Plant and Soil Science

Journal homepage: https://agriculturalscience.com.ua/en
Plant and Soil Science, 13(3), 7-17
Received: 04.03.2022 Revised: 30.06.2022 Accepted: 01.08.2022

UDC 641.53.092: 683.958:664.71-11
DOI: 10.31548/agr.13(3).2022.7-17

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Yield and quality of rolled cereal from spelt wheat grain depending on the duration of irradiation with an ultrahigh-frequency electromagnetic field

Abstract. Spelt wheat has great prospects in the technology of manufacture of products of the highest biological value. In the technology of rolled cereal, water-heat treatment is energy-consuming. Therefore, the study of technological parameters of ultrahigh-frequency electromagnetic field irradiation in the technology of spelt wheat cereal is relevant. The purpose of the study is to examine the yield and quality of rolled spelt wheat depending on the duration of exposure to an ultrahigh-frequency electromagnetic field. The study used laboratory (determination of croup yield) and statistical methods. It was identified that the total yield of cereal with the use of the grain of the Holikovs`ka variety substantially increased to 97.3% with the use of irradiation for 60-80 seconds. The yield of premium rolled cereal is the highest with irradiation for 80-100 seconds. Water-heat treatment of cereal from the Holikovs`ka variety grain did not substantially increase the yield of cereal. The highest total yield of rolled cereal was obtained in the LP 1152 line with a duration of irradiation of 100-120 seconds – 93.2-94.9%. The highest yield of rolled cereal of the highest grade was obtained with an irradiation duration of 120-140 seconds. Notably, water-heat treatment substantially affected the yield of cereal (96.0-96.1%). In the technology of production of rolled cereal from spelt wheat of the Holikovs`ka variety using an ultra-high frequency electromagnetic field, the duration of irradiation is 80-100 seconds without moistening. When using cereal No. 1 from spelt wheat of the LP 1152 line, it is necessary to moisten it by 0.5% with an irradiation duration of 120-140 seconds. The duration of cooking of premium rolled cereal is 10.7-11.3 minutes. The materials of the study are of practical value for low-productivity cereal enterprises in the production of spelt wheat cereal products. If the electromagnetic field is used in the technological process, it is possible to use improved modes

Keywords: microwave oven, cooking time of cereal, peeling index, cooking time, grain crop

INTRODUCTION

According to FAO (Food and Agriculture..., 2021), wheat is the main cereal crop with a gross grain production of about 765 million tonnes. Evidently, wheat grain is the main raw material for food production. Spelt wheat has great prospects in the technology of manufacture of products of the highest biological value. In addition, it has a number of advantages during cultivation. Modern spelt wheat varieties are characterised by the highest resistance to major fungal diseases and are able to form a grain crop on low-fertile soils. The grain forms a higher protein content, which is more balanced in amino acid composition. Therefore, research on expanding the range of grain products and improving the technological modes of their production is relevant.

Cereal products are an important component of nutrition and raw materials for the production of other products. Among them, rolled cereals are the most popular, especially in the technology of fast-cooking cereals or cereals that do not require cooking. Thus, according to the State Statistics Service of Ukraine (State Statistics

Suggested Citation:
Hospodarenko, H.M., Liubych, V.V., Leshchenko, I.A., Novikov, V.V., & Oliinyk, O.O. (2022). Yield and quality of rolled cereal from spelt wheat grain depending on the duration of irradiation with an ultrahigh-frequency electromagnetic field. *Plant and Soil Science, 13(3), 7-17.*

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Service..., 2022), 165.28 thousand tonnes of rolled cereal were produced in 2021, while rice – 11.70, and other types of cereal – 49.43 thousand tonnes.

Water-heat treatment is performed in overpressure apparatuses with a continuous or periodic principle of operation. Notably, this process is energy-intensive, which increases capital investment. In addition, depreciation operations during the technological process are high, and the danger to service personnel increases (Schmidt *et al.*, 2018). Thus, the study on the effectiveness of using new methods of water-heat treatment of raw materials in the technology of cereal products is relevant. Especially for processing grain that has the highest biological value.

Ultrahigh-frequency electromagnetic field radiation (UHF-EMR) exposure is quite common in food technology. In addition, it is a promising method of conducting water-heat treatment in the technology of cereal products. Its use affects the physical and chemical parameters of raw materials. Usually, UHF-EMR increases the temperature of the grain and causes denaturation of its biochemical components, while reducing the number of microorganisms (Lamacchia *et al.*, 2016). The efficiency of UHF-EMR depends on the technological properties of raw materials, their humidity, the duration of irradiation, the power of the electromagnetic field, and its frequency (Qu *et al.*, 2017).

Currently, in the technology of rolled cereal, water-heat treatment with water vapour under pressure is used. It is performed using the steaming and infrared radiation. Therewith, the humidity of the finished product increases substantially. After the precedure, it is necessary to use drying. An ultrahigh-frequency electromagnetic field causes internal heating of materials due to fluctuations in electric charges. The key dipole is water. When the grain is heated, some of the moisture converts into a gaseous state. Due to this, the grain volume increases and a certain part of the moisture evaporates (Lucas, 2018).

UHF-EMR exposure does not affect the amount of protein in the grain. At high temperatures (>65-75°C), thermal denaturation of glutenin proteins occurs in the grain (Ma & Baik, 2021). After tempering the grain with infrared radiation at a temperature of 102°C for 90 seconds, there is a substantial decrease in the activity of vitamin B_2 (Aguilar *et al.*, 2019). After keeping the grain at a temperature close to 100°C, processes similar to cooking occur. This increases the nutritional value of the product and the absorption of nutrients (Ma & Baik, 2021).

Currently, the demand for a sparsely distributed tetraploid type of wheat – spelt wheat, is growing intensively (*Triticum dicoccum* Schuebl (Schrank.)) due to the highest biological value of grain and a number of economically valuable properties during cultivation. In scientific sources, it is known as hulled wheat and emmer. Marketing of producers of this crop contributes to an increase in demand. They offer it as an alternative to soft wheat (de Sousa *et al.*, 2021). The emphasis is reduced to the following advantages: the highest content of protein, vitamins, microelements, and the possibility of using it for people with allergy to gluten group protein (Lindfors *et al.*, 2019). Although it is warned that with celiac disease, it should be excluded from the diet. For the most part, spelt wheat is grown in organic farming. This is facilitated by high tolerance to certain diseases, unpretentiousness to the soil, and the ability to grow in mountainous areas (Dubois *et al.*, 2017).

The growing popularity of spelt wheat as an environmentally friendly product with increased nutritional value actively encourages researchers to examine possible applications to obtain food products of improved quality (Silletti *et al.*, 2019). Now spelt wheat grain is a raw material for the production of flour (varietal and whole grain) and many types of cereal. One of the options for processing spelt wheat grain is the production of rolled cereal. This type of cereal has gained popularity among the population as a full breakfast. They are made in different sizes and from a variety of grain raw materials: oats, triticale, spelt, buckwheat, corn. Spelt wheat cereals are known to have excellent taste properties. Semolina has better culinary properties compared to soft wheat and is similar to durum wheat (Dhanavath & Prasada Rao, 2017). In general, the culinary quality of spelt wheat cereals has certain characteristic features: a well-defined smell and taste that differs from conventional wheat cereal and a crumbly consistency of porridge with yellow or cream colour. Due to the properties of the shells, there is no need for strict grain peeling modes (Liubych *et al.*, 2020). However, to improve the functional properties of spelt wheat grain, it is better to remove a certain number of shells since their surface contains bacterial and fungal microflora and soil particles adversely, and they affect the work of the gastrointestinal tract of a person with chronic diseases. It is known that a decrease in the content of shells in grain negatively affects the yield of cereal, including rolled ones (Liubych *et al.*, 2022).

Thus, spelt wheat has prospects for obtaining high-quality grain products. Therewith, the use of UHF-EMR irradiation in cereal technology has not been sufficiently investigated. Therefore, it is necessary to conduct more detailed studies in the laboratory to examine the effectiveness of the UHF field.

The purpose of the study is to determine the effect of the duration of ultrahigh-frequency electromagnetic field irradiation and water-heat treatment on the yield of spelt wheat cereal products.

MATERIALS AND METHODS

The experimental part of the study was conducted in the educational-scientific laboratory of the Department of Food Technologies "Assessment of the quality of grain and its processed products" of the Uman National University of Horticulture during 2020-2021. Spelt wheat of the Holikovs`ka variety (spring type of development) and the LP 1152 line (winter type) grown in the Right-Bank Forest-Steppe were used. The grain of both samples had a vitreous endosperm (≥70%), the grain moisture content was 12.5%, and the protein content was 14.3 and 15.2%, respectively.

Experiment scheme

The experiment scheme was developed in accordance with the Rules for organizing and conducting the technological process at the cereal factories (Kroshko *et al.*, 1998), which included the technological components shown in Fig. 1. The experiment is repeated three times.

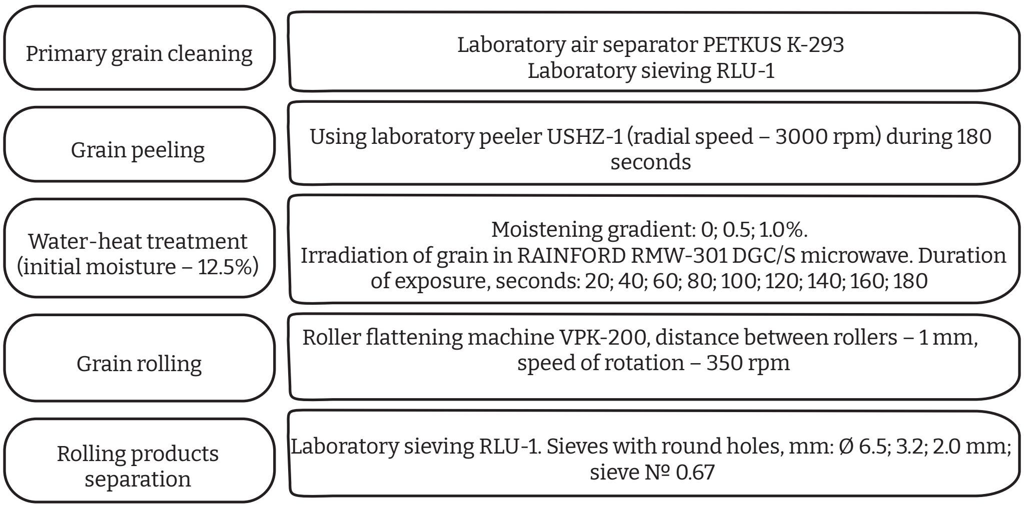

Figure 1. Experiment scheme

Grain peeling

After peeling the grain in the laboratory husker USHZ-1, whole cereal from spelt wheat No. 1 was obtained. The weight of the peeling sample was 150 g. The separation of flour from the pile was conducted on laboratory sieving RLU-1 (sieve No. 0.67). The grain peeling index was 13-15%.

Conducting water-heat treatment of whole wheat spelt cereal No. 1

Water-heat treatment (WHT) of grain was conducted by drip method, and the amount of water was determined by the formula (1):

$$\text{В} = 3 \cdot \left(\frac{100-\text{А}}{100-\text{Б}}\right) - 1 \quad (1)$$

where W is the required mass of water for water-heat treatment of grain, g; G – grain weight during analysis, g; M – grain moisture before processing, %; R – required grain moisture, %.

Water-heat treatment and flattening of whole spelt wheat cereal No. 1

Raw materials were irradiated with an electromagnetic field in a RAINFORD RMW-301 DGC/S microwave oven with a rated power of 1000 W and a microwave frequency of 2450 MHz. The sample weight in the studies was 100 g. The sample was evenly distributed (layer thickness <1 cm) on a round plate (245 mm). After processing, the raw material was rolled, while it was not allowed to cool down. For flattening, a VPK–200 roller flattening machine was used, the distance between the rolls was 1 mm. Rifled rolls (grooved slope 4°, relative position – horizontal), rotation speed 350, 450 rpm.

Determining the yield of cereal

Cereal products were cooled in a ventilated box to room temperature. The cereal products were then separated by RLU-1 sieving. For this purpose, sieves of different sizes were used. As a result, five varieties of the product were obtained (Table 1).

Table 1. Characteristics of products after flattening

Product name	Sieves sizes	Flake diameter, mm
stuck together grains	Sieves with 6.5 mm holes	1%
premium rolled groats	sieve passage with 6.5 mm holes sieve descent with 3.2 mm holes	6.5-3.2
first grade rolled groats	sieve passage with 3.2 mm holes sieve descent with 2.0 mm holes	3.2-2.0

Table 1, Continued

Product name	Sieves sizes	Flake diameter, mm
(grits) crumb	sieve passage with 2.0 mm holes sieve descent with No. 0.67 holes	2.0-0.67
feed flour	screen passage with holes No. 0.67	>

Culinary evaluation of cereal

The culinary evaluation was performed by cooking cereal in measuring cylinders. Since the duration of irradiation did not affect the smell and taste of porridge, the duration of its cooking was determined. The readiness of porridge was determined organoleptically.

The competence of the commission was determined based on a previously improved methodology (Liubych *et al.*, 2020). The commission that conducted the culinary assessment of cereal products included four experts. The overall competence of the commission was 82 points. Therefore, it can be argued that the competence of the commission was very high.

Statistical analysis

Statistical analysis was performed using the STATISTICA 12 programme (StatSoft, Inc., USA). Variance analysis of the results was performed by the least squares method using the Student's criterion. Differences were considered statistically substantial if the probability exceeded 95% ($p<0.05$). All analyses were performed in three repetitions. Experimental results are expressed as mean ±SD (standard deviation).

RESULTS AND DISCUSSION

Yield of rolled croup by UHF-EMR irradiation

Modelling of the process of water-heat treatment by irradiation with a UHF-EMR field is conducted using specialised laboratory equipment or household appliances. Structurally, they differ from industrial equipment. In addition, especially in household microwave ovens, there is no possibility of a perfect study of all the parameters of the technological process. However, the yield trend and the quality of the finished product will correspond to the production parameters. In addition, investigating the effectiveness of UHF-EMR on industrial equipment requires substantial costs (Mazima *et al.*, 2018).

The results of statistical processing indicate that with an increase in the duration of exposure to UHF-EMR from 20 to 80 seconds, the total yield of cereal products substantially increased (from 93.8 to 97.3%) (Table 2). With an increase in the duration of irradiation to 100-180 seconds, this indicator substantially decreased to 85.5-95.3% compared to the option where cereal was treated for 80 seconds. The decrease in the yield of cereal is due to an increase in the yield of crumb and flour. Moistening of cereal No. 1 before irradiation substantially reduced the yield of cereal products by 0.5% compared to options where no moistening was performed. The exception was the irradiation of cereal for 20-40 seconds. The yield of cereal was at the level of options without moistening. Notably, the moistening of cereal No. 1 before irradiation by 1.0% had a similar trend compared to options where humidity increased by 0.5%. During the moistening of cereal No. 1 from spelt wheat, the total yield of cereal products decreased due to a substantial increase in the yield of crumb and flour.

Table 2. Yield of cereal from spelt wheat depending on the duration of irradiation and water-heat treatment (Holikovs`ka variety), %

Duration of exposure, seconds	Yield of cereal products				Flour
	Rolled groats, variety		Crumb	total	
	higher	first			
Without moistening					
20	3.4±0.2	45.4±0.7	45.0±1	93.8±0.3	6.2±0.3
40	24.3±1.1	54.7±0.9	16.1±0.5	95.1±0.2	4.9±0.2
60	67.0±1.2	23.2±0.9	7.1±0.4	97.3±0.2	2.7±0.2
80	82.1±0.7	12.5±0.6	2.7±0.1	97.3±0.2	2.7±0.2
100	77.8±0.5	12.4±0.5	5.1±0.2	95.3±0.2	7.6±0.3
120	68.7±0.1	14.9±0.7	8.8±0.4	92.4±0.3	7.6±0.3
140	58.4±1.5	18.2±0.9	13.7±0.6	90.4±0.5	9.6±0.5
160	44.8±0.9	25.7±1.2	16.0±0.3	86.5±0.6	13.5±0.6
180	39.6±2.4	23.6±1.0	22.2±0.9	85.5±0.5	14.5±0.5

Table 2, Continued

Duration of exposure, seconds	Yield of cereal products				Flour
	Rolled groats, variety		Crumb	total	
	higher	first			
Moistening of cereal No. 1 by 0.5%					
20	20.4±1.1	53.1±1.6	20.7±0.6	94.2±0.3	5.8±0.3
40	43.8±2.0	39.3±1.7	12.0±0.5	95.0±0.2	5.0±0.2
60	62.0±1.6	26.7±1.3	6.4±0.3	95.1±0.2	4.9±0.2
80	78.7±0.7	10.9±0.6	5.0±0.3	94.6±0.4	5.4±0.4
100	73.8±0.7	12.2±0.6	6.9±0.3	92.9±0.2	9.6±0.3
120	66.8±0.7	14.9±0.7	8.8±0.4	90.4±0.3	9.6±0.3
140	57.0±1.9	21.3±1.0	10.2±0.4	88.5±0.6	11.5±0.6
160	43.2±2.2	20.8±0.9	19.8±0.8	83.8±0.5	16.2±0.5
180	36.7±1.7	19.1±0.9	25.7±1.1	81.5±1.1	18.5±1.1
Moistening cereal No. 1 by 1.0%					
20	19.7±0.9	53.0±1.5	2.0±0.9	94.7±0.1	5.3±0.1
40	40.4±2.1	38.1±1.9	16.4±0.5	94.9±0.3	5.1±0.3
60	60.1±1.9	24.5±1.7	10.1±0.5	94.7±0.1	5.3±0.1
80	79.2±0.7	14.1±0.5	3.5±0.2	96.8±0.1	3.2±0.1
100	71.5±1.2	16.5±0.6	6.5±0.4	94.5±0.4	8.7±0.2
120	66.1±1.0	17.8±0.8	7.4±0.4	91.3±0.2	8.7±0.2
140	60.0±1.7	21.6±1.0	9.1±0.4	90.7±0.4	9.3±0.4
160	54.4±2.0	22.1±1.0	11.3±0.5	87.8±0.5	12.2±0.5
180	47.8±1.9	23.4±1.1	13.9±0.6	85.1±0.5	14.9±0.5

The yield of premium rolled cereal varied differently. Thus, the lowest yield was provided by irradiation for 20 seconds – 3.4%. The highest yield was provided by irradiation for 80 seconds – 82.1%. Therewith, exposure for 100 seconds substantially reduced this indicator to 77.8%, but it was substantially higher compared to exposure for 60 seconds. Moistening of cereal No. 1 substantially increased the yield of rolled cereal of the highest grade during the duration of irradiation for 20-40 seconds. With an increase in the duration of exposure, the yield of premium rolled cereal was substantially lower compared to non-moistening options. A similar trend was identified when moistening cereal No. 1 by 1.0%. The yield of first grade rolled cereal, the yield of flour and crumb was inversely proportional to the indicator of premium cereal products.

Thus, in the technology of rolled cereal from shelled spelt wheat of the Holikovs`ka variety, the duration of irradiation for 60-80 seconds is sufficient, provided that the total yield of cereal products is high without moistening. It is necessary to irradiate the peeled grain with a duration of 80-100 seconds without moistening to obtain a high yield of rolled cereal of the highest grade.

The yield of cereal (highest and first grade) from cereal No. 1 spelt wheat of the Holikovs`ka variety can be expressed by a multiple nonlinear models (2, 3):

$$\text{for highest grade} = -15.4208+1.6357\,x + 6.4776\,y-0.0075x^2-0.0291\,xy + 0.1186y^2 \tag{2}$$

$$\text{for first grade} = 68.8229-0.9049\,x-6.6215\,y+0.0036x^2 + 0.0108\,xy + 5.5779y^2 \tag{3}$$

where x – the duration of grain irradiation in a microwave oven, seconds; y – water-heat treatment mode, %.

The highest total yield of cereal products (94.9%) in the LP 1152 line was obtained by irradiation for 120 seconds, provided that no moistening is conducted (Table 3). With the extension of the duration of exposure, this indicator substantially decreased to 89.5-92.3%. In this scenario of water-heat treatment, the yield of cereal was at the level of 50.7-64.3%.

Table 3. Yield of spelt wheat cereal depending on the duration of irradiation and water-heat treatment (LP 1152 line), %

Duration of exposure, seconds	Yield of cereal products				Flour
	Rolled groats, variety		Crumb	total	
	higher	first			
Without moistening					
20	3.6±0.2	47.3±1.7	40.3±1.1	91.2±0.5	8.8±0.5
40	8.7±0.4	44.3±1.5	39.7±0.9	92.7±0.3	7.3±0.3
60	13.5±0.4	40.4±2.0	39.1±1.3	93.0±0.3	7.0±0.3
80	20.7±0.7	44.1±1.9	28.8±1.0	93.5±0.2	6.5±0.2
100	44.9±1.9	29.9±1.3	18.4±0.7	93.2±0.2	6.8±0.2
120	64.3±0.7	18.5±0.9	12.1±0.5	94.9±0.3	5.1±0.3
140	50.7±1.4	27.7±1.3	13.9±0.5	92.3±0.3	7.7±0.3
160	42.3±1.7	32.4±1.4	17.0±0.6	91.7±0.3	8.3±0.3
180	30.5±1.3	40.3±0.4	18.7±0.8	89.5±0.7	10.5±0.7
Moistening of cereal No. 1 by 0.5%					
20	19.9±0.4	43.3±1.9	29.7±1.2	92.9±0.3	7.1±0.3
40	30.1±1.4	40.2±0.7	24.3±0.8	94.6±0.2	5.4±0.2
60	41.4±2.2	36.6±1.6	17.2±0.5	95.2±0.2	4.8±0.2
80	51.1±1.3	28.9±1.1	15.5±0.8	95.5±0.2	4.5±0.2
100	61.7±1.6	17.5±0.7	16.8±0.7	96.0±0.2	4.0±0.2
120	70.5±1.4	15.1±0.7	10.5±0.5	96.1±0.2	3.9±0.2
140	64.6±1.6	19.3±0.9	8.8±0.4	92.7±0.3	7.3±0.3
160	42.2±1.7	38.9±1.0	9.4±0.4	90.5±0.4	9.5±0.4
180	33.1±1.6	42.2±1.8	11.3±0.5	86.6±0.6	13.4±0.6
Moistening cereal No. 1 by 1.0%					
20	24.4±0.5	40.1±0.4	28.7±0.6	93.2±0.3	6.8±0.3
40	35.1±1.8	32.3±1.9	26.1±1.2	93.5±0.3	6.5±0.3
60	46.3±1.0	28.6±1.1	18.8±0.9	93.7±0.3	6.3±0.3
80	60.2±0.9	19.5±0.9	15.3±0.6	95.0±0.3	5.0±0.3
100	68.8±0.8	17.4±0.7	8.0±0.3	94.2±0.2	5.8±0.2
120	73.1±0.3	12.4±0.5	7.4±0.3	92.9±0.3	7.1±0.3
140	62.4±0.6	22.8±0.9	5.9±0.3	91.1±0.4	8.9±0.4
160	44.5±0.7	34.5±1.5	10.5±0.3	89.5±0.4	10.5±0.4
180	36.6±0.5	38.2±1.6	11.8±0.7	86.6±0.8	13.4±0.8

Notably, moistening cerealubstantially increased the yield of products to 19.9-70.5% with the duration of irradiation for 20-140 seconds. Increasing the duration of irradiation did not substantially affect the yield of this grain. Therewith, the total yield of cereal products was substantially higher with irradiation for 20-120 seconds.

The highest yield of premium rolled cereal was obtained during the duration of UHF-EMR irradiation for 120-140 seconds. The yield of rolled cereal increased due to a decrease in the yield of first grade cereal, crumbs, and flour.

Moistening of cereal No. 1 from spelt wheat by 1.0% did not substantially affect the overall yield of cereal products compared to options where moisture was increased by 0.5%. Therewith, the yield of rolled cerealubstantially increased during the duration of irradiation for 20-120 seconds – 24.4-73.1%. The highest yield of this cereal was obtained for the duration of irradiation for 100-120 seconds – 68.8-73.1%.

Thus, in the technology of production of rolled cereal from spelt wheat of the LP 1152 line using UHF-EMR, the duration of irradiation for 120-140 seconds is sufficient with moistening of cereal No. 1 by 0.5% and without water-heat treatment. If cereal No. 1 is moistened by 1.0%, the duration of irradiation can be 100-120 seconds.

The yield of cereal from the LP 1152 line is described by the following multiple models:

$$\text{For higher grade} = -33.5914+1.3257\,x + 58.087\,y-0.0053x^2-0.1701\,xy-21.9329y^2 \quad (4)$$

$$\text{For the first grade} = 69.2838-0.7404\,x-18.5229\,y + 0.0033x^2+0.0822\,xy + 1.5036y^2 \quad (5)$$

where x – the duration of grain irradiation, seconds; y – water-heat treatment mode, %.

Results of the examination of the effect of microwave processing and moistening on the yield of spelt wheat groats

Using the methods of dispersion analysis, a reliable effect (p<0.05) of varietal characteristics, the duration of irradiation in a microwave oven and the WHT on the total yield of cereal and the yield of rolled cereal of the highest grade was established (Fig. 2, Fig. 3).

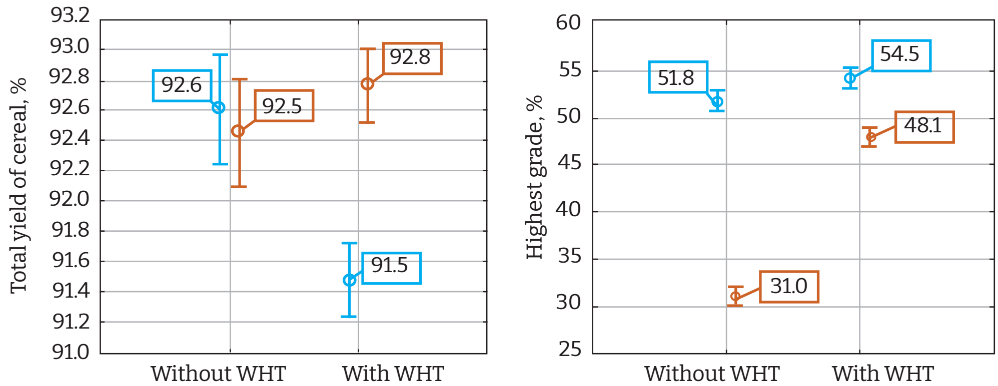

Figure 2. Variance analysis of the influence of technological parameters on the yield of cereal (vertical bars indicate a 0.95 confidence interval)

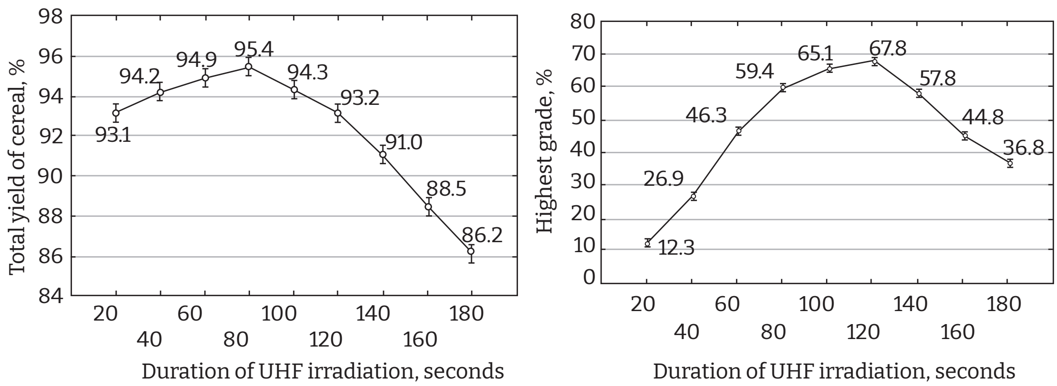

Figure 3. Results of variance analysis of the dependence of the influence of technological parameters on the yield of cereal (vertical bars indicate a 0.95 confidence interval)

The total yield of cereal products when using spelt wheat of the LP 1152 line and the Holikovs`ka variety without the WHT did not differ substantially. The moisture content of cereal No. 1 had different effects depending on the variety or line. Thus, the total yield of cereal when using the LP 1152 line increased, but when using the Holikovs`ka variety, it decreased. The reason for the opposite effect is the morphological features of the grain. There was an increase in the yield of premium rolled cereal after moistening for both varieties.

Exposure to the UHF electromagnetic field for 60-100 seconds provided the highest total yield of cereal products (94.3-95.4%). However, to obtain the highest yield, rolled cereal of the highest grade should be irradiated for 80-120 seconds. An increase in the duration of irradiation (>120 seconds) led to an increase in the grinding of flakes, as a result – a decrease in the yield of premium cereal and cereal in general.

Notably, the total yield of cereal depended more on the variety, and moistening had a low level of influence (η^2=0.53). But the yield of rolled cereal of the highest grade depended most substantially on the duration of exposure to the microwave field. Varietal characteristics were affected the least by strong exposure levels (η^2=0.87). These judgments are confirmed by Pareto diagrams ($p<0.05$) (Fig. 4).

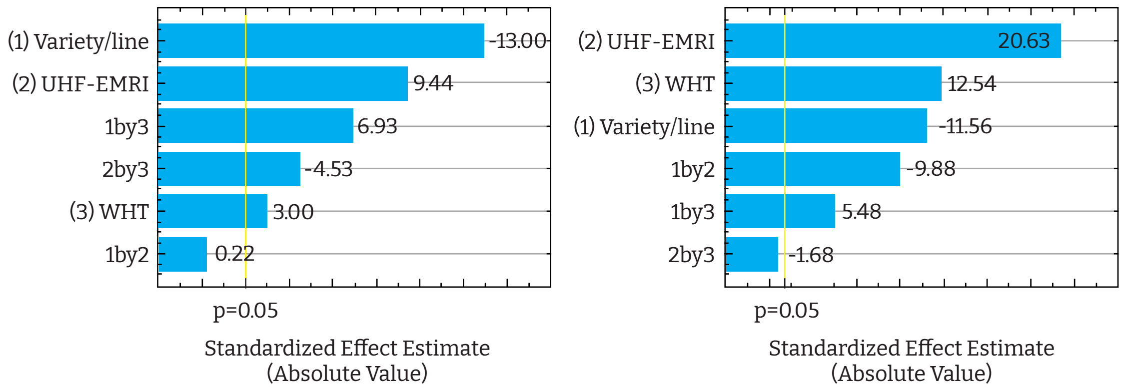

Figure 4. Pareto diagram showing the influence of varietal characteristics, duration of UHF-EMR irradiation and WHT on the total yield of cereal and premium cereal

The results obtained indicate that the efficiency of water-heat treatment depends on the technological parameters of spelt wheat grain. Thus, if the grain of spelt wheat of the Holikovs`ka variety is processed using UHF-EMR, it is not necessary to moisten cereal No. 1. When producing rolled cereal from spelt wheat of the LP 1152 line, moistening cereal No. 1 substantially increases the yield of cereal products, especially premium rolled cereal. During the irradiation of cereal No. 1, changes occur with biochemical components that contribute to the development of flakes and retain their shape after cooling. This statement is proved in the papers of other researchers (Aguilar *et al.*, 2018; Mobolade *et al.*, 2019). In addition, it was identified that the yield of cereal varies depending on the operation parameters of the UHF-EMR equipment itself. This changes the structure of the final product.

In the research of other researchers (Liangchen *et al.*, 2022; Wang *et al.*, 2018), it is proved that the yield of rolled cereal can depend on the protein content in the grain. The protein is able to form strong complexes that have the ability to retain endosperm pstudys after its flattening. Especially if the cereal is low in moisture before rolling. Thus, in the studies, the protein content in the grain of spelt wheat of the Holikovs`ka variety was substantially lower compared to the grain of the LP 1152 line. In addition, it is known that the effectiveness of UHF-EMR also depends on the moisture content of the grain, starch content, fibre, hardness, and thermophysical parameters of the grain.

The efficiency of water-heat treatment can also vary depending on the rate of penetration of free moisture into the grain. Therefore, the effectiveness of moistening can also vary depending on the variety of spelt wheat, which is confirmed in the work (Ding *et al.*, 2018; Barba *et al.*, 2020). In addition, the technological properties of wheat grains of sparsely distributed species differ substantially from soft wheat and durum wheat (Mefleh et al., 2019).

In addition to the protein content, other technological parameters of the grain may affect the efficiency of water-heat treatment using UHF-EMR. Therefore, further research will be aimed at investigating such features to develop optimal UHF-EMR modes regardless of the spelt wheat variety. This is especially important for large batches of grain of this crop, since it can include several varieties.

Culinary evaluation of premium rolled cereal

An important technological indicator of the culinary quality of cereal is the duration of its cooking (Lamacchia *et al.*, 2016). Due to irradiation in a microwave oven, the product is heated. As (Wang *et al.*, 2018) state, heating causes an intense transition of water to a gaseous state, loosening the internal structure of the endosperm. The result of these processes is a change in the duration of cooking cereal (Figure 5). After processing in a microwave oven for 20 seconds without WHT, the cooking time of rolled cereal of the highest grade was 18.3 minutes for the Holikovs`ka variety and 17.7 minutes for the LP 1152 line. An increase in the duration of irradiation (up to 180 seconds) led to a reduction in the cooking time to 15 and 13.7 minutes, respectively. Moistening also led to a reduction in the cooking time by 6-15%.

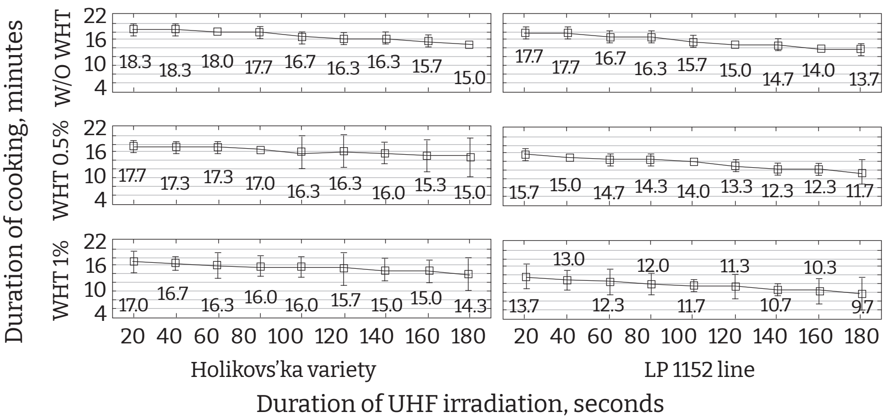

Figure 5. Duration of cooking of rolled cereal of the highest grade, depending on the variety and mode of water-heat treatment

Notably, cereal made from spelt wheat of the LP 1152 line were characterised by a shorter cooking time of 2-3 minutes compared to the Holikovs`ka variety. The duration of cooking rolled cereal (LP 1152 line) of the highest grade after 180 seconds of irradiation coincides with the results obtained after rolling a similar whole cereal after steaming and moistening for 3 minutes (grain peeling index 11.6%) (Liubych *et al.*, 2022).

Changes in the duration of microwave exposure and moistening did not affect organoleptic parameters and overall culinary assessment. However, the culinary quality of cereal depended on the varietal characteristics of spelt wheat. Similar patterns were obtained by other researchers (Barba *et al.*, 2020). According to (Liubych *et al.*, 2020), increasing the protein content of wheat grains improves the smell and taste of the finished product. The results obtained are similar to the known results of the study. Thus, rolled cereal from spelt wheat of the LP 1152 line prevailed by 1 point in taste, smell, colour, and consistency during chewing. Porridge from both varieties had a very high overall culinary rating (8.2-9 points).

Since organoleptic parameters do not change depending on the duration of irradiation in a microwave oven, it is worth choosing production modes that will provide the highest yield of cereal of the desired variety.

Although the study has certain disadvantages, namely the low level of investigating of the parameters of the microwave electromagnetic field and the frequency of processing raw materials, which is due to the specific features of the laboratory installation. However, the results obtained indicate a reliable and positive effect of UHF-EMR on the yield of rolled cereal, regardless of the grade of processed raw materials. Therefore, a more detailed study of the parameters of grain processing in the microwave electromagnetic field and its testing under production conditions are promising.

The results obtained and presented in the paper are of practical importance for production. The use of the proposed method in the conditions of existing production facilities of low productivity will substantially reduce costs for depreciation and maintenance of hot air conditioning systems, and abandon the use of energy carriers (fuel or gas). For the design of new enterprises, the absence of the need for moistening after grain processing in the microwave electromagnetic field substantially reduces the cost of construction, and therefore, the risk of capital investment. Notably, the duration of irradiation may vary depending on the level of moisture content of the cereal. This makes it necessary to determine the optimal modes during UHF-EMR. Further research of economic indicators related to the integration of this technology is required.

CONCLUSIONS

As a result of the study, optimal UHF-EMR modes of cereal No. 1 from spelt wheat were determined. The influence of the duration of irradiation and moistening on the yield and duration of cooking rolled cereal of two varieties of spelt wheat was identified. It was determined that during the production of rolled cereal from spelt wheat of the Holikovs`ka variety, moisture did not substantially affect its yield. Therewith, the total yield of cereal products was also the highest. Moistening of cereal No. 1 from spelt wheat of the LP 1152 line substantially increased the total yield of cereal products and premium rolled cereal. Therewith, for 0.5% moistening, irradiation for 120-140 seconds was effective, and for 1.0% – 100-120 seconds.

Changing the duration of treatment in a microwave oven did not affect the culinary quality. The duration of cooking of rolled cereal depends on the duration of exposure in the microwave, the moisture index, and varietal characteristics. Spelt wheat groats of the LP 1152 line are characterised by a shorter cooking time.

In the technology of production of rolled cereal from spelt wheat of the Holikovs`ka variety, when using UHF-EMR, the duration of irradiation is 80-100 seconds without moistening. The use of such parameters provides a yield of premium rolled cereal of 77.8-82.1%, first grade – 12.4-12.5%, crumb – 2.7-5.1%, and flour – 2.7-7.6%. The duration of cooking of premium rolled cereal is 16.0 minutes. When using cereal No. 1 from spelt wheat of the LP 1152 line, it is necessary to moisten it by 0.5% with an irradiation duration of 120-140 seconds. At such parameters of UHF-EMR, the yield of premium rolled cereal is 64.6-70.5%, first grade – 15.1-19.3%, crumb – 8.8-10.5%, and flour – 3.9-7.3%. The duration of cooking of premium rolled cereal is 10.7-11.3 minutes.

Promising areas are the research of the use of irradiation with whole grain No. 1 obtained from spelt wheat varieties, which have technological properties different from the Holikovs`ka variety and the LP 1152 line. In addition, it is necessary to establish the duration of storage of spelt wheat cereal products exposed to radiation. The research on ways to store such cereal is promising.

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Вихід і якість плющеної крупи із зерна пшениці полби залежно від тривалості опромінення електромагнітним полем надвисокої частоти

Анотація. Пшениця полба має велику перспективу в технології виробництва продуктів вищої біологічної цінності. У технології плющеної крупи водотеплове оброблення є енерговитратним. Тому дослідження технологічних параметрів опромінення електромагнітним полем надвисокої частоти у технології крупи із зерна пшениці полби є актуальними. Мета дослідження – вивчення виходу та якості плющеної крупи із пшениці полби залежно від тривалості опромінення електромагнітним полем надвисокої частоти. У дослідженнях використано лабораторний метод (визначення виходу круп) і статистичний. Встановлено, що загальний вихід крупи за використання зерна сорту Голіковська достовірно зростав до 97,3 % за опромінення впродовж 60-80 с. Вихід крупи плющеної вищого сорту найвищий за опромінення впродовж 80-100 с. Водотеплове оброблення крупи із зерна сорту Голіковська достовірно не підвищувало вихід крупи. Найвищий загальний вихід плющеної крупи отримано в лінії LP 1152 за тривалості опромінення впродовж 100-120 с – 93,2-94,9 %. Найвищий вихід плющеної крупи вищого сорту отримано за тривалості опромінення 120-140 с. Слід відзначити, що проведення водотеплового оброблення достовірно впливало на вихід крупи (96,0-96,1 %). У технології виробництва плющених круп з пшениці полби сорту Голіковська за використання електромагнітного поля надвисокої частоти тривалість опромінення становить 80-100 с без проведення зволоження. За використання крупи №1 із пшениці полби лінії LP 1152 необхідно проводити зволоження на 0,5 % з тривалістю опромінення 120-140 с. Тривалість варіння крупи плющеної вищого сорту становить 10,7-11,3 хв. Матеріали статті мають практичну цінність для круп'яних підприємств малої продуктивності під час виробництва круп'яних продуктів із пшениці полби. За умови використання електромагнітного поля в технологічному процесі можливе застосування удосконалених режимів

Ключові слова: мікрохвильова піч, тривалість варіння крупи, індекс лущення, тривалість варіння, зернова культура