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THE USE OF CORN AND TAPIOCA STARCH IN THE PRODUCTION OF LOW-PROTEIN COOKIES FOR PATIENTS WITH PHENYLKETONURIA

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ABSTRACT

The article describes the effect of the use of corn, tapioca starches, xanthan gum and maltodextrin on sensory and physical-chemical properties of low protein dough and cookies. The problem of nutrition and phenylalanine metabolism for people with phenylketonuria is reported. The phenylalanine content in raw materials which can be used in cookies production is given. Three recipe composition of low protein cookies with corn, tapioca starches, maltodextrin and xanthan gum were investigated. Designed cookies made without flour, eggs, and milk products, so the phenylalanine content is close to 0. The main ingredients are starches, butter, sugar, structuring agents. Recipes were created in such a way that by combining different types of starch with hydrocolloids, it was possible to simulate the properties of gluten and recreate the structural and mechanical properties of traditional dough for wheat cookies for mass consumption. Dough preparation process is given. Low protein cookies and cookies from wheat flour were studied and compared. Taste and quality indicators of investigated cookies were similar to cookies from wheat flour. Sensory assessment of cookies (taste, scent, color, shape, surface condition, view in the rift, consistence) made by testers showed that cookies made from blend of corn and tapioca starches (in proportion 80 and 20% respectively), maltodextrin and xanthan gum had the higher rating. Sample from corn starch and maltodextrin had the highest moisture content while sample from corn and tapioca starches and maltodextrin had the lowest moisture content. Samples made from corn starch had comparatively the same water absorption capacity. The use of tapioca starch in the production of low-protein cookies can significantly increase water absorption capacity, while use of maltodextrin can decrease it. Hardness of all investigated low protein cookies is higher than hardness of traditional cookies. Cookies made with maltodextrin had the highest hardness, while addition of 20% of tapioca starch showed no influence on hardness.

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ВИКОРИСТАННЯ КУКУРУДЗЯНОГО ТА ТАПІОКОВОГО КРОХМАЛЮ У ВИРОБНИЦТВІ НИЗЬКОБІЛКОВОГО ПЕЧИВА ДЛЯ ХВОРИХ НА ФЕНІЛКЕТОНУРІЮ

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У статті описано вплив використання кукурудзяного крохмалю, крохмалю тапіоки, ксантанової камеді та мальтодекстрину на органолептичні та фізико-хімічні властивості низькобілкового тіста і печива. Описано проблему харчування та метаболізму фенілаланіну у хворих на фенілкетонурію. Наведено вміст фенілаланіну в сировині, яку можна використовувати у виробництві печива. Досліджено три рецептурні композиції низькобілкового печива з кукурудзяним, тапіоковим крохмалем, мальтодекстрином і ксантановою камеддю. Розроблене печиво виготовляється без борошна, яєць і молочних продуктів, тому вміст фенілаланіну близький до 0. Основні інгредієнти — крохмаль, вершкове масло, цукор і структуроутворювачі. Рецептури створювалися таким чином, щоб шляхом поєднання різних видів крохмалю з гідроколоїдами можна було змоделювати властивості клейковини та відтворити структурно-механічні властивості традиційного тіста для здобного печива. Наведено процес приготування тіста. Вивчено та порівняно печиво з низьким вмістом білка та здобне печиво з пшеничного борошна. Смакові властивості та показники якості показники досліджуваного печива були подібними до відповідних показників здобного печива з пшеничного борошна. Органолептична оцінка печива (смак, запах, колір, форма, стан поверхні, вид у розриві, консистенція), показала, що печиво, виготовлене із суміші крохмалів кукурудзи та тапіоки (у співвідношенні 80 та 20% відповідно), мальтодекстрину та камеді ксантану. мало вищий бал. Печиво, виготовлене із кукурудзяного крохмалю та мальтодекстрину, мало найвищий вміст вологи, тоді як зразок, виготовлений із суміші кукурудзяного і тапіокового крохмалю та мальтодекстрину мав найнижчий вміст вологи. Зразки, виготовлені з кукурудзяного крохмалю, мали порівняно однакову намочуваність. Використання крохмалю тапіоки у виробництві печива з низьким вмістом білка може значно збільшити намочуваність, тоді як використання мальтодекстрину може її зменшити. Міцність усього дослідженого низькобілкового печива вища за міцність здобного печива, виготовленого з пшеничного борошна. Печиво, виготовлене з додаванням мальтодекстрину, мало найвищу міцність, тоді як додавання 20% крохмалю тапіоки не вплинуло на цей показник.

Ключові слова: *фенілкетонурія, фенілаланін, низькобілкове печиво, ксантанова камедь, мальтодекстрин.*

Problem definition and its relationship with important practical tasks. One of the most important human values is health. Nowadays humanity faces a large number of diseases which are not eligible for effective medical and pharmacological treatment. Among them, inherited diseases associated with genetic mutations take place. Such diseases include phenylketonuria. The only known effective method to treat patients with phenylketonuria (PKU) is lifelong diet treatment (Al Hafid et al., 2015).

People with PKU can't consume amino acid phenylalanine, which is a part of almost all proteins. Diet for people with PKU includes consumption of low protein food and medical supplements with all essential amino acids excluding phenylalanine (Burgard et al., 2017). Almost all flour confectionery which are produced in the world have high phenylalanine content. Due to this people with PKU can't consume such products, and that is why it is important to investigate low protein flour confectionery and study influence of different raw materials on sensory, physico-chemical properties of low protein dough and cookies

Analysis of recent research and publications. Phenylketonuria is an autosomal recessive genetic disease caused by mutation in a gene responsible for phenylalanine metabolism. Phenylalanine is an essential amino acid which is obtained by organism with food. As a result of the absence of phenylalanine-4-hydroxylase, phenylalanine undergoes pathological transformation, which leads to an increase in blood level of phenylalanine and products of improper amino acid metabolism. They adversely affect lipid metabolism in the brain, which provokes mental retardation (Al Hafid et al., 2015). Chemical pathways involved in phenylketonuria are shown on Figure 1. Due to the lack of tyrosine, the synthesis of neurotransmitters which regulate the nervous system is disrupted (Hagedorn et al., 2013; Ford et al., 2018). Increased blood phenylalanine and its metabolic products leads to damage of the central nervous system, manifested by mental disorders and nervous deficits (Wahlsten et al., 2019; Burgard et al., 2017).

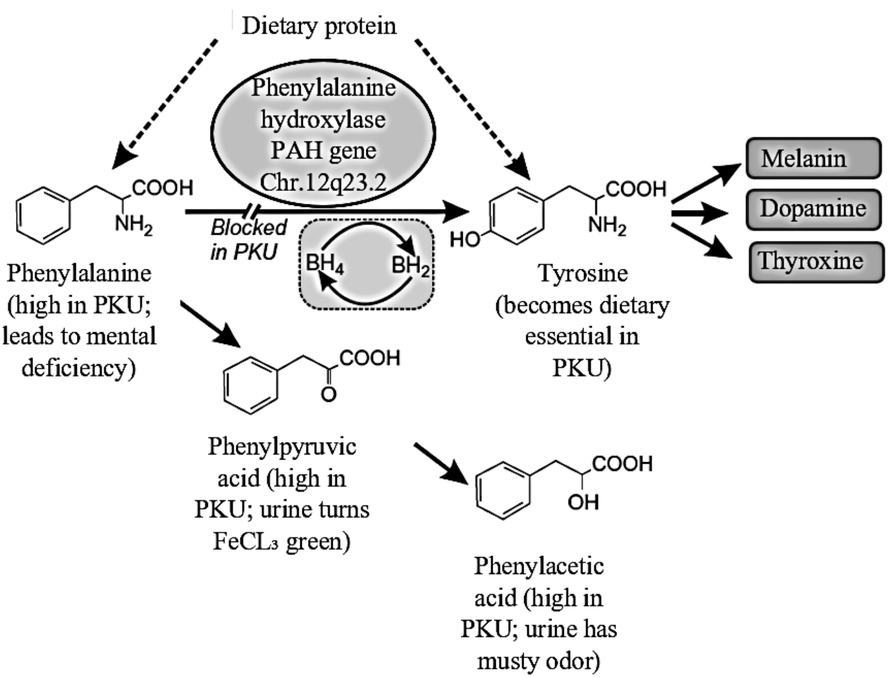

Fig. 1. Chemical pathways involved in PKU

A complete therapeutic diet for patients with PKU is formed of two components — a vegetarian menu using low-protein foods and daily intake of the medicinal product in the form of a mixture of amino acids or protein hydrolysates. Medical products are made with low or no phenylalanine, and the addition of vitamins and trace elements complexes to replace natural food protein (Firman et al., 2020).

Amount of protein obtained using natural products in the diet is calculated based on the allowable daily amount of phenylalanine for patients of different age. At the same time, it makes up to 20—22% of the age physiological norm in the diet. The normal amount of protein is supplemented by the medical products. (Firman et al., 2020; Kose et al., 2019; Krämer, et al., 2015).

Phenylketonuria is prevalent in Europe and the US. The incidence of this condition is approximately 1 per 10000 newborns. It is relatively common in some parts of China but is rare in Africa. The highest incidence is observed in Turkey where the incidence is up to 1 per 2600 newborns (Cleary et al., 2019). Globally 0.45 million individuals have PKU, with global prevalence 1 per 23930 live births (Hillert et al., 2020).

Nowadays the range of low-protein products around the world is quite small, in some countries there is no production of this category of food. Therefore, the development and production of low-protein foods is an urgent task.

The purpose of the research was to study influence of use corn, tapioca starches, xanthan gum and maltodextrin on sensory and physico-chemical properties of low protein dough and cookies.

Materials and methods. The following raw materials were used:

- Corn starch (produced by Dr. Oetker, Germany)
- Tapioca starch (produced by Edward & Sons, Let's Do Organic, USA)
- Maltodextrin (bought from "Pekar-Konditer", Ukraine)
- Sugar (produced by S-Trans, Ukraine)
- Butter sweet 72,5% (produced by Loostdorf, Ukraine)
- Xanthan gum (produced by Creamo, Ukraine)
- Baking soda (produced by Dr. Oetker, Germany)
- Vanillin (bought from "Pekar-Konditer", Ukraine)

Dough preparation. The process of dough preparation consisted of two phases: emulsion preparation and dough preparation. To prepare the emulsion, butter, sugar and water were beaten for 7 minutes using mixer. Starch, maltodextrin, xanthan gum, baking soda and vanillin were mixed in a separate container. After that, the free-flowing components were added to the emulsion and mixed until homogeneous condition.

Heat treatment of low protein cookies. Heat treatment of the dough (baking) was carried out in an oven at a temperature of 200°C for 10 minutes.

Moisture content in the dough. Determination of the mass fraction of moisture was carried out by the express method on the Chizhova's device. The principle is based on drying the material at a temperature of 160°C for 5 minutes.

For rapid removal of moisture drying in infrared rays are used, which are perceived not only by the surface, but also penetrate into the product to a depth from 2 to 3 mm, which causes its intense heating. The sources of infrared rays were heated metal surfaces, which give radiation in the wavelength range of 0.76…343 nm. Chizhova's device works on this principle. It consists of two massive round metal plates (an alloy of aluminum and cast iron), between which a thin layer of the analyzed material is placed. The plates are hinged together and heated by electrical elements placed on the outside of the appliance, which ensures rapid dehydration of the product. During operation, the distance between the plates is 2 mm, the temperature is controlled by two thermometers. The heating of the plates can be strong or weak. Strong heating is used in the case of initial heating, and weak — to maintain the desired temperature (to switch the heating mode there is a special switch). The contact thermometer provides constancy of the set temperature within ±1°C (Дорохович та ін., 2015).

Sensory analysis of low protein cookies. The Delphi expert survey method was used to determine the sensory parameters (Brady, 2015; Okoli and Pawlowski, 2004).

Moisture content in low protein cookies. Determination of moisture content in low protein cookies was carried out using drying chamber at a temperature of 130°C for 30 minutes (Дорохович та ін., 2015).

Water absorption capacity of low protein cookies. Determination of water absorption capacity was carried out by immersion of cookies in water at a temperature of 20 for 3 minutes and characterized by the ratio of the mass of products after wetting to the mass of dry products (in mass percentages) (Дорохович та ін., 2015).

Alkalinity of low protein cookies. Alkalinity of low protein cookies was determined by titration of the product filtrate with 0.1 N sulfuric or hydrochloric acid solution with Bromothymol blue indicator. The alkalinity index shows the content of alkali in the product, expressed in degrees or percentages. Degrees of alkalinity is the amount of ml of 1 N acid solution which goes to neutralize the alkali contained in 100 g of product. (Дорохович та ін., 2015).

Hardness of low protein cookies. The hardness of cookies is determined by the load that can withstand cookie until it breaks. The essence of the procedure is to create constant and increasing pressure on the center of the product, which is fixed between two supports. The display records the data on the current load on the product. When the instance is broken, the device will remember the peak load and save it until the next check. The arithmetic mean of the cookie strength was calculated from 5 parallel tests (Дорохович та ін., 2015).

Results and discussion. *Rationale for the choice of raw materials.* Traditional flour confectionery are often made from raw materials which contain large amount of protein and the amino acid phenylalanine (table 1). The information regarding protein and phenylalanine content were taken from Food data (frida.fooddata.dk), version 4, 2019, National Food Institute, Technical University of Denmark.

Table 1. **The content of protein and phenylalanine in the raw materials used for the production of traditional cookies**

Product name	Protein content, g per 100 g of product	Phenylalanine content, mg per 100 g of product
1	2	3
Wheat flour	9.7	538
Rice flour	7.3	393
Chicken eggs	10.2	667
Chicken eggs, dried	82.3	5140
Milk whole 3.5%	3.4	172
Dried milk	23.9	1200
Coconut meat, desiccated	6.5	295
Hazelnut, dried	13.2	667
Almond, raw	21.2	1210

Continuation of Table 1

1	2	3
Rice starch	0.8	43
Cocoa, powder	17.1	756
White sugar	0	0
Brown sugar	0	0
Butter, salt added	0.7	34
Margarine, (more than 50% fat), average	0	0

Proteins, in particular gluten, play an important role in dough formation. It forms a gluten-free skeleton, which gives the dough viscoelastic properties and keeps air bubbles in the dough. The functionality of gluten should be simulated through the use of other raw components, such as gum (guar, xanthan, carob) carboxymethylcellulose, pectin, carrageenan, polydextrose, various types of highly purified starches (wheat, corn, tapioca, potato and potato) (Mohsen et al., 2010; Scortegagna et al., 2019; Yaseen et al. 2011).

Low protein cookies preparation. Using low-protein raw materials, three recipes for low-protein cookies were investigated. They could be consumed by people with phenylketonuria.

Sample 1 — made from corn starch, maltodextrin and xanthan gum;

Sample 2 — made from blend of corn and tapioca starches (in proportion 80 and 20% respectively), maltodextrin and xanthan gum;

Sample 3 — made from corn starch and xanthan gum.

The formation of the dough consists of mixing water and raw materials to a homogeneous mass with specific physical properties.

The dough is formed due to complex physico-chemical, colloidal, biochemical processes which occur under the action of water and enzymes during mixing of the dough components. As a result of physicochemical processes, the components are mixed, wetted, and then the dough mass is plasticized (Дорохович та ін., 2015).

Swellable biopolymers: starch, pentosans, as well as shell particles are involved into colloidal processes in the process of formation low protein dough.

Thus, water plays a key role in dough formation. The amount of water required for kneading the dough is determined experimentally.

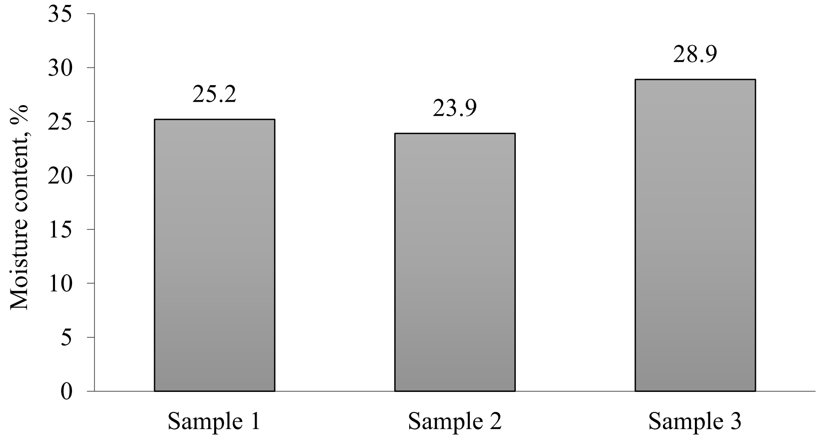

Fig. 2. Moisture content in the dough of low protein cookies

Dough from corn starch and xanthan gum had the highest moisture content while dough with addition of tapioca starch and maltodextrin had lower moisture content. This can be justified by the fact that corn starch absorbs more water.

Sensory analysis of low protein cookies. Baked low protein cookies were given to the experts who didn't follow low protein diet for evaluation.

Cookies made from blend of corn and tapioca starches (in proportion 80 and 20% respectively), maltodextrin and xanthan gum (sample 2) had the higher rating of all samples, while cookies made with corn starch and xanthan gum had the lowest (Table 2). All samples of low-protein cookies had light color due to the low protein content, and as a result there was almost no Maillard reaction. The Maillard reaction is a chemical reaction between amino acids and reducing sugars which typically proceeds rapidly from around 140 to 165°C that gives browned food its distinctive flavor (Nursten, 2005).

Table 2. **Sensory analysis of low protein cookies**

Quality indicator	Sensory analysis of low protein cookies		
	Sample 1	Sample 2	Sample 3
Taste	Starch is a little sensible in the mouth, no aftertaste	Starch is almost imperceptible in the mouth, aftertaste is absent	Starch is sensible in the mouth, no aftertaste
Scent	Sweet cream, barely noticeable		
Color	White with a yellowish tinge, uniform		
Shape	Correct, the edges are smooth		
Surface condition	Not burnt, smooth	Not burned, there is a small number of cracks	Not burnt, smooth
View in the rift	Baked, uniform porosity, with small cavities and traces of impermeability	Baked, uniform porosity, without cavities and traces of impermeability	Baked, uneven porosity, no cavities and traces of impurities
Consistence	Hard	Hard, brittle	Hard
Overall rating:	**4.2**	**4.5**	**4.0**

Physico-chemical parameters of low protein cookies. Water is an important component of food. It is contained in products as a cellular and extracellular component, as a dispersing medium and solvent, which determines the consistency and structure of food, affects appearance, taste and stability of products during storage. The amount of moisture in the product determines its energy value, because the more water it contains, the less useful dry matter (proteins, fats, carbohydrates, etc.) per unit mass (Дорохович та ін., 2015). The stability of the product during storage and its transportability are closely related to the water content, as excess moisture promotes enzymatic and chemical reactions, increase the activity of microorganisms, including those which cause spoilage of the product, including mold. Therefore, the moisture content of the product determines the storage conditions and shelf life (Дорохович та ін., 2015).

Cookies made from blend of corn and tapioca starch had the lowest moisture content (4.7%), while coolies made from corn starch and maltodextrin had the highest moisture content (8.0%) (Figure 3). All studied samples had acceptable moisture content in comparison with traditional cookies made from wheat flour and was within the limits established by normative and technical legislation.

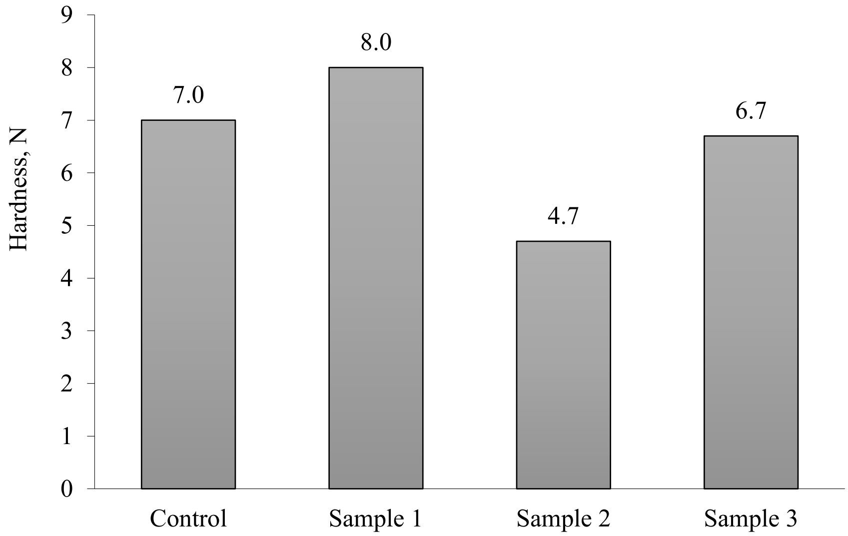

Fig. 3. Moisture content of low protein cookies and traditional cookies from wheat flour

Water absorption capacity is an indirect indicator of the porosity of cookies, which is determined by the increase in the mass of flour confectionery when immersed in water with a temperature of 20°C for a set time. Water absorption capacity depends on chemical composition and structure of the products (Дорохович та ін., 2015).

Cookies made from corn starch had comparatively the same water absorption capacity as cookies made from wheat flour. Obtained data shows that the use of tapioca starch in the production of low-protein cookies can significantly increase this indicator, while use of maltodextrine can decrease it.

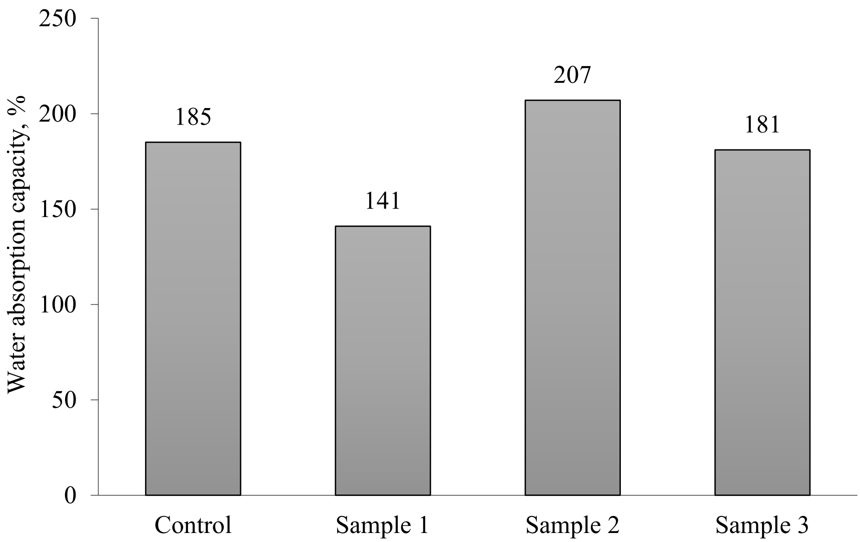

Fig. 4. Water absorption of low protein cookies and traditional cookies with wheat flour

Alkaline-reacting substances are added to cookies in the form of baking soda. A high degree of alkalinity of baked products may indicate that not all of the baking soda has degraded during the heat treatment. Alkalinity of all samples was 0.6 degrees, and it indicates that almost all baking soda in the product underwent thermal degradation during baking.

Hardness of confectionery depends on the chemical composition, interactions between the main biopolymers and the structure of the products. The high hardness reduces the consumer properties of cookies, such products are difficult to bite. At the same time, products with low strength are easy to crumble (Дорохович та ін., 2015).

Hardness of low protein cookies was higher than hardness of traditional cookies. At the same time, using maltodextrin in low protein cookies increased hardness, while there was no significant difference in hardness of cookies made from corn starch and cookies made from blend of corn and tapioca starches.

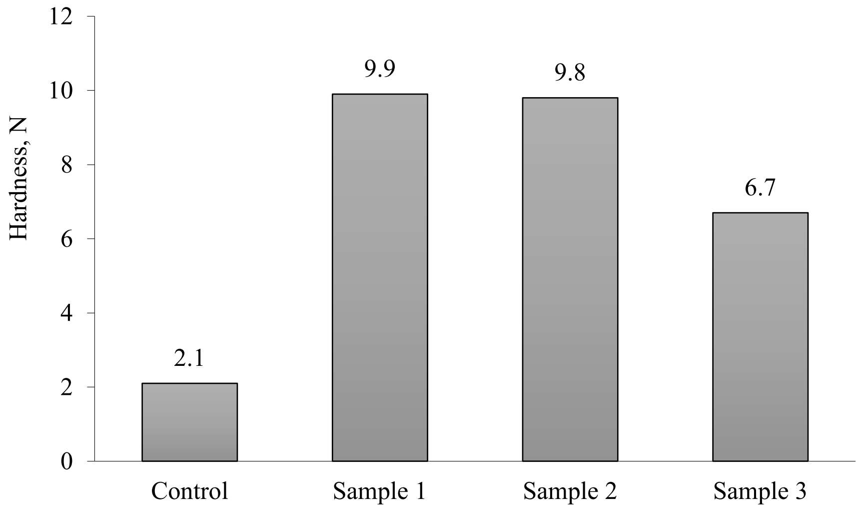

Fig. 5. Hardness of low protein cookies and traditional cookies from wheat flour

Conclusions

Gluten-free corn and tapioca starches are suitable, phenylalanine-free components for production of low protein cookies. Investigated low protein cookies recipe composition was made from corn and tapioca starches, xanthan gum and maltodextrin without flour, eggs and milk products, so the phenilalanin content is close to zero. Taste and quality indicators of investigated cookies were similar to traditional cookies from wheat flour. Cookies made from blend of corn and tapioca starches (in proportion 80 and 20% respectively), maltodextrin and xanthan gum had higher rating by sensory characteristics. Sample from corn starch and maltodextrin had the highest moisture content (8,0%) while sample from corn and tapioca starches and maltodextrin had the lowest moisture content (4,7%). Samples made from corn starch had comparatively the same water absorption capacity. The use of tapioca starch in the production of low-protein cookies can significantly increase this indicator, while use of maltodextrin can decrease it. Hardness of low protein cookies is higher than hardness of traditional cookies by 4.6—7.8 N.

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