Rheological properties of composite mixtures from wheat and amaranth flour

N M Derkanosova¹, A A Stakhurlova¹, M Vukic² and D Vujadinovic²

¹ Voronezh State Agrarian University n.a. Peter the Great, 1, Michurina st., Voronezh, 394087, Russia
² University of East Sarajevo, 34a, Karakaj, Zvornik, 75400 Republic of Srpska, Bosnia and Herzegovina

E-mail: 106@adm.vsau.ru

Abstract. The lack of essential nutrients in the population’s diet contributes to the expansion of the range of traditional products through the production of fortified products. Enrichment is often carried out by adjusting the traditional recipe by introducing unconventional raw materials, characterized by an increased content of deficient substances, primarily protein, alimentary fiber, minerals and vitamins. Changes in the properties of the dough lead to a change in the characteristics of the finished bakery. The influence of different dosages of unconventional raw materials (in the article - flour from extrudate amaranth grain, from 10 to 20 %) on the rheological properties of the dough was investigated using Brabender instruments.

1. Introduction
At the present time, the problem of rational nutrition is relevant – it is one of the main factors that determine the state of human health, efficiency, resistance to the influence of various unfavorable environmental factors. A decrease in the consumption of certain food elements causes an increase in the number of diseases among the population [1]. Therefore, the problem of preserving the health of the population is closely related to the production of biologically complete and safe food products [2]. Recently, the production and use of functional food has become widespread, in particular, the enrichment of food for mass consumption with scarce nutrients (alimentary fiber, vitamins, protein, etc.). Bakery rightfully belongs to traditional and mass products, therefore, adjusting their recipes can have an impact on the nutritional status of the population.

Enrichment of bakery products is often carried out at the expense of rare plant sources with promising properties. One of these plants is amaranth. Due to the high content of essential amino acids, vitamin E, mono- and polyunsaturated fatty acids, the use of amaranth in daily food helps to stimulate the immune system, detoxify the body, has antimicrobial, anti-cancer and fungicidal effect [3, 4].

Due to the small size of the grain and the presence of a dense gemmicelulose shell on its surface, amaranth must be additionally processed. Extrusion can be chosen as such a technological process. A great advantage of extrusion as a technological method is an increase in the degree of product assimilation. Additionally, a decrease in the severity and softening of the aroma of extruded amaranth compared to whole-grain was noted.
Amaranth flour is posing as a gluten-free material, and using it in traditional recipes contributes to testing of dough, which can describe an influence of amaranth flour on traditional raw-material. Reliable and informative data can be got by composite dough analysis with Brabender instruments.

2. Materials and methods
As it was established earlier that the chemical compositions of amaranth varieties are too different. Based on preliminary analysis have a Universal amaranth as an object of study. Universal is characterized by a high content of protein, lipids, minerals, including phosphorus, calcium, iron, as well as trace elements such as zinc and manganese. An extruded amaranth grain was obtained from whole semi-defatted grains of amaranth of the Universal variety on a laboratory extruder (EUS-1) at a temperature of 110–120 °C. As a control sample and basic of mixtures we choose first grade wheat bakery flour conformed GOST 26574-2017. Investigated mixtures contained 10, 15 and 20 % of flour from amaranth extrudate.

Informative data on the strength of flour mixtures of first grade wheat bakery flour and flour from amaranth extrudate were obtained using measuring complexes from Brabender - farinograph and extensograph. The studies were carried out in the conditions of the Center of food technology of the University of East Sarajevo (Republic of Bosnia and Herzegovina).

Studies of the rheological properties of the dough on complexes from Brabender allow us to obtain a number of characteristics: consistency, development time, extension, stability, dilution. Description of methodologies is contained in GOST ISO 5530-1-2013 and GOST ISO 5530-2-2014.

3. Results and discussion
Farinograms of control - wheat flour of the first grade dough - and model mixtures with the ratio of wheat flour and flour from amaranth extrudates are shown in Figure 1. The averaged test values are shown in Table 1.

| Indicator | Wheat flour : amaranth extrudate ratio |
|-----------|---------------------------------------|
|           | 100:0 (control) | 90:10 | 80:20 |
| Consistency, FU | 519 | 489 | 500 |
| Duration of dough development, min | 2.1 | 1.8 | 4.8 |
| Dough stability, min | 5.2 | 1.1 | 1.6 |
| Dilution, units | 33 | 55 | 88 |
| Water absorption capacity, % | 61.8 | 64.0 | 65.0 |
| Degree of softening, FU | 78.6 | 69.3 | 62.5 |

Traditionally, it is recommended to test various samples at a constant numerical value of the maximum dough consistency of 500 FU, which is achieved by varying the mass of water for the dough kneading. In the studies it was decided to maintain the moisture content of the dough to compare the rheological characteristics obtained. This led to a change in the test consistency indicator and the need to interpret the results taking this factor into account.

As shown by the research results, in general, the regularities established earlier in rheological studies on the valorigraph are repeated [5].

With an increase in the dosage of flour from the amaranth extrudate the duration of dough development and its water absorption capacity increase. This correlates with an increase in dietary fiber in the mixture, water withdrawal by them during the formation of the dough structure and, accordingly, an increase in the duration of kneading. At the same time, in comparison with the control, the stability of the dough decreases, which characterizes the duration of the dough retaining the maximum consistency level during kneading. A decrease in the content of gluten in the flour mixture does not allow the dough to retain its consistency under mechanical action during the kneading period.
And, if in studies on a valorigraph the dilution indicator fluctuates between 80-90 units, then in studies on a farinograf this indicator changes significantly, especially in comparison with the control. In general, a comprehensive assessment shows the expected decrease in the strength of the flour and,
accordingly, in the quality of finished products with an increase in the dosage of flour from the amaranth extrudate. The manifestation of this regularity in the block of studies on the farinograph, apparently, is associated with the higher baking properties of flour, taken as the basis in model mixtures. At the same time, even such results allow predicting a decrease in traditional quality by no more than 20%. This is perfectly acceptable from a consumer’s point of view for enriched bakery.

Additionally, in conditions of the Center of food technology, rheological studies of first grade wheat flour and mixtures of wheat flour and flour from amaranth extrudate were analyzed on an extensograph. In these studies, the curve of the dependence of the tensile dough on the load is used to assess the quality of flour and its reaction to the introduction of improving, in our case, fortifying additives.

The results of research are shown in tables 2-5 and in Figure 2 (where mixture a is a control sample; b - with a content of 10% flour from amaranth extrudate; c - with a content of 15% flour from an amaranth extrudate; d - with a content of 20% flour from amaranth extrudate).

**Table 2. Numerical values of the extensogram of mixture a**

| Indicator / Time, min | 45     | 90     | 135    |
|----------------------|--------|--------|--------|
| Resistance to Extension, BU | 366    | 434    | 456    |
| Maximum, BU          | 511    | 623    | 642    |
| Energy, cm²           | 117    | 130    | 138    |
| Extensibility, mm     | 167    | 158    | 163    |
| Ration number (50 mm) | 2,2    | 2,8    | 2,8    |
| Ratio number (Max.)   | 3,1    | 3,9    | 3,9    |

**Table 3. Numerical values of the extensogram of mixture b**

| Indicator / Time, min | 45     | 90     | 135    |
|----------------------|--------|--------|--------|
| Resistance to Extension, BU | 341    | 494    | 568    |
| Maximum, BU          | 461    | 643    | 706    |
| Energy, cm²           | 95     | 118    | 132    |
| Extensibility, mm     | 152    | 140    | 134    |
| Ration number (50 mm) | 2,2    | 3,5    | 4,0    |
| Ratio number (Max.)   | 3,0    | 4,6    | 5,1    |

**Table 4. Numerical values of the extensogram of mixture c**

| Indicator / Time, min | 45     | 90     | 135    |
|----------------------|--------|--------|--------|
| Resistance to Extension, BU | 324    | 440    | 589    |
| Maximum, BU          | 410    | 476    | 685    |
| Energy, cm²           | 84     | 102    | 112    |
| Extensibility, mm     | 148    | 125    | 128    |
| Ration number (50 mm) | 2,2    | 3,5    | 4,6    |
| Ratio number (Max.)   | 2,8    | 4,5    | 5,4    |

**Table 5. Numerical values of the extensogram of mixture d**

| Indicator / Time, min | 45     | 90     | 135    |
|----------------------|--------|--------|--------|
| Resistance to Extension, BU | 320    | 460    | 607    |
| Maximum, BU          | 444    | 586    | 699    |
| Energy, cm²           | 86     | 111    | 105    |
| Extensibility, mm     | 151    | 147    | 122    |
| Ration number (50 mm) | 2,1    | 3,1    | 5,0    |
| Ratio number (Max.)   | 3,0    | 4,0    | 5,7    |
The main characteristics that make it possible to evaluate the baking properties of flour by the rheological properties of the dough obtained with extensograph are the dough resistance to extension and its maximum. Energy is determined from the area of the recorded curve. Energy characterizes the work expended to stretch the dough sample. The ratio number (50 mm and Max.) is used as an additional factor to describe the properties of the dough.

Figure 2. Extensograms

As shown by the research results, with an increase in the dosage of flour from the amaranth extrudate, the stability of the dough after 45 minutes kneading decreases. However, after 90 and 135 minutes, this figure rises with an increase in the dosage of flour from the amaranth extrudate. In this regard, can be discussed two options. First, the binding of moisture by the alimentary fibers of the extrudate and their strong retention during the swelling of the latter. Secondly, the impact of the proteolytic enzymes on the gluten of the dough when stabilizing the structure of the dough with an extrudate with alimentary fiber. In this case, the energy spent on stretching the sample declines with an increase of the amaranth extrudate in the mixture. Extensibility naturally decreases as a result of a reduction in gluten content and a moisture deficit for its swelling. The ratio of resistance to extension increases, which also confirms the decrease in the strength of flour mixtures with an increase of the amaranth extrudate dosage in the mixture.

With an increase of amaranth extrudate in the proportion is possible a decrease of the bread capacity, a deterioration in the porosity structure and its decrease in general.

4. Conclusion
The dynamics of the obtained results shows the advisability of using single-phase, possibly accelerated technologies for making bread using flour from amaranth extrudate or the use of a large thick dough with minimization of the fermentation period of the dough, when kneading it, it is advisable to add an enriching ingredient.
In general, the obtained results confirm the previously established regularities for a decrease in the strength of flour mixtures with an increase in the proportion of flour from amaranth extrudate in them and the need to establish an upper boundary value that provides an enriching effect with an acceptable level of sensory characteristics of bakery.

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