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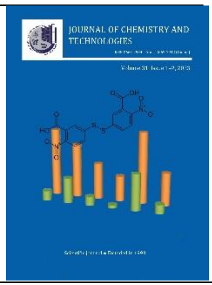

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INNOVATIVE TECHNOLOGY OF BISCUIT PRODUCTION BASED ON THE USE OF SECONDARY PRODUCTS OF SOYBEAN PROCESSING

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Abstract

There is a growing interest in nutrient-rich residues from the food industry, which can be used as alternative food ingredients. Okara is a nutrient-rich by-product of soy milk and tofu production. So far okara residues are already used as animal feed, but often they are openly burned or sent to landfills, which is environmentally hazardous. Including okara in the human diet is a promising valorization pathway. Flour confectionery products, particularly sugar cookies, could use okara flour as a substitute for conventional flour to increase its nutritional value. This study investigated the impacts of mixing okara flour into wheat sugar cookie dough on the contents and quality of gluten, the rheological properties of dough and the organoleptic quality and nutritional value of the sugar cookies. Okara flour was introduced into the dough in 10%weight by weight, 20 % w/w and 30 % w/w, replacing its equivalent amount of wheat flour. This reduced the raw gluten contents of the flour mixtures and, therefore, the elasticity and hydration capacity of the dough. With the addition of 20 % w/w of okara flour, the structural strength of the dough mass increased by 23 % and reduced the adhesive strength by 32%, making it less sticky and easier to form. The assessment of organoleptic quality indicators showed that the experimental sugar cookies with 10 % w/w and 20 % w/w okara flour surpassed the control wheat sugar cookies in taste, color, and appearance. Higher mass fractions of okara flour (30 % w/w) did not meet anymore organoleptic quality standards. It was found that compared with the control cookies the protein content in the 20 % w/w experimental sugar cookies was +30 %, dietary fiber 100 times, potassium +83.5 %, phosphorus +64 %, iron +57%, magnesium +20% and calcium 4.4 times. The 20 % w/w experimental sugar cookies also showed favourable isoleucine, leucine, tryptophan and phenylalanine+tyrosine contents. Overall, substituting wheat flour by okara flour in sugar cookies can improve the dough rheology and the nutritional value of the sugar cookies substantially. These results may help to further enhance and diversify confectionery products with okara flour and add to valorization pathways for food industry residues.

Keywords: okara; flour confectionery; sugar biscuits; rheological properties of dough; nutritional value; amino acid composition; dietary fiber.

ІННОВАЦІЙНА ТЕХНОЛОГІЯ ВИРОБНИЦТВА ПЕЧИВА НА ОСНОВІ ВИКОРИСТАННЯ ВТОРИННИХ ПРОДУКТІВ ПЕРЕРОБКИ СОЇ

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Анотація

Зростає інтерес до багатих на поживні речовини відходів харчової промисловості, які можна використовувати як альтернативні харчові інгредієнти. Окара – це багатий на поживні речовини побічний продукт виробництва соєвого молока та тофу. На сьогоднішній день залишки окари вже використовуються як корм для тварин, але часто їх відкрито спалюють або відправляють на звалища, що є екологічно небезпечним. Включення окари в раціон харчування людини є перспективним шляхом валоризації. Борошняні кондитерські вироби, зокрема цукрове печиво, можуть використовувати борошно окари як замінник звичайного борошна для підвищення їхньої поживної цінності. У цьому дослідженні вивчали вплив додавання борошна окари до тіста для пшеничного цукрового печива на вміст і якість клейковини, реологічні властивості тіста, а також органолептичні властивості та поживну цінність цукрового печива. Борошно сорту

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Окара вносили в тісто у кількості 10 % мас., 20 % мас. та 30 % мас., замінюючи еквівалентну кількість пшеничного борошна. Це зменшило вміст сирої клейковини в борошняних сумішах і, відповідно, еластичність та гідратаційну здатність тіста. З додаванням 20 % мас. борошна окари структурна міцність тістової маси збільшилася на 23 %, а адгезійна міцність зменшилася на 32 %, що зробило його менш липким і легшим у формуванні. Оцінка органолептичних показників якості показала, що дослідне цукрове печиво з 10 % та 20 % борошна окари перевершило контрольне пшеничне цукрове печиво за смаком, кольором та зовнішнім виглядом. Більші за 30 % масові частки борошна окари не відповідали органолептичним показникам якості. Було виявлено, що порівняно з контрольним печивом вміст білка в дослідному цукровому печиві з 20 % мас. ч. збільшився на 30 %, харчових волокон – у 100 разів, калію – на 83.5 %, фосфору – на 64 %, заліза – на 57 %, магнію – на 20 % і кальцію – у 4.4 рази. Експериментальне цукрове печиво з 20 % мас. ч. також показало сприятливий вміст ізолейцину, лейцину, триптофану та фенілаланіну + тирозину. Загалом, заміна пшеничного борошна борошном окари в цукровому печиві може суттєво покращити реологію тіста та поживну цінність цукрового печива. Ці результати можуть сприяти подальшому вдосконаленню та урізноманітненню кондитерських виробів з борошном окари та доповнити шляхи валоризації відходів харчової промисловості.
Ключові слова: окара; борошняні кондитерські вироби; цукрове печиво; реологічні властивості тіста; харчова цінність; амінокислотний склад; харчові волокна.

Introduction

Food products based on soybeans are in high and fast growing demand. At the same time, the disposal of residues obtained from the processing of soybeans to soy milk and tofu is a challenge [1]. It is estimated that each kilogram of tofu produces about 1.2 kg of residues, called okara, consisting of insoluble parts of the soybeans that remain after pureed soybeans are filtered to produce soy milk and tofu [2]. In China, for example, yearly over 2.8 million tons of okara are made, of which the largest amounts remain unused [3], and are openly burned or sent to a landfill, which is environmentally hazardous [1]. Therefore, feasible valorization routes for the residual resource okara should be explored to transfrom the by-products to value-addedd products and stimulate environmental benefits. Value-added products from biodegradable wastes, such as okara, are livestock feed, biofuels, bioaactive compounds, e.g. isoflavones, biopolymers or bioplastics.

Okara proteins have high moisture retention, fat binding ability, and good emulsion properties [3]. Okara protein contains 16 amino acids, including all nine essential ones [4]. Except for tyrosine, cysteine, and methionine contents, it is close to the requirements for ideal proteins [5] and has a high degree of digestibility [6]. Dietary fiber of okara has high sorption properties, high moisture-binding ability, and a therapeutic and physiological effect on motility and intestinal microflora [3; 7]. Okara can be consumed raw, dried as flour, or fermented [2]. It is used in vegetarian burger patties or as dough ingredients in baked goods [1]. Okara flour is also used in bakery products intended for patients with celiac disease, as it is gluten-free [8; 9].

The confectionery industry is well-established in Ukraine. With 15 kg of confectioneries per capita per year, Ukraine has the 8th largest per capita consumption in the world [10]. The Ukrainian confectionery industry produces about 500,000 tons of products per year. The largest market segment comprises flour confectionery products (FCPs, such as biscuits, waffles, cakes and crackers) with 52 % of the total production volume [10]. The segment of sugar products (caramel, dragees and candies) has 20 %, and the segment of chocolate products has 28 % of the total production [10]. FCPs, along with bread and other bakery products, are thus regularly consumed products in Ukraine. Bakery products and FCPs have an unbalanced nutritional composition: high caloric and carbohydrate content, relatively low protein content and almost complete absence of important biologically active substances such as vitamins, macro- and microelements or dietary fibers.

Reducing calories and introducing raw materials containing high protein, vitamins, or minerals are strategies to improve the nutritional values of FCPs and have been investigated by several researchers [11–13]. A recent study investigated the use of legumes, in particular pea flour, in the production of FCP [14]. They determined the optimal mass fraction of pea flour in the recipe of FCPs to improve the organoleptic quality of those products [14]. Similarly, the cookie recipe can add flaxseed flour as a biologically active food additive [15]. Flaxseed is becoming an important functional food ingredient due to its high contents of α-linolenic acid, lignans and dietary fiber. Flax protein helps prevent and treat cardiovascular diseases and supports the immune system [15]. Other researchers [16] found that the most promising raw materials for the enrichment of FCPs were vegetable powders, as those would supplement the population with biologically active substances. Results suggested positive effects on the chemical composition of the products, saturating them with the necessary micro- and macronutrients [16; 17].

Fresh okara and okara flour were recently used to increase sugar cookies' nutritional and biological value. Park et al. [18] used fresh okara without and with starch, soy flour and hydroxypropyl methylcellulose additives to produce okara cookies. Lee et al. [9] incorporated dried okara, autoclaved okara and fermented okara into wheat flour sugar cookies (20–40 % w/w flour substitution). Ostermann et al. [8] used okara flour and commercial manioc flour with four different okara mass fractions (0 %, 15 %, 30 % and 50 % weight by weight (w/w) of okara flour). Momin et al. [20] produced sugar cookies with wheat and okara flour (2 %, 4 %, 6 % and 8 % w/w okara flour). Results suggested that mixed flour cookies surpassed wheat flour cookies in physicochemical, nutritional, textural, and sensory characteristics [20]. Higher mass fractions of okara flour to wheat sugar cookies should thus be investigated further to increase the nutritional values of wheat sugar cookies as often consumed in Ukraine.

This study aimed to develop a recipe for sugar cookies with higher mass fractions of okara flour and test them for their nutritional values and organoleptic qualities. The study i) determines the effect of okara flour on the gluten contents and quality, ii) investigates the rheological properties of dough with added okara flour, iii) determines the organoleptic quality of end products, and iv) comparatively assesses the nutritional value of cookies with and without okara flour.

The enterprises produce about 500 thousand tons of confectionery products per year. The structure of the confectionery industry is successfully dominated by flour products and chocolate. The most significant segment - flour products (biscuits, waffles, cakes and crackers) occupies up to 52% of the total production volume. The segment of sugary confectionery products (caramel, dragees and candies) occupies 20.05 %, and the segment of chocolate products - 27.95 % (Fig. 1) [10].

Fig. 1. Structure of confectionery market of Ukraine

As can be seen, flour products occupy an important place in the structure of the range of confectionery products, and the share of biscuits accounts for about half of the total production and it is the most popular among all products. The stability of consumption of flour confectionery products (FCP) by the population of Ukraine makes it possible to consider them, along with bread and other bakery products, as products of paramount importance. Despite the wide range of bakery products, their common distinguishing feature is their unbalanced composition: high calorie content, high carbohydrate

Materials and methods

Sugar cookie samples

Control and experimental dough samples were produced. The control sample for this study was the sugar cookie "Voloshka" according to the unified recipe № 23 [21]. As experimental samples, sugar cookies with a mass fraction of okara of 10 %, 20 % and 30 % weight by weight (w/w), replacing its equivalent amount of wheat flour, were produced. The okara flour used was produced by "Soybean factory agroprod" LLC. Preparation of sugar cookies in the laboratory was carried out with the following steps: (1) preparation of emulsion and adding of flour, (2) dough kneading, (3) dough moulding, (4) baking of dough pieces, (5) cooling of biscuits (Fig. 2).

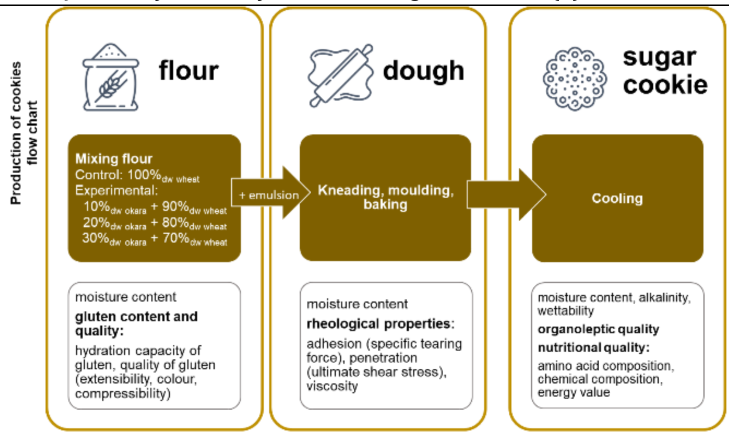

Fig. 2. Flow chart for the production of sugar cookies and quality assessment parameters investigated in this study

Different methods were used to assess the quality parameters of the flour, dough, and sugar cookies (Figure 2). For each quality assessment, triplicates of control and experimental samples were measured.

Flour Quality Assessment

The moisture content of okara flour was determined following the State Standard of Ukraine (DSTU) GOST 29144:2009 [22]. The content of raw gluten in okara flour, hydration capacity and gluten quality assessment (i.e., extensibility, colour and compressibility of gluten) were carried out according to the methods in Drobot [23].

Dough quality assessments

The moisture content of the dough was determined by an accelerated method (DSTU 4910:2008) [24]. This entailed drying a crushed weight of 5 g in pre-dried buns in a drying oven at a temperature of 130 ± 2 °C for 40 min [23]. The adhesive stress was determined by the normal detachment of the plate from the structured body (dough) using the apparatus developed by the Odessa National Academy of Food Technology [23]. The ultimate shear stress was determined on a penetrometer AP-4/1. The value was calculated using the Rebinder formula [23].

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The viscosity of the dough was determined on a rotational viscometer RV-8 by M. P. Vola-Sidorovich. The device gives good convergence of results and allows to obtain viscosity values in a wide range of 0.5–106 Pa·s^{-1}. Viscosity was determined using two vertically arranged coaxial cylinders with hemispheres in the lower part, the radius of which is equal to the radius of the cylinders. The test substance was placed in the gap between them. The inner cylinder is rotating, and the outer one is fixed using an installation flange. The cylinder is driven in rotation by a shaft and pulley, on which threads are wound and thrown over the blocks and cups with weights. There is a brake for starting and stopping the cylinder. The frequency of rotation of the cylinder during the study period was measured. The cylinders are placed in a water thermostat equipped with electric heating elements in the assembled device. Three thermocouples are placed in the outer cylinder at different heights to control the temperature.

The determination was carried out as follows. First, the idle friction force of the viscometer P_0 (in g) was determined. Then the device was loaded with the test substance, and the minimum load P_1 (< 2.5 g) required for the cylinder rotation was determined. After that, the static ultimate shear stress τ (Pa) was calculated by:

$$\tau = 10^5 \cdot (P_1 - P_0) \cdot K_1,$$

where P_1 is the minimum load required to rotate the cylinder (g); P_0 is the idling friction force of the viscometer (g); K1 is a constant that depends on the size of the device and is calculated by

$$K_1 = R \cdot g / (2 \cdot \eta \cdot r_1^2 \cdot h + \eta \cdot r_1^3 / 2),$$

where R is the radius of the pulley on which the thread is wound (cm); g is (981 cm·s^{-2}); η is plastic viscosity; r_1 is the radius of the inner cylinder and hemisphere (cm); and h is the height of the cylindrical part of the body of revolution immersed in the test medium (cm).

After that, the load was increased, and the plastic viscosity η (Pa·s^{-1}) was determined at increasing loads and rotational speeds of the cylinder by the formula:

$$\eta = 10^5 \cdot (P_2 \cdot P_0) \cdot K_2 / N,$$

where P_2 is the weight (g) rotating the cylinder of the viscometer (the sum of two equal weights suspended on both threads of the device); P_0 is the idling friction force of the viscometer; N is the frequency of rotation of the cylinder (s^{-1}); and K_2 is the constant depending on the size of the device (cm^{-1} · s^{-2}) and is calculated by:

$$K_2 = R \cdot g/8 \cdot \eta^2 \cdot [h \cdot r_1^2 \cdot r_2^2 / (r_2^2 \cdot r_1^2) + r_1^3 \cdot r_2^3 / (r_2^3 \cdot r_1^3)],$$

where R is the radius of the pulley on which the thread is wound (cm); g is (981 cm· s^{-2}); η is plastic viscosity; h is the height of the cylindrical part of the body of revolution immersed in the test medium (cm); r_1 is the radius of the inner cylinder and hemisphere (cm); and r_2 is the radius of the outer cylinder and hemisphere (cm).
The deformation rate D (s^{-1}), was calculated by the formula:

$$D = 2 \cdot \eta \cdot r_1 \cdot N / (r_2 \cdot r_1),$$

where η is plastic viscosity; N is the frequency of rotation of the cylinder (s^{-1}); r_1 is the radius of the inner cylinder and hemisphere (cm); and r_2 is the radius of the outer cylinder and hemisphere (cm).

The adhesion experiments of dough were carried out on an adhesiometer, which tears a plate made of a particular structural material from the food mass. For the experiments, a plate made of St. 3 with a fineness of processing RZ 6.3 was used as an enclosing surface; the surface temperature of the plate was 18 ± 2 °C in all experiments.

Sugar cookie guality assessment

The moisture content of sugar cookies was determined by an accelerated method (DSTU 4910:2008) [24]. A crushed weight of 5 g was placed in pre-dried buns in a drying oven at a temperature of 130 ± 2 °C for 30 min [23]. The alkalinity of the cookies (DSTU 5024:2008) [25] was determined by titrating the product filtrate with a solution of hydrochloric acid of a molar concentration of 0.1 mol·L with a bromothymol blue indicator (Drobot, 1999) [23]. The ability to wetting (DSTU 5023:2008) [26] was measured by increasing the weight of flour confectionery products when immersed in water at a temperature of 20 °C for a specified time [23].

The organoleptic quality score is based on the quantitative expression of individual quality indicators of products using a 5-point rating scale and the determination of the overall quality as the sum of the rated quality indicators [27]. An organoleptic quality of the control and experimental sugar cookies was carried out in a blind-tasting evaluation. The control and experimental cookies were rated by a tasting commission of 7 people using a 5-point rating scale (1 = very unpleasant to 5 = very pleasant). The sensory assessment was conducted at the Sensory Analysis Laboratory of the Odesa National University of Technology. The sensory panel consisted of seven qualified experts (aged 30 to 49 years, 85,7 % women) who were trained in the use of the sensory profiling method [28] and provided consents to the quality testing.

Distribution chromatography determined qualitative and quantitative analysis of products' amino acid composition [27]. The amino acid score of flour was calculated as the ratio of the actual amount of essential amino acids compared to the reference protein [27]. The chemical composition and energy value of sample and experimental sugar cookies were calculated according to [27] based on the determined chemical composition of flour raw materials and reference tables of the chemical composition of food products.

Statistical analysis

Results of triplicate measurements are presented as means with standard deviations. One-way analysis of variance and Tukey's tests were performed using R Statistical Software (v4.2.3; R Core Team 2023) [29] to test the significance of differences among mean values at $p \leq 0.05$.

Results and discussion

Flour quality of control and experimental samples

The main component of the control cookie is wheat flour, which plays a significant role in the formation of the rheological properties of the dough and the texture of the finished products. The experimental samples contained okara flour with 10 % w/w, 20 % w/w and 30 % w/w mass fractions substituting the amount of wheat flour. The resulting change in quantity and quality of gluten in the wheat-okara flour mixtures can impact the quality of the dough and was determined (Table 1).

Table 1

Quantity and quality of gluten extracted from the flour mixtures

	Mass fraction of okara flour in the flour mixture			
	0% w/w	10% w/w	20% w/w	30% w/w
Amount of raw gluten in flour (% w/w)	34 ± 0.50[a]	30 ± 0.50[b]	27 ± 0.50[c]	24 ± 0.0[d]
Extensibility of gluten (cm)	13 ± 0.20[a]	11± 0.20[b]	11 ± 0.44[b]	10 ± 0.15[c]
Colour of gluten	light	light	light	light grey
Compressibility of gluten (unit of device, IDC^{-1})	60 ± 0.27[a]	58 ± 0.17[b]	56 ± 0.10[c]	54 ± 0.27[d]
Hydration capacity of gluten (%)	176 ± 0.47[a]	170 ± 0.20[b]	168 ± 0.60[c]	163 ± 0.30[d]

All values (except the colour of gluten) are means with standard deviation (n=3). Different letters within the same row differ significantly from each other ($p < 0.05$)

The introduction of okara flour significantly reduced the gluten content in the mixed flours ($p < 0.05$). The gluten protein of bakery wheat flour forms threads or fibres when swelling during the dough-kneading process. These threads are connected to each other in the form of bundles, which are facilitated by vigorous mixing. As a result, gluten forms a cohesive elastic skeleton of wheat dough. With the introduction of okara, which contains a high amount of dietary fibers, the ability of gluten to resist compression is less than that of the control sample ($p<0.05$). This is explained by the high moisture-binding ability of dietary fibers, which is manifested while kneading the dough and prevents the ability of gluten to swell and form complexes between gluten proteins. The decrease in the amount of crude gluten with an increase in the mass fraction of okara is explained by the fact that more dietary fibers bind more water and thus prevent the swelling of gluten, which in turn contributes to their washing out of the dough along with starch and other components. It can be assumed that a large part of the gluten is washed out, which generally builds short-stretchable structures with high resistance to deformation. The hydration capacity of gluten is the ability of gluten dredges to absorb water and then swell. As the amount of raw gluten in the test samples decreases with increasing mass fractions of okara, the hydration capacity of the dough also decreases significantly ($p<0.05$). As also found by Yildiz et al. [30], the change in the amount of gluten in the dough can make it less extensible and, consequently, improve the quality of sugar cookies, i.e. the cookies can have a more uniform porosity and keep their shape better.

Dough quality of control and experimental samples

The effect of okara flour on the physicochemical and rheological parameters of the dough was investigated (Table 2).

Table 2

Physico-chemical and rheological parameters of the control and experimental dough

	Mass fraction of okara flour in the dough			
	0% w/w	10% w/w	20% w/w	30% w/w
Moisture content (%)	16 ± 0.30a	17.5 ± 0.17b	18.5 ± 0.26c	21 ± 0.42d
Ultimate shear stress, τ_o, (kPa)	5.1 ± 0.05a	5.7 ± 0.05b	6.3 ± 0.21b	6.0 ± 0.17b
Specific tearing force, T (Pa)	128.9 ± 0.22a	109.5 ± 0.28b	87.5 ± 0.40c	86.9 ± 0.24c

All values are means with standard deviation (n = 3). Different letters within the same row differ significantly from each other ($p < 0.05$)

Dough moisture is an important property. Moisture content affects all biochemical processes occurring in the dough, its structural and mechanical properties and the quality of end products, i.e. the sugar cookie. With an increase in the mass fraction of okara flour, the moisture content of the dough increases significantly (Table 2, $p < 0.05$). Specifically, when 30 % w/w okara is used, the dough moisture content increases by 31 % compared to the control sample. As stated by Lian et al. [31], the increase in moisture in the dough mass occurs due to the binding of additional moisture by dietary fibers, which will prevent the biscuits from drying out during storage, reducing the water activity index.

Confectionery dough is a complex heterogeneous, colloidal, dispersed system. The mass fractions and properties of the main ingredients determine its mechanical properties. When developing new confectionery products, the rheological characteristics, need investigation, as they mainly influence the quality of the endproducts, such as porosity or shape of the sugar cookies. Important rheological characteristics are yield stress, relaxation times, penetration properties and viscosity. Penetration characteristics are approximated by the ultimate shear stress τo (kPa) of penetration through the penetrometer cone into the dough mass and is an objective characteristic that reflects the material's resistance to crushing and shear stresses. Therefore, the penetration properties of the material are related to its structural strength (strength of dough), which the ultimate shear stress τo can quantify.

The experimental samples showed a significantly increased strength of the sample doughs (Table 2; $p < 0.05$). For the experimental samples of the dough containing 10 % w/w, 20 % w/w, and 30 % w/w okara flour, τo was 11 %, 23 % and 17 % higher than in the control sample. The increase in the strength of the dough mass between experimental cookies is not statistically significant ($p > 0.05$). The increase in the strength of the dough can be explained by the formation of disulfide bonds between the protein fractions of gluten that are stabilized by the okara dietary fiber, as discussed, e.g. in Yang et al. [32]. However, increasing the mass fraction of okara up to 30 % w/w leads to some weakening of this effect, probably due to the content of okara insoluble dietary fibers with its sorption characteristics. This would need additional investigation.

During the dough kneading, molding, and baking of dough pieces, there is a contact interaction of the dough mass with the surface of the working bodies of machines, devices and apparatus. The formation of an adhesive bond between the biopolymers of the dough and the surface of the structural materials of the equipment is influenced by the rheological properties of the dough, the roughness of the contacting surface, the duration of contact and voltage of the contact devices, the temperature of the food mass and the surface, and the method and speed of detachment. The amount of adhesion of the dough on the surface is characterized by the specific tearing force T (Table 2). The increasing mass fraction of okara flour in the dough decreases its adhesive strength significantly ($p < 0.05$), probably because the dietary fibers that make up the okara have a high water-binding capacity and bind the free moisture. As a result, the dough is less sticky, will interact weaker with the contact surface, and baked products will be easier to remove from the kneading, forming, and baking devices [33]. No significant difference in the adhesive strength of 20 % w/w and 30 % w/w cookies was found.

The influence of varying mass fractions of okara flour on the viscosity properties of the dough at a temperature of 25 °C was determined (Fig. 3).

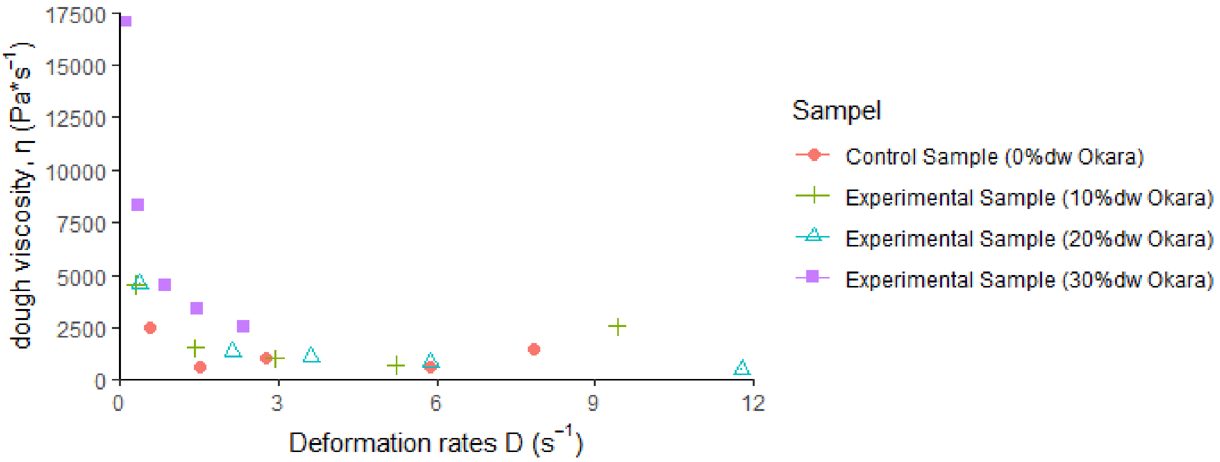

Fig. 3. Change of dough viscosity, η, with varying mass fractions of okara flour (% w/w) in the dough under different deformation rates, D.

The dough mass's viscosity increases with the increasing mass fraction of okara flour in the dough. This is because high molecular weight carbohydrates are introduced into the dough mass, i.e. by adding dietary fibers [31]. A viscosity increase will positively affect the process of dough molding.

Sugar cookie quality of control and experimental samples

All samples meet the requirements of the regulatory quality indicators as per the standard DSTU 3781-98 [34] (Table 3).

Table 3

Physico-chemical parameters of the control and experimental sugar cookies

	Mass fraction of okara flour in the sugar cookie			
	0 % w/w	10% w/w	20% w/w	30% w/w
Moisture content (%)	7.0 ± 0.18[a]	7.5 ± 0.10[b]	7.7 ± 0.17[b,c]	8.0 ± 0.10[c]
Titratable alkalinity* (mL/100g)	0.7 ± 0.00[a]	0.7 ± 0.05[a]	0.7 ± 0.04[a]	0.7 ± 0.02[a]
Wettability (%)	171.0 ± 0.87[a]	185.0 ± 0.50[b]	200.0 ± 1.73[c]	230.0 ± 3.00[d]

All values are means with standard deviation (n=3). Different letters within the same row differ significantly from each other ($p < 0.05$)

*The degree of titratable alkalinity is determined by the amount of mL of 1 n hydrochloric acid (sulphuric acid) solution required to neutralise the alkaline substances contained in 100 g of product, with the indicator bromthymol blue. The method is applicable to flour confectionery made with chemical leavening agents.

The moisture content with the addition of okara increased significantly ($p < 0.05$) but remained within the range prescribed by the standard, according to which the moisture content of sugar biscuits should not exceed 8.5 %. The alkalinity index of the control and experimental samples of biscuits with the addition of okara did not significantly change ($p > 0.05$). The results of studies on the wettability of biscuits, as an indirect indicator of porosity, show that adding okara to the cookie recipe leads to a significant increase in wettability by 8, 17 and 35 %, respectively, for samples with 10 % w/w 20 % w/w and 30 % w/w okara ($p < 0.05$). Based on the results, it can be concluded that all sugar cookies made with okara meet the regulated quality characteristics of food products according to DSTU 3781-98 [34].

The introduction of 10 % w/w and 20 % w/w of okara flour into the composition of the sugar cookies led to an increase in perceived organoleptic quality (Fig. 4). A total of 29 and 30 points were reached respectively compared to 26 points for the control sample and 23 points for the 30 % w/w sample.

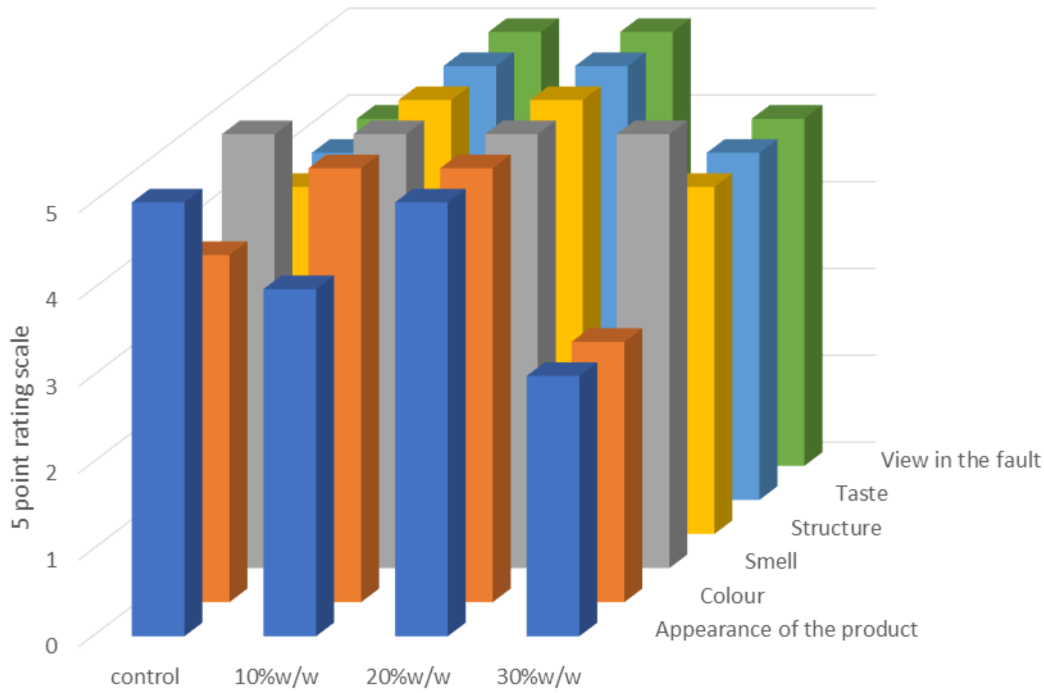

Fig. 4. Ratings of organoleptic quality of control and experimental cookies (mean values of n =7 tasters; 1 = very unpleasant to 5 = very pleasant).

Experimental sugar cookies with 10 % w/w and 20 % w/w had an attractive appearance, a pleasant golden color, a pronounced taste, a uniform porosity, no traces of unprocessed dough, a glossy surface without microcracks, and the cookies held their shape well (Fig. 5). In the sample with 30 % w/w of okara flour however, the organoleptic characteristics deteriorated, i.e., replacing wheat flour with okara led to the spreading of the biscuits and brown color, its structure became denser, harder, cracks and irregularities formed on the surface. Thus, the maximum amount of okara flour that should be added to sugar cookie recipes not to risk negative organoleptic characteristics is about 20 % w/w.

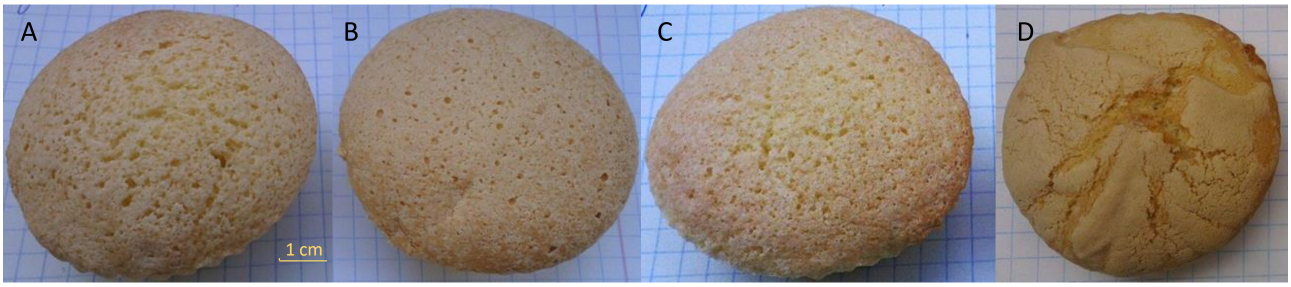

Fig. 5. Pictures of cookies containing different weight fractions of okara after backing (A) 0 % w/w okara, B) 10 % w/w okara, C) 20 % w/w okara D) 30 % w/w okara)

Nutritional values of the 20 % w/w were compared to the control cookies (Table 4). Protein contents in sugar cookies with 20 % w/w of okara flour increased by 30 %. In addition, it compared favourably with the control sample in terms of dietary fibers and minerals. The amount of dietary fibers increased 100 times. In the experimental sample, the content of minerals increased: potassium +83.5 %, phosphorus +64 %, iron +57 %, magnesium +20 % and calcium 4.4 times. The energy content of the experimental and control samples remained almost unchanged, with a slightly higher value in the experimental cookies. This might be due to the experimental cookies' higher fat content than the control cookies. Despite its higher calorific values, it is to be noted that previous studies indicate that okara fatty acid esters can have additional health benefits, such as antioxidant, antimicrobial, anticancer and immune-modulating properties [35]. No triplicate measures were performed for these properties thus, these results are indicative and need further investigations for significant results.

Table 4

Chemical composition and energy value of control and experimental cookie with 20 % w/w okara flour

Indicators	Control	Biscuits with 20 % w/w okara
Moisture (%)	7.0	7.7
Protein (g ·100 g^{-1})	7.3	9.5
Fat (g ·100 g^{-1})	14.9	16.4
Carbohydrates, (g *100 g^{-1}) including dietary	71.2	67.6
fiber, (g ·100 g^{-1})	0.1	6.0
Ashes, (g ·100 g^{-1})	0.7	1.1
Energy value (kcal)	429.2	438.1
Mineral substances (mg *100 g^{-1})		
Na	134.3	136.9
K	91.5	167.9
Ca	21.3	94.4
Mg	11.3	13.7
P	68.8	112.7
Fe	1.02	1.6

The biological value of food proteins is characterized by the amino acid ratio, which is calculated as a percentage of the amino acid contents in the studied proteins compared to their contents in an "ideal protein" that meets the body's needs (FAO & WHO, 2001) [5]. A comparative analysis of the amino acid composition of the control and experimental sugar cookies (20 % w/w of okara flour) is shown in Table 5.

In the experimental cookie samples, the amount of isoleucine increased by 11 % compared to the control cookie, lysine by 38 %, tryptophan by 20%, and phenylalanine + tyrosine by 4 %. Lower amounts of amino acids in the experimental cookies compared to the control cookies were found for leucine (–9 %) and methionine + cystine (–22 %). Comparable values were found for valine and threonine.

Table 5

Amino acid contents (g ·100 g^{-1} protein) of control and experimental cookie proteins and ideal protein (FAO & WHO, 2001)

	Protein (g)	Amino acids (g·100 g^{-1} protein)							
		Valine	Isoleucine	Leucine	Lysine	Methio-nine+ cystine	Threonine	Tryptophan	Phenylal-anine+ tyrosine
amino acid composition in ideal protein	100	5.0	3.5	7.0	5.5	3.5	4.0	1.0	6.0
control sample	100	4.6	4.5	7.7	3.4	3.69	3.1	0.97	7.54
with 20%w/w of Okara	100	4.52	4.9	6.95	4.69	2.87	3.17	1.17	7.77

Compared to the ideal protein, the experimental cookies show favorable isoleucine, leucine, tryptophan, and phenylalanine + tyrosine contents. No triplicate measures were performed thus these results need further investigations.

Based on the results of the research, a recipe for biscuits "Sunshine" with an okara content 20 % was developed (Table 6).

Table 6

Recipe of "Sunshine" biscuits

Name of raw materials	Mass fraction of SR, %	Raw material consumption, kg per 1 ton of finished products (without wrapping materials)	
		In nature	In dry substances
Wheat flour of the highest grade	85.5	510.12	436.15
Powdered sugar	99.85	239.11	238.75
Egg melange	27.0	40.17	10.85
Cream butter	84.0	165.15	138.72
Salt	96.5	3.19	3.08
Ammonium	-	0.77	-
Soda	50.0	3.83	1.92
Vanilla powder	99.85	5.36	5.35
Inverted syrup	70.0	31.24	21.86
Milk	12.0	31.88	3.82
Okara	94.6	115.26	109.04
Total	-	1158	969.54
Output	95.5	1000.0	955.0

As a result of a comparative assessment of the chemical composition of the finished product, it was found that the protein content in biscuits with okara increased, in addition, it compared favorably with the control sample in terms of dietary fiber and minerals. Thus, the protein content in the experimental samples was 30 % higher than in the control, and the amount of dietary fiber increased 100 times. In the experimental sample, the content of minerals increased significantly: potassium – by 83.5 %; phosphorus – by 64 %; iron – by 57 %, magnesium – by 20 % and calcium – by 4.4 times. The energy value of the experimental and control samples remained almost unchanged.

Adding okara to the biscuits will enrich them with protein, dietary fiber, minerals and, as a result, increase their nutritional value.

Conclusions

This study investigated the feasibility of okara flour as a substitute for conventional wheat flour to explore a new valorization pathway for okara residues. When adding mass fractions of 10 – 30% w/w of okara flour to the recipe of sugar biscuits, the amount of raw gluten is reduced.

This reduces the elasticity and hydration capacity of the dough. The change in the rheological properties of the control and experimental doughs were investigated, and it was found that with the addition of okara, the strength of the dough mass increases by 11 % (10 % w/w okara), 23 % (20 % w/w) and 17 % (30 % w/w).

Also, the addition of okara helps to reduce the adhesive strength, as a result of which the dough becomes less sticky, and its interaction with the contact surface decreases.

The experimental sugar cookies with 20 % w/w achieved the highest organoleptic quality ratings and surpassed the control cookies' perceived quality.

Adding okara flour in the amount of 20 % w/w in the experimental samples increases the protein contents of the cookies by 30 %, potassium by 83.5 %, phosphorus by 64 %, iron by 57 %, magnesium by 20 % and calcium by 4.4 times.

Also, the contents of dietary fiber increased by 100 times, and the experimental cookies show favorable contents of isoleucine, leucine, tryptophan, and phenylalanine+tyrosine.

Overall, it was found that substituting okara flour in wheat sugar cookies is feasible and improves the dough rheology and the nutritional value of the sugar cookie.

These results may help to further enhance and diversify confectionery products with okara flour and add to circular valorization pathways for food industry's residues.

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