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Impact of ultrasound-enhanced homogenization on physical properties of soybean milk

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In this study, research was based on influence of high intensity ultrasound treatment on degree of homogenization of soybean milk. Inhomogeneous milk was treated using ultrasonic equipment (maximal nominal power - 100 W) with the constant frequency of 24 kHz, set to different nominal power (P = 20, 60, 100W), with the time of treatment (t = 2, 6, 10 and 15 minutes).

Changes on size of fat globules were monitored with the optical microscopy (1000 × magnification). All samples were captured with high resolution digital camera, and images were analyzed in "Image J" software. Obtained data were statistically analyzed in "Statistica 6" software, and dimensions of fat globules were represented with "Log – Normal distribution" graph. Physical properties of ultrasonically treated homogenized milk, which include measuring of density, viscosity, and pH – value before and after treatment were also conducted. Influence of process parameters (nominal power and time) on physical properties and degree of homogenization (variance) were represented with "Pareto chart of standardized effects"

Increase of the power (nominal power up to 100 W) leads to increase of degree of homogenization, and decrease in size of fat globules in samples. Maximum nominal power (100 W) used during maximum times (10,15 minutes), shows highest degree of homogenization, while size of fat globules rapidly drops with the increase of nominal power and time. Longer time of treatment with ultrasound showed significant changes on all physical properties.

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Introduction

Utilization of high intensity ultrasound in food technology and biotechnology is in the sense of this progressive technology usage on most usable technological processes in food industry. Those include mixing, drying, homogenization, extraction, crystallization, grinding and many other operations. High intensity ultrasound (intensities above 1 W/cm^2) is capable to change physical and chemical properties of treated materials (Cucheval and Chov, 2008.).

The first ultrasound emulsification was developed and published by Wood and Loomis and the first patent for ultrasound emulsification was approved in 1944 in Switzerland. Homogenization is frequently defined as a physical treatment by which the substance or mixture of substances is made uniform. In food process industry homogenization is more important step in the processing of milk. Milk homogenization increases the stability of fat globules because they becomes smaller and they will no longer go up to the top of the milk when is consumed (Cucheval and Chov, 2008.) (Luque de Castro M.D.Priego Capote F., 2007.).

High amplitude of ultrasound and longer exposure time ensure greatest effect on degree of homogenization. The mechanisms which are contribute to fat globules disruption is known as the “capillary waves mechanism”. Decreasing of fat globules is possible only if the diameter of fat globules is significantly larger than the oscillation wavelength and for oil – water systems is approximately 10 µm. Cavitation is the most accepted mechanism for ultrasound emulsification. This mechanism is based on the implosion bubbles which produce powered shock waves in the milk surrounding the ultrasonic probe and jets of high velocity. This micro jets effectively cause fat globules disruption (Luque de Castro M.D.Priego Capote F. (2007.).

Materials And Methods

1. Sample: Inhomogeneous soybean milk with following chemical composition: fat content 0,6%; total sugar 8,8%; protein content 0,92%; total solids 4,59% (The meaning of marked sample 20/2 – sample is treated with ultrasound, nominal power 20W and the time of treatment is 2 minutes).
2. Ultrasound homogenization: 150 ml of each sample were homogenized with 30 kHz Ultrasonic processor “UP 100 H” The ultrasound nominal power was adapted by changing the ultrasonic output level. Probe used in this research was cylindrical with diameter of 10 mm.
3. Microscopy: After the ultrasonic treatment samples were monitored and analysed under the microscope (Nikon Labophot 2) with magnification of ×1000. Digital camera (Olympus SP – 350) was attached on the top of the microscope and the pictures are recorded in high resolution.
4. Determination of physical properties: measuring of density (Density meter DMA 4500), viscosity (Brookfield digital viscometer, model DV – E and pH –

value (pH/ISE Meter) are also conducted before and after the treatment with ultrasound

5. Statistical analysis: Statistical analysis was performed using Statistica 6 software. Statistical significance are expressed over p – values ($p<0.05$).

Results And Discussion

Table 1. Physical properties of inhomogeneous soybean milk and after ultrasonic treatement.

	Process parameters		Physical properties		
Marked samples	*P* [W]	*t* [min]	μ [mPa s]	ρ [g/cm^3]	*pH*
Inhomogeneous soybean milk	-	-	1.80	1.01021	6.73
20/2	20	2	1.45	1.00986	6.70
20/6	20	6	1.43	1.00983	6.89
20/10	20	10	1.44	1.00974	6.61
20/15	20	15	1.42	1.00970	6.93
60/2	60	2	1.43	1.00996	6.66
60/6	60	6	1.44	1.00974	6.90
60/10	60	10	1.45	1.00988	6.66
60/15	60	15	1.47	1.00978	7.01
100/2	100	2	1.44	1.00977	6.60
100/6	100	6	1.45	1.00983	6.90
100/10	100	10	1.48	1.01025	6.96
100/15	100	15	1.52	1.01037	7.00

Table 2. Results of ANOVA test - Influences of process parameters on viscosity (μ).

	β – Standardized effect	p - value
P [W]	7.182472	**0.000094**
t [min]	5.356813	**0.000680**

Table 3. Results of ANOVA test - Influences of process parameters on density (ρ).

	β – Standardized effect	p - value
P [W]	3.417177	**0.009126**
t [min]	1.343145	0.216081

Table 4. Results of ANOVA test - Influences of process parameters on pH - value (pH).

	β – Standardized effect	p - value
P [W]	0.9278423	0.380631
t [min]	2.463557	**0.039101**

Physical properties of inhomogeneous soybean milk and ultrasonically treated homogenized milk are presented in Table 1. Analysis of variance (ANOVA) showed significant influences of process parameters on all physical properties (Tables 2-4.). Nominal power and time of treatment significantly influenced the viscosity. Positive standardized effects (β) indicate that the increase of both power and time increase the viscosity. Also, it is indicated that power has higher effect on viscosity (higher β) than time. Furthermore, nominal power significantly influenced the density, while time treatment was not statistically significant. Increasing nominal power increases the density, which is indicated by positive standardized effect. pH was found to increase with increasing time treatment, while nominal power did not change pH significantly.

In order to describe and quantitativelly interpret the degree of homogenization we caracterized fat globule size distribution of soybean milk. Raw data obtained from image analysis were described with distribution model. The data were best fitted by Log-normal distribution expressed with equation(1):

$$f(d) = \frac{1}{\sqrt{2\pi}d\ln\sigma}\exp\left(-\left[\frac{\ln d - \ln\bar{d}}{\sqrt{2}\ln\sigma}\right]^2\right) \qquad (1)$$

where is: d – diameter of fat globules; $\bar{d}$ - mean value; σ - variance. (Gregory J., 2006.).

In this way the distribution of fat globule diameter is described by two parmeters: mean diameter and variance. The data and fitted distributions of inhomogeneous and ultrasound homogenized soybean milk, using nominal power of 100 W with time of treatment 10 minutes, are given in Figure 1. It can be seen that maximum diameter of fat globules significantly decreases when ultrasonically treated ($p<0.01$). This is also in direct correlation with decreasing of variance, thus obtaining better dispersion (degree of homogenization). Maximum difference in maximum diameters of fat globules was observed between inhomogeneous soybean milk and sample 100/10 (Δd_{max} = 5.10µm).

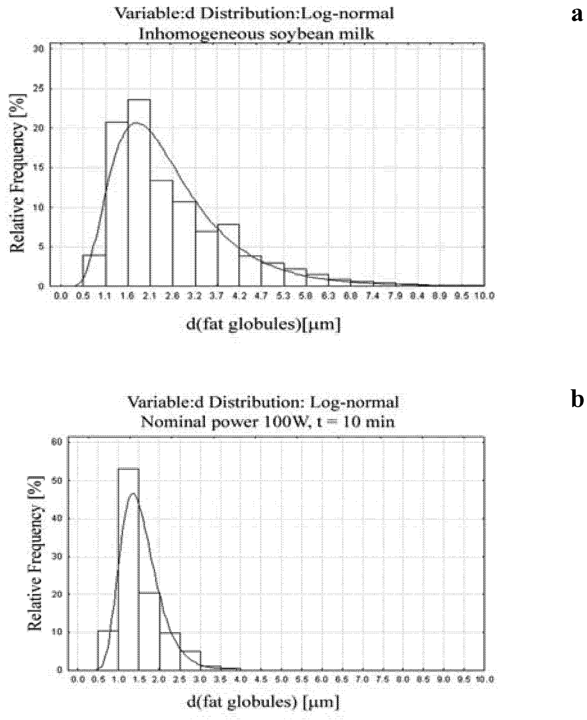

Figure1. Log – Normal distribution graph of (a) inhomogeneous soybean milk and (b) ultrasound homogenized soybean milk using nominal power of 100 W with time of treatment 10 minutes.

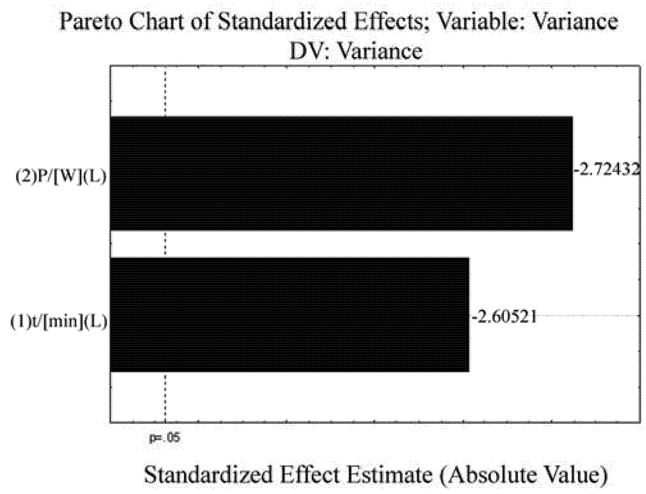

Figure 2. "Pareto chart of standardized effects" – Influence of process parameters on variance (degree of homogenization).

Influence of nominal power and time on variance of Log – Normal distribution model (degree of homogenization) is represented with Pareto chart (Figure 2). Both nominal power and time of treatment statistically influence the variance, where nominal power had slightly higher impact. Variance decreases with increasing nominal power and time of treatment which is indicated by negative values of standardized effects.

Conclusions

1. Highest degree of homogenization was obtained during maximum nominal power (100 W) and maximum time treatments (10, 15 minutes).
2. Process parameters (nominal power and time of treatment) have significant influence on changes of all physical properties.
3. The largest influence of ultrasonic treatment on physical properties was observed in viscosity.

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