Use of high hydrostatic pressure for food sterilization and seed treatment

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Abstract. Experiments with high hydrostatic pressure to sterilize meat, sauces, mayonnaise, milk and yoghurts have been conducted. We also used the hydrostatic processing to increase the speed of germination and productivity of various plants (radishes, tomatoes, licorice, etc.). It was found that, after high pressure processing, the microbial contamination of all food products was reduced. It resulted in a significant increase in the shelf life of food (from 3 to 5 times). It was shown that the high pressure processing was a way to significantly increase the crop yield of tomatoes (by ~65%) and the germination of legumes (almost by an order).

1. Introduction

Obtaining bulk samples of fine-grained and nanostructured materials requires applying high pressures and shear stresses to workpieces. This is why modern materials science laboratories are equipped with powerful presses and high-performance hydraulic high-pressure pumps. For example, it was with the use of a hydraulic press with a force capacity of 10 MN that we developed a technology for producing a thin magnesium plate with an ultrafine-grained structure and unusually high plasticity [1]. Hydroextrusion with the use of boosters developing the pressure up to 1.5 GPa made it possible to obtain high-strength binary and ternary composites, which contain up to one million thin Mg-filaments in Cu or Al-matrices [2]. Meanwhile, this powerful equipment is in great demand in areas that are far from the materials science.

For example, increasing the shelf life of food and semi-finished products is an important applied research task. Most often, to achieve this goal, various preservatives are added to food products and modified gas media are used for storage. The most developed methods of physical impact on food products in Russia are ionizing radiation treatment and ultrasonic waves. Meanwhile, a new trend is being dynamically developed, which consists in the processing of food products by means of high hydrostatic pressure (high pressure processing, HPP) [3]. In a number of countries (Germany, USA, Japan), HPP is used in pilot production of "green products". The shelf life of such products is at an acceptable level without the introduction of any preservatives. On the territory of the former USSR, scientists from Donetsk and Lugansk have achieved the most progress in the field of high pressure food processing. In Russia, this field of biotechnology is nearly unknown to commodity producers. The availability of powerful high-pressure equipment gives metal scientists a unique chance to try themselves in a completely new field, i.e. in biophysics.
The purpose of this work was to study the influence of such parameters of HPP as pressure value and exposure time on microbiological, organoleptic and some other parameters of various food products and semi-finished products. In addition, we conducted experiments to find out the effect of high-pressure seed treatment on the speed of their germination and crop yield of plants.

2. Materials and methods

High-pressure devices and equipment designed and manufactured at the Institute of Metal Physics of the Ural Branch of the Russian Academy of Sciences were used for conducting experiments. A laboratory hydrostat was used for pressure processing up to 250 MPa. The capacity of its container is 5 l, high pressure is created in it by an oil pump. If a higher pressure (up to 650 MPa) was required, a 3 l container was used and the pressure in it was created by a plunger connected to a hydraulic press. For experiments under a pressure of up to 1500 MPa, a hydroextrusion unit was used, where a plug was installed instead of a matrix. The diameter of the working part of the container in this unit is 22 mm, the working length of the container is 70 mm. Before conducting the experiments, all samples were placed in a sealed latex shell. When processing seeds, liquids were sometimes added into this shell: water, fertilizer solution, etc. The high pressure processing was carried out at room temperature; the soaking time depended on the processed product and the selected process pressure, but did not exceed 30 minutes.

3. Results and discussion

3.1. HPP of meat products and semi-finished products

The experiments were carried out on meat products (chilled beef) and sausages, and samples of minced meat and chicken were also processed. As an example, Table 1 shows the change in microbiological parameters of sausages Rossiyskie after processing under the pressure of 250 MPa for 15 minutes. As a comparison, parameters of the control group of sausages that were not subjected to HPP are also presented. The experiment was carried out as follows. On the day indicated by the manufacturer as the last day of the shelf life, the packaging was opened and the material of the control and test groups was inoculated to determine mesophyll aerobic and optional-anaerobic microorganisms (QMA&OAMO) and the presence of coliform bacteria. The obtained parameters were taken as a baseline. The subsequent removal of the products for analysis took place after 1, 2 and 3 days of storage beyond the expiry date. In accordance with the storage rules established by the manufacturer for a specific product, both control and test samples were kept in a household refrigerator at a temperature of 4±2°C.

It was found that the sausages Rossiyskie taken for the experiments completely withstood the shelf life specified by the manufacturer: in the baseline parameters, the content of aerobic and anaerobic mesophyll microflora, as well as coliform bacteria, did not exceed the established limits. During further storage, the number of opportunistic pathogenic microorganisms in the control group of sausages begins to significantly exceed the permissible level after two days. In turn, the rate of change in QMA&OAMO in the test group is significantly lower (see table 1). Based on the dynamics of the increase in microbiological points, the processed sausages will still meet the standards for another week of storage beyond the expiry date. Coliform bacteria were not detected in both the test and control samples during the entire experiment.

In the course of the experiments, it was found that HPP increased the shelf life of meat and meat products at least 2.5 times. Figure 1 confirms well the different rates of bacterial reproduction in samples of chilled beef after 10 days of storage in a home refrigerator (4±2°C). No change in the organoleptic, physico-chemical and toxicological properties of the processed meat products was detected.

A certain decrease in the moisture-retaining properties of meat semi-finished products can be indicated as one of the negative consequences of HPP. For example, the mass fraction of moisture in the sausages Rossiyskie, which we studied, is 62.6±0.2%. After HPP under 600 MPa for 1 minute, the mass fraction of moisture in them decreased to 57.0±0.2%. Obviously, this effect should be taken into account in the manufacture of products from processed meat. It was also shown that pressure above 850 MPa led
to a protein degradation in meat products. In fact, after such processing, meat products become cooked. Comparative experiments showed that an increase in the pressure of HPP from 250 to 600 MPa causes a slight increase in the shelf life of meat products with a significant increase in the cost of equipment. From this point of view, the 500-600 MPa HPP pressure values specified in some patents seem excessive and are most likely a marketing ploy by equipment manufacturers.

Table 1. Test results of sausages Rossiyskie.

| Control points | Control group | Test group | Norm acc. to Technical Regulation of Customs Union TR TS 034-2016 |
|----------------|---------------|------------|---------------------------------------------------------------|
| At the end of the shelf life (baseline) | $9.5 \times 10^4$ | $1.0 \times 10^5$ | Not exceeding $5.0 \times 10^6$ |
| 24 hours | $4.0 \times 10^4$ | $2.5 \times 10^5$ | |
| 48 hours | $2.2 \times 10^7$ | $8.0 \times 10^5$ | |
| 72 hours | Above $3.0 \times 10^7$ | $9.0 \times 10^5$ | |

Figure 1. Visualization of bacterial and microbial colony growth (QMA&OAMO) in control (a) and test (b) samples of chilled (4±2°C) beef after 10 days of storage. The test beef samples were processed under the pressure of 250 MPa for 30 minutes.

3.2. HPP of oil-fat products and milk

The experiments were carried out on samples of mayonnaise, ketchup, milk and other products. The HPP pressure was 500 MPa. It was found that the organoleptic parameters of all the studied products remain almost unchanged after HPP. However, the microbiological parameters of samples after HPP differ significantly from the control group. For example, as a result of HPP, the total microbial count in mayonnaise samples decreased 100 times; the number of yeast cells – almost $10^3$ times. Using the example of a vegetable-fat filled spread, it was found that mold was also sensitive to high-pressure processing. The content of lactobacilli in all samples remained unchanged. Pathogenic microorganisms and a group of indicator bacteria were not detected in both control and test samples.

After HPP, the pasteurized milk with 3.5% fat survived 20 days of storage. It was found that souring is slower compared to the control sample. However, milk after HPP acquires an extraneous taste (presumably due to proteolysis of protein components under high pressure). The resulting taste defect
makes it impossible to recommend HPP as a way to increase the shelf life of milk. Experiments with yoghurts showed that excessive pressure over certain values kills lactobacilli.

Based on the results of the experiments, it can be concluded that HPP of mayonnaise, ketchup, milk and various oil and fat products can be used to increase their microbiological parameters. However, in each case, long-term experiments are required to select the optimal processing pressure.

3.3. Effect of high pressure on germination of seeds and crop yield of plants

The use of various physical methods of seed treatment is a well-known way to accelerate their germination and increase of the crop yield of plants. At present, various shock or pulse effects (for example, cryoprocessing, hydraulic shock, etc.) have been tested and used. We carried out experiments of HPP of seeds of different varieties of radishes, tomatoes, potatoes and licorice. It was found that HPP of radish seeds significantly accelerated their germination, but did not lead to an increase in crop yield. At the same time, a significant increase in the volume of tops was noted, which is also important for agricultural producers. In turn, HPP of tomatoes killed some of the seeds, but the crop yield of the surviving seeds increased by more than 60%. It was established that HPP of radish seeds significantly accelerated their germination, but did not lead to an increase in crop yield. All the described experiments aimed at an increase in the crop yield were carried out at pressures below 100 MPa. In turn, an increase in the HPP pressure to 500 MPa leads to guaranteed death of all pathogenic microflora on the seeds. It can be used as a method to fight against fungal diseases in cereals.

4. Conclusions

From the results obtained, it follows that short-term exposure of meat and oil-fat products to high pressure does not cause changes in organoleptic parameters, but delays the growth and development of vegetative microflora. Thus, HPP has a positive effect on maintaining the freshness of products for a long time without the use of preservatives. We did not confirm experimentally that the pressure of 500-600 MPa is optimal to HPP. Indeed, HPP that we performed at 250 MPa gave similar results. We can assume with caution that the increased HPP pressure is most likely a marketing ploy. High-pressure processing of legume seeds is an effective measure of fighting against seed hardness. The example of tomatoes showed that, in a number of cases, HPP of seeds led to a significant increase in the crop yield of plants.

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