Ultrasonic treatment of the coffee extract

D V Gerasimov, E P Suchkova and R Hussaineh
ITMO University, Lomonosov str. 9, St. Petersburg, Russian Federation

E-mail: silena07@bk.ru

Abstract. Coffee is one of the most popular beverages in the world. Coffee gives strength, stimulates brain activity and increases concentration. There are many biologically active substances in its composition. Instant coffee is an important coffee product that would benefit on an extended shelf life. The introduction of modern methods of treatment, as the ultrasonic treatment, may be used to increase the shelf life of this kind of products. Ultrasound is a modern method of treatment biological systems. It can help to intensify the extraction process of biologically active substances. Ultrasound can also be used as a method of sterilization. The object of this study was to investigate the improvement the production technology of natural instant coffee using ultrasonic treatment. The affect of ultrasound on the coffee extract was determined by measuring the water activity, caffeine and 5-(hydroxymethyl)-furfural (HMF) content. Ground coffee dissolved in water was subjected to sonication from 1 to 3 minutes and with power varying from 2 to 8 W. Water activity was shown to be reduced with increasing duration and power of sonication. The caffeine content varied with time and processing power. When processing for 1 or 2 minutes, an increase in caffeine content was observed with increasing power. When processing for 3 minutes, there was an increase in caffeine content at a power of 2 to 4 W and a decrease in power from 4 to 8 W. According to this research the possibility of using sonication in coffee extract to improve its quality was concluded due to the achievement of lower water activities and higher caffeine content.

1. Introduction
Coffee is one of the most popular worldwide beverages. This can be explained by its taste and aromatic properties. But the main reason for the popularity of coffee is its effect on the human body. In particular, coffee helps to stimulate the cerebration, gives strength and cheerfulness [1].

These features are a consequence of the existence in the chemical composition of coffee a large number of compounds, including biologically active substances.

It is known that caffeine is the main active ingredient of coffee [2]. The caffeine content influences tremendously the perceived quality of the products. The caffeine content of coffee beans depends on the species and the variety and ranges from 0.6 to 3.0% on dry basis [3]. However, nowadays in Russia, natural instant coffee is more popular instead of natural roasted coffee beans. The caffeine content in natural instant coffee must be at least 2.3% on dry basis [4].

Production technology of natural instant coffee is a complicated multi-step process. It includes acceptance of green beans, sorting, roasting, grinding, extraction, drying and packaging of natural instant coffee [5].

The coffee extraction is one of the most important stages of production. It is a process of solids and liquids extraction from the mixture using a solvent. Extraction is carried out in several stages, at each of them extracts with different concentrations of dry matter extracts are obtained – from 1.5 to 50.0% [6].
Further extracts are mixed in the desired proportions and adjusted to the required standard concentrations. There are different conditions for obtaining extracts at each stage.

Maximizing the usage of raw materials is an important issue for any other industries as well as for the coffee industry. That is the maximum recovery of useful substances in the coffee extract from the coffee grounds. One of the traditional methods for intensifying extraction of solids in the extract is using of high pressure and temperature [6]. Ultrasound can be an alternative or additional method. It is a wave-like spreading the vibrational motion of medium particles. Ultrasonic vibrations can be focused and directed radiation can be formed.

In recent years ultrasonic processing is more commonly used in the industry to increase the yield. 20 kHz is typical industrial frequency of ultrasonic treatment [7, 8]. Ultrasound can have mechanical, physical, chemical, thermal and biological, as well as the sterilizing effect. This can lead to an intensification of the extraction process [9].

Thus, sonication may be used for the coffee extraction, particularly, to maximize the yield [10]. It will help to reduce losses of raw materials. This aspect can be seen in the concept of non-waste technology. Waste-free production is an actual goal of any manufacturing.

It is impossible to evaluate the quality of the coffee extract just on the concentration of solids and caffeine. Other factors for the quality control are administered. One of them is the 5-(hydroxymethyl)-furfural (HMF).

HMF is formed during high temperature processing of foods. According to the level of its content is judged on the quality, safety and availability of manufactured product [11]. The soluble coffee contains about 2480 mg kg⁻¹ HMF [12]. If the HMF content is lower, the product is less harmful. Since the ultrasound radiation has chemical and thermal effects on the treated objects, then in the case of its application in the coffee extraction, the determination of HMF is necessary.

Water activity, which measurement is more common in Europe than in Russia, is another characteristic of the food products and intermediates. Water activity is the ratio of vapor pressure of water above the solution to the vapor pressure of the pure solvent at the same temperature.

The practical significance of water activity is to characterize the state of the investigated substance. It indicates the status of the system and the tendency of substance to spoilage [13].

As part of the coffee production water activity can characterize the state of semi-finished product, its energetic state after passing through the production stage.

2. Objects and methods of research

Samples of the natural roasted coffee beans were used for research. Coffee grains were milled with the coffee mill, particles’ size of ground coffee was determined using a sieve. More than 80% of them had a size of less than 1 mm.

The natural roasted ground coffee in amount of 7 g was placed in 100 ml of distilled water and extracted at a temperature of 96–98 °C for 10 minutes. Then the samples were cooled to 25°C and sonicated under these conditions (table 1).

| Table 1. Modes of ultrasonic treatment. |
|----------------------------------------|
| Duration of ultrasonic treatment, min | Ultrasonic power, W |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 2 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| 3 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |

After sonication the samples were filtered in order to separate the coffee grounds from the coffee extract. Water activity, the content of caffeine and content of HMF were determined in obtained samples of coffee extract.
Determination of water activity was carried out with AWK–4 (by Saratov State Agrarian University named after Vavilov). It includes three main elements: freezing unit, sensor, sample cuvette. AWK–4 was connected to the computer with the required software.

The cuvette with a sample of coffee extract was placed in a freezing unit. Sensor was immersed in the cuvette. Freezing the sample to -7°C was performed. Measurements of temperature were taken and recorded in the work file using the software. Then the program determined the cryoscopic point and expected water activity sample [14]. Measurements were executed in tenfold frequency.

Caffeine content was determined by high performance liquid chromatography [15].

The content of 5-(hydroxymethyl)-furfural was determined by spectrophotometric method of analysis at a wavelength 284 nm. Measurements were executed in triple frequency.

3. Results and discussion

Figure 1 shows the values obtained by measuring the water activity in samples of coffee extract. The value of water activity in a control sample was 0.9957.

![Figure 1](image_url)

**Figure 1.** Comparison diagram of water activity values in the samples of coffee extract, depending on the modes of sonication.

One can see in figure 1 with increasing ultrasonic power the water activity of samples of coffee extract reduces. The same dependence was observed within one power sonication with increasing exposure time.

The caffeine content in the coffee extract samples is presented in figure 2. The caffeine content in the control sample was 3.94%.

Figure 2 shows that with an ultrasonic treatment duration of 1 and 2 minutes and an increase in ultrasound power from 2 W to 8 W, the caffeine content increases. However, there is another tendency in the case of sonication extract samples for 3 minutes. When the ultrasound power is from 2 W to 4 W, the caffeine content increases, but with a further increase in power to 8 W, it decreases.

The determination of 5-(hydroxymethyl)-furfural coffee extract samples gave the results presented in Figure 3. The content of HMF in the control sample was 1.098 mg kg$^{-1}$.

The diagram in figure 3 shows that as the ultrasound power increases from 2 W to 5 W, the HMF content increases. However, with an increase in power from 5 W to 8 W, the HMF content decreases.
In addition, with an increase in the duration of ultrasonic treatment within the power value, the HMF content decreases.

![Comparative diagram of the caffeine content in the dry substance of the coffee extract samples, depending on the modes of sonication.](image1)

**Figure 2.** Comparative diagram of the caffeine content in the dry substance of the coffee extract samples, depending on the modes of sonication.

![Comparative diagram of 5-hydroxymethylfurfural content in samples of coffee extract, depending on the mode sonication, mg kg\(^{-1}\), on dry basis.](image2)

**Figure 3.** Comparative diagram of 5-hydroxymethylfurfural content in samples of coffee extract, depending on the mode sonication, mg kg\(^{-1}\), on dry basis.

4. **Conclusion**
Ultrasound helps to increase caffeine content of the extract. It's necessary to follow the research data for the control of ultrasound power, because the caffeine is destroyed with increasing duration of influence.
Ultrasound has an influence on the content of HMF. The content of harmful substance is reduced in the rigid treatment conditions, which is a positive effect.

Ultrasound influence on the water activity is also present in the coffee extract. When the power and the duration of treatment increases, free moisture content in the extract decreases. Focusing on the importance of water activity, one can speak about the quality of the extraction.

Obtained results show that ultrasonic treatment of the coffee extract is really perspective method for intensification the extraction of biologically active substances. However, further research of ultrasonic treatment regimes is recommended.

Acknowledgments
This work was partially financially supported by Government of Russian Federation, Grant 074-U01.

References
[1] Razali M S and Ismail M N 2010 The Effect of Caffeine on Sedentary 24-hour Energy Expenditure in Malaysian. *Lean and Obese Adults Malaysian Journal of Sport Science and Recreation* 6 (1) 47–62
[2] Tatarchenko I I, Mokhnachev I G and Kasyanov G I 2003 Chemistry of subtropical food and flavoring products (Moscow: “Akademiya”) p 256
[3] GOST R 52088–2003 Natural roasted coffee. General specifications
[4] GOST R 51881–2002 Natural instant coffee. General specifications
[5] Sivetz M and Foote H E 1963 *Coffee processing technology*. (Westport, Connecticut) pp 598
[6] Tatarchenko I I, Mokhnachev I G and Kasyanov G I 2004 *Technology of subtropical food and flavoring products* (Moscow: “Akademiya”) p 384
[7] Suchkova E P, Shershenkov B S and Baranenko D A 2014 Effect of ultrasonic treatment on metabolic activity of Propionibacterium shermanii cultivated in nutrient medium based on milk whey *Agronomy Research* 12 (3) 813–20
[8] Khmelev V N, Slivin A N, Barsukov R V, Tsyganok S N and Shalunov A V 2010 Application of ultrasound of high intensity in the industry (Biisk) p 203
[9] Akopyan B V and Ershov Y A 2005 *Basics of ultrasound interaction with biological objects*. (Moscow: MGTU) p 224
[10] Gerasimov D V and Suchkova E P 2014 The theoretical basics of employment ultrasound for food systems processing in order to regulate the content of bioactive components *Scientific journal NRU ITMO Series “Processes and Equipment for Food Production”.* 4 (22) 53–60
[11] Kowalski S, Lukasiewicz M, Duda-Chodak A and Ziec G 2013 HMF – Heat-Induced Formation, Occurrence in Food and Biotransformation *Pol. J. Food Nutr. Sci.* 63 (4) 207–25
[12] Arribas-Lorenzo G and Morales F J 2009 Estimation of dietary intake of 5-hydroxymethylfurfural and related substances from coffee to Spanish population *Food Chem Toxicol* 48 (2) 644–49
[13] Tsukanov M F and Chernomorets A B 2010 Technological aspects of an indicator “activity of water” and its role in ensuring quality of production of public catering *TTPS* 11 58–63
[14] Zabodalova L A, Solovyova M S and Gorshkova S B 2011 *Determination of water activity in foods: Guidelines for laboratory work on the subject “Food Chemistry” for students of direction 240700 “Biotechnology” of all studying forms* (St. Petersburg) p 18
[15] ISO 20481–2008 Coffee and coffee products – Determination of the caffeine content using high performance liquid chromatography (HPLC) – Reference method