02^{a}	6.94 ± 0.26^{h}	113.20 ± 3.36^{d}
	5 min, 50°C	19.65 ± 1.58^{h}	0.40 ± 0.27^{e}	0.72 ± 0.18^{bc}	7.30 ± 0.34^{e}	103.28 ± 3.10^{f}
	10 min, 30 °C	20.12 ± 2.43^{g}	0.20 ± 0.40^{f}	0.71 ± 0.15^{f}	7.76 ± 0.15^{b}	112.28 ± 3.44^{e}
Cheese matrix	*10 min, 40°C*	18.88 ± 1.56^{i}	1.00 ± 0.19^{b}	0.73 ± 0.23^{bc}	6.11 ± 0.20^{k}	84.22 ± 2.12^{k}
	10 min, 50°C	18.82 ± 1.66^{i}	0.10 ± 0.15^{fg}	0.74 ± 0.22^{b}	7.55 ± 0.05^{c}	99.56 ± 2.46^{g}
	15 min, 30 °C	17.44 ± 1.86^{j}	0.90 ± 0.32^{c}	0.74 ± 0.08^{b}	7.21 ± 0.05^{f}	73.51 ± 1.28^{l}
	15 min, 40°C	16.33 ± 1.76^{k}	0.60 ± 0.26^{g}	0.71 ± 0.15^{c}	6.34 ± 0.18^{j}	70.44 ± 3.18^{n}
	15 min, 50°C	15.22 ± 2.44^{l}	0.70 ± 0.30^{e}	0.71 ± 0.18^{c}	6.72 ± 0.11^{i}	72.62 ± 3.14^{l}
Untreated samples		35.04 ± 2.44^{a}	1.30 ± 0.18^{a}	0.56 ± 0.02^{e}	6.03 ± 0.20^{l}	118.32 ± 1.44^{c}

Mean (*n=3*) values with different letters represents the significant case at P<0.05.

Table 4- The effect of probe ultrasound on the texture parameters of raw milk and cheese matrix

Type of ultrasound treatment		Hardness (N)	Adhesiveness(mJ)	Cohesiveness	Springiness (mm)	Chewiness (mJ)
Raw milk	*2 min, 30 °C*	19.86±1.52^{b}	0.40±0.01g	0.63±0.23^{f}	7.36±0.36^{d}	92.08±1.90^{c}
	2 min, 40°C	18.45±1.50^{e}	0.70±0.19^{e}	0.66±0.15^{de}	6.45±0.66^{ij}	78.54±2.16^{q}
	2 min, 50°C	16.82±2.04^{f}	0.80±0.15^{d}	0.76±0.20^{ab}	7.68±0.25^{b}	58.54±3.12^{q}
	4 min, 30 °C	18.24±1.88^{f}	0.30±0.02^{h}	0.66±0.10^{de}	6.52±0.23^{hi}	78.49±1.11^{j}
	4 min, 40°C	16.98±1.14^{g}	1.00±0.12^{b}	0.69±0.14^{a}	7.78±0.28^{a}	87.64±2.25^{e}
	4 min, 50°C	15.43±2.15^{m}	1.02±0.10^{b}	0.70±0.05^{c}	7.13±0.19^{e}	77.01±1.46^{l}
	6 min, 30 °C	16.43±1.15^{b}	0.30±0.05^{h}	0.68±0.05^{d}	6.87±0.27^{a}	76.77±1.64^{m}
	6 min, 40°C	15.78±1.48^{k}	0.90±0.06^{g}	0.56±0.24^{c}	6.76±0.18^{g}	59.74±1.18^{p}
	6 min, 50°C	14.94±2.04^{o}	0.80±0.05^{d}	0.62±0.15^{f}	6.32±0.22^{k}	58.54±1.21^{q}
Cheese matrix	*2 min, 30 °C*	19.32±2.22^{c}	0.20±0.01^{c}	0.66±0.16^{de}	7.40±0.08^{cd}	94.36±1.70^{d}
	2 min, 40°C	18.42±2.06^{e}	0.30±0.25^{h}	0.64±0.30^{b}	6.55±0.26^{h}	77.22±2.70^{k}
	2 min, 50°C	17.04±1.84^{g}	0.10±0.27^{e}	0.78±0.18^{a}	7.63±0.26^{b}	101.42±1.66^{b}
	4 min, 30 °C	17.02±1.78^{g}	0.30±0.02^{h}	0.68±0.26^{d}	7.40±0.15^{cd}	80.45±2.18^{h}
	4 min, 40°C	18.88±1.56^{d}	0.30±0.19^{h}	0.66±0.34^{de}	7.48±0.14^{c}	84.03±2.12^{f}
	4 min, 50°C	15.42±2.14^{m}	0.40±0.05^{g}	0.74±0.04^{b}	7.08±0.05^{e}	80.78±3.56^{g}
	6 min, 30 °C	16.24±1.55^{j}	0.40±0.12^{c}	0.71±0.30^{c}	6.92±0.05^{f}	79.79±1.28^{i}
	6 min, 40°C	15.66±2.44^{l}	0.50±0.26^{f}	0.62±0.02^{f}	6.81±0.18^{g}	66.12±1.28^{n}
	6 min, 50°C	15.12±1.64^{n}	0.40±0.03^{g}	0.68±0.18^{d}	6.38±0.35^{jk}	65.60±2.24^{o}
Untreated samples		35.04±2.44^{a}	1.30±0.18^{a}	0.56±0.02^{g}	6.03±0.20^{l}	118.32±1.44^{a}

Mean (*n=3*) values with different letters represents the significant case at P<0.05.

Conclusion

In summary, it can be stated that ultrasound treatment increases the cheese making yield and moisture content and decreases the cheese pH. It was found that with increasing temperature and time of treatment ultrasound, cheese yield and moisture content decreased. In relation to the pH, with increasing ultrasound treatment time, pH decreased but with increasing ultrasound treatment temperature, first pH slightly increases and then decreases. According to the TPA results, the hardness of cheese samples with increasing time and temperature of ultrasound treatments significantly decreased compared to control samples. Adhesiveness and chewiness parameters decreases by ultrasound treatment compared to control samples. But parameters of cohesiveness and springiness faced no discernable change trends. It can be concluded that ultrasound treatment increases the cheese making yield and improves the quality and texture of the cheese

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اثرات امواج فراصوت بر راندمان، بافت و برخی خصوصیات کیفی پنیر

سید مهدی حسینی بحری[1]- رضا اسماعیل زاده کناری[2*]

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چکیده

در تحقیق حاضر، تاثیرات تیمار اولتراسوند حمام و پروب بر راندمان، خصوصیات بافتی (سختی، چسبندگی، انسجام، فنریت و قابلیت جویدن)، pH و محتوای رطوبت پنیرسفید تازه مورد ارزیابی قرار گرفت. زمان‌های 2، 4، 6 دقیقه و 5، 10، 15 دقیقه به‌ترتیب در روش پروب (فرکانس 20 کیلوهرتز) و حمام (فرکانس 37 کیلوهرتز) در دماهای 40، 50 و 60 درجه سانتی‌گراد در دو مرحله (شیر خام گاو و ماتریکس پنیر) استفاده گردید. نتایج نشان دادند که اعمال تیمار اولتراسوند در مقایسه با نمونه شاهد باعث افزایش معنی‌دار ($P<0.05$)راندمان پنیرسازی، محتوای رطوبت و کاهش pH گردید. به‌طوری که بالاترین محتوای رطوبت و راندمان پنیرسازی مربوط به تیمار اولتراسوند پروب و زمان 2 دقیقه و دمای 30 درجه سانتی‌گراد بود. نتایج مربوط به آنالیز بافت نشان دادند که میزان سختی نمونه‌های پنیر در مقایسه با نمونه شاهد و همچنین با افزایش زمان و دمای تیمار اولتراسوند به‌طور معنی‌دار کاهش یافت ($P<0.05$). همچنین پارامترهای چسبندگی و قابلیت جویدن در اثر اعمال تیمار اولتراسوند نسبت به نمونه‌های شاهد کاهش یافتند، ولی پارامترهای انسجام و فنریت روند تغییرات مشخصی نداشتند.

واژه‌های کلیدی:اولتراسوند حمام و پروب، راندمان، ویژگی‌های کیفی، ویژگی های بافتی، پنیر

1- دانشجوی دکتری، گروه علوم و صنایع غذایی، دانشگاه علوم کشاورزی و منابع طبیعی ساری و عضو هیئت علمی مرکز آموزش و تحقیقات منابع طبیعی و کشاورزی،ورامین،ایران
2-دانشیار، گروه علوم و صنایع غذایی، دانشگاه علوم کشاورزی و منابع طبیعی ساری ،ساری، ایران.
(*- نویسنده مسئول: Email: reza_kenari@yahoo.com)