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Formulating Composite Whole-Grain Wheat-Hemp Flour for Bakery Products

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ABSTRACT

Introduction: Composite flour mixtures used for the production of products of increased nutritional value are able to diversify the business of the bakery industry. Whole-ground composite wheat-hemp flour, which is a product of joint milling of plant-based products, has potential for use in the production of healthy bakery products, which necessitates the assessment of its technological properties in relation to the quality indicators of finished products.

Purpose: To develop composite whole-ground wheat-hemp flour of various compositions for the production of bakery products of increased nutritional value and expanding the range of healthy food products.

Materials and Methods: As objects of research, wheat grains of 4 varieties were used - spring "Radmira" and "Jubilee" and winter varieties "Nemchinovskaya 85" and "Nemchinovskaya 24" of the 2023 harvest; hemp seeds of the "Surskaya" variety; laboratory samples of composite whole-ground flour; laboratory samples of bakery products developed on the basis of composite flour. The production of laboratory samples of composite flour was carried out using a knife mill, seeding on laboratory sieving E1-URL. The physico-chemical parameters of the obtained flour samples were determined using the SpectaStar 2500 XL infrared grain and flour analyzer. During the trial laboratory baking, scales, a two-speed spiral dough mixer Abat TMS, a proofing cabinet, a convection oven KPP-4-1/2E were used. The physico-chemical parameters of the obtained wheat and hemp products were determined using: OHL-2 volume meter, Structurometr CT-1, Quartz-21M moisture analyzer, CAS SW-5 WDD portion scales. The determination of the nutritional value of bakery products was carried out by calculation. The experimental results obtained were processed using mathematical statistics methods using the Microsoft Office and Excel 2021 application software package.

Results: Addition of hemp seeds to the milling mixture with wheat grain in an amount of 4 to 10% affects not only the technological and physicochemical parameters, but also the overall yield of composite flour. Comparison of the yield of composite flour at a component ratio of 90:10 with a similar parameter of a sample of whole-grain wheat flour established its absolute increase by 1.1%. It was found that the fat content in the composite flour samples increases from 4.4% to 6.8% for milling batches with the addition of 4–10% hemp, which is 2–3.1 times more than in the control sample of whole-grain flour. The PUFA content in the products was 5.4 g/100 g for composite flour with 10% hemp, while omega-3 fatty acids were 0.8 g/100 g.

Conclusion: The results of the study demonstrate the potential for the use of composite whole wheat-hemp flour in bakery technology as a source of vegetable protein, omega-3 fatty acids, minerals (magnesium, zinc) and vitamins (thiamine and niacin), providing a high content of dietary fiber, which allows expanding the range of healthy food products and offering consumers updated products with increased nutritional value.

Keywords: bakery products; composite whole wheat-hemp flour; quality indicators; nutritional value

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Разработка композиционной муки из цельнозерновой пшеницы и конопли для производства хлебобулочных изделий

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АННОТАЦИЯ

Введение: Композитные мучные смеси, применяемые для производства продукции повышенной пищевой ценности, способны диверсифицировать бизнес хлебопекарной отрасли. Цельносмолотая композитная пшенично-конопляная мука, являющаяся продуктом совместного помола продуктов растительного происхождения, имеет перспективы применения для производства хлебобулочных изделий здорового питания, что обуславливает необходимость проведения оценки её технологических свойств во взаимосвязи с показателями качества готовой продукции.

Целью исследования является разработка композитной цельносмолотой пшенично-конопляной муки различного состава для производства хлебобулочных изделий повышенной пищевой ценности и расширения ассортимента продуктов здорового питания.

Материалы и методы: В качестве объектов исследований использовали зерно пшеницы 4-х сортов - яровой «Радмира» и «Юбилейная» и озимых сортов «Немчиновская 85» и «Немчиновская 24» урожая 2023 года; семена конопли сорта «Сурская»; лабораторные пробы композитной цельносмолотой муки и хлебобулочных изделий, выработанные на основе композитной муки. При проведении исследований применяли ножевую мельницу, лабораторный рассев Е1-УРЛ, весы, спиральный тестомес Abat TMC, расстойный шкаф, конвекционную печь КПП-4-1/2Э. Для определения показателей качества объектов исследования использовали: инфракрасный анализатор зерна и муки SpectraStar 2500 XL, объемометр ОХЛ-2, Структурометр СТ-1, влагомер Кварц-21М, весы порционные CAS SW-5 WDD. Показатели пищевой ценности изделий определяли расчетным путем. Результаты обрабатывали методами математической статистики с использованием программ Microsoft Office и Excel 2021.

Результаты: Добавление семян конопли в помольную смесь с зерном пшеницы в количестве от 4 до 10 % оказывает влияние не только на технологические и физико-химические показатели, но и на общий выход композитной муки. Сравнение выхода композитной муки при соотношении компонентов 90:10 с аналогичным показателем цельносмолотой пшеничной муки установил его абсолютное повышение на 1,1%. Установлено, что содержание жира в образцах композитной муки возрастает с 4,4 % до 6,8 % для помольных парий с внесение 4–10 % конопли, что в 2–3,1 раза больше, чем в контрольном образце цельносмолотой муки. Содержание ПНЖК в изделиях составило для композитной муки с 10 % конопли — 5,4 г/100 г, при этом омега-3 жирных кислот – 0,8 г/100 г.

Выводы: Результаты исследования демонстрируют возможности применения композитной цельносмолотой пшенично-конопляной муки в хлебопекарном производстве в качестве источника растительного белка, омега-3 жирных кислот, минеральных веществ (магния, цинка) и витаминов (тиамина и ниацина), обеспечивая высокое содержание пищевых волокон, что позволяет расширить ассортимент продукции здорового питаниям и предложить потребителям обновленные продукты повышенной пищевой ценности.

Ключевые слова: хлебобулочные изделия; цельносмолотая пшенично-конопляная мука; показатели качества; пищевая ценность

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INTRODUCTION

Despite its significant development and advanced technology, the bakery industry is faced with a number of challenges while seeking to ensure consistent quality, increase the nutritional value of its products, and reduce production costs[1]. These challenges have become even stronger in the context of competition and economic difficulties caused by the sanctions imposed on Russia, which reduced the number of producers and increased the prices for bakery products (Latysheva, 2023). To overcome these challenges, food scientists are searching for alternative and more nutritious raw materials such as composite flours containing components with high biological value (Bogatyreva, 2020; Alonso-Esteban, 2022; Farinon, 2020).

Modern baking technologies include innovative automation and control systems that improve the efficiency and quality of production (Krasavina, 2024; Shen, 2024). However, to remain competitive, producers are introducing new solutions to increase the nutritional value of their products and reduce raw material costs (Latysheva, 2023; Savostin, 2024; Drannikov, 2021; Chen, 2024). One of such solutions is the use of composite flour with hemp seeds (*Cannabis sativa*). The industrial use of this crop in Russia is regulated by law (Serkov, 2022), and its nutritional value has been confirmed by a number of studies (Galushina, 2021; Vorsheva, 2023; El-Sohaimy, 2022).

Hemp seeds are rich in protein (up to 25 %), amino acids, and polyunsaturated fatty acids, including omega-3 and omega-6 (Grigoryev, 2019; El-Sohaimy, 2022; Ushchapovsky, 2022). Hemp flour can improve the protein, antioxidant, and fatty acid contents in bakery products (Alonso-Esteban, 2022; Farinon, 2020; Illarionova, 2014). Its antioxidant properties and high content of polyunsaturated fatty acids make hemp a promising ingredient for fortifying bakery products (Bakin, 2016; Bubnova, 2020; Kolomnikova, 2016; Shakhrai, 2021).

Despite quite extensive research into some individual components of hemp, the use of composite wheat-hemp flour in bakery production remains understudied. In particular, there is a lack of data on the optimal ratios of its components, its effect on the sensory and processing characteristics of bakery products, or its cost effectiveness on an industrial scale. Thus, there is a need for a comprehensive study of the properties of composite wheat-hemp flour and its effect on the quality of bakery products.

In this study, we aimed to develop composite whole-grain wheat-hemp flour with different ratios of components for a wide range of healthy bakery products with increased nutritional value.

MATERIALS AND METHODS

Study Objects

Our study objects included 1) wheat grains of four varieties, namely Radmira and Yubileinaya (spring wheat) and Nemchinovskaya 85 and Nemchinovskaya 24 (winter wheat), harvested in 2023 (Table 1); 2) hemp seeds of the Surskaya variety; 3) laboratory samples of composite whole-grain flour; 4) laboratory samples of bakery products (bread) from composite flour.

Equipment and Study Design

Our study was conducted at the laboratories of the Department of Grain, Bakery and Confectionery Technologies, Russian Biotechnology University (ROSBIOTECH). It was designed in two stages. The first stage involved the grinding of whole wheat-hemp flour with different ratios of plant components. The second stage involved the baking of bread samples to determine the quality indicators of composite flour and evaluate the sensory and physicochemical characteristics, as well as the nutritional value, of the bakery products.

A wheat blend was made from the samples of four wheat varieties (Table 1) in equal proportions (25 % each). Before milling, the wheat blend was cold conditioned to 16.0 % moisture and then left to rest for 16 hours. Hemp seeds were added to the wheat for grinding in a laboratory knife mill at 25,000 rpm. The same grinding mode was applied to all wheat-hemp blends and the control wheat sample.

An E1-URL laboratory sifter was used for sifting intermediate mill products (the control wheat sample and wheat-hemp mill mixes with different ratios of components) and flour.

[1] Katsnelson, Yu.M. (2024). *The bread market is saturated. What will it be like tomorrow?* Empire of Cold, 5, 46–48.

Table 1

Quality Indicators of Spring and Winter Wheat Grain Samples

Indicator	Indicator values			
	Spring varieties		Winter varieties	
	Radmira	Yubileinaya	Nemchinovskaya 85	Nemchinovskaya 24
Swelling, %	136.3 ± 0.4	134.4 ± 0.5	137.7 ± 0.4	137.7 ± 0.5
Weight of 1000 grains, g	28.86 ± 0.05	35.92 ± 0.05	31.04 ± 0.05	48.46 ± 0.05
Volume weight, g/l	722.8 ± 1.0	718.2 ± 1.0	599.7 ± 1.0	738.4 ± 1.0
Moisture, %	13.3 ± 0.5	12.1 ± 0.5	13.2 ± 0.5	13.9 ± 0.5
Crude protein, %	9.89 ± 0.5	11.7 ± 0.7	12.9 ± 0.4	13.14 ± 0.9
Gluten, %	24.91 ± 1.4	19.95 ± 1.6	23.2 ± 1.5	22.93 ± 1.8
Gluten quality, units (Gluten Deformation Index)	83.2 ± 1.8	81.0 ± 1.6	74.4 ± 1.5	75.5 ± 1.9
Ash, %	1.89 ± 0.05	1.68 ± 0.05	1.73 ± 0.05	1.79 ± 0.05
Falling number, s	426 ± 15	353 ± 15	352 ± 13	361 ± 14
Acidity, %	2.8 ± 0.4	2.8 ± 0.4	3.4 ± 0.4	2.4 ± 0.2

A SpectraStar 2500 XL infrared analyzer was used to determine the chemical and physicochemical parameters of the composite whole-grain wheat-hemp flour samples with different ratios of the components, as well as the control wheat flour.

To determine the effect of different ratios of wheat grain and hemp seeds on the baking properties, samples of wheat-hemp bread were baked from composite flour with different amounts of hemp seeds. The control was a sample from whole-grain wheat flour.

The production of wheat-hemp breads consisted of the following stages. First, we prepared the raw materials (sifted flour, a salt solution, and a yeast suspension) according to the formulation (Table 2). The amount of water was based on the dough moisture of 49.0 %.

Table 2

Formulation of Wheat Bread and Wheat-Hemp Bread

Component	Amount, %
Flour (control or composite)	100
Table salt	1.0
Pressed yeast	2.5
Drinking water	as calculated

The raw materials were placed into the bowl of an Abat TMS two-speed spiral dough mixer and kneaded for 4 minutes at the first speed and then for another 4 minutes at the second speed. The dough was then placed into a container to ferment at 30 ± 2 °C for 150 minutes, with kneading every hour. The fermented dough was divided into 400 g pieces for pan bread and 200 g pieces for hearth bread. The dough pieces were formed and sent for final proofing in a proofing cabinet until ready at 38 ± 2 °C and 80 % humidity. The humidity level was maintained by a steam humidification system using a water tank at the bottom of the working chamber, as well as uniform air circulation in the proofing cabinet.

The dough pieces from the control wheat flour and wheat-hemp flour with different ratios of the components were baked in a KPP-4–1/2E convection oven at 210 ± 10 °C for 25 minutes (pan bread) and 20 minutes (hearth bread). The breads were then cooled at 25 ± 2 °C and subjected to quality analysis.

The physicochemical parameters of the wheat-hemp breads were analyzed on an OKhL-2 volume meter, a ST-1 structure meter, a Quartz-21M moisture analyzer, and CAS SW-5 W DD portion scales. The nutritional value of the breads was determined by calculation.

Data Analysis

The experimental results were processed by methods of mathematical statistics using STATISTICA and MS Office Excel.

RESULTS

Quality Assessment of Composite Whole-Grain Wheat-Hemp Flour and Bran

At the first stage, we milled blends of wheat and hemp grains at the wheat-to-hemp ratios of 96:4, 94:6, 92:8, and 90:10 to obtain composite whole-grain wheat-hemp flour and wheat-hemp bran (Table 3). We found that adding more than 10 % of hemp seeds to the mill mix caused the intermediate mill products to stick to the milling knives and clog the sieves due to a high fat content in hemp seeds.

Then, we determined the effect of various hemp contents on the chemical and physicochemical properties of the composite wheat-hemp flour samples compared to the control wheat flour (Table 4).

The nutritional values of the control wheat sample and the composite wheat-hemp flour samples are presented in Figure 1.

Bran is a by-product of flour production that has nutritional value and can be used in food technology when proven safe. The nutritional values of wheat bran and wheat-hemp bran are presented in Table 5.

Table 3

Yield of Whole-Grain Wheat-Hemp Flour and Bran

Wheat-to-hemp ratio	Yield (flour and bran), %			
	Fraction	Pass 1	Pass 2	Total
100:0 (control)	Through	81.7	12.1	93.8
	Residue	18.3	6.2	6.2 (bran)
96:4	Through	82.2	12.0	94.1
	Residue	17.8	5.9	5.9 (bran)
94:6	Through	82.5	11.9	94.4
	Residue	17.5	5.6	5.6 (bran)
92:8	Through	82.7	11.9	94.6
	Residue	17.3	5.4	5.4 (bran)
90:10	Through	82.8	12.1	94.9
	Residue	17.2	5.1	5.1 (bran)

Table 4

Physicochemical Indicators of Whole-Grain Wheat and Wheat-Hemp Flours

Indicator	Value for flour with wheat-to-hemp ratio, %				
	100:0 control	96:4	94:6	92:8	90:10
Ash, %	1.65 ± 0.09	1.96 ± 0.07	2.11 ± 0.07	2.5 ± 0.09	2.62 ± 0.10
Fiber, %	1.23 ± 0.05	1.19 ± 0.05	1.12 ± 0.05	1.2 ± 0.05	1.2 ± 0.05
Dietary fiber, %	11.0 ± 0.5	10.9 ± 0.5	10.8 ± 0.5	10.7 ± 0.5	10.6 ± 0.5
Moisture, %	13.7 ± 0.5	13.6 ± 0.5	13.8 ± 0.5	12.5 ± 0.5	12.2 ± 0.5
Whiteness, units	19.1 ± 0.6	18.8 ± 0.5	15.4 ± 0.6	11.3 ± 0.7	10.2 ± 0.4
Gluten content, %	23.7 ± 0.5	20.47 ± 0.6	19.87 ± 0.4	17.96 ± 0.5	17.16 ± 0.4
Gluten quality, units (Gluten Deformation Index)	63.7 ± 1.5	56.7 ± 1.5	58.2 ± 1.5	59.1 ± 1.5	63.5 ± 1.5
Falling number, s	310 ± 7	308 ± 8	305 ± 7	298 ± 7	289.5 ± 6

Figure 1

Effect of Hemp Content on the Nutritional Value of Whole-Grain Wheat-Hemp Flour

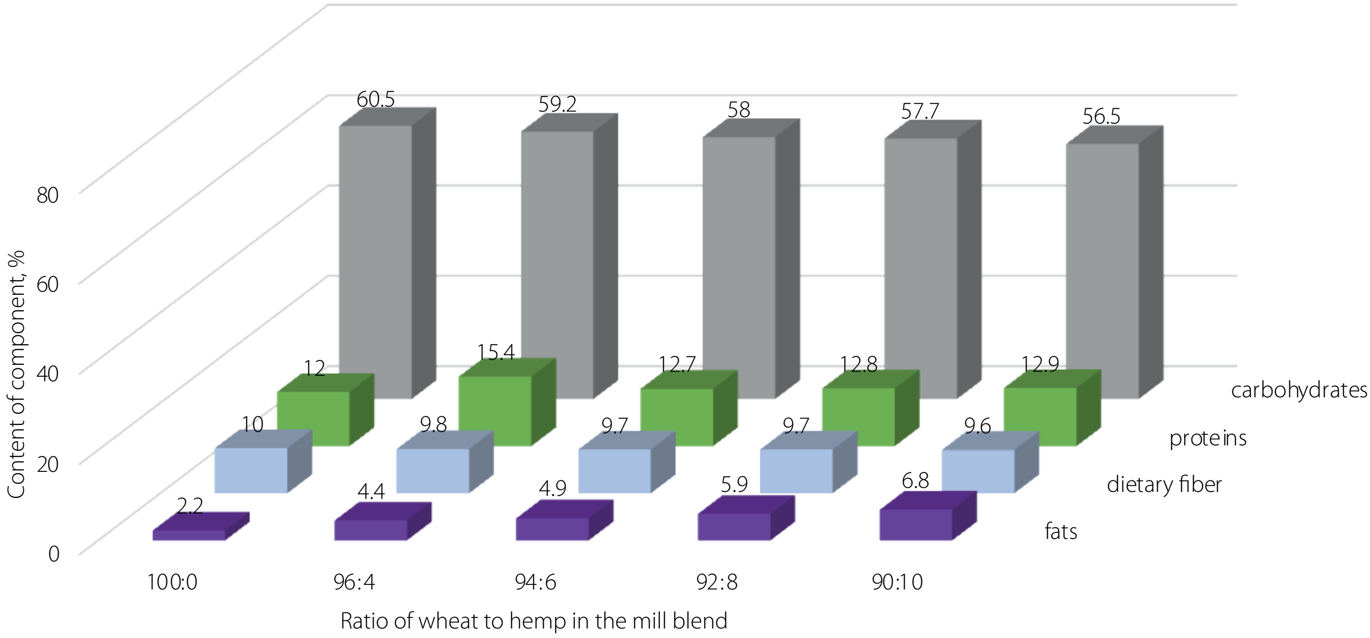

Table 5

Nutritional Value of Wheat and Wheat-Hemp Bran

Indicator	Value for bran in blends with wheat-to-hemp ratio, %				
	100:0	96:4	94:6	92:8	90:10
Fat, %	3.53 ± 0.05	4.06 ± 0.05	4.10 ± 0.05	4.26 ± 0.05	4.31 ± 0.05
Ash, %	5.25 ± 0.15	5.42 ± 0.15	5.98 ± 0.15	6.13 ± 0.15	6.41 ± 0.15
Fiber	43.12 ± 0.43	45.16 ± 0.50	45.02 ± 0.61	46.19 ± 0.49	47.08 ± 0.52
Protein, %	12.53 ± 0.25	14.42 ± 0.25	14.87 ± 0.17	15.06 ± 0.25	15.48 ± 0.25
Moisture, %	14.2 ± 0.15	13.36 ± 0.16	12.18 ± 0.18	12.26 ± 0.14	11.83 ± 0.14
Magnesium, %	0.41 ± 0.01	0.42 ± 0.01	0.41 ± 0.01	0.41 ± 0.01	0.42 ± 0.01
Phosphorus, %	0.92 ± 0.02	0.91 ± 0.02	0.91 ± 0.02	0.92 ± 0.02	0.93 ± 0.02

As can be seen, increased contents of hemp in the mill blends led to higher contents of protein, fat, and minerals, as well as lower moisture in the bran. When proven safe, bran can be used to develop new food products or increase the nutritional value of feed.

Quality Assessment of Breads from Composite Wheat-Hemp Flour

At the second stage of our study, we determined the baking properties of the composite wheat-hemp flour samples with different ratios of the components in comparison with the control.

The samples of pan and hearth wheat-hemp breads are presented in Figures 2–4. Their sensory indicators, which characterize their potential consumer properties, are shown in Table 6.

Figure 2

Pan Breads from Control and Composite Wheat-Hemp Flour

100:0 control | 96:4 | 94:6 | 92:8 | 90:10

Figure 3

Hearth Breads from Composite Wheat-Hemp Flour

96:4 | 94:6 | 92:8 | 90:10

Figure 4

Cross-Section of Pan Breads from Composite Wheat-Hemp Flour

96:4 | 94:6 | 92:8 | 90:10

Table 6

Sensory Indicators of Breads from Wheat and Composite Wheat-Hemp Flour

Indicator	Description of bread from composite flour with wheat-to-hemp ratio, %				
	100:0	96:4	94:6	92:8	90:10
Appearance:					
— shape	regular with oven break	regular	regular	regular	regular
— surface	quite smooth	smooth, uniform	smooth, uniform	smooth, uniform	smooth, uniform
— color	light yellow	light brown, uniform	light brown, uniform	light brown, uniform	light brown, uniform
Crumb condition:					
— doneness	well-baked	well-baked	well-baked	well-baked	well-baked
— stickiness	non-sticky	non-sticky	non-sticky	non-sticky	non-sticky
— kneading	well-kneaded	well-kneaded	well-kneaded	well-kneaded	well-kneaded
— porosity	quite even and uniform	quite even and uniform	quite even and uniform	quite even and uniform	quite even and uniform
— elasticity	good	good	good	good	good
— color	dark, uniform, grayish	dark, grayish-brown	dark, grayish-brown й	dark, grayish-brown	dark, grayish-brown
Crunch	non-crunchy	non-crunchy	non-crunchy	non-crunchy	non-crunchy
Taste	bread-like	bread-like, typical of a bran product, with a slight aftertaste	bread-like, typical of a bran product, with a slight aftertaste	bread-like, typical of a bran product, with aftertaste	bread-like, typical of a bran product, with a distinct aftertaste
Aroma	bread-like	bread-like, with a light aroma	bread-like, with a light herbal aroma	bread-like, with a light herbal aroma	bread-like, with a light herbal aroma

Table 7

Physicochemical Indicators of Breads from Wheat and Composite Wheat-Hemp Flour

Indicator	Value for bread from composite flour with wheat-to-hemp ratio, %				
	100:0	96:4	94:6	92:8	90:10
Volume, ml	1015±5	1005±5	995±5	1050±5	1035±5
Weight, g	351±1	353±1	359±1	352±1	356±1
Specific volume, cm3/g	2.89±0.15	2.84±0.16	2.77±0.15	2.98±0.15	2.90±0.17
Porosity, %	71.5±0.5	72.5±0.5	71.5±0.5	74.0±0.5	73.0±0.5
Shape stability (H/D)	—	0.50±0.04	0.51±0.05	0.55±0.06	0.59±0.08
Crumb acidity, degrees	4.1±0.2	4.2±0.2	4.2±0.2	4.6±0.2	4.8±0.2
Moisture, %	45.4±0.5	45.2±0.5	44.8±0.6	44.5±0.5	43.8±0.5
Structural indicators of crumb, mm					
Total deformation	12.1±0.17	9.45±0.14	9.48±0.16	12.53±0.14	11.09±0.16
Elastic deformation	10.05±0.15	7.85±0.13	7.00±0.16	9.14±0.17	8.14±0.15
Plastic deformation	2.05±0.15	1.6±0.14	2.48±0.16	3.39±0.16	2.95±0.16

Table 8

Nutritional Value of Breads from Wheat and Composite Wheat-Hemp Flour

Indicator	Value for bread from composite flour with wheat-to-hemp ratio, %				
	100:0	96:4	94:6	92:8	90:10
Proteins, g	8.2	8.4	8.5	8.7	8.8
Fats, g	1.5	2.8	3.4	4.0	4.6
PUFA, g	0.7	1.7	2.2	2.7	3.1
Carbohydrates, g	40.5	39.3	38.8	38.2	37.7
Mono- and disaccharides, g	1.8	1.8	1.8	1.8	1.8
Dietary fiber, g	7.3	7.2	7.2	7.1	7.1
Minerals, mg:					
Sodium (Na)	270	268	268	267	266
Potassium (K)	238	236	236	234	233
Calcium (Ca)	41	42	42	43	43
Magnesium (Mg)	74	90	98	105	113
Phosphorus (P)	257	274	282	290	298
Iron (Fe)	3.7	3.8	3.8	3.8	3.9
Zinc (Zn)	1.44	1.64	1.75	1.85	1.94
Manganese (Mn)	1.04	1.54	1.63	1.7	1.74
Vitamins, mg:					
Thiamine (B1)	0.31	0.33	0.34	0.35	0.36
Riboflavin (B2)	0.11	0.11	0.11	0.11	0.11
Niacin (PP)	3.78	3.87	3.92	3.97	4.02
Energy value, kcal	210	220	220	220	230

The physicochemical parameters of the breads from whole-grain wheat and wheat-hemp flour are presented in Table 7.

The nutritional value of the wheat-hemp breads (Table 8) indicates the benefits of adding hemp seeds to the mill mix and using the resulting wheat-hemp flour to produce fortified bakery products.

DISCUSSION

According to our results, adding hemp seeds to wheat mill mixes had a significant effect on the processing and physicochemical properties of composite flour, as well as the overall yield of bread. In particular, higher contents of hemp in the mill mix increased the yield of whole-grain wheat-hemp flour and decreased the yield of bran. For example, a wheat-to-hemp ratio of 90:10 increased the yield of composite flour by 1.1 % compared to the control wheat flour (Table 3). This result is consistent with that of Vorsheva (2023), who reported that adding hemp to the wheat mill mix stabilized the properties of composite flour.

The physicochemical analysis showed a decrease of 9 units in the whiteness index of the composite flour with 10 % hemp. This was due to a higher pigment content in hemp seeds. However, the gluten indicators remained stable, which is important for the rheological properties of the dough. The samples of bread made from the composite wheat-hemp flour had good baking properties (Tables 6–7, Figures 2–4).

The composite flour with higher hemp contents had lower moisture due to reduced moisture in hemp seeds and the presence of hydrophobic triacylglycerides. However, the contents of ash and dietary fiber increased since hemp is rich in vitamins and minerals (Grigoryev, 2019; El-Sohaimy, 2022). The fat content in the composite flour increased from 4.4 % to 6.8 %, which is 2–3.1 times as high as in the control wheat flour. This can be explained by a high content of polyunsaturated fatty acids in hemp seeds (Al-Sohaimy, 2022). The presence of omega-3 fatty acids (0.8 g/100 g) in the flour with 10 % hemp is a distinctive characteristic of this flour, which is confirmed by Illarionova (2014).

The protein content in the composite flour increased from 12.4 % to 12.9 %, which is 3.3–7.5 % higher than in the control flour. Conversely, the carbohydrate content decreased by 2.1–6.6 %, making the flour more suitable for low-calorie products. This confirms the potential of using hemp seeds to fortify bakery products, which is consistent with the data of Farinon (2020).

According to the sensory evaluation, the bread made from the composite flour with 8–10 % hemp seeds had a high specific volume, a stable shape, a uniformly colored crust, and good crumb porosity (Tables 8–9). This confirms that wheat-hemp flour can be used to create functional bakery products (Vorsheva, 2023).

The nutritional value of the composite flour bread was higher in terms of protein, phosphorus, calcium, magnesium, iron, and vitamins (4.9–35 % higher for individual components), compared to the control. According to its content of omega-3 fatty acids, this bread can be classified as a product with a high content of polyunsaturated fatty acids (State Standard R 55577).

Our study was limited by the use of wheat with medium baking properties. Further research should focus on the effect of varietal characteristics on the parameters of bakery products.

Table 9

Meeting Average Daily Nutritional Requirements with the Consumption of Wheat-Hemp Bread

Indicator	Degree of meeting nutritional requirements with the consumption of bread from wheat-hemp flour, %				
	100:0	96:4	94:6	92:8	90:10
Proteins	10.9	11.2	11.3	11.6	11.7
Fats	1.8	3.4	4.1	4.8	5.5
PUFA	6.4	15.8	20.0	24.5	28.2
Carbohydrates	11.1	10.8	10.6	10.5	10.3
Mono- and disaccharides	2.8	2.8	2.8	2.8	2.8
Dietary fiber	29.2	28.8	28.8	28.4	28.4
Minerals:					
Sodium (Na)	20.8	20.6	20.6	20.5	20.5
Potassium (K)	6.8	6.7	6.7	6.7	6.7
Calcium (Ca)	4.1	4.2	4.2	4.3	4.3
Magnesium (Mg)	17.6	21.4	23.3	25.0	26.9
Phosphorus (P)	36.7	39.1	40.3	41.4	42.6
Iron (Fe)	37.0	38.0	38.0	38.0	39.0
Zinc (Zn)	12.0	13.7	14.6	15.4	16.2
Manganese (Mg)	52.0	77.0	81.5	85.0	87.0
Vitamins:					
Thiamine (B1)	22.1	23.6	24.3	25.0	25.7
Riboflavin (B2)	6.9	6.9	6.9	6.9	6.9
Niacin (PP)	21.0	21.5	21.8	22.1	22.3
Energy value	8.3	8.6	8.8	8.9	9.1

Study Limitations

This study has several limitations that need to be considered when interpreting its results and planning further research. Firstly, we used wheat grains with medium baking properties, which may have affected the quality indicators of the composite flour. This warns against generalizing the findings to all wheat varieties and calls for additional research to use wheat with different quality indicators and determine optimal production parameters. Secondly, the milling and dough preparation were adapted to laboratory conditions, which may differ from production conditions in industrial enterprises. Therefore, the results need to be further validated and the technology needs adapting to ensure data reproducibility prior to the industrial application. A third limitation is about consumer awareness and perception. Despite their high nutritional value, bakery products fortified with hemp seeds may face limited demand due to insufficient consumer awareness of their benefits. Moreover, some consumers may have individual reactions to hemp seed components, such as allergies or intolerances, which may affect the market acceptance of these products. Finally, our study does not cover long-term stability and storage characteristics of the products, so additional tests are needed to assess the functional and sensory properties of composite flour-based bakery products during prolonged storage.

CONCLUSION

Expanding the range of healthy food products, including bakery products, is an important condition for making industrial processing enterprises more efficient. Composite flour made with renewable plant materials such as hemp can improve the technology of processing grains, particularly wheat. According to our results, adding hemp seeds to mill mixes can enhance the physicochemical and processing properties of composite whole-grain flour and increase its overall yield.

The wheat-hemp flour formulated in our study can be used as a source of omega-3 fatty acids, minerals and vitamins, and dietary fiber. These components make it a promising ingredient for healthy bakery products with good sensory and physicochemical characteristics, as confirmed by our study.

Our study showed that the composite wheat-hemp flour is highly suitable for various bakery production technologies. The bread produced from this flour had high nutritional value and excellent functional properties. Therefore, by using this flour, bakers can offer consumers new healthy food products with improved nutritional characteristics.

Further research should focus on creating new types of products with composite flour, such as flour confectionery or cereal products, as well as developing new processing and nutritional properties of these products. This can be done by fractionating components, thermoplastic or infrared processing, and other methods to design new products for healthy and specialized nutrition in Russia and other countries.

CONTRIBUTIONS

Irina G. Belyavskaya: ideas; design of methodology, formal analysis, investigation; original draft preparation; writing, review &editing.

Roman Kh. Kandrokov: formulation of research goals and aims; creation of a research model; research project management; investigation; preparation of the published work.

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