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IMPROVING THE QUALITY OF WHEAT BREAD BY ENRICHING TEFF FLOUR

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The research of the influence of teff flour on the technological process and quality of wheat bread was present in the article. The analysis of the chemical composition of teff flour indicated, that it is a valuable raw material for enriching wheat bread. However, its dosage in the quantity of 10 and 20 % to the weight of wheat flour leads to decrease in the amount, springy and extensibility of gluten in the dough. Alveograph studies also confirmed that dosage of 20 % of teff flour the most decreases springy of the dough and it becomes more plastic.

The improvement of the structural and mechanical parameters of bread with teff was applied the biotechnological method of preparation on sourdough that created on the pure cultures of lactic acid bacteria "Biolight". The experimental studies were proving that utilizing of teff flour in the quantity of 10 % and sourdough improved both the quality and nutritional value of wheat bread. In particular, the specific volume of bread increased by 4.0 %, acidity – by 2.9 % compared to the control; and the product was distinguished by a pleasant "nutty" taste and aroma. Close correlations between the percentage of teff addition and the spread of the dough ball were established, $r=0.98$ ($n=10$, $p\leq 0.05$) and the form stability of the bread, $r=(-0.95)$ ($n=10$, $p\leq 0.05$). It allowed establish that wheat bread with teff addition need to make in the mould.

It was calculating that consumption of the daily norm of bread with 10 % teff the consumer will be receiving a sufficient quantity of valuable food nutrients. Thus, the need of protein was covered by 42.9 and 49.8 %; iron – by 32.3 and 28.5 %; vitamin B5 – by 17.6 and 24.2 %, respectively, for men and women; and the need for phosphorus – by 26.7 %, for both groups.

The technology of wheat bread with teff of high quality for mass consumption that recommended for wide industrial implementation has been develop

Keywords: wheat bread, teff flour, lactic acid bacteria, technological process, nutritional value

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1. Introduction

Bread made from wheat flour, especially from high-grade and first-grade, characterized by a low amount of dietary fiber, an unbalanced composition of amino acids and a depleted content of vitamins and minerals. Therefore, such products require adjustment to enhance their nutritional and biological value by incorporating essential functional substances. With aim to balance the nutritional and biological value of bread, it was enriching by including plant-based raw materials in the recipe that sources of beneficial substances for the human body [1, 2]. The various grains and seeds, processed products of oil crops, fruits and vegetables, medicinal plants, and other similar raw materials are using in the technology of wheat bread production [1, 3]. Another approach is the utilization of processed products from cereal crops, including flour, as a nutritious medium for creating spontaneous fermentation sourdoughs in bread baking [4].

In order to enhance the nutritional and biological value of wheat-based bakery products, they are enriched by incorporating non-traditional raw materials into the recipe, such as spelt flour, amaranth, walnuts, seeds of flax, among others. The one perspective additive for improving the nutritional value of wheat bread is teff seeds that have a balanced chemical composition [5]. Scientific research in this field is significant and pertinent as it enables the expansion of the market segment for wheat bread with enhanced nutritional value, intended for mass consumption, with a focus on its health-promoting and preventive properties.

2. Literature review and problem statement

Teff (*Eragrostis tef*) is an ancient cereal crop that has been cultivated for centuries in Ethiopia and Eritrea, where it used still to make a sourdough-like bread called "injera" that resembles pancakes or pita. It has gained widespread cultivation, research and utilization in the production of feed and food products in India, Australia, Canada, the United States and South Africa due to the favourable combination of nutritional and bioactive compounds in teff seeds [6, 7]. Teff consider a non-traditional grain raw material that start grown in Ukraine but investigations its properties have not been conduct thus far.

The results of studies of teff seeds given in publications [8, 9]. It shown that the size of its grain is the smallest among all cereal crops in the world (the length is approximately 1.0 mm; the width is 0.6 mm). Teff seeds have a similar protein content to other more spread grain crops, such as wheat, but it characterized by a higher level of essential amino acids compared to wheat [9, 10]. The teff seeds is absence of gluten [7, 9] therefore, the products with teff can be using for the prevention and treatment of disease such as celiac disease, diabetes, and anemia [10]. It has been establishing that teff flour (TF) significantly surpasses wheat flour in terms of protein content, dietary fiber, vitamin B_5, potassium, phosphorus and iron. For example, it contains 1.3 times more protein, 2.8 times more niacin and 6.3 times more iron compared to high-grade wheat flour. Additionally, TF contains copper and manganese, as opposed to wheat flour [6–8, 10]. Moreover, teff seeds have a low glycemic index and a good source of essential fatty acids [11], minerals (especially calcium and iron) and bioactive substances (polyphenols and phytates) [12]. In articles [11, 12], a comprehensive analysis of the chemical composition and growth characteristics of teff seeds was conducted but its technological properties were not investigated. In the publication [13], the effectiveness of utilization of pure cultures of microorganisms for teff fermentation was confirm. However, this applies to the technology of gluten-free bread and only monocultures of *Pediococcus acidilactici*, *Pediococcus pentosaceus* and *Enterococcus durans* species were use.

The grain size is an objective factor that complicating the removal of bran [14] and therefore teff seeds processed into whole grain flour. The publication [15] demonstrates the influence of the grinding way of teff seeds on the organoleptic characteristics of gluten-free lavash, but the impact of particle dispersion on the quality of wheat bread with teff addition remains unexplored. A comparative analysis of the quality indicators of wheat, teff and rice-teff flours was conduct in the paper [16], but a comparison of wheat bread with a specific percentage of teff with other variants is absent. This research predominantly focuses on gluten-free bread.

The publications [17, 18] investigated the effect of teff flour (TF) on dough formation by replacing wheat flour. It was establishing that increasing the dosage of TF more than 5 % decreased the volume of the final products. However, this quantity of TF is insufficient for a complete enrichment of the products by essential nutrients.

In the paper [19], it was proposing to incorporate 10 % TF into the weight of high-grade wheat flour in wheat bread technology. One fault of the study is the utilization of a non-sourdough method of dough preparation that requires additional technological techniques to enhance the expansion of coarser teff bran particles. The resulting products may be exhibit a "unleavened", does not expressed taste and aroma and lower physicochemical indicators.

The prospects of using TF in the production of bakery and pastry products [20, 21] are undeniably high. However, there are still unresolved questions regarding with technological methods of producing wheat bread with teff. This may be attribute to objective challenges related to the high fiber content and elevated levels of dietary fiber present in TF. Consequently, the inclusion of TF in the bread formulation negatively affects the structural and mechanical properties of the dough and as a result decreasing the quality of the final product.

Some authors recommend using techniques such as sourdough fermentation, spontaneous fermentation and others [22, 23] for solvent this problem. However, the dry sourdough proposed in [22] has lower quality indicators and require an additional rehydration cycle. Spontaneous fermentation [23] does not fully ensure process stability and does not guarantee microbiological purity of the final products.

The research results regarding the determination of the optimal dosage of TF into wheat flour to ensure high nutritional value of the resulting bread are highly varied. According to the researchers, they change within wide ranges from 5 to 77.5 % [13, 17–19, 22]. Despite the practical significance of these results, the scientific community lacks sufficient exploration of dough preparation methods that would improve the volume and structural-mechanical properties of bakery products with TF. Therefore, there is a need for research to establish effective technological approaches for producing wheat bread with TF that allowing the production of products with high nutritional value.

3. The aim and objectives of the study

The purpose of this work is to improve the nutritional value of wheat bread enriching by of TF that will allow expand the segment of health and preventive products for mass consumption.

To achieve this aim, the following objectives are accomplished:

– to establish the quality indicators of TF that was obtain from teff seeds;

– to investigate influence of TF on the quantity and quality of wet gluten, rheological properties of wheat dough;

– to create sourdough from pure cultures of lactic acid bacteria (PC of LAB) for utilize in the technology of bread with teff;

– to establish the influence of TF and sourdough on the quality of dough and bread.

4. The study materials and methods

4. 1. Hypothesis of Researches

The object of the investigation was the technology of wheat bread with TF.

TF was added to the recipe for improve the nutritional value of wheat bread and the biotechnological method of bread production was utilizing with using created baking sourdough.

4. 2. Examined materials

Materials. The materials produced in Ukraine were use in the investigations. Wheat flour (TM Zernari), teff seeds of the *Mania* variety (Agrofirma Kolos), yeasts (TM Kryvorizky yeast), salt (DP Artemsil), sunflower oil (TOV Kama), sugar (TOV Sarkara-Group) and water.

Reagents. The following reagents were use in the researches: sodium hydroxide (ToV NVP Alfarus, Ukraine), phenolphthalein indicator (Bio-Optica, Italy) and methylene blue indicator (Bio-Optica, Italy). All materials and reagents complied with regulatory documentation and were stored under that was indicate by the manufacturer.

4. 3. Methodology and methods of investigations

TF was prepared from teff seeds of the *Maniya* variety that grown in the Kyiv region of Ukraine. The seeds were clean from admixtures in laboratory conditions, grind on a LZM-1 mill (Olis, Ukraine) and then successively sieve by kapron sieves with holes in diameter of 160 and 250 μm.

Wheat bread made by palyanitsa recipe: high-grade wheat flour, pressed baker's yeasts, table salt, white crystalline sugar, sunflower oil and water [24]. The dough prepared by sourdough-free method of dough preparation [25]. The duration of fermentation was 100±2 min. at the temperature of 32±2 °C until the volume increases by 1.5 times. The dough kneaded during 15±1 min. by KVL4100S kneading machine (China) and then manually was forming dough portions. The proofing time was 36±2 min. at the temperature of 35±2 °C in the proofing cabinet XLT 133-UNOX (Italy) (the weight of the dough portions was 290±10 g). The readiness of the dough portions in the proofing process was determine by their volume. The dough portions were bake in the Unox XFT133 oven (Italy) at the temperature of 180–200 °C during 32±2 min.

Organoleptic indicators of flour quality were determined according to the methodology [24]. The acidity of the flour determined by a water suspension of flour in the presence of the phenolphthalein indicator. Falling number was determined by device PCHP-3 (Analyt Prylad, Ukraine) according to the methods [26]. Coarseness was determined by sifting on sieves with size of holes 160 μm and 250 μm. Mass fraction of protein determined by the Kjeldahl method [27]. Ash content determined by the method of ashing (burning) in a muffle furnace SNOL 8.2/1100 (Lithuania) with using accelerator of the magnesium acetate [27].

Flour contamination by pests and the mass fraction of fiber determined by the Henneberg-Stoman method according to [27]. The activity of lactic acid bacteria of sourdough was determined according to the method [24]. The titrated acidity of sourdough and dough was determined according to the method [26]. The mass fraction of moisture of sourdough and dough was determined by express drying on a Chyzhova device (Olis, Ukraine) [26]. The dough lifting power determined by the floating test according to the method [24]. Gas formation in the dough was studied using the AG-1M device (ToV Laboratorna tehnika, Ukraine) using the volumetric method. The gas-holding capacity of the dough was determined by measuring the studding volumetric method by changing of specific volume of the dough in measuring cylinders with using AG-1M device (ToV Laboratorna tehnika, Ukraine and form-holding capacity was determined by measuring the spread of the dough ball [26]. The dough's springy, extensibility, P/L ratio, and specific work of deformation were determined using of alveograph-consistograph NG (Chopin, France) [26]. The determination of sensory and physicochemical quality indicators of finished bread (moisture content, acidity, specific volume, form stability, porosity) was carried out according to [27] after 4 hours of baking. The moisture content of the bread was determined by the standard method of drying a sample in a drying oven SESh-3M (LLC UkrAnalityka, Ukraine) at a temperature of 130 °C [27]. Porosity was measure using a Zhuravlev device (LLC NVF Standard-M, Ukraine) [24]. Calculation of the nutritional value was carrying out using an integral score, and statistical analysis of all obtained results was performing according to [24].

5. Results of research of the influence of teff flour on the process production and quality of wheat bread

5. 1. Preparation teff flour and researching its quality

TF was obtain as a result grinding of teff seeds by mill and subsequent successive sieving through the sieves with holes of 160 and 250 μm, respectively. The obtained product was evaluating on the main indicators of quality and chemical composition. The results of the investigations presented in the Table 1.

Table 1

Quality indicators of teff flour (n=10, $p\leq$0.05)

Indicators	Value
Mass weight of moisture, %	8.8±0.1
Mass weight of protein, % on dry matter	12.2±0.1
Mass weight of fibre, % on dry matter	4.8±0.1
Acidity, degrees	3.8±0.2
Mass weight of metal impurities, mg per 1 kg of flour	2.0±0.02
Ash content (in recalculation on dry matter), %	0.4±0.01
Mass fraction of product that pass through a sieve of 160 μm, %	68.0±0.1
Mass fraction of product that pass through a sieve of 250 μm, %	2.2±0.1
Infestation by barn pest, pcs/kg	Not found

The results presented in the Table 1 indicate that TF had a higher acidity, compared to high-grade wheat flour (the acidity of high-grade wheat flour is 3.0±0.2 degrees) and a bigger particle size. The content of protein and fibre in the TF had high values, that is agrees with literature data [6–8, 10, 14].

Sieve analysis showed that TF is similar to bolted wheat flour that has 70 % of particles with size about 200 µm. At the same time, TF is significantly different from sort wheat flour that has about 50 % of the particles with size smaller than 40–50 µm. The composition of TF similarity to whole grain flour that contains endosperm and peripheral particles that heterogeneous in size. Larger size and heterogeneity of particles will probably worsen the course of the technological process and the quality of finished bread with addition of TF to the recipe.

The study of the effect of temperature and duration of hydration TF on its water absorption capacity (WAC) was carry out. The suspensions of TF and water in a ratio of 1:5 prepared and kept during 60 min in the thermostat at the temperature range of 20–80 °C. The results of the research shown in the Fig. 1.

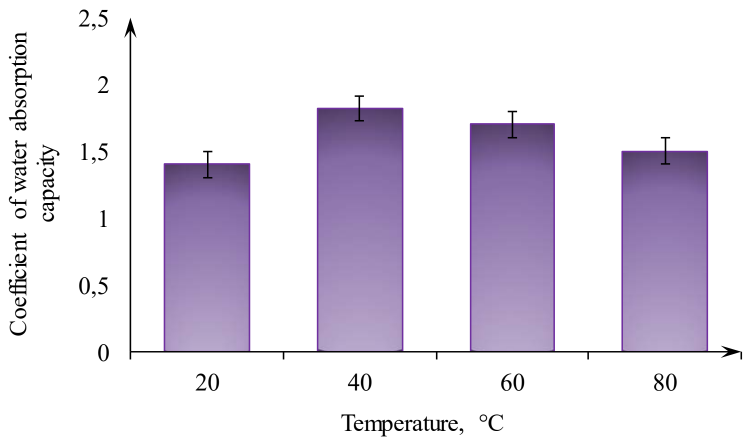

Fig. 1. Effect of temperature on water absorption capacity of teff flour

As can be seen from Fig. 1, coefficient WAC of TF reached its maximum value at temperature of 40±1 °C, while within the temperature range from 30 to 40 °C (the temperature of dough fermentation and proofing of future dough portions), the WAC coefficient was also quite high.

Further, the dynamics of swelling of teff flour was study according the index of WAC within 5–25 min. at the temperature dough fermentation – 32±1 °C. The results presented in the Fig. 2.

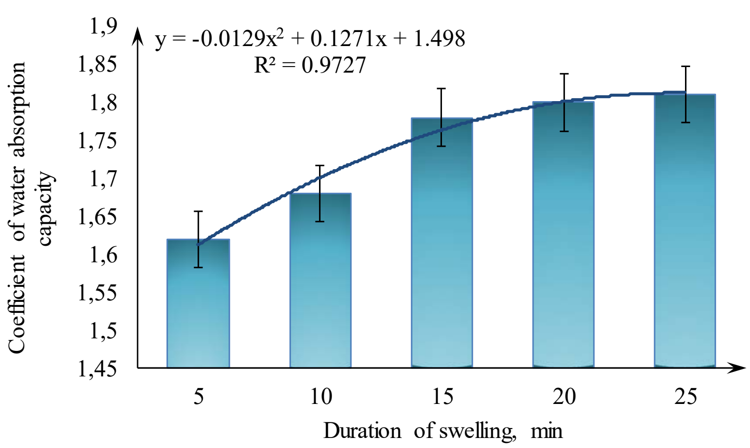

Fig. 2. Effect of duration of swelling on water absorption capacity of teff flour

It shown that with the increase duration of the swelling, the coefficient of the WAC also increased, while its value practically stabilized after 15 min exposure.

5. 2. Investigation of the influence of teff flour on the quantity and quality of the wet gluten and rheological properties of wheat dough

It known, that the quantity and quality of wet gluten are of decisive importance in the formation of the structural and mechanical properties of dough from wheat flour. The ramified gluten framework that formed by flour proteins, effects on the elasticity and springiness of the dough, the ability to retain carbon dioxide that released during fermentation and the form stability of the dough portions during proofing and baking [24].

The determination effect of TF on the quality and quantity of wet gluten carried out by washing according of the generally accepted method in experimental samples of flour mixtures. The dosage of TF chosen based on data from literary sources. Thus, some researchers showed that the addition of TF in the quantity of 10–20 % to the weight of wheat flour did not significant changed of the quality indicators of bread products [17–19]. The results of our research presented in the Table 2.

The results shown in Table 2 indicate that adding 10 % and 20 % TF reduced the amount of gluten by 1.5 % and 3.8 %, springiness by 2.7 % and 6.7 % and extensibility by 7.1 % and 17.8 %, respectively, compared to the control.

Table 2

The influence of teff flour on the quantity and quality of wet gluten in wheat dough (n=10, p≤0.05)

Quantity of teff flour, %	Weight of wet gluten, g	Hydration capacity, %	Springiness, units of the VDK device	Elasticity	Extensibility, cm
control	26.0±0.1	180±2	75±1	good	14.0±0.3
10	25.6±0.1	194±2	77±1	good	13.0±0.3
20	25.0±0.1	198±2	80±1	good	11.5±0.3

With the help of the NG alveograph-consistograph, the effect of TF on the dough system made of high-grade wheat flour was investigate. Alveographic curves were analyse physical properties of the dough and determine how changed the strength of wheat flour as a result TF addition.

The results of the alveograms analysis presented in Table 3.

The data given in the Table 3, show that the addition of TF in the quantity of 10 and 20 %, respectively, decreased in the springiness of the dough by 14.0 and 24.0 %, increase in extensibility – by 11.1 and 22.2 % and reduction of the specific work of dough deformation – by 15.8 and 21.6 %, compared to the control.

Table 3

Properties of wheat dough with the addition of teff flour determined by alveograph-consistograph NG (n=10, $p\leq$0.05)

Indicators	Control	Quantity of teff flour, %	
		10	20
Dough springiness, *P*, mm	50±0.1	43±0.1	38±0.1
Dough extensibility, *L*, mm	54±0.1	60±0.1	66±0.1
P/L	1.7±0.1	1.4±0.1	1.2±0.1
Specific work of dough deformation, units of device	190±2	160±2	149±2

5. 3. Development of baking sourdough from pure cultures of lactic acid bacteria "Biolight"

For ensuring of high quality indicators of bread products with TF, there is a need to develop a method of preparing dough that will create conditions for improving the volume of finished products and the structural and mechanical properties of the crumb [17].

A purposeful search was conducted and among the general microbiota of cultivated spontaneous sourdoughs from wheat and spelt flour were selected PC of LAB of strains of *Lactobacillus plantarum, L. ramnosus, L. fermentum, and L. brevis.*

From the most active strains, a bacterial composition called "Biolight" was formed that was used to prepare wheat sourdough. A method for preparing wheat sourdough was developed that consisting of two cycles: the propagation cycle and the production cycle. The propagation cycle for preparing sourdough with the selected bacterial cultures was conducted according to Table 4.

Table 4

Recipe and preparation conditions for sourdough with pure cultures of lactic acid bacteria "Biolight"

Raw materials, semi-finished products and process indicators	Phases of the propagation cycle			
	I	II	III	IV
Lactobacillus brevis, cm^3	7.5±0.02	–	–	–
Lactobacillus plantarum, cm^3	7.5±0.02	–	–	–
Lactobacillus rhamnosus, cm^3	7.5±0.02	–	–	–
Lactobacillus fermentum, cm^3	7.5±0.02	–	–	–
Pre-prepared sourdough, kg	–	0.25±0.02	0.63±0.02	1.38±0.02
The quantity of flour in the sourdough, kg	–	0.11±0.02	0.28±0.02	0.61±0.02
Wheat flour of the highest grade, kg	0.11±0.02	0.17±0.02	0.33±0.02	0.66±0.02
Water, cm^3	0.14±0.1	0.21±0.1	0.42±0.1	0.84±0.1
Total weight, kg	0.25±0.02	0.63±0.02	1.38±0.02	2.9±0.02
Mass fraction of moisture, %	69.0±0.1	69.0±0.1	68.8±0.1	68.0±0.1
Acidity titrated, degree	15.5±0.1	16,8±0.1	17.5±0.1	18.0±0.1
Duration of fermentation, hours	19±0.1	13±0.1	9±0.1	9±0.1
Fermentation temperature	30±2 °C			
LAB activity, min	90±1	80±1	60±1	35±1

The sourdough obtained at the end of the 4th phase of the propagation cycle was ready for use in the production cycle. In the production cycle, a portion of the sourdough (50 %) was taken for bread production, while the remaining portion (50 %) was used for its renewal. The selected sourdough was refreshed with a nutritive mixture from flour and water in an approximate ratio of 1:1.5.

The sourdough in the production cycle exhibited by high quality indicators: acidity – 18.0±0.1 degrees; moisture content – 68±0.1 %; LAB activity – 35±1 min.

5. 4. Investigation of the influence of teff flour and sourdough on the quality of dough and bread

The sourdough of PC of LAB "Biolight" that was obtain in the production cycle dosages of 10 % of TF to the weight of flour [25] and was using for the preparation of wheat bread with and without the addition of TF.

An important indicator in the production of bread is the intensity of dough fermentation. The quantity of accumulated carbon dioxide in the process of dough fermentation allows to predict the further course of dough fermentation and dough portions during their proofing.

Therefore, the influence of TF on the processes of gas formation in wheat dough with sourdough during fermentation was investigating.

In Fig. 3, it is shown that in all proofing dough samples on sourdough with TF, more intense fermentation and release of carbon dioxide was observed, compared to the control, throughout the fermentation period.

Then, trial laboratory baking was carried out in order to determine the technological parameters for the preparation of bread products with TF.

It was established that the initial acidity of sourdough dough increased by 0.4–0.6 degrees when TF was added (Table 5).

In the researching samples with 10 and 20 % TF, the acidity of the dough during the fermentation period increased by 1.0 degree, in the control – by 0.8 degrees. It is also observed an increase in dough lifting power by 4 and 8 %, respectively when adding 10 and 20 % TF. However, the index of spread of the dough ball elevated with increasing dosage TF and the dough with 20 % TF the worst kept its shape.

The characteristics of the organoleptic properties of the ready bread are given in the Table 6.

Bread made with the addition of 10 % TF had by excellent taste and good appearance (Fig. 4, *b*).

Otherwise, in the case of adding 20 % TF to the bread recipe, an uncharacteristic "grassy" taste and crunch of teff particles was felt and the crumb of the bread acquired a brown color with a gray tint (Table 6, Fig. 4, *c*).

The results of the analysis of the physical and chemical indicators of the quality of finished products are presented in the Table 7.

It was found that when TF was added to the dough in the quantity of 10 and 20 %, the specific volume of bread increased by 4.2 and 2.5 %, respectively and the porosity decreased by 2.8 and 7.1 % compared to the control (Table 7).

Calculations of the nutritional value based on the integral score of wheat bread with the addition of 10 % TF for people of the 1st labor intensity group aged 40–59 years – scientists, workers of mainly mental work, light physical activity were carried out. It was determined that with the consumption of 277 g of such bread (the daily norm of bread consumption specified in the "consumer basket" approved by the Cabinet of Ministers of Ukraine No. 780 dated 11.10.2016), the daily need for protein is covered by 42.9 % for men and 49.8 % for women.

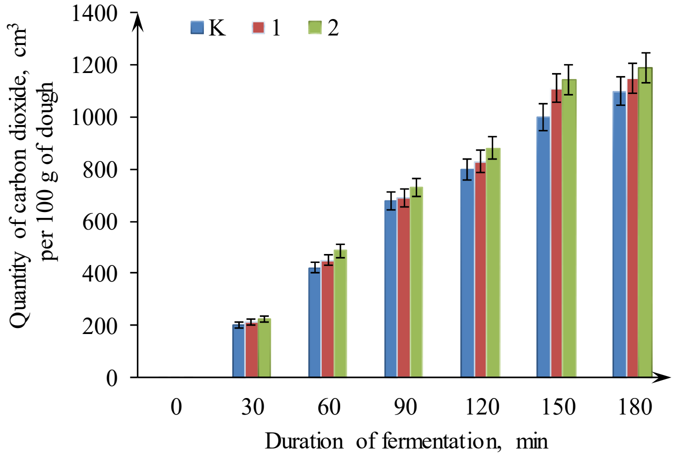

Fig. 3. Intensity of carbon dioxide accumulation in wheat dough on sourdough with of flour teff, cm^3/h per 100 g of dough: K – control; 1 – 10 % of flour teff; 2 – 20 % of flour teff

The daily need for phosphorus is covered by 26.7 % for both categories, iron – by 32.3 and 28.5 % and vitamin B_5 – by 17.6 and 24.2 %, respectively, for men and women.

a *b* *c*

Fig. 4. Finished products of wheat bread with teff flour on sourdough (in section): *a* – control; *b* – 10 % teff flour; *c* – 20 % teff flour

Table 5

Indicators of technological process and quality of wheat dough with teff flour on sourdough (n=10, $p\leq$0.05)

Indicators	Dough samples with sourdough		
	Control	10 % TF	20 % TF
Mass fraction of moisture, %	43.2±0.1	43.6±0.1	44.0±0.1
Titrated acidity, initial, degrees	3.0±0.1	3.4±0.1	3.6±0.1
Titrated acidity, final, degrees	3.8±0.1	4.4±0.1	4.6±0.1
Dough lifting power, sec	50±5	48±5	46±5
The specific volume of dough during the period of fermentation and proofing, % to the initial one	500±5	520±5	515±5
Spread of the dough ball, %, to the initial diameter of the ball	217±5	227±5	235±5
Duration of fermentation, min	100±2		
Duration of proofing, min	37±1	35±1	35±1

Table 6

Organoleptic indicators of the quality of wheat bread with teff flour on the sourdough

Indicators	Sample of bread on the sourdough		
	Control	10 % TF	20 % TF
Appearance	The shape is regular, the surface is smooth, without cracks and ruptures		
Color of crust	Light brown		Brown
Texture of bread crumb	Yellow-brown of color, elastic, springy, porosity is good and uniform, small in size, does not crumple	Light brown of color, elastic, springy, porosity is good and uniform, small in size, does not crumple	Brownish-gray of color that untypical for wheat bread, not sufficiently elastic and springy, porosity is good and uniform, medium in size, does not crumple
Taste and aroma	Characteristic for wheat bread	Characteristic for wheat bread with a pleasant «nutty» taste	A «herbal» taste is felt
Chewiness ability of the crumb	Chews well, does not clump	Chews well, does not clump	Chews well, does not clump, feeling the inclusions (crunch) of additive

Table 7

Physical and chemical indicators of quality of wheat bread with teff flour on the sourdough (n=10, $p\leq$0.05)

Indicators	Sample of bread on the sourdough		
	Control	10 % TF	20 % TF
Specific volume, cm^3/100 g	2.4±0.1	2.5±0.1	2.46±0.1
Form stability of the floor bread (h/d)	0.6±0.05	0.67±0.05	0.72±0.05
Porosity, %	70±2	68±2	65±2
Mass fraction of moisture, %	42.3±0.1	42.8±0.1	43.2±0.1
Acidity, degrees	3.5±0.1	3.6±0.1	3.8±0.1

6. Discussion of the research results of the influence of teff flour on the quality of dough, baked bread and its nutritional value

It is known that high-grade wheat flour is a highly refined raw material that free from the bran, certain amounts of minerals, vitamins, partially proteins and dietary fibers [28]. Therefore, mass-produced sorts of wheat bread are prioritized for enrichment to expand the range of products for health-enhancing and preventive purposes.

The organoleptic indicators of the quality of pastries and bakery products are insufficiently expressed and rather barren, as they are mainly formed by fat components, while high-grade wheat flour is basis of most traditional recipes. They require adjustments and improvements in terms of nutritional value [2]. In the baking industry, there is a perspective trend of utilizing non-traditional types of flour as substitutes of wheat flour [2, 3, 29]. Some authors have reported on the positive impact of teff flour on the WAC that it added to various product formulations. Specifically, an increase in WAC and paste viscosity [30], WAC of wheat dough [17, 31], increasing WAC of emulsions in sausage production and etc. [32] has been observed.

The investigations that improving and developing the technology of producing wheat bread with teff are actual considering the high content of essential nutrients, micro- and macroelements and vitamins in teff flour.

The organoleptic evaluation of flour from teff of *Mania* variety grown in the Kyiv region of Ukraine was establishing that the flour had a light brown color and a characteristic, non-musty and non-moldy aroma. The utilizing of teff flour for making wheat bread, improvements and diversification in its taste qualities were observed, along with the emergence of a pleasant "nutty" flavour that aligns well with the results of other researchers [19, 25].

The results of the physicochemical analysis of teff flour showed that it had acidity level of 0.8±0.2 degrees higher compared to wheat flour. Therefore, when teff flour is added, the acidity of the dough will be also increasing. This needs to be taken into account when formulating recipes and bread production techniques. Confirmation of this can be seen in the results of utilization teff flour in wheat bread production in the ranges 6 till 24 %. It was established that the acidity of the crumb was directly depending from the on quantity of teff flour. The higher quantity of teff flour added promoted to increasing the acidity of the crumb [28].

It has been found that as the temperature increased, the WAC of TF also increasing. The maximum WAC value was observed at a temperature of 40±1 °C. Further, it gradually decreased at temperatures ranges 60 till 80 °C. It may be connected with partial temperature-induced denaturation of the protein components of the flour and starch gelatinization that promoting to reduce of water absorption by the biopolymers of teff flour. The most significant swelling of teff flour occurred within the temperature ranges of 30 to 40 °C that corresponds to the temperature of fermentation and proofing of dough portions (Fig. 1). Subsequently, dough fermentation was conducted at a temperature of 32±1 °C and proofing dough portions at a temperature of 35±2 °C. These temperatures represent optimal conditions, including for the development of the bakery microbiota.

It has been demonstrated that the WAC of TF increased proportionally with the duration of incubation in the thermostat at the dough fermentation temperature of 32±1 °C. The WAC reached maximum value of 1.78±0.2 after 15 minutes and remained relatively unchanged afterwards (Fig. 2). This indicates the necessity of extended dough kneading up to 15 minutes when added teff flour.

The investigation of the impact of TF on the quantity and quality of the wet gluten indicated that these parameters were most worsen in the sample that containing of 20 % TF. Specifically, the gluten content decreased by 3.8 %, springiness by 6.3 % and extensibility by 17.8 % compared to the control (Table 2). Collectively, these processes led to reduction in the springy of crumb and porosity of the final products with TF. This could be attributed to the formation of complexes between TF proteins and wheat gluten proteins that does not washing out and were lost during the analysis. Similar reductions in gluten content during the production of wheat bread with TF have been observed by other researchers. They recommended utilization of TF in a quantity of 5 % to avoid significant reductions in gluten content [17]. In contrast to these results, it has been found that in the sample with 10 % TF, the values of the studied indicators decreased insignificantly, therefore there was no negative effect on the crumb properties in the finished products either (that will be shown later).

The investigation of the impact of TF on the quality and strength of the dough, determined by the alveograph, revealed a deterioration in dough strength and an intensified negative influence of TF on dough quality with increasing TF dosage, as the *P/L* ratio values exceeded the optimal range (Table 3). It is known, the *P/L* ratio is a complex indicator of dough quality that has a decisive influence on dough quality and has optimal values (0.8–1.1) that correspond to high dough strength [24].

With aim enhances of physical, textural, and sensory properties of dough and bread the researchers recommend utilizing of various combinations of enzymes, such as xylanase and amylase, amylase and glucose oxidase, glucose oxidase and xylanase, lipase and amylase, etc. [5]. An alternative approach is the biotechnological method of producing teff bread with using a sourdough. For this purpose, sourdough is created and applied. It consists of pure cultures of breadmaking microorganisms with name of "Biolight" that allowing for improved hydration of teff flour components and enhanced rheological and functional properties of the final products.

The graphical analysis of total gas production in dough on the sourdough confirmed that the fermentation process was more vigorous in samples with teff. Specifically, the amount of carbon dioxide after 180 minutes of fermentation in samples with 10 % and 20 % teff increased by 4.3 % and 7.6 %, respectively, compared to the control (Fig. 3). This can be attributed to the improved chemical composition of teff that contains proteins, dietary fibers and sugars that utilization as nutrients for the sourdough microflora and yeast. Similar conclusions regarding the positive impact of teff on the activity of CO_2 accumulation in wheat dough have been reported by other researchers as well [19, 29].

The investigation of the technological process and quality indicators of sourdough-based dough revealed that the initial acidity of the dough increased by 0.4-0.6 units with an increase in the quantity of teff added (Table 5). This is due to the higher initial acidity of teff compared to high-grade wheat flour. The elevated acidity of teff is attributed to its chemical composition, particularly the presence of fatty acids, phosphoric acid compounds and others. Consequently, the addition of teff leads to an increase in the initial acidity of the dough and intensification of alcoholic and lactic acid fermentation. In the studied samples with 10 and 20 % TF, the lifting force improved by 4 and 8 %, respectively that is confirmed by previous studies of the increase in the intensity of carbon dioxide accumulation in dough with TF (Fig. 3).

It has been demonstrated that as the dosage of teff flour increased to 20 %, the form stability of bread decreased by 20.0 % (Table 7) that is supported by an increase index of spread of the dough ball (Table 5). Strong correlational relationships have been established between the percentage of teff incorporation and spread of the dough ball, r=0.98 (n=10, $p\leq0.05$) and between the percentage of teff incorporation and form stability of bread r=(–0.95) (n=10, $p\leq0.05$). Therefore, the form stability of the final products can be predicted by analysing the index of spread of the dough ball. It has been determined that wheat bread products with teff are best produce in the mold.

The sensory evaluation of the finished products indicated that the crumb elasticity remained unchanged in the sample with 10 % teff compared to the control. However, an increase in the dosage of teff to 20 % resulted in a deterioration of crumb elasticity, springy and other sensory attributes. The best specific volume and porosity of the finished products were observed in the sample with 10 % teff. This dosage of teff provided excellent sensory characteristics, including a pleasant "nutty" flavor (Table 6, Fig. 4).

The developed technology was tested in the baking workshop of LLC Agrofirma Kolos (Kyiv region). The results of the production trials confirmed the effectiveness of the high-quality wheat bread production technology with teff and its implementation for wide-scale industrial adoption was recommended.

It should be noted that the research is limited by created sourdough from PC of LAB that isolated from spontaneous sourdoughs of wheat and spelt flour. The results of the study may be differing from presented in the article when using other bakery sourdough that using only yeast and/or PC of LAB of other taxonomic groups.

Despite these limitations, the results of this research can be utilized to improve the quality of wheat bread.

Further investigations should be focus on selecting highly active strains of bakery microbiota on the base of dissolved spontaneously sourdough from teff flour.

7. Conclusions

1. It has been demonstrated that TF available on the market of Ukraine with a balanced chemical composition is perspective source of plant protein for the enrichment of bakery products. TF has higher acidity, compared to wheat high grade flour, particle size – close to the whole grain flour, high water absorption capacity that must be taken into account when modelling the recipe and developing technology for making wheat bread with TF.

2. It has been established that dosage of TF increasing therefore quality of wet gluten and structural and mechanical parameters of the dough deteriorate, but in the quantity of 10 % to the weight of wheat flour, the influence of TF is insignificant.

3. It has been established that in order to improve the swelling of the constituent parts of TF, it is advisable to produce products with utilization of sourdough and incorporate intensive or extended dough kneading. The developed sourdough on the PC of LAB "Biolight" had a positive impact on the biochemical and microbiological processes in teff-added dough and intensifying the dough maturation processes. The proofing time of the dough portions was reduced by 5.4 % compared to the control sample. Moreover, the products exhibited high volume and porosity, required the regulatory standards and had a pleasant nutty flavour.

4. The obtained results regarding the optimal dosage of TF – 10 %, the utilization of the created sourdough from the PC of LAB "Biolight" in the production of bread with teff were basis for the development of recipe, technological instructions with purpose of industrial implementation and expansion of the assortment of bread products for health and preventive purposes.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has no associated data.

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