Optimization of processing parameters of amaranth grits before grinding into flour

I M Zharkova, Yu A Safonova, Yu I Slepokurova

Voronezh State University of Engineering Technology, 19, Revolution Avenue, Voronezh, 394036, Russia

E-mail: zharir@mail.ru

Abstract. There are the results of experimental studies about the influence of infrared treatment (IR processing) parameters of the amaranth grits before their grinding into flour on the composition and properties of the received product. Using the method called as regression-factor analysis, the optimal conditions of the thermal processing to the amaranth grits were obtained: the belt speed of the conveyor – 0.049 m/s; temperature of amaranth grits in the tempering silo – 65.4 °C; the thickness of the layer of amaranth grits on the belt is 3 - 5 mm and the lamp power is 69.2 kW/m². The conducted researches confirmed that thermal effect to the amaranth grains in the IR setting allows getting flour with a smaller size of starch grains, with the increased water-holding ability, and with a changed value of its glycemic index. Mathematical processing of experimental data allowed establishing the dependence of the structural and technological characteristics of the amaranth flour on the IR processing parameters of amaranth grits. The obtained results are quite consistent with the experimental ones that proves the effectiveness of optimization based on mathematical planning of the experiment to determine the influence of heat treatment optimal parameters of the amaranth grits on the functional and technological properties of the flour received from it.

1. Introduction

The careful raw material selection and pre-treatment promotes obtainment of the products will not only require organoleptic and physico-chemical indicators of quality, but it also ensures their safety for the consumer. Obtaining the new types of products not subjected to prolonged processing and also development of food products with defined properties make the basis of modern technologies development in grain raw materials processing, which include heat treatment that increases the degree of digestibility of the grain nutrients.

One of the varieties of heat treatment of grain is its micronization, which essence consists in the rapid intense heating of raw materials with infrared rays. Rapid internal heating of the grain is achieved with high frequency vibration of molecules (80 – 170 million cycles/s) caused with infrared rays. The moisture in the grain has no time to evaporate and thus it turns into a vapor that leads to the destruction of the grain structural frame; its form and strength change that affects the grinding process [1].

The flour received from such grain has modified physico-chemical properties: there is dextrinization and partial gelatinization of starch that increases several times the attachment with glucoamylase; proteins exposed to a denaturiration change of the fractional composition of the protein complex (the proportion of water-soluble and salt-soluble fractions decreases and the contents of
proteins dilaceration increases); there are not significant changes in the lipid complex; the activity of anti-nutritive substances of the grain significantly reduces. Besides, it should be noted that such processing method makes it possible to retain vitamins (Thiamin, Niacin, Riboflavin) [2], and also to get products with improved digestibility by increasing the accessibility of raw material components to a digestion process [3].

Using the preliminary IR processing of the amaranth grain allows one to obtain an ingredient, promising for use in new functional products that have high quality and desired properties [4, 5].

The article contains the research results about influence of different IR flux density combinations of specialized installation halogen lamps and that of the amaranth grits speed passage with a layer of varying thickness through the heat treatment area on the properties of the resulting amaranth flour with subsequent modes optimization.

2. Materials and methods
The amaranth raw materials (grits) were carried out using heat treatment with the help of the IR method on installation UTZ-4. The equipment consists of a heating chamber, which contains 3 cassettes, each one includes 27 quartz halogen lamps. The lamps are arranged above the conveyor belt, made of heat-resistant material. There is a possibility of regulation by changing the length of the grain in the processing zone of the belt speed, as well as the thickness of the material layer on the belt.

The chemical composition of amaranth flour was determined according to standard procedures: – GOST 9404 (mass fraction of moisture); GOST 10846 (mass fraction of protein); GOST 10846 (mass fraction of starch); GOST 51636 (mass fraction of soluble carbohydrates). The particle size of flour was determined on laboratory sieve analysis according to GOST 27560: the installation includes a set of sieves of silk or synthetic (GOST 4403 – 91) and wire mesh No. 45 and No. 067, has a frequency of sieves oscillation equal to 180 – 200 rpm./c^{-1}. Water holding ability of flour was determined as the amount of water held in 1 g of flour.

The evaluation of the morphological structure and the granulometric composition of native and heat-treated aramantic starch was carried out using the Jeol JSM-6380 LV scanning electron microscope in a high vacuum mode.

Determination of the glycemic index was performed according to the method described in [8].

The optimum conditions of the infrared processing the studied raw materials were established using regression-factor analysis. The criterion of adequacy is the coefficient of determination R^2, whose value allows setting the degree of selected optimal mode compliance to the actual conditions of the process.

3. The study of the functional and technological properties of amaranth flour, depending on the method of preparing grits for milling
Passing the amaranth grains through the installation UTZ-4 leads them to heating to 110-150 °C. At the same time, volume moisture, initially the uniformly distributed through the grits, begins to move towards the center in the direction of the heat flux, the significant temperature facilitates the moisture to transfer into the steam that causes a sharp pressure increase and, accordingly, the braking down of the structural framework of the grits. This leads to decreasing the strength of grain raw materials. Heat-treated amaranth grits are easier for grinding.

The evaluation of the heat treatment process of amaranth grits was carried out with its IR processing on this apparatus. For this purpose, a layer of grits of different thickness was passed (sample 1: 2 to 3 mm, sample 2: 3 to 5 mm, sample 3: 5 to 7 mm) with an initial temperature of 22 °C along the conveyor of the apparatus at a variable speed (0.025 - 0.11 m/s).

The authors studied the influence of heat treatment parameters of amaranth grits before grinding on the properties of obtained products.

The size of flour grinding is an important technological characteristic in production of bread, bakery and flour confectionery. Flour with sufficiently large particles looks darker, has a low water
absorption capacity that leads to slow dough formation, and the finished bakery is obtained by a slightly colored crust, uneven coarse thick-walled crumb porosity and insufficient volume [2].

The authors have tested a number of combinations of the infrared radiation flux density and the duration of the varying thickness of the amaranth grits in the heat treatment zone of the plant. Good results were obtained with a conveyor belt speed of 0.042 m/s and a lamp output of 69.2 kW/m². The results of fractionation by laboratory sieving of the products obtained after IR treatment of amaranth grits are presented in Table 1.

**Table 1. The results of the fractionation according to the particle size of amaranth grits subjected with IR-treatment**

| The name of the faction | The proportion of fraction, %, for sample 1 | sample 2 | sample 3 | control (source grit) |
|------------------------|--------------------------------------------|----------|----------|-----------------------|
| Sieve residue № 067    | 82.9                                       | 74.8     | 71.2     | 62.54                 |
| Sieve residue № 045    | 12.9                                       | 21.4     | 25.7     | 34.56                 |
| Sieve residue № 27     | 4.2                                        | 3.8      | 3.1      | 2.90                  |
| The average particle size, mkm | 651                                        | 632      | 594      | 582                   |

The analysis of the data in Table 1 showed that as a result of micronization in this regime (samples 1 - 3), one could see that the particle size of the grits was increased by 2.06 - 11.86 %, respectively, compared to the initial grit.

The heat-treated amaranth grits were ground; as a result, obtaining a yield of amaranth flour was larger than ground native grits (Table 2).

**Table 2. The results of the amaranth flour screening**

| The name of the faction | The proportion of fraction, %, for sample 1 | sample 2 | sample 3 | control (source grit) |
|------------------------|--------------------------------------------|----------|----------|-----------------------|
| Sieve residue № 27     | 1.0                                        | 0.9      | 1.6      | 2.58                  |
| Sieve residue № 35     | 9.1                                        | 6.7      | 12.6     | 13.80                 |
| Sieve residue № 38     | 12.1                                       | 11.3     | 14.5     | 15.60                 |
| Sieve residue № 43     | 4.7                                        | 4.9      | 4.5      | 3.92                  |
| Pass through the sieve № 43 | 73.1                                      | 76.2     | 66.8     | 64.10                 |
| The average particle size, mkm | 117                                        | 115      | 122      | 126                   |

The obtained results indicate that the preliminary IR processing of amaranth grits before grinding has a favorable effect on the grinding efficiency and one can see more complete separation from the shell particles of the perisperm.

The analysis of the data in Table 2 also showed that the minimum particle size is typical for flour produced from the grits of sample 2 obtained under the above-mentioned IR-processing regime when the layer thickness is 3 - 5 mm, and the maximum is typical for flour produced from the control sample - native grits.

The main functional and technological characteristic of flour is its water-holding ability (WHA). The major factor that determines it is the protein complex of flour and the presence of activators and inhibitors of proteolysis. The strength of the flour protein structure and its amount influence on how proteinase would attack it; the lower the proteinase activity and the less the proteolysis activators in flour, the higher the absorption of water by flour [6]. The amaranth flour has a high water-holding ability, as it has a significant mass fraction of protein and fiber compared to wheat flour. By the way, the strength of water binding is significantly influenced by the properties of starch grains: the smaller they are and the more damaged, the higher the water absorption. For amaranth seed and flour, it is characterized by a smaller size of starch granules than wheat and rye flour. The difference between
starch granules of amaranth is also in their characteristic form with pronounced facets, whereas in wheat and rye they have a rounded shape. According to the chemical composition study, we can note an increase in the proportion of starch in a sample that was subjected to preliminary heat treatment (sample 2) on 15 %, and an increase in the proportion of water-soluble carbohydrates on 74 %, compared with thermally untreated flour (control) [1, 7]. When it is the heat treatment processing of amaranth grits, the starch grains are destroyed, their shape becomes more heterogeneous, the size becomes much smaller.

The experimental sample (Figure 1), obtained by grinding the heat-treated IR-method of amaranth grits with the power of lamps 69.2 kW/m² and the speed of the installation belt 0.042 m/s were the most active in moisture absorption terms. The thickness of the treated layer of grains was 3 - 5 mm (sample 2) that could be explained with a higher content of protein and fiber in amaranth flour compared to wheat flour and with the presence of smaller starch particles.

The next step was the parameters of the IR processing of optimizing amaranth grits.

Formalized mathematical models allow us to find optimal solutions for various technological processes design, including heat treatment of amaranth grits by IR-method [9]. In the implementation of mathematical plans, the determining factors were: $X_1$ – temperature of amaranth grits in the tempering bunker of UTZ-4, °C; $X_2$ – belt speed, m/s. At the same time, the values of the thickness of the amaranth coarse layer on the conveyor belt (3 – 5 mm) and the power of the lamps (69.2 kW/m²) were recorded.

The basis for the development of mathematical models [10] was the experimental data on the influence of the heat treatment of amaranth grits conditions (duration and temperature of IR-processing) on the functional and technological properties of amaranth flour obtained by grinding the grains.

The functional dependence of the grinding size of amaranth grits on the raw material temperature and conveyor belt speed $Y_1=f(X_1, X_2)$ is a second-degree polynomial:

$$Y_1 = 119.14 - 2.5X_1 - 1.48X_2 + 3.75X_1X_2 - 7.26X_1^2 - 1.76X_2^2.$$  \hspace{1cm} (1)

Graphical interpretation of the obtained dependence can be seen in Figure 2 (a).
The response surfaces for the output parameters: a – $Y_1$ (average particle size of amaranth flour, mkm); b – $Y_2$ (WHA of amaranth flour, g/g); b – $Y_3$ (GI of amaranth flour, %) with input factors of IR-processing of amaranth grits: $X_1$ – the temperature of grits, °C; $X_2$ – belt speed, m/s

The functional dependence of the WHA of amaranth flour on the raw material temperature and conveyor belt speed $Y_2=f(X_1, X_2)$ is a second-degree polynomial:

$$Y_2 = 115 - 2.5X_1 - 2.15X_2 - 6X_1X_2 - 2.12X_1^2 - 2.62X_2^2.$$  (2)

Graphical interpretation of the obtained dependence can be seen in Figure 2 (b).

The functional characteristics of amaranth flour include the magnitude of the glycemic index (GI). Since amaranth flour is used primarily as a prescription ingredient in the development of functional products, such as elderly nutrition flour. It is interesting to analyze how the value of GI of amaranth flour obtained from heat-treated IR-grits would change.

The temperature of the raw material and the speed of the conveyor belt movement influence on the GI of the resulting amaranth flour $Y_3=f(X_1, X_2)$ is described by a polynomial of the second degree:

$$Y_3 = 101.8 + 6.62X_1 + 5.58X_2 - 5X_1X_2 - 15.28X_1^2 - 15.56X_2^2.$$  (3)

Graphical interpretation of the obtained dependence can be seen in Figure 2 (c).

From the obtained dependences (1) - (3), the authors found the values of variables $X_i$, $i=1,2$, when the size of the grinding size ($Y_1$) decreased, the value of the WHA indicator ($Y_2$) increased and the GI ($Y_3$), on the contrary, decreased. It was necessary to solve the optimization problem of two criterions and determine the values of $X_1$ and $X_2$: $Y_1, Y_3\rightarrow\min, Y_2\rightarrow\max$.

Optimum values of processing parameters of amaranth grits were determined before grinding to obtain flour having the specified technological and functional properties. The conveyor belt speed was 0.049 m/s; the temperature of amaranth grits in the tempering hopper is 65.4 °C, the thickness of the amaranth coarse layer on the conveyor belt was 3 - 5 mm and the power of the lamps is 69.2 kW/m². The optimum values of the output factors were: $Y_1 = 118.25$ mkm; $Y_2 = 115.44$ g/g and $Y_3 = 96.61$ %.

4. Conclusion

The IR-processing of grain raw materials, in particular, amaranth grits before its grinding, has a significant influence on the quality of the flour: researches confirmed that pre-treatment allows obtaining the flour with a smaller size of starch grains with increased water-holding ability and with changed value of its glycemic index. Mathematical processing of experimental data allowed establishing the dependence of the structural and technological characteristics of amaranth flour on the parameters of grids IR-processing. The obtained results are quite consistent with the experimental ones that proves the effectiveness of optimization based on mathematical planning of the experiment.
determine the influence of heat treatment optimal parameters of the amaranth grits on the functional and technological properties of the flour received from her.

5. Acknowledgments
This work was executed with financial support of applied researches by the Ministry of Education and Science of the Russian Federation in the framework of the Federal target program "Research and development on priority directions of scientific-technological complex development of Russia for 2014-2020" with the agreement on grant No. 14.577.21.0256 of 26 September 2017, the Unique identifier, PYAR RFMEFI57717X0256.

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