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Review Article

VARIATION OF GRANULOMETRIC COMPOSITION OF DIETARY FIBERS BY MILLING THEM IN A VERTICAL MILL

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ABSTRACT

In this work, we analyzed the multiple literary sources and summarized the material regarding beet dietary fibers. Their composition, physicochemical, physicomechanical and hygrothermal properties were studied. The study of the particle-size distribution showed that the content of the insoluble fraction exceeded the content of the soluble fractions in all the samples. The use of the secondary products of processing of the plant raw material is also critical; they allow improving the preventive properties of products and enriching them with dietary fibers, protein, and mineral elements. The properties and quality of the raw material are, to the large extent, determined by and depend upon its granulometric composition, that is, upon the size of particles that compose this object. The authors determined the granulometric composition of the studied nutritional supplements. It was found out that the use of the combination of the impacts together with the abrading impact led to the intensification of the process, a decrease in the milling time and the uniformity of the obtained granulometric composition. The choice of the vertical mill as milling equipment in combination with the metal balls added to it to increase the efficiency of milling and uniformity of the granulometric composition of beetroot fibers was proved experimentally.

INTRODUCTION

Nutritional supplements and improvers made of plant raw material mainly of the local origin have become widely used in recent times. The enrichment of confectionery products with natural plant products has advantages in comparison with chemicals and mixtures used for the same purpose because in all natural products salts, vitamins and proteins have natural relations and are in the form of natural compounds. Thus, the main advantages of natural products are the complexity of their chemical composition and, consequently, the possibility of using them to enrich the flour and other components of confectionery products with proteins, mineral substances and dietary fibers.

Dietary fibers have a positive impact on the organism of a human. They help to treat and prevent obesity, diabetes and cardiovascular diseases, improve the blood circulation and prevent the formation of blood clots, increase the activity of the beneficial microflora of the intestine. They also decrease the content of cholesterol, lipids, and glucose in the blood, increase the content of globulins, hemoglobin and erythrocytes in the blood, help to ingest ferrum, possess the antibacterial and antimutagenic properties, help to bind and eliminate toxins, bile acids from the organism, help to clean the intestine, facilitate the food transit, and the renewal of the intestinal epithelium (Melnikova, *et al*., 2012).

Dietary fibers are not digested and are not absorbed in the small intestine. The main place of action for fibers is the large intestine where more soluble

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dietary fibers are fermented and less soluble fibers act as filler increasing the volume and frequency of stool (Kostina, *et al*., 2011).

The advantage of using the secondary products of processing of the plant raw material as a source of dietary fibers is that together with the enrichment with the dietary fibers, the nutritive value of the product is added with the mineral substances and vitamins. And this can be considered as a compensation for the loss of those mineral substances and vitamins that can be bound in the intestine by insoluble dietary fibers and eliminated from the organism (Bakhtin, *et al*., 2013).

An example of the preparation of fiber of the domestic manufacture is beetroot fibers. This is a secondary product of the sugar production, that is, sugar chips, milled into the granules of 2-3 mm, the distinctive feature of which is a high content of pectin, fiber and cellulose. The content of dietary fibers in this fiber is min. 70%. Beetroot fibers are recommended for the production of cooked sausage products, paste and canned products at the stage of stuffing composition in the hydrated form (1:5) in the amount of up to 10% of the mass of the raw material. In addition to the enrichment of the system with undigested fibers, their use helps to increase the water binding ability of the forcemeat, and as a result, to increase the output of the end product by 5% on the average. The dietary fibers of the sugar beet are characterized by a relatively poor digestibility in the digestive tract of a human, and this suggests the possibility of the transit of the ions of heavy metals adsorbed by them. It was revealed (Glagoleva, *et al*., 2010) that the dietary fibers of sugar beet are able to interact in the digestive tract with the incorporated heavy metals forming the insoluble salts that are eliminated from the organism. It is also known that they have a beneficial impact on the motor function of the intestine, the level of cholesterol in the blood, etc. The author (Tarasenko and Krasina, 2014) studied the functional and technological properties of unclarified beet fibers; their impact on the technological properties of fat components was revealed and estimated qualitatively, which allowed obtaining waffle products with high nutritive value.

The objective of the work is to study beet dietary fibers, their composition, physicochemical, physicomechanical and hygrothermal properties.

The objects of the research are unclarified and clarified beet fibers that are the secondary products of sugar production, manufactured from the side-product of sugar beet production – sugar beet pulp.

METHODS

At the first stage of the research, we studied the peculiarities of the chemical composition and properties of the dietary fibers. The mass share of protein was determined using the system of qualitative identification of N2/protein DKL8 of the manufacturer VELP SCIENTIFICA, Italy. The biological value of the powder of sainfoin seeds was studied by means of the experimental determination of the amino acid composition using the system of capillary electrophoresis KAPEL-105M of the manufacturer Lumex, Russia (Tarasenko, *et al*., 2015).

The granulometric composition and solubility of the dietary fibers in the water were determined by the sedimentation method at the temperature of 25°C, based upon the measurement of the mass of the residue of the product precipitated from the suspension for the particular periods of time (*GOST 19283.93, 1993)*.

The active acidity of the dietary fibers was determined in their solution of 10% concentration using the pH-meter I-130 (Lurie, 1978).

The estimation of the results of the experiments was conducted using the modern methods for calculating the statistical significance using the programs Statistica 6.0, Microsoft Office Excel 2007 and Mathcad.

All studies were conducted using the equipment of the CUC Research Centre of Nutritive and Chemical Technologies, and the Federal State-Funded Educational Institution of Higher Education Kuban State Technological University.

RESULTS

When modifying the baked confectionary products into the functional product, the efficient method is its enrichment by physiologically functional ingredients. Therefore, unclarified and clarified beet dietary fibers were chosen as an object of the enricher to save the specific taste of the confectionery and add functional properties to them.

To ground their applications in the technology of the confectionary products, the organoleptic estimation was conducted and the physical and chemical values of these dietary fibers were studied. The results of the research of the organoleptic values of the quality of dietary fibers are shown in Table 1.

As Table 1 shows, the organoleptic estimation of dietary fibers revealed that beet fibers have a clear, neutral taste, without foreign odors; consequently, they can keep and intensify the taste and odor of

Table 1. Organoleptic estimation of dietary fibers

Criteria	Name of dietary fibers	
	Unclarified beet fibers	Clarified beet fibers
Appearance	powder	powder
Color	beige	light beige
Taste	neutral	slightly acid
Odor	absent	absent

Table 2. Physical and chemical criteria of quality of dietary fibers

Criteria	Name of dietary fibers	
	Unclarified beet fibers	Clarified beet fibers
Humidity, %	10	10
Active acidity	6.5	4.4
Bulk density, g/L	85 ± 12.5	85 ± 12.5
Fineness of grinding, micron	90% < 35 micron	90% < 35 micron
Water activity	0.4	0.5
Whiteness, unit of device	80	83

other compound components and additive added enlarging the gustatory sensations of the product by this. The clarified beet fibers have a slightly acid taste and this can to a greater or lesser extent impact the taste properties of the finished products.

Table 2 shows the data of the physical and chemical criteria of the quality of all studied samples.

From the data shown in Table 2, we can conclude that all samples are different from each other by the sizes of particles and this is determined by the bulk density of the product and also the degree of whiteness.

As dietary fibers consist of the cell walls of the raw material from which they are obtained, they have a different composition as they contain the complex of insoluble and soluble fractions. The study of the particle-size distribution showed Table 3 that in all samples the content of insoluble fractions exceeds the content of soluble fractions.

The cellulose contained in beet fibers (25%) intensifies the intestinal motility, improves its motor and evacuation activity, helps to normalize the cholesterol metabolism, improves the microflora of the gastrointestinal tract, restores the hepatic function, cleans the large gut from slags.

Concerning the pectin-cellulose complex insoluble in normal conditions, it is decomposed under the impact of gastric enzymes into pectin and cellulose, and pectin adsorbs, holds and eliminates heavy and toxic elements and radionuclides from the organism, decreases the level of sugar in the blood of diabetic patients, helps to eliminate the putrefactive microflora of the intestine. And its concentration in unclarified beet fibers is 2 times higher than in clarified fibers.

The studied dietary fibers are obtained using various technologies and due to this their chemical composition can be significantly different. The results of the research of the chemical composition of the studied dietary fibers are shown in Table 4.

The analysis of the results of Tables 1-4 revealed that organoleptic and physical and chemical values of the dietary fibers allowed using them as ingredients for the production of confectionery products.

As they are prepared by mixing of the raw material, the degree of their dispersion will depend to a great extent upon the uniformity of the used raw material. The property and quality of the raw material is mainly determined by and depends upon its granulometric composition, that is, the size of particles than compose this object. Therefore, the determination of the granulometric composition of the studied dietary fibers was of practical interest.

As the dispersion of the main raw material of the baked confectionery products influences

Table 3. Particle size distribution of dietary fibers

Criteria	Name of dietary fibers	
	Unclarified beet fibers	Clarified beet fibers
Content of dietary fibers, %	79	75
Their fractions		
insoluble	73.4	69.1
soluble	5.6	5.9
Weight fraction, %		
Cellulose	21	20
Hemicellulose	30	27
Pectin	22	20
Lignin	7	7

Table 4. Chemical composition of the dietary fibers

Criteria	Name of dietary fibers	
	Unclarified beet fibers	Unclarified beet fibers
Weight fraction, %		
Moisture	10	10
Proteins	10	7
Carbohydrates, Incl.	75	78
Dietary fibers	71.8	68.2
Mineral substances	5	5

significantly the process of dough formation and the structural and mechanical properties of the dough, we considered it reasonable to determine the granulometric composition of the studied dietary supplements.

Nowadays, the following machines for fine milling are widely used in the processing methods of the raw material preparation: cyclone mill, centrifugal mill, four-way impact mill, etc.

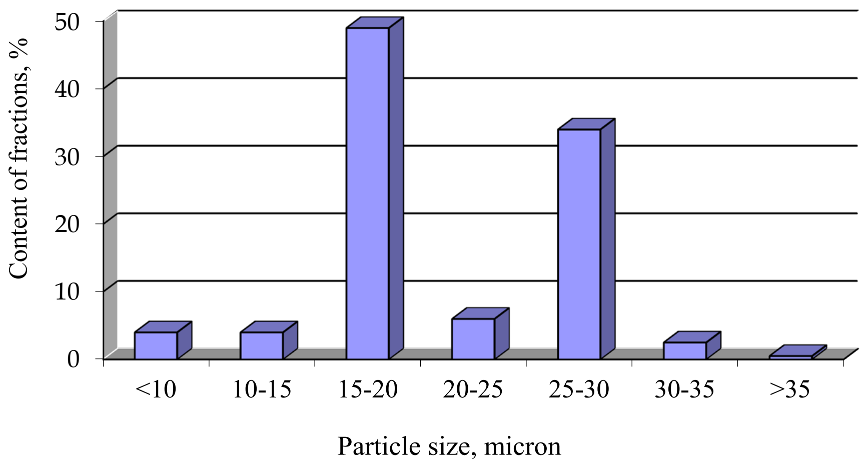
The results of the determination of the granulometric composition obtained for the functional additives milled in the cyclone mill are shown in (Fig. 1).

The unclarified beet fibers (Fig. 1a) are rather uniform in comparison with the clarified beet fibers; 83% are the particles of two fractions with a size of 15…20 microns and 25…30 microns; the fraction of <10 microns is only 4% and the large fraction more than 35 microns is insignificant – 0.5%.

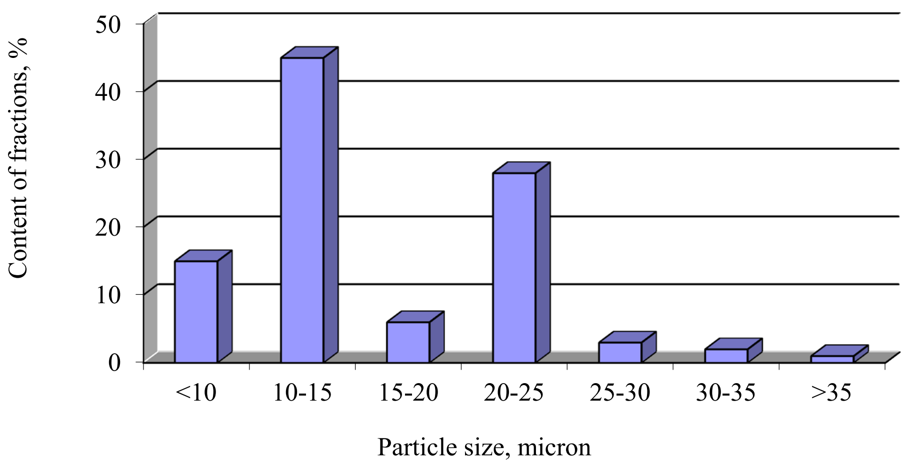
Clarified beet fibers (Fig. 1b) have a rather high degree of milling, the heaviest is the fraction of 10…15 microns. The particles of 20…25 microns are also present and they are about 28% of the total amount of particles.

The research performed allowed concluding on the diversity of the granulometric composition of the functional additives and this will certainly influence their ability to absorb and lock in moisture and fat.

It was revealed (Fig. 1) that fibers had a significant dispersion and finally it had a negative impact on the quality of the end products as their structural and mechanical values decrease, in particular, the porosity, specific weight, working head, etc. It can be presupposed that such criterion as low dispersion positively influences the values of the end products as there are no significant differences between the flour, raw material subjected to the partial substitution and the studied additive during the



a



b

Fig. 1 Histogram of the granulometric composition of the dietary fibers: a – Unclarified beet fibers; b – Clarified beet fibers.

batch and baking. The significant content of dietary fibers in the studied raw material can result in the significant change of colloid, physical and chemical processes during the batch and baking of the cooked confectionery products.

Thus, it is necessary to obtain and control the uniformity of the granulometric composition of functional additives. Nowadays, it is difficult to find a modern direction of the development of science and technology not connected to the processes of milling and grinding. Every branch has its own process methods based upon the use of physical and chemical phenomena, providing the required properties that are peculiar for its products. Nowadays, there are a lot of works in different branches – agriculture, food industry, machine building, medicine, etc. that are dedicated to the obtaining of various materials with the uniform distribution of the particles according to the size, volume, crystalline state and properties, on the base of the theoretical study of the solid matter, influence of the local temperature, pressure, friction, and impact of the milled material during its contact with the parts of equipment.

On the base of the theoretical study of the energy processes occurring during milling, the work of surface deformation and the destruction of particles depend upon the sizes of particles and are proportional to the square of surface. Basing upon this, the dependence is known determining the energy consumption under the conditions of the volumetric fracture behaviour (obtaining of new surfaces) of particles (Paladeeva, & Tabarin 2004; Oshkordin, Lavrova, & Usov 2010):

$$de = \frac{9\alpha_2}{\alpha_1} l \frac{dS}{S} + \left(\frac{3\alpha\beta l - \gamma}{\alpha_1} + \sigma\right) ds - \frac{\alpha_2 \beta l^2}{4\alpha_2} SdS,$$

where e is energy for the execution of work of the particular elastic deformation, $e = p^2 / 2E$

α_1 is a coefficient of the square of a particle;

α_2 is a coefficient of the volume of a particle;

1 is a thickness of the layer where plastic deformation occurs, 1=100°A;

S is a specific surface of the milled material;

β is the density of energy of plastic deformations preceding the brittle fracture, $\beta = \frac{\tau^2}{2E}$;

γ is the surface density of work or friction and energy of formation and destruction of particles,; $\gamma = f(f_\tau)$;

σ is a free energy of the surface unit.

In this equation of milling dependence, the first part determines the energy consumption for the volumetric deformation of the solid body according to the Kirpichev-Kick law, the second part is the energy consumption for nonelastic deformation, work or friction and formation of new surfaces, the third part takes into account the change of volume of the area of plastic deformations when changing the size of the milled particles.

To obtain the uniform granulometric composition, the laboratory vertical mill was used (Fig. 2).

To increase the speed and intensity of milling and also to obtain the uniformity of the granulometric composition, the metal hard-alloy balls were added to the vertical mill together with the functional additives (Pavlygo, *et al.*, 2008). As a result, we obtained not only abrasive effect on the particles of the functional additives but also various combinations of the impact action – in the process of rotation of the vertical mill there is an impact on the border: "agitator of mill – functional additive – metal ball", "wall of working chamber – functional additive – metal ball", "metal ball – functional additive – metal ball" (Fig. 3).

The use of the combinations of impact actions together

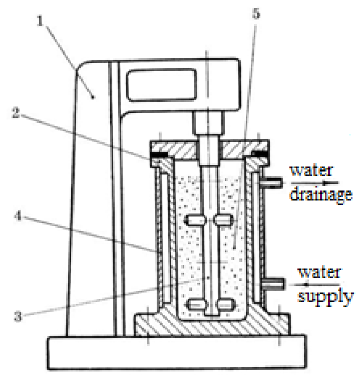


Fig. 2 Diagram of the vertical mill: 1 – Base, 2 – Working chamber; 3 – Agitator with cross rods, 4 – Cavity of water cooling, 5 – Functional additives.

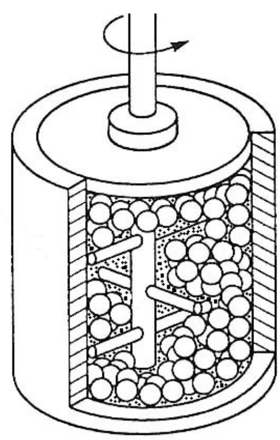


Fig. 3 Diagram of vertical mill with metal walls and functional additives.

with the abrasive effect led to the intensification of the process, a decrease of the milling time and the uniformity of the obtained granulometric composition (Fig. 4).

The main functional and technological properties of food products are water and fat binding, moisture retaining capacity and swelling property.

Basing upon the above said, these functional and technological properties of the studied dietary fibers were studied.

Swelling is not always resulted in the solution and as the first stage of the solution process it is typical for many high-molecular compounds. The reason of swelling is the diffusion of water molecules into the high-molecular substance.

To estimate the degree of swelling of the studied dietary fibers, the value of the water retaining capacity was used that shows the maximal volume of water that the object can absorb and retain till it reaches the dynamic balance.

The results of the research of the technological properties are shown in Table 5.

The data shown in Table 5 reveal clarified beet fibers have the lowest water retaining capacity 550 against 650 for the unclarified fibers and most probably it is connected to the higher concentration of the soluble pectin in the clarified beet fibers because the soluble pectin becomes the liquid fraction decreasing the volume of the hydrated mass.

It is known that the size of particles depends directly upon their specific surface. That is, the smaller the particles in the sample, the bigger the surface of contact with water, and the faster the moisture is absorbed.

Thus, on the base of the obtained data, we can conclude about the functional and technological properties and reasonability of application of unclarified beet fibers as the functional ingredients.

DISCUSSION

The provided data show that the studied dietary fibers correspond to all safety requirements imposed on the additives and products of the plant origin and there are no obstacles for using them in the production of food products.

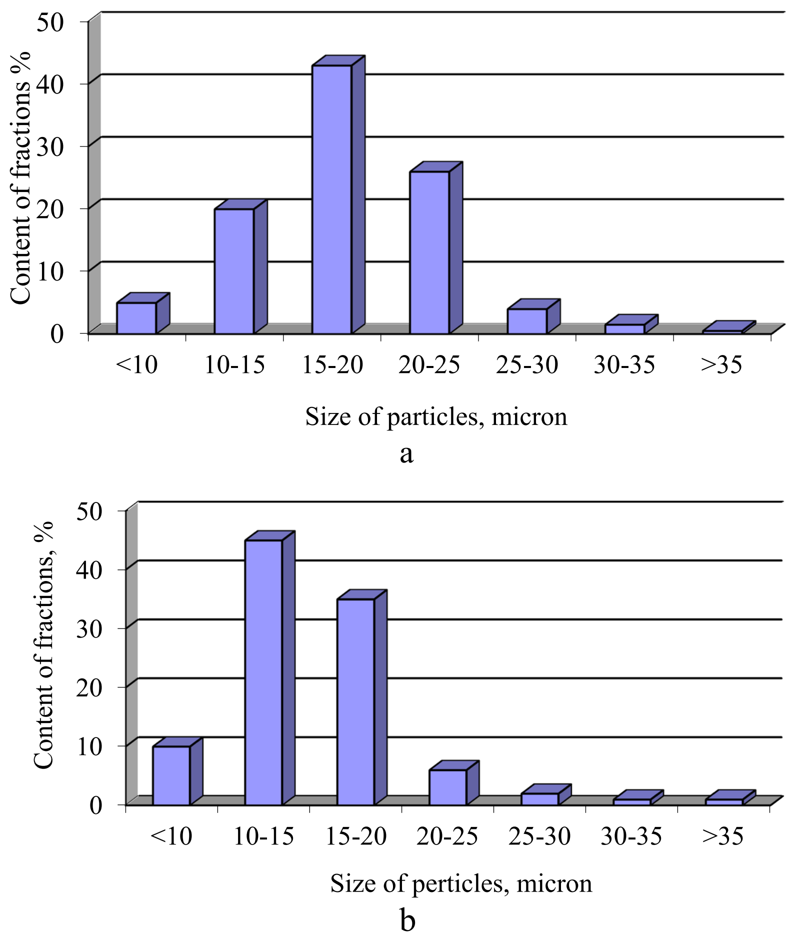


Fig. 4 Histogram of granulometric composition of dietary fibers after milling in the vertical mill with metal balls: a – Unclarified beet fibers; b – Clarified beet fibers.

Table 5. Technological properties of dietary fibers

Criteria	Name of dietary fibers	
	Unclarified beet fibers	**Unclarified beet fibers**
Moisture binding capacity, g/kg	600	640
Water retaining capacity, %	650	650
Fat retaining capacity, %	130	150

The comparative analysis of dietary fibers allows concluding about the reasonability of use of unclarified beet fibers in the production of the confectionary products of functional application that are a rich source of protein and pectin-cellulose complex.

The comparative analysis of the methods and means of milling of beet fibers allows concluding about the reasonability of using highly efficient milling equipment that can combine the multiple combinations of impact and abrasive actions.

CONCLUSION

The performed complex of research of the functional and technological properties of additives allowed determining the main directions of their application when forming the food systems of functional application with the advance set final properties and structure.

The possibility and reasonability of using unclarified beet fibers as a functional ingredient for regulation of the technological properties of products was theoretically and experimentally proved.

It was revealed that unclarified beet fibers had a high concentration of ballast substances (79%) that contained a significant amount of hemicellulose (38%) and pectin (27.8%) that allowed using them as a functional ingredient.

The choice of the vertical mill as milling equipment in combination with the metal balls added for the improvement of the efficiency of milling and the uniformity of the granulometric composition of beet fibers was experimentally proved.

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