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Pancakes for a healthy diet: low-carb, prebiotic, gluten-free

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Abstract. The work aims to develop pancake recipes corresponding to the standards of a healthy diet by replacing traditional components with ingredients containing nutritional functional properties. Corn and rice flour are gluten-free and can be used to design gluten-free pancakes. Barley flour contains beta-glucans, a large amount of fiber, reduces the glycemic index of products, is useful not only for a healthy diet but also for people suffering from diabetes and obesity. Rye flour is low in calories, as millet flour contains dietary fiber, vitamins, and lowers cholesterol. Dietary fiber and inulin contribute to the regulation of intestinal microbiota. The results show the possibility of 100% replacement of wheat flour with other types of flour in the production of low-carb, prebiotic, and gluten-free pancakes. The water absorption capacity of flour, dough viscosity, humidity, texture of products, and sensory analysis of finished products were investigated. Replacing wheat flour with alternative types of flour can improve the nutritional value of products, increase the content of dietary fiber, and reduce the calorie content of pancakes.

Key words: pancakes, functional properties, dietary fiber, healthy nutrition.

INTRODUCTION

According to the World Health Organization, there is an increase in the number of patients with alimentary-dependent diseases (Smyth & Heron, 2006), which primarily include functional disorders and chronic digestive diseases, as well as obesity and diabetes, which are interrelated (Mayurnikova & Ashirova, 2011).

People with inflammatory bowel disease, type 2 diabetes (T2DM), and celiac disease have a decrease in bacterial diversity (Hiippala et al., 2018; Cancello et al., 2019; O'Callaghan & Corr, 2019). 'Musso et al. (2011) noted the interaction between intestinal microbiota and host metabolism predisposing to obesity and diabetes'. It has been shown that intestinal microbiota plays an important role in influencing the development of both T1DM and T2DM. This is confirmed by the results of studies in humans and animals (Baothman et al., 2016). Prebiotics nourish the intestinal microbiota, which is affected by dysbiosis, infectious diseases, as well as intestinal diseases, gradually reducing the amount of harmful and increasing the concentration of beneficial microflora (Sekirov et al., 2010; Duncan & Flint, 2013). The prebiotic potential of arabinoxylan, resistant starch, and inulin is well known; they modulate healthy bacteria such as *Bifidobacterium*, *Fecalibacterium*, and *Lactobacillus* (Yang et al., 2020). More than that, partially hydrolyzed guar gum and xanthan can act as a prebiotic and stimulate the growth of native intestinal microflora. An *in vivo* study showed that supplementation of mice with xanthan gum alters the susceptibility of mice to *C. difficile* colonization, maintaining the microbiota during antibiotic treatment. (Mudgil et al., 2018; Schnizlein et al., 2020). 'Tuohy et al. (2001) determined the prebiotic effect of buscuits containing partially hydrolyzed guar gum, which is retained in the final product, as evidenced by an increase in the number of bifidobacteria in human volunteers participating in the research'. It has been established that fructans such as inulin contribute to the development of bifidobacteria. Animal studies have shown that inulin or inulin-type fructan can alter intestinal microbial diversity and *Bifidobacterium sp.* (Licht et al., 2006; Catry E. et al., 2018). Inulin improves bowel function and selectively stimulates the growth of bifidobacteria (Bouhnik et al., 1999; Brighenti et al., 1999; Kruse et al., 1999).

Currently creating products for people with diabetes, lactase deficiency, who are overweight. The production of gluten-free products for people with celiac disease is also relevant (Bazhenova et al., 2018). Celiac disease is characterized by chronic inflammation of the intestinal mucosa, intestinal villous atrophy, which interferes with the absorption of nutrients from food (De la Hera et al., 2013) and several clinical manifestations (Niewinski, 2008). The nutrition of patients with celiac disease is based on the exclusion from the diet of products containing gluten; limiting the amount of easily digestible carbohydrates; the introduction of protein ingredients; microflora correction using products with probiotic and prebiotic factors (Mayurnikova & Ashirova, 2011). Thus, to prevent and reduce metabolic diseases, it is necessary to maintain a healthy lifestyle and proper nutrition. Treatment of people with obesity and diabetes involves dietary correction and the systematic use of functional foods with a low glycemic index, high fiber content, and the use of sweeteners (Skripleva & Arseneva, 2015). When developing gluten-free products, they must have high nutritional value (Sciarini et al., 2010), since removing the gluten-free ingredient from the products leads to loss of nutrients (Mariani et al., 1998; Dubrovskaya et al., 2017).

The mixture of rice, soy flour, and corn starch improved the sensory and nutritional qualities of gluten-free muffins (Man et al., 2014). Biscuits for celiac disease patients were made from a mixture of rice, corn flour, and sorghum flour and had high nutrition value and sensory characteristics similar to biscuts made from wheat flour (100% gluten) (Ali & Abol-Ela, 2019).

For traditional Russian pancakes known to a wide variety of recipes, including various additives that provide high sensory indicators and the attractiveness of the product for the consumers. However, there are practically no recipes for pancakes for dietary and preventive purposes.

Corn flour does not contain gluten, which allows its use in the development of gluten-free food products (Shi et al., 2016). Besides, cornmeal contains a large number of vitamins and minerals, including potassium, phosphorus, zinc, calcium, iron, thiamine, niacin, vitamin B6, and folate (Sabanis & Tzia, 2009; Makinde & Taibat, 2018). Cornmeal reduces blood cholesterol (Kahlon & Chow, 2000), normalizes sugar levels in diabetics (Granfeldt et al., 1995), improves intestinal function and normalizes lipid metabolism, which allows it to be used in the production of low-carbohydrate foods (Mahalko et al., 1984). Corn flour has a higher antioxidant ability compared to wheat, oat, and rice (Soong et al., 2014).

Barley flour contains a large amount of fiber 4.5 g per 100 g of product, potassium, calcium, phosphorus, iron, as well as copper, manganese, iodine, and others (Tipsina & Selezneva, 2011). Barley products are effective natural enterosorbents. They contribute to the elimination of various toxicants from the human body, in particular, organochlorine compounds of inorganic metal salts (Vybornov & Anisimova, 2013). Barley flour contains beta-glucans, a soluble dietary fiber. It was found that β-glucan and cereal products containing it perform useful physiological functions: they reduce the glycemic index of starch-containing products, serum lipids, and lower cholesterol (Miyamoto et al., 2018; Rieder et al., 2019), which makes barley flour is useful for patients with diabetes and obesity (Gapparov et al., 2009). Barley flour improves the physicochemical properties of bakery products, increases their nutritional value, as well as the content of dietary fiber, β-glucan, minerals, vitamins, and antioxidants (El-Taib et al., 2018).

Millet grain has a large number of nutrients, including proteins, sulfur-containing amino acids, minerals such as iron and calcium, carbohydrates and phenolic compounds that have antioxidant properties (Adebiyi et al., 2017). Millet has a positive effect on the cardiovascular system, helps lower blood pressure, cholesterol, and has a lipotropic effect (Truswell, 2002). Products from millet flour remove antibiotics and toxins from the body. Millet flour is a valuable source of vitamins, minerals, fiber, and is an excellent alternative to wheat flour (Kuvandykova & Vayskrobova, 2017).

Rye is characterized by the lowest calorie content of grain among all crops and at the same time contains much more trace elements, vitamins, and essential amino acids than wheat. Rye flour contains 3.5 times more dietary fiber compared to wheat flour. Also, rye flour contains large amounts of high molecular weight pentosans - mucus, which along with dietary fiber improve the functioning of the gastrointestinal tract, as well as adsorb and remove metabolic products and harmful substances from the body (Lapteva, 2012).

Rice flour can be used in the production of gluten-free products, as it has high nutritional value and digestibility and does not cause an allergic effect (Demirkesen et al., 2013). 'According to Pereira et al. (2016), rice flour can be used as a technological additive in a healthy diet, as an emulsifier and fat substitute in foods, and can also be used as a structuring agent for a wide group of products'.

Dietary fiber plays an important role in the prevention and treatment of overweight and obesity, reducing the risk of developing cardiovascular, gastrointestinal, oncological diseases, metabolic syndrome, contribute to lowering cholesterol, slowing down the absorption of carbohydrates, and regulating the intestinal microbiota (Khramtsov et al., 2018) and performs an immunoregulatory function (Zimmerman, 2013). Inulin was added to pancake recipes to obtain products with prebiotic properties. Inulin is a prebiotic and stimulates the growth of microflora in the intestines, which improves human health. 'The effect of inulin on the microbiota of the human intestine has been extensively studied both in vivo and in vitro by Shoaib et al. (2016)'. 'Morris C. & Morris G. (2012) concluded that inulin and oligofructose exhibit prebiotic properties when consumed 5–15 g per day for several weeks'.

The work aims to develop recipes and techniques for the preparation of pancakes (low-carb, prebiotic, and gluten-free) that correspond to the standards of a healthy diet by replacing traditional components with ingredients containing nutritional functional properties.

MATERIALS AND METHODS

Materials

For research using wheat, rice, corn, rye flour of the Kudesnitsa brand produced by the St. Petersburg Mill Plant, as well as barley and millet flour from the manufacturer Garnets. Dry whey curd milk with a protein content of 6% manufacturer Tagris Milk.

Salt, maltodextrin, inulin, dietary fiber, baking powder, dry egg melange, xanthan gum, vegetable oil for making pancake dough were purchased at local stores.

The technology of preparation of pancakes

Several healthy pancakes have been developed gluten-free, low-carb, and prebiotic formulations are presented in tables. Pancakes prepared using wheat flour were used as a control sample. All flour was sieved before use. Water and vegetable oil was added to the mixture of dry ingredients, mixed for 1 min with a mixer, and left for 30 min to swell the proteins. The 130–140 g batter was poured onto a pre-heated pan t = 190 °C and baked for 90 s, then the pancakes were turned on the other side and baked for 40–60 s. After baking, the pancakes were cooled to room temperature over 30 minutes, then the diameter, thickness, and weight of the pancakes were measured.

Weight and overall dimensions of pancakes

The diameter and thickness of each pancake were measured using a caliper. The mass of pancakes was determined using a high-precision electronic laboratory-scale VK II. The size and weight of the products were determined by measuring 5 pieces of products. The average value was taken for the final result.

Sensory evaluation of pancakes

For sensory analysis of pancakes, 12 participants from the Faculty of Food Biotechnology and Engineering of ITMO University (aged 22–65 years) were selected and trained, who were given plates with numbers of pre-cut samples and were asked to evaluate each sample by five sensory characteristics–appearance, texture, color, smell, and taste using a linear scale (ISO 4121:2003) from 1 (‘really dislike’) to 5 (‘really like’).

During the analysis, the quality of individual characteristics of taste, smell, and color, as well as the presence of extraneous odors and tastes, were evaluated. When establishing the appearance was evaluated the shape of the product and surface condition.

Analysis of indicators

The viscosity of the batter was determined on a Rheotest RV2.1 rotational viscometer (Messgerate Medingen GmbH, Germany), with a speed gradient of 5.4 s^{-1} and a temperature of 20 °C (Starshov et al., 2017). For each sample, two sequential determinations were performed. Kinematic viscosity was determined as the ratio of dynamic viscosity to batter density at the same temperature. All ingredients of batter were mixed for 1 min with a mixer and left for 30 min.

The water absorption capacity of flour was determined using a Chopin mixolab device (CHOPIN Technologies, France) (Xhabiri et al., 2016).

The mass fraction of moisture was determined by the accelerated weighing method on an Eleks-7 moisture meter (Technotest Group, Ukraine) at a temperature of 160 °C for 5 minutes.

The determination of soluble and insoluble fibers was carried out by the enzymatic gravimetric method. The method is based on the enzymatic hydrolysis of starch and non-starch compounds using enzymes to mono sugars and peptides. Dietary fiber is precipitated with ethanol and dried (McCleary et al., 2012).

The elasticity of pancakes was determined using a texture meter (Shimadzu, EZ test, Japan) using the basis for testing products for elasticity (346-52275-02) and equipment for assessing the elasticity of 5 mm (346-51687-02) at a speed of 100 mm min^{-1}. The measurements were performed 3 times on each sample, and the average value was taken for the final result (López-Mejía et al., 2019).

Energy value was calculated using conversion factors: proteins and carbohydrates– 4 kcal g^{-1}, fats - 9 kcal g^{-1} (Grigelmo-Miguel et al., 1999).

RESULTS AND DISCUSSION

To obtain products with high sensory characteristics, it is necessary to take into account the structural and mechanical properties of pancake dough (viscosity, plasticity, elasticity) from gluten-free flour.

The gluten-free flour dough does not contain gluten, which provides elastic properties, so the dough becomes less elastic, has a lower viscosity compared to wheat flour dough. The viscosity of pancake dough affects the appearance, texture, and sensory characteristics of the finished product. It was found that the dough made from rice and amaranth flour has a lower viscosity (Fig. 1).

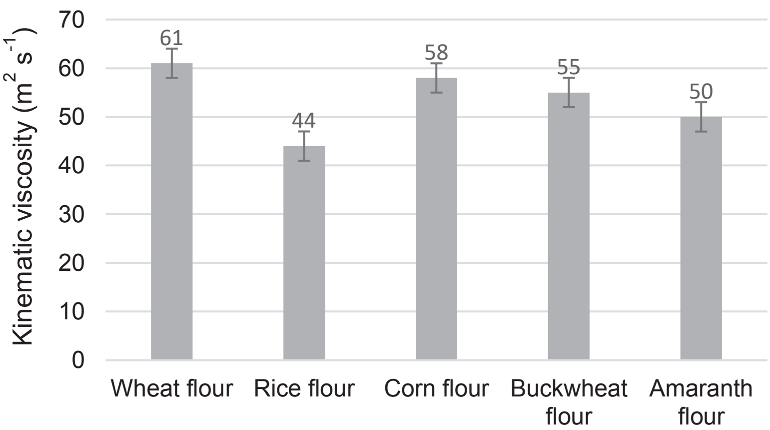

Figure 1. Kinematic viscosity of dough from different types of flour.

'Shih et al. (2006) also report that the viscosity of rice flour dough is significantly lower than that of wheat dough. Besides, rice flour has a lower water-holding capacity and absorbs less water than wheat flour'. Thus, to obtain the necessary structural and mechanical properties, it is advisable to mix flour (buckwheat and corn), which has a high kinematic viscosity, with other types that have a lower kinematic viscosity (rice and amaranth). The possibility of developing pancake recipes from mixtures of rice and corn flour was investigated as a substitute for a standard of wheat flour. Amaranth flour has a high cost, and buckwheat gives the product a specific color and flavor, so it was decided to refuse to use them in further research.

Pancakes from gluten-free types of flour were prepared by replacing wheat flour with rice and corn in a different percentage ratio of 50 : 50, 70 : 30, 75 : 25, 85 : 15 (Table 1).

Table 1. Recipes for gluten-free pancakes with a different ratio of rice and corn flour

Name of raw materials	The ratio of rice : corn flour, %				
	0	50 : 50	70 : 30	75 : 25	85 : 15
	quantity of raw materials, g				
Wheat flour	100.0	-	-	-	-
Rice flour	-	50.0	70.0	75.0	85.0
Corn flour	-	50.0	30.0	25.0	15.0
Wheat fiber	-	3.0	3.0	3.0	3.0
Dry egg melange	14.0	14.0	14.0	14.0	14.0
Salt	1.0	1.0	1.0	1.0	1.0
Xanthan gum	0.1	0.1	0.1	0.1	0.1
Maltodextrin	5.0	5.0	5.0	5.0	5.0
Baking powder	4.0	4.0	4.0	4.0	4.0
Vegetable oil	5.0	5.0	5.0	5.0	5.0

Pancakes with increasing addition of cornmeal had a more pronounced yellow color, but they broke, were torn and had a crumbling texture. Zaitseva et al. (2020) recommend introducing various polysaccharides into the recipe as structural agents and thickeners to improve the structural and mechanical properties of gluten-free products. Xanthan gum was added to increase the elasticity of the finished products. Sample 85 : 15 received the highest sensory scores (Fig. 2).

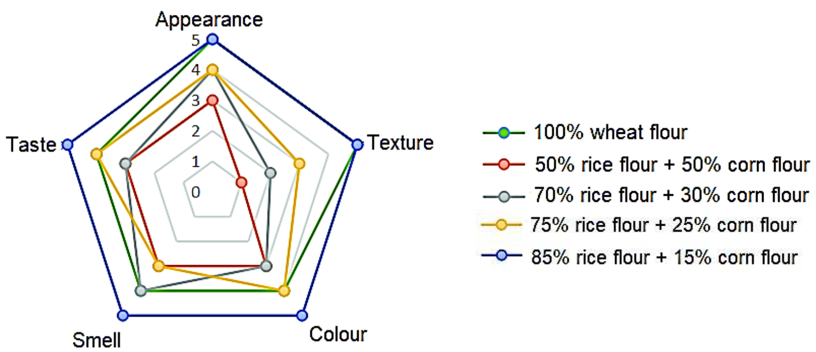

Figure 2. Sensory properties of gluten-free pancakes prepared with different ratio of rice flour to corn flour.

Low-carb and prebiotic pancakes were developed taking into account such an indicator as to the water absorption capacity of flour, which affects the viscosity of the dough and the quality of the finished products, this fact is also confirmed by the work of

Meleshkina & Popova (2011) and Anistratova et al. (2019). Water absorption was determined during the kneading dough (Fig. 3).

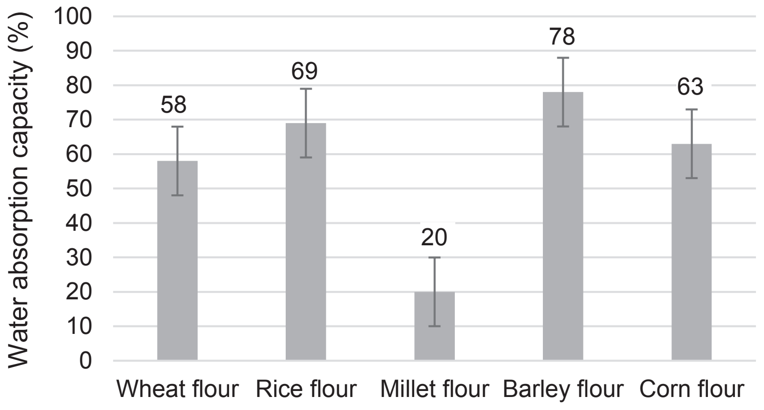

Figure 3. Water absorption capacity of various types of flour.

'Rye and barley flour have a high water absorption capacity, similar data were obtained by Holtekjolen et al. (2008) and Stępniewska S. et al. (2018)', therefore, it is advisable to use them with other types of gluten-free flour, which are characterized by low water absorption, such as millet and corn.

Prebiotic pancakes were prepared by replacing wheat flour with rye and millet in a different percentage ratio of 70 : 30, 60 : 40, 55 : 45, 50 : 50, 30 : 70. Furthermore, inulin was added to pancake recipes to give products prebiotic properties (Table 2).

Table 2. Recipes for prebiotic pancakes with a different ratio of rye and millet flour

Name of raw materials	The ratio of rye : millet flour, %						
	0	70 : 30	60 : 40	55 : 45	50 : 50	40 : 60	30 : 70
	quantity of raw materials, g						
Wheat flour	100.0	-	-	-	-	-	-
Rye flour	-	70.0	60.0	55.0	50.0	40.0	30.0
Millet Flour	-	30.0	40.0	45.0	50.0	60.0	70.0
Dry curd milk whey	26.0	26.0	26.0	26.0	26.0	26.0	26.0
Dry egg melange	14.0	14.0	14.0	14.0	14.0	14.0	14.0
Salt	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Inulin	-	5.0	5.0	5.0	5.0	5.0	5.0
Maltodextrin	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Baking powder	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Vegetable oil	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Kneading the dough, it was found that the gluten content in millet flour is less than in wheat and rye. Also, the gluten of millet flour has a low water absorption capacity, as a result of which the dough is more liquid and the water exfoliates. Due to the settling of millet flour, the dough is uneven, so it is necessary to sift the millet flour through sieves.

The quality of the finished products was determined by the amount of introduced millet and rye flour. With an increase in the amount of millet flour, the finished pancakes had a more pronounced yellow color, but they held their shape worse and acquired a crumbling texture. An increase in the content of millet flour over 50% led to a deterioration in the rheological properties of the dough and the appearance of the finished product. Finished products stuck to the pan and torn, and the excess humidity of the finished pancakes was noted.

With an increase in the amount of rye flour, the products had a dark color not typical for pancakes and denser consistency. Sample 55 : 45 received the highest sensory scores (Fig. 4).

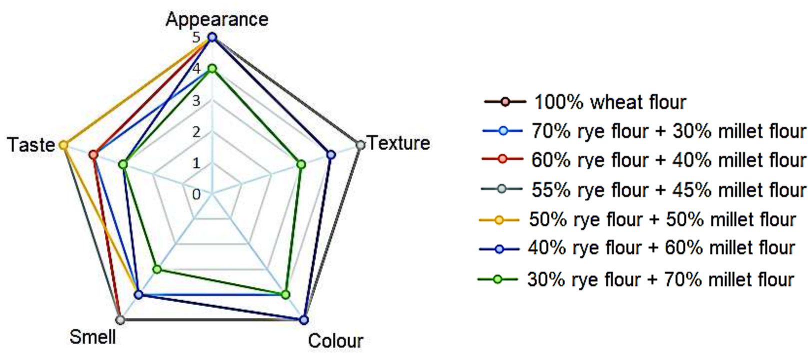

Figure 4. Sensory properties of prebiotic pancakes with a different ratio of rye and millet flour.

'A mixture of rye and millet flour (55 : 45) does not form gluten (although rye flour contains gliadin protein), but the elasticity of pancakes is similar to a control sample of wheat flour. This can be explained by the presence in rye flour of a large amount of mucus and water-soluble pentosans, which add viscosity to the dough and have a high water absorption capacity, similar results were obtained by Anistratova et al. (2019)'. It was found that the recipe composition for pancakes, consisting of a mixture of wheat, rye, and oatmeal, in comparison with the control sample (wheat flour), has higher viscosity and water absorption capacity.

Developing recipes for low-carb pancakes, wheat flour was replaced with barley and corn in various percentages (Table 3).

Table 3. Recipes for low-carb pancakes with a different ratio of barley and corn flour

Name of raw materials	The ratio of barley : corn flour, %				
	0	90 : 10	80 : 20	75 : 25	70 : 30
	quantity of raw materials, g				
Wheat flour	100.0	-	-	-	-
Barley flour	-	90.0	80.0	75.0	70.0
Corn flour	-	10.0	20.0	25.0	30.0
Dry curd milk whey	11.0	11.0	11.0	11.0	11.0
Wheat fiber	-	3.0	3.0	3.0	3.0
Dry egg melange	20.0	20.0	20.0	20.0	20.0
Baking powder	2.0	2.0	2.0	2.0	2.0
Xanthan gum	0.5	0.5	0.5	0.5	0.5
Vegetable oil	2.0	2.0	2.0	2.0	2.0

Beta-glucans contained in barley flour (2.5–11.3%) have a high water absorption capacity, i.e. bind a large amount of water, and make it less accessible for the development of gluten, which can adversely affect the quality of finished products. Holtekjolen et al. (2008), also noted that the quality of bakery products made from a mixture of wheat and barley flour is affected by the total content of β-glucan, which has a significant effect on the water absorption capacity of flour. Therefore, it is important to use barley flour in a mixture with other types of flour, which are characterized by low water absorption capacity (Rieder A. et al., 2012), such as corn.

With an increase in the amount of barley flour 80–100%, the viscosity of the dough increased significantly, which made it difficult to evenly distribute in the pan, the pancakes had an unusual pale-beige color, torn and acquired a more dense consistency. An increase in the content of corn flour over 30% led to a deterioration in the rheological properties of the dough and the appearance of the products. Pancakes were tough and crumbly.

To improve the rheological properties of the dough and consumer properties of the finished products, xanthan gum was introduced into the recipes. The addition of xanthan gum to the pancake dough gave the products a more elastic structure, the pancakes did not tear, did not crumble. Thus, a sample was selected with a ratio of barley and corn flour 75 : 25 (Fig. 5).

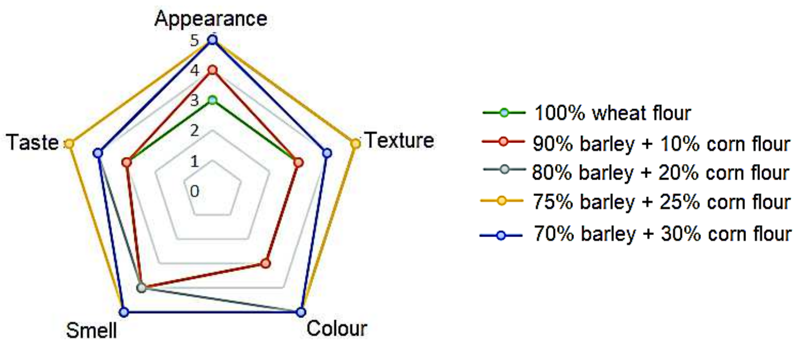

Figure 5. Sensory properties of low-carb pancakes with a different ratio of barley and corn flour.

Brennan & Cleary (2005), as a result of clinical trials, found that grain beta-glucans lower the glycemic index, cholesterol, and also slows the increase in blood sugar, which means they can be used to create dietary products.

Wheat dietary fiber and inulin were added to pancake recipes. 'The addition of inulin did not significantly change the structure and properties of the dough, which is also confirmed by Hager et al. (2011)'. Also, 'Rosell et al. (2010) note that inulin improves the structure of the dough and increases its stability'. 'The beneficial effects of dietary fiber on intestinal bifidobacteria and lactobacilli have been demonstrated in many works by Makki et al. (2018), Khramtsov et al. (2018), Pyryeva & Safronova (2019)'. 'However, Slavin et al. (2013) note that the consumption of wheat dietary fiber also leads to a decrease in the conditionally pathogenic microflora, for example, the content of bacteroids–Cl. Perfringens'.

Moisture content, weight, and overall dimensions of pancakes–diameter and thickness are presented in Table 4.

Table 4. Moisture content, weight and overall dimensions of pancakes

Name of indicator	Results		
	gluten free	prebiotic	low carb
Weight, g	103.0	103.0	102.0
Diameter, cm	29.0	28.5	29.0
Thickness, mm	2.0	2.0	2.0
Moisture content, %	50.5	51.2	50.8

The difference in pancake thickness, weight, and diameter was insignificant and was almost the same for all samples.

The nutritional and energy value of pancakes was calculated. In each recipe, as a control sample for comparison, there were pancakes made from 100% wheat flour (instead of experimental) and without adding dietary fiber (Table 5).

Table 5. Nutrition and energy value of pancakes per 100 g of product

Name of indicator	Results, g per 100 g					
	control for gluten free	gluten free	control for prebiotic	prebiotic	control for low carb	low carb
Proteins	8.62	6.18	6.37	7.18	9.58	10.71
Fats	5.27	5.60	4.90	4.62	6.70	1.34
Carbohydrates	38.70	36.35	34.20	30.81	29.68	24.46
Energy value, kcal / kJ	229 / 939	220 / 902	207 / 849	193 / 791	222 / 910	139 / 570

Table 5 shows that the developed recipes have insignificant differences in the content of protein and fat in comparison with samples from wheat flour. However, the introduction of pancake recipes rye, barley, millet, rice, and corn flour, instead of wheat, reduces the number of carbohydrates and calorie content.

The content of dietary fiber was determined in the developed products and for comparison, we used the recipe of pancakes from wheat flour without the additional introduction of dietary fiber (Fig. 6).

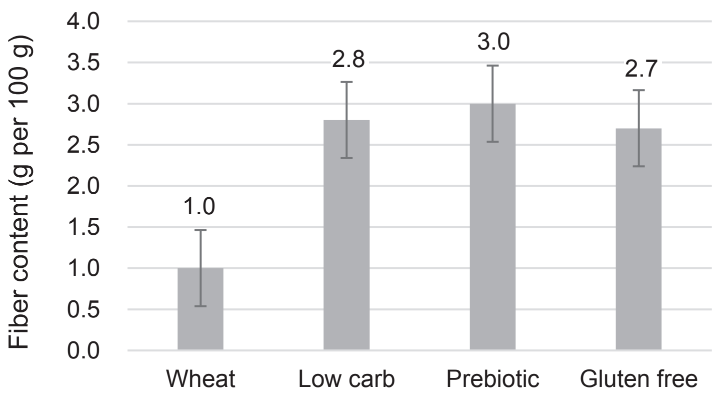

Figure 6. Dietary fiber content in pancake.

According to Fig. 6, the amount of dietary fiber per 100 g of developed products is 2.7–3.0 g, which is 3 times more compared to traditional pancakes (wheat). Thus, with the use of one such pancake, the daily need for dietary fiber will be satisfied by 14–15% with a norm of 20 g per day (Onishchenko, 2008).

As a result of measuring the elasticity of pancakes, it was found that the gluten-free pancakes had the lowest elasticity value, and the prebiotic and low-carb pancakes also had lower elasticity compared to their wheat flour pancakes (Fig. 7).

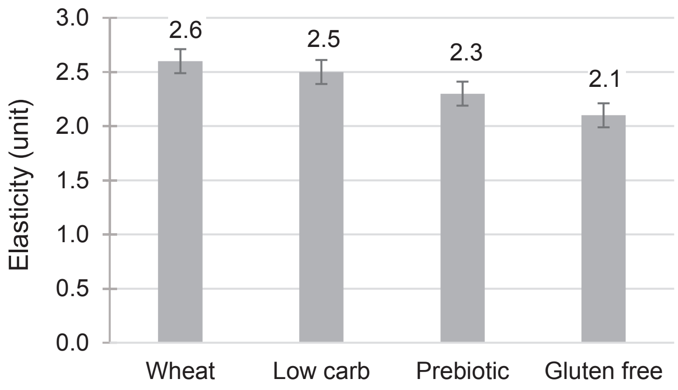

Figure 7. The value of elasticity of gluten-free, prebiotic, low-carb pancakes and pancakes from wheat flour (control).

The lack of gluten in the recipe helps to reduce the elasticity of products. Gluten with gelatinized starch forms a binder mass, which gives elasticity to products. 'Similar results were obtained by Vavilova (2020) in the production of pasta'. 'López-Mejía et al. (2019) showed that the elasticity of products is affected by the content of dietary fiber that was added to the product's recipes'.

CONCLUSION

Replacing wheat flour with alternative types can improve the nutritional value of products, increase the content of dietary fiber. As a result of the analysis of the sensory characteristics of the developed pancake recipes, the best formulation ratios of various types of flour (barley, rye, millet, corn, rice) were determined. These types of flour, unlike wheat flour, are characterized by a low glycemic index and a high fiber content, which makes it possible to use them in a healthy diet, as well as in a specialized one, for diseases such as celiac disease, obesity, diabetes mellitus, for the regulation of intestinal microbiota.

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