Comparative Study of Mechanical and Ultrasonic Homogenization in the Production of Food Oil–Water Emulsions

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Abstract

This study examines laboratory methods for producing food-grade oil–water emulsions based on purified reheated vegetable oils using phospholipid emulsifiers. Conventional mechanical homogenization and ultrasonic homogenization were compared in terms of emulsion quality and stability. The effects of oil concentration, emulsifier type, processing temperature, and mixing time were evaluated. Ultrasonic homogenization at 20 kHz produced finely dispersed emulsions with droplet sizes of 0.1–0.5 µm and stability of up to 30–35 days. Optimal stability was observed at oil contents of 15–20% and temperatures of 50–60 °C. The results show that emulsions from reheated oils are comparable to those from fresh oils and can be effectively used as release agents in bakery and confectionery production.

Keywords: Food emulsions; reheated vegetable oils; ultrasonic homogenization; phospholipid emulsifiers; oil–water systems; emulsion stability; bakery release agents; cavitation.

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1. Introduction

At present, the production of food products, ensuring their safety, and improving their quality are of great global importance. Therefore, the use of natural raw materials in food production is increasingly required not only to enhance nutritional value but also to improve commercial quality. Confectionery, bread, and bakery products may be cited as examples of such foods. Bread and bakery products are staple foods consumed daily by humans; consequently, their commercial and quality characteristics are of considerable scientific and practical significance.

Worldwide, extensive research is being conducted on obtaining food-grade emulsions for lubricating molds used in the production of bread and confectionery products. In this regard, particular attention is paid to the selection of vegetable oils; identification of their reserve sources; determination of their physicochemical properties; selection of suitable emulsifiers for producing emulsions based on vegetable oils and water; optimization of emulsifier dosage in oil–water systems; improvement and kinetic study of the homogenization process; and the development of food emulsion production technologies.

Based on theoretical principles, the chemical composition, organoleptic, physicochemical, and technological properties of selected emulsifiers (phospholipids) used for obtaining food-grade release emulsions were studied.

2. Methods

The phospholipid product "Emulsol" was dissolved in a water bath at 60 °C and subsequently added to vegetable oil preheated to 55–60 °C. The choice of emulsifier depended on the type of emulsion to be obtained.

Food emulsions were prepared using a conventional homogenizer as well as an ultrasonic homogenizer (Ultrasonic Processor). The operating mechanism of ultrasonic treatment is shown schematically in Figure 1.

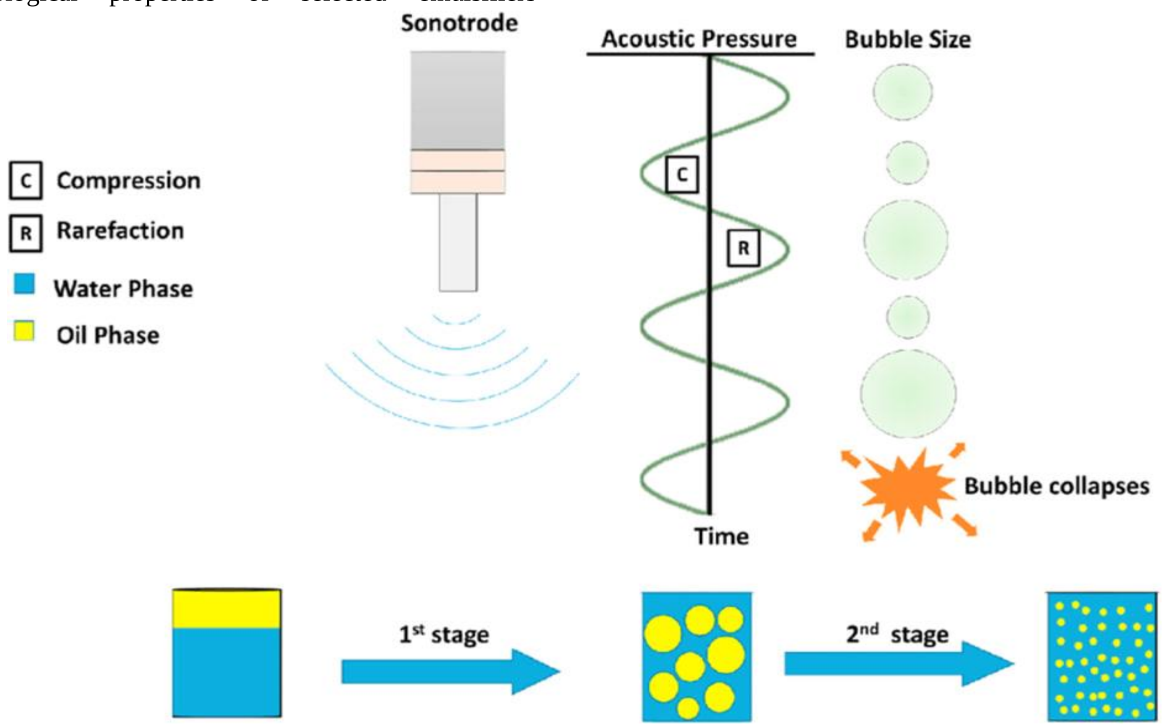

Figure 1. Operating mechanism of an ultrasonic homogenizer.

Sonotrode: The sonotrode is the component that transmits ultrasonic waves into the liquid medium. It vibrates at high frequency, generating acoustic waves within the liquid.

Acoustic pressure (compression and rarefaction): Under ultrasonic action, two alternating states occur in the liquid:

Compression (C), where pressure increases

Rarefaction (R), where pressure decreases

This process repeats over time and is represented as a wave pattern in the diagram.

Bubble formation (cavitation): During rarefaction, microscopic bubbles (gas or vapor) form within the liquid. These bubbles grow and then collapse violently when pressure increases, a phenomenon known as cavitation.

Effects of bubble collapse

When bubbles collapse:

Extremely high localized temperatures and pressures are generated

Strong microjets and shock waves are produced

As a result:

Oil droplets are finely dispersed

Phases are thoroughly mixed

Water and oil phases

The water phase is shown in blue and the oil phase in yellow.

Stage 1: Oil is dispersed in water as large droplets

Stage 2: Under ultrasonic action, oil droplets are finely dispersed, forming a stable emulsion

This process is widely used in the food industry for emulsion preparation.

The high-frequency generator converts mains voltage (40–50 Hz) into a high frequency of 20 kHz and stabilizes the alternating voltage. It converts direct current into high-frequency alternating voltage, producing a constant high-frequency output ("pure sound"). The ultrasonic transducer converts electrical energy generated by a high-efficiency system generator into mechanical energy (20 kHz ultrasonic vibrations).

The ultrasonic homogenizer represents one of the most effective dispersion methods, achieving up to 95% efficiency, with particle sizes in the range of 0.1–0.5 µm and providing long-term emulsion stability.

Principle of operation of the homogenizer:

For homogenization, the liquid is introduced into the working chamber and subjected to ultrasonic treatment. To intensify the homogenization process, the sample is placed in a conical vessel.

Ultrasonic treatment is an effective method for grinding both hard and soft particles, based on cavitation processes generated by alternating low and high pressures. Under low pressure, bubbles form in a vacuum-like environment; when they transition to a high-pressure zone, their collapse leads to thorough mixing of the system.

3. Results And Discussion

A microscopic image of the emulsion obtained using the ultrasonic homogenizer is shown below.

To determine the physicochemical parameters of raw materials and finished products, rapid, accurate, and modern analytical methods were selected. A magnetic stirrer and an ultrasonic homogenizer were chosen as laboratory equipment for food emulsion preparation. Using statistical methods, an approach for evaluating analytical errors in the analysis of food emulsions and raw materials was developed.

Figure 2. Emulsion obtained by ultrasonic homogenization.

Figure 2 presents a microscopic image of the emulsion obtained by ultrasonic homogenization. As can be seen, the emulsion produced using the ultrasonic homogenizer exhibits a well-defined microstructure, indicating maximum dispersion of oil in water. Based on these observations, the relationship between mixing time and emulsion stability was investigated. The results are presented in the table below.

Table 1. Dependence of emulsion stability on mixing time for emulsions obtained by ultrasonic homogenization

Reheated oil (%)	Lecithin (%)	Water (%)	Time (min)	Stability (days)
15	2	73	7	22
20	2	73	7	25
25	2	73	7	27
30	2	73	7	30

From the table, it can be observed that emulsions obtained within 7 minutes using the ultrasonic homogenizer remain stable for 20–30 days. Subsequently, the effect of oil content on emulsion stability was studied. The obtained results are presented in Figure 3.

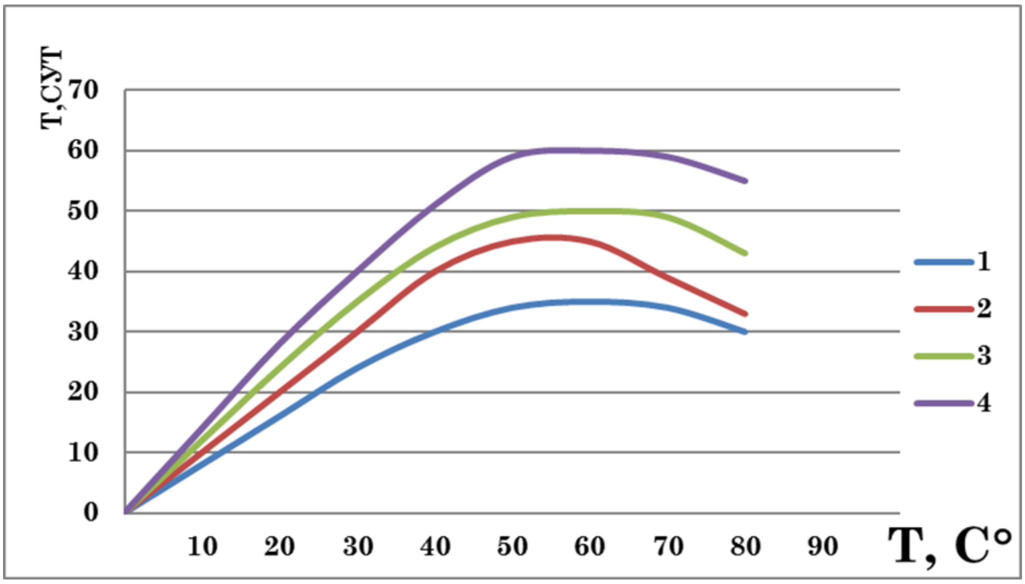

Figure 3. Effect of oil content on emulsion stability and storage duration: 1 – 15% oil; 2 – 20% oil; 3 – 25% oil; 4 – 30% oil

The results show that emulsions containing 15% oil remained stable for 30–35 days. Increasing the oil content from 15% to 30% was found to nearly double emulsion stability. However, considering economic feasibility, increasing oil content beyond 20% was deemed impractical; therefore, an optimal oil content of up to 20% was considered sufficient.

From Figure 3, it is evident that maximum emulsion stability corresponds primarily to a temperature range of 50–60 °C. This is attributed to the fact that conducting emulsification at excessively high or low temperatures leads to a loss of stability during storage.

In particular, polyoxyethylene-derived nonionic surfactants are highly sensitive to temperature. As a result, temperature variation enables the formation of different emulsion types: oil-in-water emulsions at moderate temperatures and water-in-oil emulsions at higher temperatures.

4. Conclusion

Thus, emulsions obtained from purified reheated oils not only serve as viable alternatives to emulsions prepared from fresh oils, but those produced using ultrasonic homogenization are also competitive in terms of energy and time efficiency, ultimately contributing to improved quality of bakery products.

To determine the physicochemical parameters of raw materials and finished products, rapid, accurate, and modern analytical methods were selected. A magnetic stirrer and an ultrasonic homogenizer were used as laboratory equipment for food emulsion preparation. Using statistical methods, an approach for evaluating analytical errors in the analysis of food emulsions and raw materials was developed.

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